The demographic dimension of climate change vulnerability: exploring the relation between population growth and urban sprawl in Dar es Salaam

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According to vulnerability literature, the expansion of built-up areas is among the non-climate factors that will combine with climate change in threatening natural ecosystems and reducing water availability. This has even worse effects on rural–urban livelihood vulnerability in sub-Saharan African cities when the vicious circle linking environmental degradation to urban sprawl through population growth and ineffective land use planning is considered. This study delves into the relationship between urban sprawl and demographic growth in Dar es Salaam, Tanzania. On the basis of land cover classification, urban sprawl over a decade is assessed and its trend compared with population census data. A methodology for population estimation is proposed that combines land cover and household density as derived through primary surveys.

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Drawing on studies conducted in Dar es Salaam, Tanzania, as part of a development initiative aimed at strengthening local government capacity in adaptation planning [5,6], a conceptual framework has been constructed for assessing the contribution of urban sprawl to climate change vulnerability.¹ The city is the most populous in Tanzania (4.4 million in 2012) and the main engine of the national economy (16.9% of the national GDP in 2001–2012). In the last decade, the population of Dar es Salaam region (which comprises the 3 municipalities of Kinondoni, Ilala and Temeke) has grown far beyond any projections (+76% against a projected +32% in 2002–2012) and the built-up areas have expanded enormously [7]. The key idea is that a vicious circle exists linking environmental degradation in the city and inner peri-urban areas to the furious rate of sprawl observed. Although such a rate is largely explained by population growth and increasing commercialization of land in Tanzania [8,9,10], this study assumes that deterioration of environmental conditions in areas of densification also plays a role. In fact, it acts as a push factor for urban and peri-urban households to relocate further out [11,12], which in turn increases human pressure in destination areas, thus driving further relocation decisions. In the absence of institutional action, this vicious circle is likely to be accelerated by the effects of climate change.

By delving into the relationship between urban sprawl and demographic growth in Dar es Salaam, an attempt is made to operationalize the proposed framework. Although these dynamics have been widely commented on, not many studies have explored them numerically [13]. This study shows that remote sensing has the potential to provide a rapid, reliable, and affordable technique for exploring trends in land development patterns and their relationship to demographic growth, thus producing information essential to assessing current processes of vulnerability generation in sub-Saharan cities. In addition, the evidence of a positive correlation between the physical expansion of the city and population growth, combined with information on household density, allowed for the development of a methodology for estimating population size in inter-censal years, data which open up the possibility of quantitative study of vulnerability factors. Results obtained from a

Introduction

In recent literature on climate change vulnerability in sub-Saharan Africa [1], there is wide consensus that climate change will exacerbate the effects of land-use change and other non-climate stressors on natural resources upon which the livelihoods of the majority depend. At the fringes of rapidly growing cities, the expansion of built-up areas (urban sprawl) together with unsustainable exploitation of the environment is already threatening natural ecosystems, thus reducing rural–urban livelihood options [2,3,4].

¹ See Macchi *et al.*, in AESOP/ACSP 5th Joint Congress eBook of Abstracts, Dublin, 2013, 245.

preliminary application of the proposed methodology are encouraging and are discussed in the conclusions.

Linking urban sprawl to climate change vulnerability: a conceptual framework

Urbanization and changes in settlement patterns (e.g. urban sprawl) are widely acknowledged as non-climatic factors [14^{••}] that influence the three key components of vulnerability to climate change: exposure, sensitivity, and adaptive capacity [15]. The type of urbanization and the context in which urbanization is embedded define whether these processes contribute to an increase or decrease in people's vulnerability [16[•]]. Land use and urban planning, river basin and land management, hazard-resistant building codes, and landscape design are all activities that can be used for adaptation by local governments [17,18], but they need time to produce significant effects [19].

As special features of developing countries, rapid population growth (including natural increase and immigration) coupled with rising investment in construction and land speculation have led to the emergence of vast informal settlements on the urban fringes [20,21[•]], in a dynamic and uncontrolled process of land use change that combines creation of an enlarged CBD, upgrading or demolition of slums, redevelopment of inner peri-urban enclaves, and new development of all kinds at the rural–urban interface [22^{••}]. In the face of the increasing number of households living in peri-urban areas, the need has arisen to improve understanding of the complex interplay between demographic growth, urban sprawl and vulnerability to climate change, to provide local governments with knowledge and tools for adaptation.

