Physics and Chemistry of the Earth xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Influence of urbanization-driven land use/cover change on climate: The case of Addis Ababa, Ethiopia

Bisrat Kifle Arsiso[a,b], Gizaw Mengistu Tsidu[c,*], Gerrit Hendrik Stoffberg[a], Tsegaye Tadesse[d]

[a] Department of Environmental Science, University of South Africa (UNISA), South Africa
[b] Department of Environment and Climate Change, Ethiopian Civil Service University, Addis Ababa, Ethiopia
[c] Department of Earth and Environmental Sciences, Botswana International University of Technology and Science, Priv. Bag 16, Palapye, Botswana
[d] National Drought Mitigation Center, University of Nebraska Lincoln, USA

ARTICLE INFO

Keywords:
Land use change
Urban scale climate
Urban heat island (UHI)
Normalized differencing vegetation index (NDVI)
Climate change

ABSTRACT

Land use change is the second most important anthropogenic influence on climate beside the emission of greenhouse gases. Urbanization is leading to significant land use changes in Africa since the continent is undergoing rapid urbanization and population growth in recent decades. Addis Ababa is one of these fast growing cities in the continent. Therefore, detection of land use change is very important to identify its impact on climate and sustainable land use management of the city. The study used Landsat images to generate land use/land cover change map for the city. The normalized difference vegetation index (NDVI) is used to detect the major changes of vegetation cover occurred between 1986 and 2011 as a result of land use and land cover change. Downscaled HadCM3 simulations under A2 and B2 emission scenarios is used to investigate future urban heat island (UHI) over the city of Addis Ababa. In the city, the analysis of Landsat images has shown that the built-up areas have increased by 121.88 km^2 within the last 25 years. This finding is consistent with NDVI images taken over the same period that reveal a decline in vegetation cover. The impact of the urbanization-driven land use/cover change has resulted in notable nocturnal urban heat island (UHI) as revealed from an average increase in minimum temperature of 1.5°*C* at the centre of the city relative to rural site over the 1960–2001 period. The mean of the 2006–2010 spatial minimum temperature anomaly with respect to the base period mean of 1981–2005 is consistent with the observed UHI. The temperature in the central areas (both commercial and residential sectors) of Addis Ababa is warmer than the surrounding areas. The thermal gradient increase from about 1.44°*C* at the centre (Arada, Addis Ketema, Lideta and Kirkos) to 0.21°*C* at the peripheral parts of the city (Gulele, Bole, Nefasilk-Lafto, Kolfe Keranio and east of Yeka sub-cities) transecting across the hot (high-density urban) to moderately warm to cool (non-built-up) areas. However, the maximum temperature and rainfall exhibit variability that follows topographic differences. Future urban climate change projections of urban heat island formation under A2 and B2 emission scenarios show that the nocturnal UHI will be intense in winter or dry season episodes in the city. The highest urban warming is from October to December (2.5°*C* to 3.2°*C*) during 2050s and 2080s.

1. Introduction

Urbanization transforms naturally covered land into impervious land cover (Xian et al., 2008). Urban land cover can have significant effects on local climate and environment (Wu and Murray, 2003; Zhou et al., 2004; Grimmond, 2006; Carter et al., 2015). Understanding urban landscape conversions and interactions between natural phenomenon and human activities is important for proper land and climate change management (Mantyka-pringle et al., 2012). Several studies have indicated that urban centers are warmer than their surrounding countryside leading to an increased urban heat island (UHI) (Babazadeh and Kumar, 2015; Mohan et al., 2012). The UHI is an anthropogenic phenomenon resulting from the distinct surface modification caused by human settlement in urban areas. In urban built-up areas, the use of air conditioners and transportation systems bring additional heat source into the urban layer (Wilby and Perry, 2006). In contrast to the countryside, building materials and non-vegetated surface covers retain more solar energy during the day, and have lower rates of radiant cooling during the night time (Santamouris, 2013). When a considerable portion of the natural land cover is changed by surface built-up, it traps or absorbs incoming solar radiation during the day time and then re-radiates it at night due to a decrease in albedo (Babazadeh and

