
Sarah Lindley

Climate moderation via green infrastructure – the potential of regulating ecosystem services to mitigate the UHI effect in Dar es Salaam

Lindley, S.[1], Kibassa, D.[2] and Cavan, G.[3]

[1] *School of Environment, Education and Development, University of Manchester, Oxford Road, Manchester, UK sarah.lindley@manchester.ac.uk*

[2] *Institute of Human Settlements Studies (IHSS), Ardhi University (ARU), P.O. Box 35124, Dar Es Salaam, Tanzania dkibassa2000@yahoo.com*

[3] *School of Science and the Environment, Manchester Metropolitan University, Oxford Road, Manchester, UK g.cavan@mmu.ac.uk*

1. Introduction

Climate projections carried out as part of the EU CLUVA project (www.cluva.eu) suggest that annual temperatures in the regions associated with five African cities will have increased by between +1.3°C and +2.5°C by the 2050s compared with a 1961-90 baseline (Giugni, et al., 2015). Within a century of the baseline, the frequency of heat wave events is expected to double and individual events are likely to last for much longer durations than in the present day. At the same time, Africa's urban population will continue to grow (Di Ruocco, et al., 2015). As a result, there will be more people exposed to heat waves and high temperatures and also the likelihood that urban development itself will lead to higher temperatures as a result of the Urban Heat Island (UHI) effect (Cavan, et al., 2014; Oke, 1982). Regulating ecosystem services can have an important role for offsetting higher urban temperatures (Bowler et al., 2010; Sproken-Smith and Oke, 1999). However, there is relatively little known about phenomena like the Urban Heat Island effect and even less about intra-urban temperature variations in the cities of sub-Saharan Africa (Ndetto & Matzarakis, 2015). Similarly, evidence of the potential of regulating ecosystem services is also scarce (Cavan et al., 2011).

2. Dar es Salaam and its characteristics

Dar es Salaam is the largest city in Tanzania. It is situated on the eastern coast of Africa (6°48'S 39°17'E) and has a population over 4.3 million. Dar es Salaam's climate is generally hot and humid throughout the year, with an average temperature of 29°C and peak temperatures occurring during the austral summer (December-February). The city centre benefits from its coastal location but development can block the cooling effect of sea breezes. The urban area can be characterised using Urban morphology Types (UMTs). UMTs are a means of recording information about urban form and function and are therefore helpful for understanding biophysical processes, e.g. for the assessment of ecosystem services and patterns of risk and vulnerability in urban areas (Cavan et al., 2014; Gill et al., 2008; Lindley et al., 2007).

The administrative area of Dar es Salaam (around 1500 km^2) has been mapped according to 11 high level and 43 detailed UMTs for 2008 and 2002. Residential UMTs cover 46.5% of Dar es Salaam, followed by agricultural UMTs (40.4%) and a further 5.1% of the land area of the administrative zone is associated with other predominately vegetated UMTs. Important vegetation also exists outside predominantly green UMTs and proportional cover varies between classes. For example, condominium residential types contain 58% vegetation on average, compared to 42% in areas of mud/wood construction (often associated with low income settlements) (Lindley et al., 2015; Kibassa, 2014).

There have been recent studies of biometerological climate in Dar es Salaam (Ndetto & Matzarakis, 2013a; Ndetto & Matzarakis, 2013b). This adds to limited existing knowledge of the city's urban climate, human thermal comfort and UHI effect, estimated to be between 2-4 °C in 2001 (Jonsson, et al., 2004; Nieuwolt, 1973). To the authors' knowledge, there has been no detailed assessment of intra-urban variation in air temperatures and their drivers in Dar es Salaam.

3. Aims, data and methodology

The research reported in this paper aims to assess the nature of the UHI effect and its implications for regulating ecosystem services in Dar es Salaam (Fig. 1) as an example of a rapidly developing city with a tropical climate. Dar es Salaam shares many characteristics with other cities in sub-Saharan Africa, such as a high proportion of people living in unplanned settlements, a high proportion of urban poor and weak planning

frameworks, making it a useful exemplar (Herslund et al., 2015).

Air temperate data were collected using ibutton sensors over seven months (June 2012 - Jan 2013). This included the main dry season (June to September/early October), and the period of short rains termed “vuli” in Swahili (from October to December/ early January). Data were analysed against a rural reference point in Kibamba, located 24 km from the city centre (and at approximately 152m a.s.l). Additional analyses were carried out in relation to the urban morphological characteristics of the immediate study sites, including the relative proportions of 11 different vegetated land cover types around the monitoring sites (such as large trees, small trees and shrubs, crops, bare ground, housing and other built surfaces). Regression analysis has been used to make an assessment of the relative strength of correlations between UHI intensity and factors known to contribute to the UHI effect. The analysis has been carried out for the urban-rural transect shown in Fig. 2.