With this scope in mind, a conceptual framework was developed that draws on reflections about the adaptive strategies of households living in peri-urban areas within Dar es Salaam's coastal plain. A survey of roughly 6000 households [12[•]] has provided evidence that the majority of households surveyed (64%) moved to their current place of residence from the city or other peri-urban areas, rather than from elsewhere in Tanzania. Thus, relocation flows of households within the urban region seem to play a dominant role in sprawl development. Reasons for these movements include deterioration of environmental conditions in the place of origin and the wish to enlarge one's property as push factors, while low-cost land availability and easier access to natural resources key to subsistence production and cash income (e.g. water, wood, raw material, and natural ecosystems) act as a pulling force. In other words, migration within the urban region is also an adaptive response to environmental change for households with a rural–urban livelihood, one that may be termed as 'maladaptation' [23] for it generates environmental degradation further out.

During interviews conducted in the coastal plain,² groundwater salinization was reported as a serious environmental concern by the majority and was selected as a case study to delve into processes of vulnerability generation. Although seawater intrusion in a coastal aquifer is a natural phenomenon [24], decreases in direct groundwater recharge and increases in groundwater withdrawals can alter the saltwater/freshwater equilibrium [25]. These dynamics are evident in Dar es Salaam [26,27,28[•],29[•]] and seriously affect access to water for households settled in coastal peri-urban areas, who depend heavily on shallow boreholes for domestic and productive (mostly agriculture-related) purposes [30]. While every household is affected to some extent since piped water service is intermittent and water sold by private vendors is expensive [31,32[•]], dependence on ground water is absolute for households living in areas where no alternative water sources (such as street vendors or natural streams) are available. In the future, the combined effects of climate change (increase in temperature and change in rainfall patterns [33[•]]) and urban sprawl are expected to further reduce the natural recharge capacity of the shallow coastal aquifer, while groundwater withdrawal is likely to increase due to the growth of both domestic and productive demand, thus resulting in a decrease in groundwater quality and quantity [34[•]].

As shown in Figure 1, a vicious circle links the effects of climate change and urban sprawl to household vulnerability to groundwater salinization. In this context, adaptation decision-making will probably benefit from up-to-date information about land cover and population dynamics, including: the extent and location of built-up areas, to assess heat island magnitude and the reduction of natural recharge to the coastal aquifer [35]; the extent of non-urban areas, to estimate the population relying on boreholes for access to water and their groundwater withdrawal; and trends in the expansion of urban and peri-urban areas, to estimate the population that may decide to relocate elsewhere following a change in their living environment.

Assessing land cover change in Dar es Salaam

Since the earliest reports by the IPCC [36], land cover change has been identified as a driver of both climate change and environmental sensitivity to climate change. In this respect, the rural–urban interface has attracted attention as a place where land cover change occurs ever more rapidly and where, especially in so-called developing countries, populations are more vulnerable to environmental/climate change in comparison to urban areas due to the high dependence of peri-urban livelihoods on natural resources available locally. Moreover, the autonomous adaptive capacity of peri-urban households is

² See ACCDAR Project's Household Survey, URL: <http://www.planning4adaptation.eu/Docs/databases/>.

Figure 1

The vicious circle linking urban sprawl to climate change vulnerability. Urban sprawl affects urban climate, which in turn combines with climate change effects on temperature and rainfall patterns, leading to an increase in expected exposure to climate change. Urban sprawl also leads to an increase in the number of households relying on boreholes for access to water (human sensitivity), as it entails a growing number of households living in new and underserved peri-urban neighborhoods. Consequently, groundwater exploitation also rises, leading to an acceleration of seawater intrusion processes (natural sensitivity). The decrease in groundwater availability results in a reduction of livelihood options and, consequently, of people's adaptive capacity. People may also decide to adapt to changes in environmental conditions by moving further away from the city, thus accelerating the sprawling process.

acknowledged as strongly based on the high level of livelihood flexibility associated with the low cost of living, the diversified range of income generating options, and easy access to land, water, wood, and minerals [5[•]].

As a result, monitoring of land cover change has grown in importance in vulnerability assessments of sub-Saharan African cities [14^{••}], especially at the urban fringe. Among the tools for monitoring the expansion of the built-up peri-urban interface, remote sensing data and GIS technology seem to be the most suitable for use by local administrations, as they can be used to create land cover maps and compare them over time with little cost and effort [37]. Indeed, remote sensing can acquire data over large areas and update spatial information over time, while a number of spatial agencies exist that freely

provide data at an adequate spatial resolution for detecting change in build-up areas on a regional scale. Various data analysis methods can be used for land cover classification to detect impervious surfaces [38[•]], entailing a varying degree of effort in terms of cost, time, output resolution, and accuracy [39,40[•]].

