Sprawling crisis? Exploring the crossroads of urban growth and natural environments with Earth Observation

WEGMANN Martin[abc], TAUBENBOECK Hannes[ab], BESSER Tim[c], SHAPIRO Aurelie[d], ZIEGLER Stefan[d], RAJASHEKARIAH Kiran[e], ESCH Thomas[b], DECH Stefan[ab]

[a] Department of Remote Sensing, University of Wuerzburg, Germany

[b] German Aerospace Center (DLR-DFD), Germany

[c] Global Change Ecology, University of Bayreuth

[d] WWF Germany

[e] WWF India

Abstract - The human pressure on natural ecosystems and protected areas is steadily increasing. Urban growth is undeniably and irreversibly converting natural habitats as it is constantly expanding with population growth. In this study we analyze the urban expansion of mega city Calcutta over four time-steps (1975, 1990, 2000, 2010) as an example of expansion over time and threat to the surrounding environment. Landsat and TerraSAR-X satellite data are selected to provide a long time-series. Various methods for information extraction, from multi-spectral optical techniques as well as radar data processing were developed to derive urban footprints semi-automatically. Urban growth rates per time-step (in hectares) were quantified, and spatial metrics were calculated to characterize the pattern of urban expansion by spatial configuration, direction and dimension. The results outline the increasing vulnerability of natural areas to the expansion of urban areas. The study showed that earth observation data, methods and products can significantly contribute to better land use planning.

Keywords: human impact, conservation, remote sensing, spatial pattern analysis, modeling

INTRODUCTION

Urban areas around the world have become the dominant living space for human population. Since 2008 more people live in urban areas than in rural ones (United Nations 2009b). While the rate of rural population growth will slowly decrease in the future, urban area populations are projected to increase at an increasing rate in future decades (United Nations 2009a). Drivers for the growing urban population include natural growth of the city population as well as rural-to-urban migration. In addition, the expanding urban area engulfs surrounding rural communities leading to a reclassification of this rural land as urban (Cohen 2004).

This trend of the increasing urbanization and its effects on the natural environment might be employed as a way to ultimately reduce the pressures on rural ecosystems and biodiversity and provide better models for sustainable land use planning. More dispersed rural human settlements convert relatively more land for human livelihood than cities (Hardoy et al. 2001; Secretariat of the Convention on Biological Diversity 2010). However, an uncontrolled expansion of the latter leads to increased direct pressures on nearby ecosystems, while a large fraction of the inhabitants of low-income megacities are living in informal areas such as slums or squatter settlements. Those often expand into ecologically sensitive areas (e.g. steep slopes, riverside or wetlands) (Hardoy et al. 2001). This expansion of residential areas as well as industrial or other urban land uses often results in a direct loss of ecosystems. This direct habitat loss endangers on biodiversity on one hand but also reduces the ecosystem's ability to provide certain services (e.g. flood protection or the attraction of tourists) (Millennium Ecosystem Assessment 2005; Secretariat of the Convention on Biological Diversity 2010). In addition to urban demand for land which is resulting in the loss of natural ecosystems, the indirect land cover changes triggered by the demand for natural resources like construction timber and fuelwood rise as the population in urban areas increases. This increase is accompanied by a degradation of ecosystems in close proximity of a city and can even impact ecosystems far beyond the city's limits. For instance in the region of Dar es Salaam, Tanzania, low-value wood for charcoal production was gathered up to a distance of 50 km in 1991 and up to a distance of 170 km already in 2005 (Ahrends et al. 2010).

Despite these described trends of the world's population, the population on the Indian subcontinent is still predominantly rural. Only about 30 percent of the national population lives in urban areas (United Nations 2009a). However, as everywhere throughout the developing world the Indian urban population is steadily growing and this growth is expected to continue for in future decades. Today, 46 Indian cities have a population exceeding the one million mark and the three Indian megacities (Delhi, Mumbai and Calcutta) rank among the top ten most populated cities of the world. Other big Indian cities also follow the example of their three big brothers and are estimated to expand widely. Chennai (Madras), Bangalore and Hyderabad are expected to develop into megacities of more than ten million people within the next few decades (United Nations 2009a). For conservation management it is crucial to adapt and mitigate

activities related to future urban sprawl in order to minimize conflicts and reduce the potential impact on protected areas.

