Urbanization: A Global Change Issue

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Abstract – Urbanization is a global issue. Virtually all of the world's population growth over the next 30 years will be absorbed by urban areas. New applications, data and ideas are needed to meet the challenges of sustainable urban development. We need to understand the nature and dynamics of urban systems as basis to develop and implement effective interventions that seek to structure and guide urban development in its broadest sense. This paper provides an overview on recent contributions of remote sensing to support this complex task with manifold up-to-date and area-wide spatial information. We provide examples of multi-sensoral, multis-scale and multi-temporal applications for different scopes. Furthermore we show value-adding interdisciplinary applications to expand the scientific perspective as well as the basic necessity for transdisciplinary acceptance and collaboration with stakeholders.

Keywords: Urban remote sensing, inter- and transdisciplinary applications, urbanization, multi-sensoral products

1. THE FUTURE WILL BE URBAN

More and more people are thrusting into cities. But what are the consequences of the ongoing, unstoppable and uncontrolled urban dynamic? What brings the future? Many cities are not able to govern themselves. With the words 'The world has entered the urban millennium' Kofi Annan, the General Secretary of the United Nations, emphasized in 2001 that the highly dynamic process of urbanization throughout the world has an irreversible impact on the earth's system.

The dynamics of urban development in recent history are nothing else than awesome. At the beginning of the 20th century, just 16 cities in the world contained at least a million people, the vast majority of which were in industrially advanced economies. Today, at the end of the first decade of the 21st century, there are more than 400 cities around the world that contain over a million residents, and about three-quarters of these are in low- and middle-income countries (Cohen, 2004). According to the latest United Nations' projections, virtually all of the world's population growth over the next 30 years will be absorbed by urban areas. During 2007, for the first time in history of the world, the proportion of the population living in urban areas exceeded 50 per cent. The world urban population is expected nearly to double by 2050, increasing from 3.3 billion in 2007 to 6.4 billion in 2050 (UN, 2007). Thus, urbanization is not insignificant or local; it is global and has among with climate change the highest impact on the world's system. Figure 1 emphasizes the prospects of population pressure in urban areas in proportion to the expected decline of population living in rural areas.

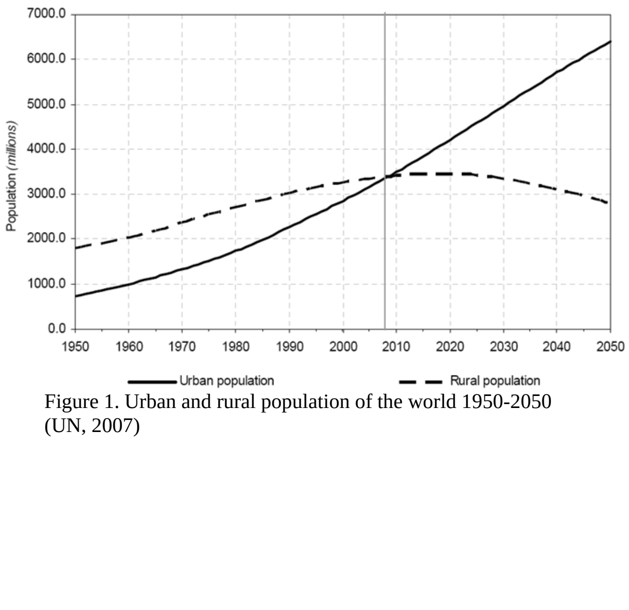

Figure 1. Urban and rural population of the world 1950-2050 (UN, 2007)

Urbanization can basically be caused by three factors: natural population increase, rural–urban migration, and annexation. The most obvious consequence results in spatial expansion, often described as 'urban sprawl'. Drivers of urban development and urban sprawl are highly diverse: There are macro-economic factors (economic growth, globalization, etc.), micro-economic factors (rising living standards, price of land, availability of cheap agricultural land, competition between municipalities, etc.), demographic factors (population growth, increase in household formation, etc.), housing preferences (more space per person, etc.), inner city problems (poor air quality, noise, small apartments, unsafe environments, social problems, lack of green open space, poor quality of schools, etc.), transportation (private car ownership, availability of roads, low cost of fuel, poor public transport, etc.), regulatory frameworks (weak land use planning, poor enforcement of existing plans, lack of horizontal and vertical coordination and collaboration, etc.) (EEA, 2006). Thus it becomes obvious that the multidimensional complexity of 'urban systems' must be analyzed from various disciplines for more holistic perspectives to measure, recognize, understand and anticipate urban processes.