Using the Dar es Salaam region as a study case, a methodology was developed to be economical, simple, and quick to execute [7[•]]. Landsat images were preferred to SPOT and CHRIS Proba ones because of their vast data archive, good spectral and spatial (30 m) resolution, and affordability (provided freely by the United States Geological Survey). A classification using the maximum likelihood algorithm was performed for five years: the national census year of 2002, the most recent year

Figure 2

Land cover classification of Dar es Salaam region, 2002 and 2011. The figure offers a quick view of the expansion of urban and peri-urban areas in Dar es Salaam between 2002 and 2011. The two maps are derived from land cover classification of Landsat images.

provided by Landsat 5 and 7 (2011), and three years during the interim period (2004, 2007, 2009) chosen according to data availability (which was a major constraint due to frequent cloud cover over the region). To contain operational costs, a plugin for the open-source software QGIS was developed that allows for the semi-automatic supervised classification of remote sensing images.³

Six land cover classes were identified in the images developed for the five selected years: Continuously Built-up (CB) (i.e. densely developed land), Discontinuously Built-up (DB) (including low-density development and rural–urban settlements), Full Vegetation, Mostly Vegetation, Soil, and Water (Figure 2).⁴

³ Available at URL: <http://fromgistors.blogspot.it/p/semi-automatic-classification-plugin.html>.

⁴ See ACCDAR Project's Land Cover Maps, URL: http://www.planning4adaptation.eu/042_Maps.aspx.

Figures obtained for the two Built-up classes over the period studied (Table 1)⁵ show an increase of over 6000 ha (+76%) of new CB areas and over 15,000 ha (+192%) of new DB areas, resulting in a rise of partly or completely developed land from 10% to 23% of the regional territory (+12 ha every day).

Information about impervious surfaces being essential for studying the heat island phenomenon and for assessing changes in recharge of the coastal aquifer, an estimation was obtained by considering the upper and lower ranges of impervious surfaces observed for the two Built-up classes of land (from 20% to 60% in DB areas and from 60% to 100% in CB areas). The impervious area of Dar es

⁵ Because of shifts in pixel coordinates from one year to another, temporal comparison between classifications has been conducted using aggregate data at the regional level, postponing a time series analysis of classifications on a per pixel basis to a further stage.

Table 1**Area of built-up land cover classes (in hectares and percentage change)**

Class	2002	2004		2007		2009		2011	
	ha	ha	%	ha	%	ha	%	ha	%
Continuously built-up	8415	10,025	+19	10,447	+24	12,370	+47	14,808	+76
Discontinuously built-up	8098	9134	+13	12,509	+54	17,318	+114	23,678	+192
Total built-up area	16,513	19,159	+16	22,956	+39	29,688	+80	38,486	+133

Salaam in 2011 resulted to be between 14,000 ha and 29,000 ha (i.e. between 8% and 17% of the region). The increase occurred in 2002–2011 appears particularly high in northern parts of the coastal plain (Figure 2), which explains the severe level of deterioration of groundwater observed there [29].⁶

Developing an indicator of urban sprawl

According to UN-Habitat, urban sprawl is to be understood as a visible misalignment of population growth and the physical expansion of the city [41]. This does not exclude the possibility of a positive relationship linking demographic growth to developed area expansion, rather it refers to circumstances where this relationship is not as directly proportional as it was and/or is desirable to be. Parallel definitions employed in the EU [42] focus more sharply on land use and density parameters, which are expected to be mixed and low respectively, and underline that expansion of low density settlements at the urban fringes is accompanied by non- or misuse of dismissed land within urban centers. Although a process of population ‘emptying out’ in the urban core of many metropolitan areas of the global south and North is observed [43], in our opinion, this cannot be generalized to sub-Saharan African cities. Rather, drawing on the case of Dar es Salaam, we would say that the city core is more marked by population turnover than growth, the latter being more typical of the urban fringes and attributable to both natural increase and immigration.

Accordingly, in the case of sub-Saharan cities, the ratio of developed land to inhabitants, or more elaborate indices such as the one proposed by the OECD [44] would not be particularly suitable as an indicator of urban sprawl. Rather, the growth rate of low-density areas relative to the total developed land is likely to perform sufficiently well in the presence of a sharply growing population.