The way in which the biggest urban agglomerations of India expand differs in many aspects. Taubenböck et al. (2008) observed the growth patterns of the three Indian megacities. While topographical settings lead to a more polycentric and complex growth in Mumbai and to a more oval one in Calcutta over period of more than 30 years, New Delhi's growth was not influenced by the terrain and developed a concentric ring-shaped structure. Still, all three megacities underwent a redensification phase of the urban core and massive sprawl in the subcenters surrounding it from 1971 to 1991. The redensification stopped until 2001 but the areal sprawl at the fridges of the cities continued (Taubenböck et al. 2008). Emerging megacities today are beginning to show the same spatiotemporal development pattern of urban sprawl as the megacities showed in the first observation period (Taubenböck et al. 2009). While many impacts on natural ecosystems have already taken place as a result of the expansion of today's megacities, the analysis of spatial patterns can be lessons learned for future ones.

It is obvious that the impact of sprawling urban areas is dependent on the past or present natural configuration of a region and varies from one city to another. Yet, the ecological footprints of the large Indian cities already have or will have a large impact within their regions and will also extend even farther into the cities' hinterlands in the future. Already in 1985, for example, the exploitation of forests for fuelwood needed in Bangalore and New Delhi happened mainly in those forests which were 150 km and 700 km from the cities, respectively (Centre for Science and Environment 1985). In order to derive spatially explicit information about changes on the earth surface, earth observation has proven to be a good tool for picturing and analyzing patterns of urban sprawl of megacities and other larger cities in India (Jat, Garg & Khare, 2008; Sudhira, Ramachandra & Jagadish, 2003; Taubenböck et al. 2008; Taubenböck et al. 2009). Far-reaching regional impacts on forests triggered by the increasing demand from the sprawling Calcutta can be analyzed using remote sensing techniques.

The objective of this study is to analyze the impact of urban growth on protected and pristine land cover as well as on biodiversity. In particular the importance of distance to urban areas, urban growth patterns and natural landscape structure will be focused. The analysis of the relationships between the urban sprawl and environmental parameters as well as the impact on the surrounding landscape is the main aim of this study.

STUDY SITE

Calcutta is the capital of the Indian state West Bengal close to the border with Bangladesh. It is located in the south-east of the state at the Hooghly River in the delta of the Ganges (**Error! Reference source not found.**). The city is the third biggest urban agglomeration in India and is home to more than 15 million people. This defines Calcutta as a megacity, while the population is still growing. Calcutta's population is predicted to reach over 20 million people by 2025 (United Nations 2009a).

The Hooghly River was crucial for determining the form of the city. The urban area mainly developed alongside the east bank of the river and due to this topographical feature the city took an oval shape. As there is no orographic barrier directing its expansion, the city could grow in a monocentric and laminar way. There was only little dispersion in the surrounding area. The urbanization processes are mainly focused on the peripheral areas (Taubenböck et al. 2008). However, indication of sprawl and dispersion were found by Bhatta (2009).

Several protected areas (PA) are situated in the close surrounding to the growing city (Figure 1). The Sundarbans are located in the south at the Bengal Bay within the largest delta area worldwide. All in all about 10,000 km² of transnational mangrove forest are separated into an Indian and a Bangladeshi part. The Indian part has a share of approximately 40% of the total area (Sundarban Biosphere Reserve 2006).
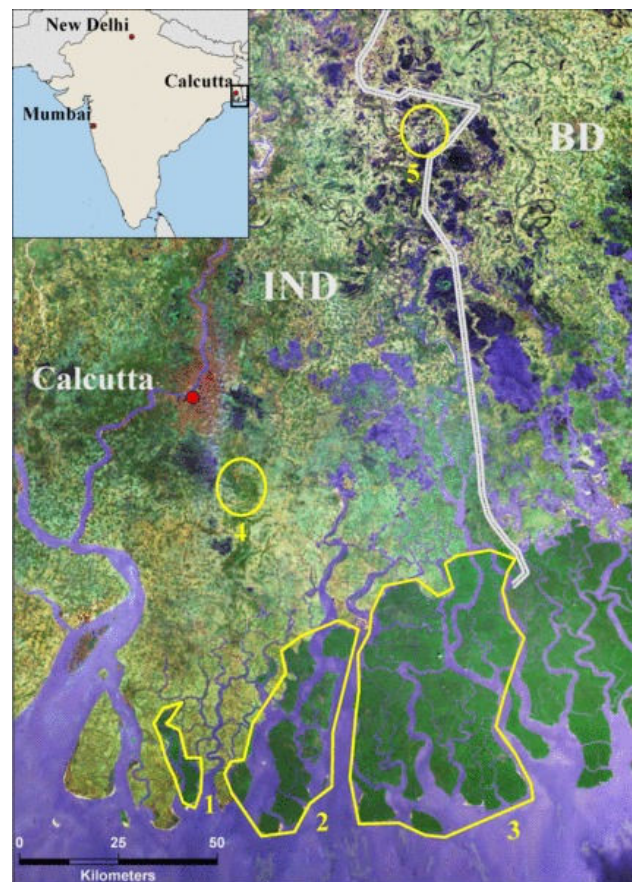