* Corresponding author.
E-mail addresses: bisrat_k2002@yahoo.com (B.K. Arsiso), mengistug@biust.ac.bw (G. Mengistu Tsidu).

https://doi.org/10.1016/j.pce.2018.02.009
Received 10 May 2017; Received in revised form 23 January 2018; Accepted 7 February 2018

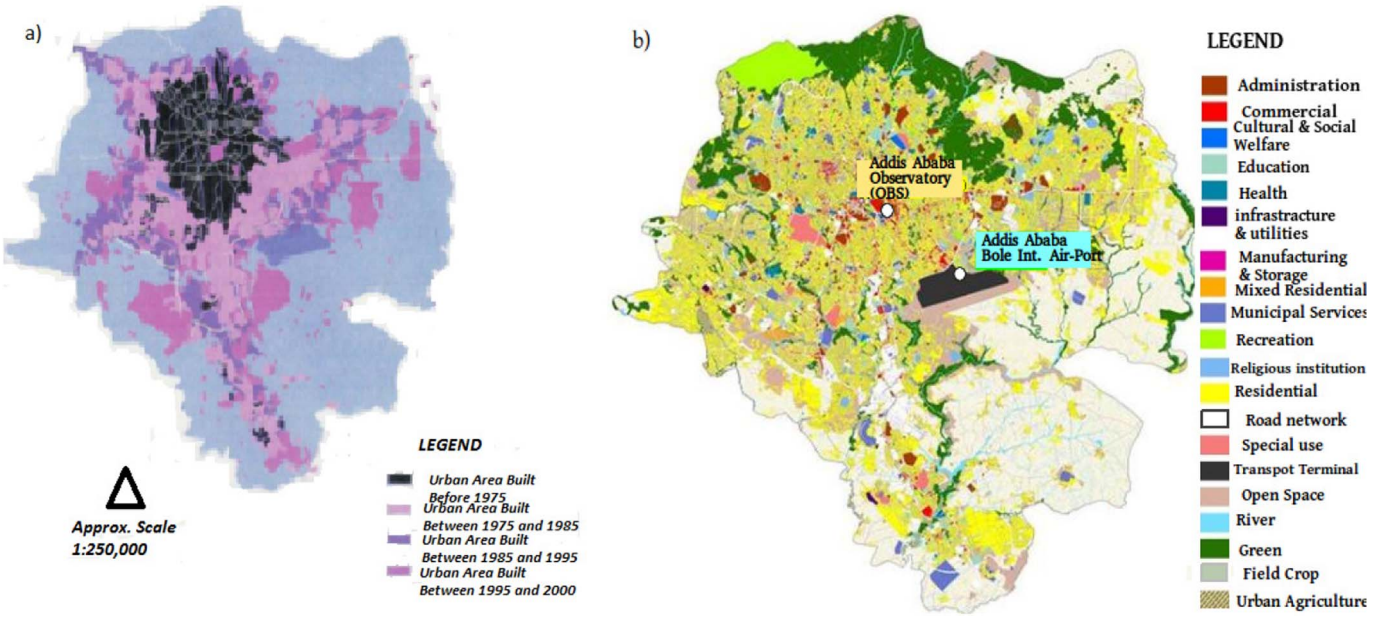

Fig. 1. Addis Ababa city a) physical expansion; and b) existing LULC and the locations of the two meteorological stations (Source: Office of the Revision Addis Ababa Master Plan (ORAAMP, 2002)).