National and local planning systems have been developed, as an attempt to guide and coordinate public and private investment in a manner which will give rise to forms and patterns of urban development that are both efficient and effective in satisfying the development goals of their citizens and societies. The often stated objective of sustainability, not matter how vague it may be, is a reflection of this search for long-term balance between the forces and actors that together make up the city (Sliuzas, 2008). But the high dynamics of the manifold urbanization processes mostly overcame any past strategies to govern or manage cities and to deal with urbanization. This raises a lot of questions: Are hitherto strategies successful? Where will future residents live and work? Who is living where and how many people will settle? How will cities organize their own future growth in space? How will be dealt with environmental and ecological problems? How can be dealt with air and noise pollution, crime, overcrowding, substandard housing, etc.? How much water and energy will be needed by the cities future industries, farms, and residents, and where will that water be stored or the energy produced? Where should future highway, transit, and high-speed rail facilities and rights-of-way be located? Most of all, how much will all this growth cost, both economically, and in terms of changes in the city's quality of life? (Bruna, 2000).

These fundamental questions for sustainable planning are inherently spatial in nature. The analysis of current situations and the prediction of urban growth and trends in city sizes over time are still constrained by one major problem, namely the lack of regular, reliable, area-wide and up-to-date data (Cohen, 2004). Systems for the acquisition, processing and delivery of spatial information are an essential component of urban planning. As a scientific discipline remote sensing exists at the cross of many other fields such as urban design, civil engineering, property development, urban geography, sociology and many others (Sliuzas, 2008). This paper outlines some of the approaches to use recent developments in remote sensing and geographic information systems technology to respond to the challenge of sustainable urban management.

2. THE CONTRIBUTION OF REMOTE SENSING TO URBAN APPLICATIONS

Remote sensing is one scientific field to provide insight into the multidimensional system of ‘urban areas’. The contribution of remote sensing to support urban planning and management goes beyond the mapping of of the built environment alone. The techniques show their value predominantly in space-oriented questions. Interdisciplinary integration of different research fields extends the capabilities significantly. Furthermore, transdisciplinary integration of stakeholders and decision makers is critical for coordinated research to actual requirements.

2.1. Remote sensing data sets

Remote sensing provides spatially consistent data sets that cover large areas with both high spatial resolution and high temporal frequency. The spectral and small-scale spatial heterogeneity of urban morphology requires a high geometric and spectral resolution of data sets that enable differentiation of objects necessary for analyzing spatial and thematic details (Taubenböck et al. 2009a). Remote sensing platforms provide a multitude of sensors with different technical specifications appropriate for various urban applications:

Very high resolution multispectral optical satellite data from i. e. GeoEye I & II, Ikonos, Quickbird, or SPOT feature a geometric resolution ranging from 41 cm to 2.5 m, which is feasible for urban environments. A highly detailed spectral coverage of the electromagnetic spectrum by hyperspectral sensors like the airborne sensors HyMap, AVIRIS (or in the near future the satellites EnMAP) enable derivation of i. e. surface materials or temperature. Laser Altimeter (LIDAR) is also an optical remote sensing technology for highly detailed profiles of 3D elevations of the earth’s surface; stereo images can also be used for that purpose. In terms of temporal analysis, optical sensors such as Landsat (since 1972), SPOT (1986), or IRS (1988) enable monitoring and detection of changes with reduced spatial resolution. In addition to optical systems, SAR antennas operate almost independently of meteorological conditions and solar illumination. There are, at present, several SAR sensors in space offering a broad and global observation of the planet (e.g., ERS-2, RadarSat, Envisat, TerraSAR-X, and the space shuttle) in different frequencies, polarizations, and geometric resolutions. Even aerial acquisitions are possible due to the full-time imaging potential of radar. Furthermore, new radar satellites such as TerraSAR-X, CosmoSkyMed, and Advanced Land Observing Satellite (ALOS) enable the extraction and analysis of urban structures based on geometric resolutions up to 1 m (Roth et al, 2005).

2.2. Multi-temporal, multi-scale and multi-sensoral applications

Recent research has used remotely sensed images to quantitatively describe the physical spatial structure of urban environments and characterize patterns of urban morphology. Studies vary from general views on city level (Sudhira et al, 2003) to highly detailed analysis of urban morphology on building / block level (Barr et al, 2004; Taubenböck, 2008).

Multi-temporal and multi-sensoral remote sensing has become an important data-gathering tool for monitoring and analyzing urbanization. The synergistic utilization of Landsat and TerraSAR-X data enables to analyze time-series from the 1970s until today to directly measure spatial effects of urbanization. Our example shows the spatial expansion of the sprawling incipient mega city Hyderabad in India. The change detection on urban footprint level allows to quantify urban growth and to analyze directions and spatial configuration of growth patterns.