Figure 1. Protected areas and landcover in the surrounding of Calcutta: (1) Lothian Island and neighbouring reserved forest; (2) reserved forest of Herobhanga, Ajmalman, Dulibasani, Chulkati and Thakuran; (3) Sundarbans Tiger Reserve; (4) Narendrapur Sanctuary; (5) Bibhutibhu

Within this part of the Sundarban a Biosphere Reserve was declared by the Indian government in 1989 and the UNESCO accepted it as one of its World Heritage Sites (WHS) in 2001. In addition, the Sundarban National Park was recognized by the UNESCO as a WHS in 1987 (Sundarban Biosphere Reserve 2006). It is also the core area of the Sundarban Tiger Reserve (Figure 1, 3) the last refuge for the world's only mangrove inhabeting tigers, and a global priority for conservation of the species. Other areas of protected forest also belong to the Sundarban (Figure 1, 1+2). The Sanctuaries of Narendrapur and Bibhutibhu are located closer inland (Figure 1, 4+5).

METHODS AND DATA

The methods used in this study are split up into different approaches. The magnitude of past urban sprawl in Calcutta is assessed based on the methods of Taubenböck et al. 2009. They used Landsat (MSS, TM, ETM+) and TerraSAR-X data of four time steps (1977, 1990, 2000, 2010). Thus, the first step in this analysis is the classification of urban/non-urban categories of a subset of the city region. Using the same time steps and the same types of satellite data, a further differentiating classification of a subset of four mosaicked data scenes is done. This classification results in different non-urban land use/landcover types (e.g. open land, wetland, grassland, forest). The temporal and structural changes within and between those classes of non-urban landscapes follows. This is done using change detection algorithms, vegetation indices (e.g. NDVI) and landscape metrics (e.g. fragmentation). Correlations between changes of natural ecosystems and the sprawling of the urban area of Calcutta are first based on the whole study site. Secondly, pixel-based correlations are applied to derive a pattern of regional differences of the impacts of the urban area growth.

The potential impact of future urban growth was derived on the basis of growth (i.e. current and expected) rates of already observed patterns. To assess different patterns of growth on the different sides of the urban area, it is beneficial to subdivide the area into several subregions. The identification of areas with a potential for an urban build-up but with an additional high flooding risk in the Monsoon season is relevant to identify certain areas which are excluded from a prediction due to unsuitable conditions.
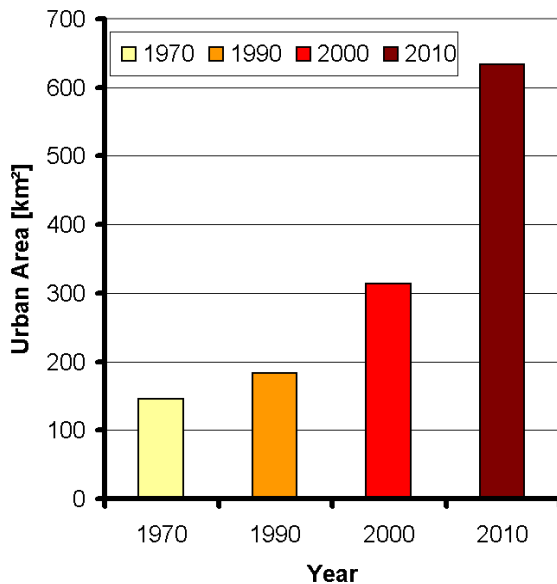

Figure 2: Quantified growth of urbanized areas from 1975 until today at mega city Calcutta, India

After using remote sensing methodologies the second study focus lies in the inspection of datasets that comprise data on temporal changes of management conditions and about the ecological state of reserves, sanctuaries and protected areas in the surrounding of Calcutta (Figure 1). Again, the results from this analysis are correlated with the megacity's spatiotemporal sprawl.