Kumar, 2015). The reduction of evaporation and evapotranspiration due to impermeable surfaces and reduced vegetation are other factors that lead to UHI. The heat generated from local infrastructure and heat trapped by urban air pollution could also play some role in aggravating the UHI effect (Oke, 1997). In urbanized areas the cooling process is made slower by keeping night-time air temperatures high (Mohan et al., 2012; Olaide et al., 2013) through condensation and inertial heat release which compensate for the radiative heat loss in contrast to surrounding rural areas. Therefore, the UHI has the strongest signal at night and in the winter months.

The UHI intensity is also found to be affected by meteorological conditions. For example, the UHI intensity is observed to decrease due to increased wind speed and high cloud coverage (Grimmond, 2006; Joseph and S, 2013) while UHI is intensified in the presence of high pressure or anticyclone system or during dry summer season (Kuttler et al., 2007; Morris and Plummer, 2001). Moreover, increases in population density of a city increases UHI intensity.

Given the scale of urbanization coupled to the dearth of available studies on Africa in general and the absence of serious efforts to understand the impact of urbanization induced land use/land cover change on climate change, this study aims to assess land use changes and their impact on urban scale climate through their UHI effects. Addis Ababa, capital city of Ethiopia, is chosen for this case study because of notable spatial expansion, population growth and many developmental activities such as rapid expansion of infrastructure (e.g., massive construction of roads, railway, buildings). This expansion is partly driven by the pressure from hosting numerous international and sub-regional and continental organizations including the United Nations Economic Commission for Africa (UNECA), the African Union (AU), the World Bank, the European Commission, and United Nations Development Program (UNDP). As a result, immense change in land cover and land use over Addis Ababa has occurred during the last decades. As noted in many cities in other part of the world (Toy and Yilmaz, 2010; Kotharkar and Surawar, 2015), this urban growth in population and industry converts the landscape from natural to more and more impervious urban land leading to major changes in natural environment and climate. The impact of land use and land cover change is highly felt through marked temperature contrast between the centre and outskirt of a city, which is a manifestation of UHI. Moreover, the increase in land utilization and modification of land use and land cover over time modify the micro-climate of a city. Therefore it is important to study existing and future occurrences of UHIs in Addis Ababa city where rapid socioeconomic development and spatial transformation are taking place.

The structure of the paper is as follows: Section 2 describes study area and its historical growth trend and the existing land use. Section 3 describes the data and methods employed. Section 4 presents the assessments made on land use and land cover changes using Landsat images. The assessment involves estimation of annual percentage changes in land use and land cover. This section also discusses the relation between physical expansion and population growth. The observed urban climate change and future Heat Island effects based on observational data and statistically downscaled HadCM3 model simulations under A2 and B2 emission scenarios are also presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Study area

Addis Ababa city, the capital city of Ethiopia since 1889 with approximate centre located at 9°*N*, 38.7°*E*, is situated in the central highlands of the country and covers an area of approximately 526 km^2 with a population of 2.9 million (CSA, 2011) according to population projections made for 2011. A study by the Office for the Revision of the Addis Ababa City Master Plan (ORAAMP, 2002) shows that, the historical growth of the built-up areas of the city could be divided in to five distinct periods (1887–1936, 1937–1975, 1976–1985, 1986–1995, and 1996–2000). The first period is the early development period that took place from 1887 to 1936 and is known for its haphazard and extended settlements of military camps and the occupation of large compound by landlords as villages. The extended area was between Gulale (in the East) and Yeka (in the West) and Entoto (in the North) and Bekulo-Bet (in the South). During this period, the total built up area was 18.63 km^2. Assuming constant growth in each year, the average growth of the built up area was 0.37 km^2 per annum (Abdissa, 2005). During the period between 1976 and 1985, the built-up area had increased by 47.88 km^2, thus increasing the cumulative total to 108.38 km^2. Similarly between 1986 and 1995, the built-up area had expanded by 29.25 km^2, increasing the cumulative total to 137.63 km^2 (Fig. 1a, see also Table 1). Simultaneously, horizontal expansion took place in all directions of the city, where both legal and squatter settlements were established. It was