Within the study on Dar es Salaam, an index was used defined as:

$$\frac{(\text{Discontinuously Built-up area})}{(\text{Total Built-up area})} * 100$$

where Total Built-up area is the sum of the CB and DB areas [45].

⁶ See ACCDAR Project’s Borehole Monitoring Database, URL: <http://www.planning4adaptation.eu/Docs/databases/>.

Increasing values of the index over time indicate that there was a process of urban sprawl in the studied region. In the case of Dar es Salaam, the figures are as follows: 49.0% in 2002, 47.7% in 2004, 54.5% in 2007, 58.3% in 2009, and 61.5% in 2011. These results suggest that a rapid sprawling process began between 2004 and 2007.

The publication of data from the Tanzanian census of 2012, reporting a population increase from 2.5 million to 4.4 million in 2002–2012, opened the possibility of better understanding the relationship between this sprawling development and demographic growth in the city. Next, an aggregate comparison of the expansion of the two built-up classes between 2002 and 2012 with population growth according to census data was performed.

As shown in Figure 3, there is an evident misalignment between population growth and the physical expansion of the city, which confirms the process of urban sprawl according to the UN-Habitat definition [41]. Moreover, unlike in the EU where urban sprawl is marked by land development in the absence of demographic growth [42], in Dar es Salaam a correlation has emerged between population growth and the expansion of built-up areas, although the two variables are not directly proportional because of the dominant pattern of urban development. In fact, the expansion of DB areas (+192%) is significantly higher than demographic growth (+75%), while the trend in CB areas (+76%) strictly follows that of population.

According to the conceptual framework above, the expansion of densely developed areas plays a role as a push factor for households to relocate elsewhere as it causes a reduction of viable options for those with rural–urban livelihoods. One should also consider that diminished population density could accompany the densification of core areas, thus driving further emigration. As is discussed below, there is an urgent need to better understand temporal variation in population density across the various land cover classes.

From land cover data to population estimate: a proposed methodology

Most of this study having been conducted in 2011, we interpreted the challenge of missing data as an incentive to develop an estimate of population size for inter-censal years. Data on population size and distribution are

Figure 3

Population growth and built-up area expansion in Dar es Salaam from 2002 to 2012. The rate of expansion of both Continuously Built-up and Discontinuously Built-up areas is compared with the population data available from the national censuses conducted in Tanzania in 2002 and 2012. The growth percentages were calculated using 2002 as a baseline.

essential for local administrations in order to be effective in providing for people's needs. Having accurate information for years between censuses is the more important the more rapid that demographic expansion is. Unfortunately, this is rarely the case in sub-Saharan African cities, where huge information gaps exist at the local government level, although lack of updated and disaggregated population data is recognized to be secondary in importance to resource availability and management capacity [46]. Commonly used approaches to address this problem include downscaling of projections from the country level to small areas (e.g. AfriPop Project, URL: <http://www.worldpop.org.uk/>) and sample surveys (such as those undertaken by National Statistical Offices and a few single-purpose international bodies, like the Demographic and Health Surveys Program, URL: <http://www.dhsprogram.com/>), often combined with remote sensing data⁷ and, more recently, participatory monitoring.

The methodology for inter-censal population estimates developed for Dar es Salaam⁸ relies on information from

⁷ Interesting techniques for estimating population density using remote sensing data are reported in R. Sliuzas, PhD thesis, University of Twente, 2004, and D W Mulatu, PHD thesis, University of Twente, 2014.

⁸ For a detailed description of the method see Congedo *et al.*, Investigating the Relationship between Land Cover and Vulnerability to Climate Change in Dar es Salaam. Unpublished. URL: http://www.planning4adaptation.eu/Docs/events/WorkShopII/WorkingPaper_Activity2_1_complete.pdf.

land cover classification (i.e. land cover data sets for inter-censal years), population census (i.e. average household size for 2002) and the 6000-household sample survey conducted in 2011,⁹ which provided input data for calculating average household density per pixel. In that survey, in order to obtain a 5% sample of households within a neighborhood the total population of which was unknown, interviewers were asked to count 20 households between each two interviewed households. The distance between two interviewed households, which were geo-referenced with a GPS, became the basis for estimating household density.