Finally, recommendations for nature conservation in face of a rapidly growing megacity will be provided. On which priority areas should conservationists focus their efforts? In which ways can urban planning in a developing country's megacity mitigate and reduce impacts of the urban landscape? Can planners in other emerging Indian megacities learn from the development of Calcutta?

RESULTS AND CONCLUSION

This study showed that the mapping and prediction of urban sprawl is needed in order to adapt conservation management strategies according to the forecasted development. The conversion of the landcover due to urban sprawl is alongside the indirect impacts on the surrounding landscape, a major pressure on ecosystems. The expansion of Calcutta from 1977 till 2010 can be seen in Figure 2. The general pattern shows that Calcutta is growing along the Hooghly river with major parts of the city located in the southern part of the map. Increased urban areas in 1990 were also mainly in the southern part, while until 2000 the expansion focused along the south-western part as well as along the river. In 2010 the major changes appeared in the northern part of the city. The sprawl of the urbanized area decreased in some parts in the southern part in 2010 but increased in the north. Hence the pattern of landscape modification changed significantly during these four decades. The reasons for these changes in the growth patterns cannot be fully linked to environmental parameters, but further socio-economic and political drivers need to be accounted if a proper spatial prediction of future changes should be conducted.

In figure 3 the overall sprawl of the urbanized area of Calcutta in India can be seen. The dramatic increase from approx. 150 km² to more than 600 km² resulted in irreversible land cover change and loss of vegetation and pristine landcover.
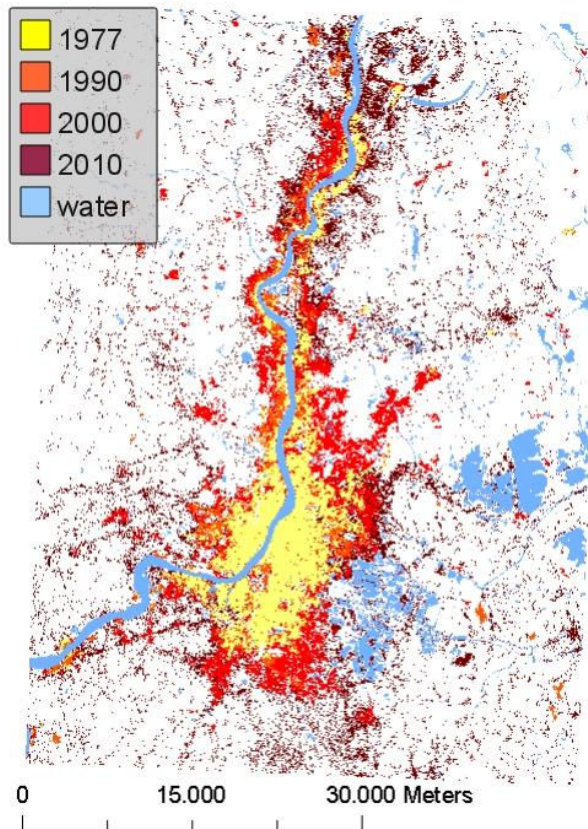
Figure 2: Urban sprawl of Calcutta across four decades.

However, in addition to the "urban area" definition of concrete large buildings within a highly sealed area, another type of urban area mapping is needed. Small settlements and roads scattered through the landscape within a slightly sealed landscape need to be mapped separately and their impact for landscape modification considered. Those settlements may play an important role relating to ecosystem degradation and conversion which could not be detected in this study. Moreover, agricultural expansion is another pressuring factor which needs to be analyzed besides urban growth. These two landcover types might interact as well. Buildings might be constructed along agricultural areas where pristine areas might be destructed in favor of urban expansion.

Nevertheless this preliminary study has shown that urban expansion can be regarded as a major threat to conservation priorities. But further human made structures as well as land-use types need to be accounted for in order to provide reliable recommendations for conservation management strategies.

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