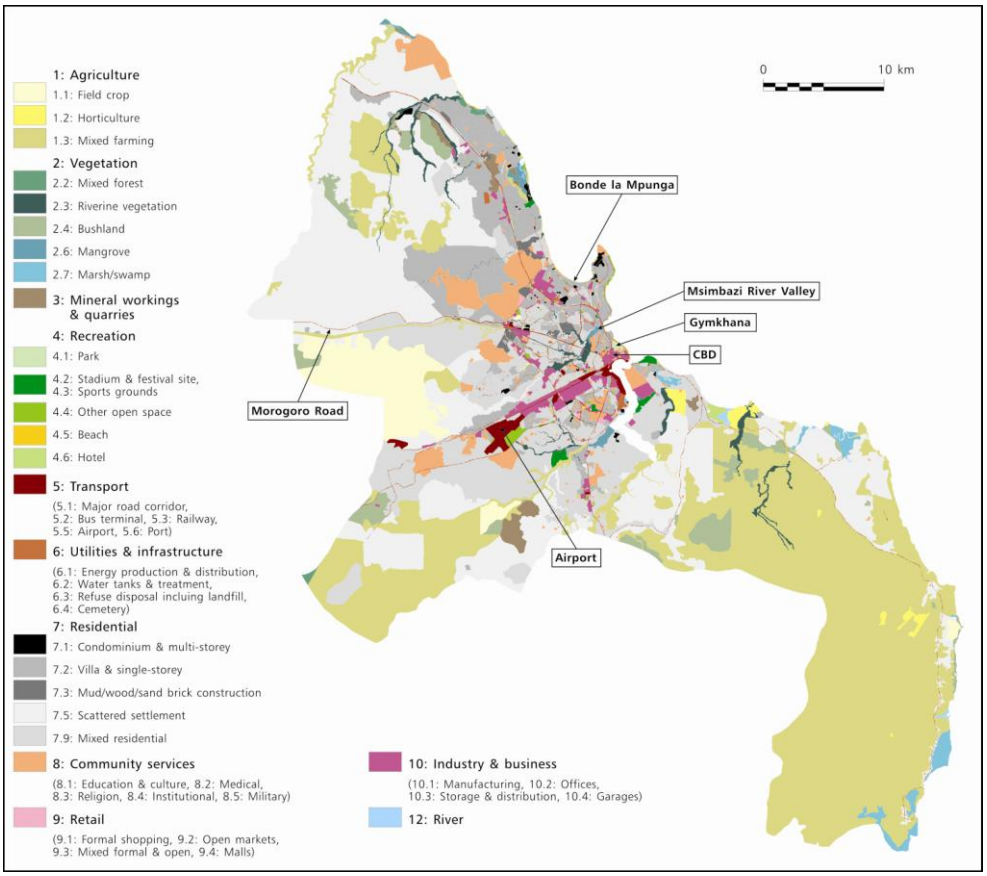

Fig. 1 The city of Dar es Salaam characterised by Urban Morphology Types (Lindley et al., 2015).

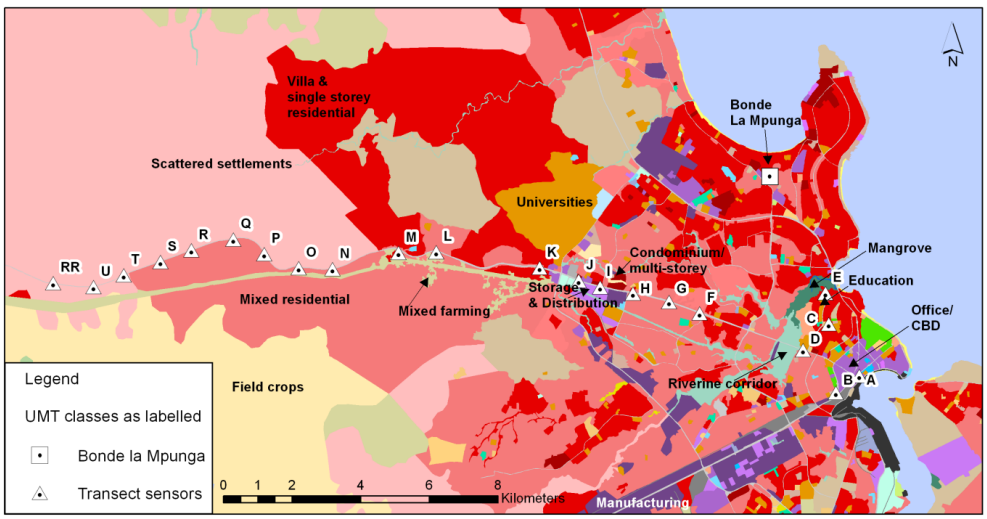

Fig. 2 Air temperature sensor locations used as the basis for the analysis.

4. Results and conclusion

The results showed an elevation-adjusted nocturnal air temperature UHI intensity of up to 2°C in August 2012 but UHI intensity which exceeds reported values at other times of the year. Strong statistically significant correlations were found with a number of UHI-related variables. The results may be indicative of UHI causality in Dar es Salaam, as well as other African cities with similar characteristics. Results are not presented in detail in this abstract as they have been written up for a paper for a forthcoming Special Issue on 'Urbanisation and ecosystem services in sub-Saharan Africa: current status and scenarios' for *Landscape and Urban Planning*, due in 2016. Please contact the first author if you wish to be notified when the full paper is available.

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