Considering the observed trends in built-up areas and the available data, the assumption was made that a direct relationship exists between demographic growth and physical expansion but it is mediated by the settlement pattern that dominates in newly developed areas.

The population estimation was carried out in three stages. A spatial density of households for the Built-up classes (two values) and the others (one value) was derived by combining the 2011 classification map with the spatial location of households participating in the survey. Then, the household number was estimated for the whole region

⁹ ACCDAR Project's Household Survey, http://www.planning4adaptation.eu/042_Maps.aspx. Unfortunately, answers about household size could not be considered for this study as they diverge too much from census data.

Figure 4

Comparison of population estimations, projections, and census data from 2002 to 2012. The chart shows the population estimates obtained through this study as well as official population projections and data from the 2002 and 2012 population censuses. The diagonal line represents a hypothetical linear trend between the two census years.

by multiplying the average household density by the related land cover area. Finally, the total population was estimated, using Dar es Salaam's average household size, provided by the Tanzanian National Bureau of Statistics [URL: <http://www.nbs.go.tz/nbs/>].

Figure 4 indicates that official projections seem to have undervalued population growth throughout the decade. However, both estimated and projected figures for 2011 are far off the hypothetical census value of 4,176,816 inhabitants (calculated by assuming a linear trend between the two census years), although in opposite directions (+15% in the case of calculated estimates, -24% in the case of official projections). As such, it would be advisable to use the two methods in combination for 10-year forecasts.

Most importantly, a reversal comes to light when comparing trends in estimated values with those in census data and official projection figures. The estimated population is 15% below the census value in 2002, equals the census value in 2009, and then exceeds it by +15% just two years later. Similarly, estimated values remain slightly below projections until 2004, are equal to them between 2004 and 2007, and then begin to grow more rapidly than projections to a significant spread of 1.6 million inhabitants. Considering that the estimation is based on land cover classifications and the same reversal is evident between the expansion trends of CB and DB areas (Figure 3), this may suggest that household size varies between CB and DB areas, with the latter being lower than the official average figure of 4.2 persons per household. On the other hand, and although little

reliable, available information from the household survey would contradict this hypothesis and would suggest that non-residential uses play a growing role in the expansion of DB areas.

At the current stage of this research, what is evident is that the relationship between urban expansion and population growth has changed over the last decade, with land development becoming less dependent on demographic growth. New factors seem to be emerging as drivers for urban sprawl in Dar es Salaam, such as the reduction of settlement density in residential neighborhoods, which could be caused by increasing middle class living standards and the tendency to build second houses for investment reasons [47,48*]. In addition, the proliferation of non-residential activities should be explored, including retail, office, and manufacturing spaces as well as tourism facilities.

Notwithstanding the need for further improvement, a first attempt at estimating the population living in the coastal plain outside of the densely developed areas (i.e. all classes except CB) was made. Results are as follows: 1,162,321 inhabitants in 2002; 1,455,784 in 2004; 1,680,791 in 2007; 2,248,700 in 2009; and 2,914,134 in 2011. These figures give an idea of the extent of adaptation challenge to be addressed, as this population is likely already suffering (or will suffer in the near future) from a lack of fresh water due to their dependence on the coastal aquifer, while simultaneously causing further seawater intrusion by trying to satisfy their water needs through the use of more and deeper boreholes.

Conclusions

This work is part of a broader project aimed at improving the adaptation planning capacity of local authorities in Dar es Salaam, with a focus on the vulnerability of coastal peri-urban neighborhoods to groundwater salinization. In this perspective, the assumption is made that it is the task of local governments to try their best to counter causative processes of vulnerability while strengthening autonomous adaptive capacity in face of present and future effects of climate change. As such, the results presented here are intended as a contribution to the knowledge of a specific vulnerability driver, urban sprawl, which is viewed as both a cause and effect of environmental degradation and households' decisions to relocate. Moreover, an attempt has been made to use this knowledge in combination with information on population dynamics in order to operationalize the conceptual framework developed for assessing the vulnerability of households with rural–urban livelihoods.

In addition to providing updated information on trends in land cover change in Dar es Salaam over the last decade, the study confirms the validity of using remote sensing and GIS for inexpensive, easy, and quick to execute assessment of urban sprawl in rapidly growing cities. Through classification of free low-resolution images, relevant information has been obtained which served as an input for estimating changes in recharge of the coastal aquifer within a broader analysis of the sensitivity to seawater intrusion of Dar es Salaam's coastal aquifer with regard to climate change [29]. This same information opens the possibility of studying the heat island phenomenon in the urban region as a further step in the investigation of urban climate in sub-Saharan African cities [49].

The major result of this research is that it has demonstrated the benefit of combining land cover change analysis and demographic data as a way to improve understanding of sprawl development. In the case of Dar es Salaam, the gap between census data and population estimates proves that a change in settlement density occurred during 2002–2012, a discovery that deserves to be delved into more deeply through case study research at the neighborhood scale along urban rural transects. Enhanced knowledge of population density patterns would be essential for improving estimate accuracy at a sub-regional level, thus allowing for an advance in the operationalization of the proposed framework. To date, although overestimated, the tentative figures suggest that almost three million people (two-thirds of Dar es Salaam's population) are trapped in a trajectory of vulnerability as regards their access to water, and they are expected to increase in number unless principles of adaptive water management are mainstreamed into current decision-making and adequate conditions for households with a rural–urban livelihood be created within the city.

As a more general conclusion, the results achieved prove the fruitfulness of an approach to the study of climate change vulnerability in sub-Saharan African cities that brings together data and ideas from different disciplinary fields in a goal-oriented manner.

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest
 - of outstanding interest
1. Niang I, Ruppel OC, Abdrabo MA, Essel A, Lennard C, Padgham J, Urquhart P: **Africa**. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, et al.. Cambridge University Press; 2014.
 - Provides an updated assessment of potential factors of vulnerability to climate change specific to Africa.
 2. Simon D: **Urban environments: issues on the peri-urban fringe**. *Annu Rev Energy Environ* 2008, **33**:167-185.
 3. Simon D: **The challenges of global environmental change for urban Africa**. *Urban Forum* 2010, **21**:235-248.
 4. Mattingly M: **Making land work for the losers. Policy responses to the urbanization of rural livelihoods**. *Int Dev Plan Rev* 2009, **31**:37-64.
 5. Ricci L: **Peri-urban livelihood and adaptive capacity: urban development in Dar es Salaam**. *Consilience J Sustain Dev* 2012, **7**:46-63.
 - A preliminary study for the research presented here, it illustrates the livelihood strategies and environmental management practices used by peri-urban dwellers in Dar es Salaam, while underlining challenges and opportunities for adaptive capacity.
 6. Macchi S: **Adaptation to incremental climate stress in urban regions: tailoring an approach to large cities in sub-Saharan Africa**. In *Climate Change Vulnerability in Southern African Cities: Building Knowledge for Adaptation*. Edited by Macchi S, Tiepolo M. Springer; 2014:3-18.
 7. Congedo L, Munafò M: **Urban sprawl as a factor of vulnerability to climate change: monitoring land cover change in Dar es Salaam**. In *Climate Change Vulnerability in Southern African Cities: Building Knowledge for Adaptation*. Edited by Macchi S, Tiepolo M. Springer; 2014:73-88.
 - Describes in details the methodology for land cover classification used to produce the results presented here.
 8. Briggs J, Mwamfupe D: **Peri-urban development in an era of structural adjustment in Africa: the city of Dar es Salaam, Tanzania**. *Urban Stud* 2000, **37**:797-809.

9. Mbiba B, Huchzermeyer M: **Contentious development: peri-urban studies in sub-Saharan Africa.** *Prog Dev Stud* 2002, **2**:113-131.
 10. Briggs J: **The land formalisation process and the peri-urban zone of Dar es Salaam, Tanzania.** *Plan Theory Pract* 2011, **12**:115-153.
 11. Kombe WJ: **Land use dynamics in peri-urban areas and their implications on the urban growth and form: the case of Dar es Salaam, Tanzania.** *Habitat Int* 2005, **29**:113-135.
 12. Ricci L: **Linking adaptive capacity and peri-urban features: the findings of a household survey in Dar es Salaam.** In *Climate Change Vulnerability in Southern African Cities: Building Knowledge for Adaptation*. Edited by Macchi S, Tiepolo M. Springer; 2014:89-107.
- Provides knowledge of the determinants and attributes of adaptive capacity in the peri-urban areas of Sub-Saharan cities, that results from a household survey conducted in Dar es Salaam with a focus on the natural resource systems upon which people depend.
13. Hill A, Hühner T, Kreibich V, Lindner C: **Dar es Salaam, megacity of tomorrow: informal urban expansion and the provision of technical infrastructure.** In *Megacities. Our Global Urban Future*. Edited by Kraas F, Aggarwal S, Coy M, Mertins G. Springer; 2014:165-177.
- Presents a simulation model capable of demonstrating patterns of future urban growth in Dar es Salaam, based on an analysis of locational decisions by poor settlers through household surveys and focus group discussions.
14. Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, Sinh BT: **Determinants of risk: exposure and vulnerability.** *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press; 2012.
- Provides a rigorous understanding of the dimensions of exposure and vulnerability, as well as a proper assessment of changes in those dimensions, as a basis for effective adaptation and disaster risk management.
15. Füssel HM, Klein RJT: **Climate change vulnerability assessments: an evolution of conceptual thinking.** *Clim Change* 2006, **75**:301-329.
 16. Smit W, Parnell S: **Urban sustainability and human health: an African perspective.** *Curr Opin Environ Sustain* 2012, **4**:443-450.
- Provides an overview of literature on three key themes relating to the intersections of environmental sustainability and urban health in Africa: ecosystems and health, climate and health, and urban food security.
17. Davoudi S, Crawford J, Mehmood A (Eds): *Planning for Climate Change. Strategies for Mitigation and Adaptation for Spatial Planners*. Earthscan; 2009.
 18. Mosha AC: **The effects of climate change on urban human settlements in Africa.** In *Climate Change and Sustainable Urban Development in Africa and Asia*. Edited by Yuen B, Kumssa A. Springer; 2011:69-99.
 19. Kithia J: **Climate change risk responses in East African cities: need, barriers and opportunities.** *Curr Opin Environ Sustain* 2011, **3**:176-180.
 20. Beall J, Fox S: *Cities and Development*. Routledge; 2009.
 21. Mabin A, Butcher S, Bloch R: **Peripheries, suburbanisms and change in sub-Saharan African cities.** *Soc Dyn* 2013, **39**:167-190.
- Provides an overview of literature on African urbanisms, with the purpose to explore what forms "suburbs" and peripheries take in various African contexts, and the various elements of what is often termed "urban sprawl".
22. Watson V: **African urban fantasies: dreams or nightmares?** *Environ Urban* 2014, **26**:215-231.
- Offers a critical view of new property development occurring in sub-Saharan Africa's larger cities.
23. Barnett J, O'Neill S: **Maladaptation.** *Glob Environ Change* 2010, **20**:211-213.
 24. Ataie-Ashtiani B, Volker RE, Lockington DA: **Tidal effects on sea-water intrusion in unconfined aquifers.** *J Hydrol* 1999, **216**:17-31.
 25. Ranjan P, Kazama S, Sawamoto M: **Effects of climate change on coastal fresh groundwater resources.** *Glob Environ Change* 2006, **16**:388-399.
 26. Steyl G, Dennis I: **Review of coastal-area aquifers in Africa.** *Hydrogeol J* 2010, **18**:217-225.
 27. Mjemah IC, Van Camp M, Walraevens K: **Groundwater exploitation and hydraulic parameter estimation for a quaternary aquifer in Dar es Salaam, Tanzania.** *J Afr Earth Sci* 2009, **55**:134-146.
 28. Mtoni YE, Mjemah I, Msindai K, Van Camp M, Walraevens K: **Saltwater intrusion in the Quaternary aquifer of the Dar es Salaam region, Tanzania.** *Geol Belg* 2012, **15**:16-25.
- A description of the occurrence of the salt water intrusion from seawater close to the coastline of Dar es Salaam Region is presented.
29. Sappa G, Trotta A, Vitale S: **Climate change impacts on groundwater active recharge in coastal plain of Dar es Salaam (Tanzania).** In *Engineering Geology for Society and Territory*, vol. 1. Edited by IAEG. Springer International Publishing; 2014:177-180.
- Presents an assessment of impacts driven by decreased precipitation and urban sprawl on groundwater active recharge in Dar es Salaam's coastal aquifer during the last decade.
30. Allen A, Dávila JD, Hofmann P: **The peri-urban water poor: citizens or consumers?** *Environ Urban* 2006, **18**:333-351.
 31. Kjellén M: *From Public Pipes to Private Hands: Water Access and Distribution in Dar es Salaam, Tanzania*. Stockholm University Publications; 2006.
 32. Smiley S: **Complexities of water access in Dar es Salaam, Tanzania.** *Appl Geogr* 2013, **41**:132-138.
- Explores the complexity of real water access, using survey data from residents in four of Dar es Salaam's wards.
33. Rugai D, Kassenga GR: **Climate change impacts and institutional response capacity in Dar es Salaam, Tanzania.** In *Climate Change Vulnerability in Southern African Cities: Building Knowledge for Adaptation*. Edited by Macchi S, Tiepolo M. Springer; 2014:39-56.
- Addresses causative factors and institutional response capacity to cope with the impacts of climate change in Dar es Salaam. Provides an overview of studies on changes in climate-related parameters occurred in the city.
34. Faldi G, Rossi M: **Climate change effects on seawater intrusion in coastal Dar es Salaam: developing exposure scenarios for vulnerability assessment.** In *Climate Change Vulnerability in Southern African Cities. Building Knowledge for Adaptation*. Edited by Macchi S, Tiepolo M. Springer; 2014:57-72.
- Presents an assessment of exposure to seawater intrusion in the northern parts of Dar es Salaam's coastal plain based on historical data integrated with an ad hoc hydrogeological survey conducted in 2010.
35. Seto KC, Shepherd JM: **Global urban land-use trends and climate impacts.** *Curr Opin Environ Sustain* 2009, **1**:89-95.
 36. McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (Eds): *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press; 2001.
 37. Brook RM, Davila J (Eds): *The Peri-Urban Interface: A Tale of Two Cities*. University of Wales and University College London; 2000.
 38. Chen X, Bai J, Li X, Luo G, Li J, Li BL: **Changes in land use/land cover and ecosystem services in Central Asia during 1990–2009.** *Curr Opin Environ Sustain* 2013, **5**:116-127.
- Illustrates various datasets available for the analysis of land use/land cover change, providing an overview of their technical features.
39. Richards JA, Jia X: *Remote Sensing Digital Image Analysis: An Introduction*. Springer; 2006.
 40. Roy DP, Wulder MA, Loveland TR, Woodcock CE, Allen RG, Anderson MC, Helder D, Irons JR, Johnson DM, Kennedy R et al.: **Landsat-8: science and product vision for terrestrial global change research.** *Remote Sens Environ* 2014, **145**:154-172.
- An excellent overview of Landsat applications in several fields from land cover to agriculture to surface temperature, evapotranspiration and drought.

41. UN-Habitat: *State of the World's Cities 2010/2011: Bridging the Urban Divide*. Earthscan; 2010.
42. European Commission: *Guidelines on Best Practice to Limit, Mitigate or Compensate Soil Sealing*. Publications Office of the European Union; 2012.
43. Richardson HW, Nam CW (Eds): *Shrinking Cities: A Global Perspective, Regions and Cities*. Routledge/Taylor & Francis Group; 2014.
Shows that shrinkage can occur at any scale from neighborhood to macro-region, and examines the factors behind shrinking cities with a special focus on metropolitan areas.
44. OECD: **Urbanisation and urban forms**. *Regions at a Glance 2013*. OECD Publishing; 2013 http://dx.doi.org/10.1787/reg_glance-2013-7-en.
45. Sauri D, Olcina J, March H, Martín-Vide J, Vera F, Padilla E, Serra-Llobet A: **Case study Mediterranean Coast of Spain (Annex 4)**. *ESPON Climate Project: Climate Change and Territorial Effects on Regions and Local Economies; Final Report: European Observation Network for Territorial Development and Cohesion (ESPON) Publication*; 2011.
46. Friedmann J: **Globalization and the emerging culture of planning**. *Prog Plann* 2005, **64**:183-234.
47. UN-Habitat: *The State of African Cities 2014: Re-Imagining Sustainable Urban Transitions*. UN-Habitat Publications; 2014.
48. Kihato CW, Royston L: **Rethinking emerging land markets in rapidly growing Southern African cities**. *Urban Forum* 2012, **24**:1-9.
Introduces a special issue comprises a collection of articles focusing on the dynamics of urban land markets in Sub-Saharan Africa, with comparative cases from Asia and Latin America.
49. Cavan G, Lindley S, Jalayer F, Yeshtela K, Pauleit S, Renner F, Gill S, Capuano P, Nebebe A, Woldegerima T *et al.*: **Urban morphological determinants of temperature regulating ecosystem services in two African cities**. *Ecol Indic* 2014, **42**:43-57.
Presents an approach for understanding climate-related impacts of differing urban areas, based on the idea of urban morphology types (UMTs). Results from applications in Addis Abeba and Dar es Salaam are also examined.