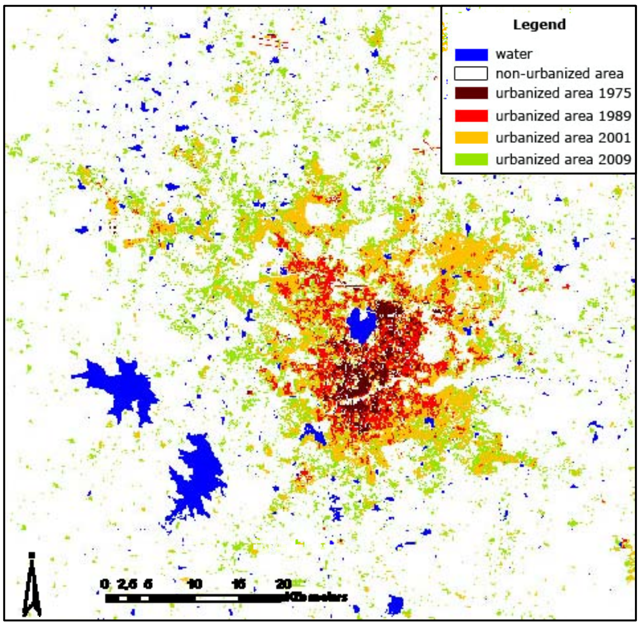

Figure 2: Multi-sensoral change detection of urbanized areas at the incipient mega city Hyderabad, India from 1975 to 2009

On higher resolution the thematic detail can be significantly improved. Using Ikonos or Quickbird data sets the small-scale and heterogeneous urban structure, defined by the spatial arrangement of buildings, streets and open spaces, can be classified on individual building level. Accuracies of automatic classification algorithms range from 75 -85 % or enable by using manual enhancement accuracies of up to 97 %. Value-adding from 2-D land-cover information to a 3-D city model increases the details. Using digital surface models enable to include the height of the buildings and map the orographic situation. In addition calculation of building sizes, roof types, rates of sealed areas or built-up density provide detailed insight into the urban morphology (Taubenböck, 2008). Utilizing the physical parameters of the individual buildings in combination with the field work experience land use can be assessed as an additional feature of every building, basically differentiating between residential, mixed, commercial and industrial usage. Figure 3 shows an example of a 3-D city model of Padang in Indonesia.

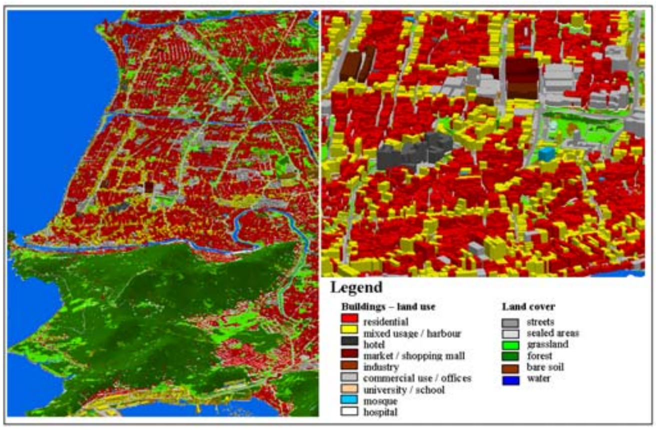

Figure 3. 3-D city model of Padang derived from high resolution satellite data and digital elevation model utilizing SRTM data

2.3. The need for interdisciplinarity

As described above the complexity of 'urban systems' needs a more holistic analysis. The integration of various scientific disciplines is promising to increase our understanding of what is happening in our cities. In the following a few examples provide ideas on value-adding of remotely sensed products by other scientific fields.

One example for interdisciplinary value-adding is the combination of methods from remote sensing and civil engineering for vulnerability assessment of structures (Taubenböck, 2008). The capability to provide area-wide information on physical parameters of structures, like e. g. size, height, roof type or age enables to correlate these building types with vulnerability functions typical for the particular building type. Thus, an assessment of building stability in case of a hazardous impact like e. g. earthquakes or tsunamis can be assessed (Münich et al, 2006).

Furthermore, census data are the principle source of information on individual cities but censuses usually occur only once a decade and then take several years to be analyzed and released (Cohen, 2004). The combination of highly detailed urban morphology parameters (cp. Fig. 3) as well as land usage with census data or punctual survey data on population make it feasible to inter- or extrapolate current population information (Taubenböck et al, 2007). The following example (Fig 4) shows a top-down distribution from generalized population information on district level on a fine spatial resolution (individual building level) for the Zeytinburnu quarter in Istanbul, Turkey.

Cities are the physical and architectonic reflection of the society that created it. Thus, we assume that urban morphology not only correlates to population distribution but also to socioeconomic parameters of the people. The idea of semantic classification aims at a first assumed interrelation between physically homogeneous sectors – e. g. highest built-up density, very small, one storey buildings are grouped together and classified as semantic class 'slum' – within the complex urban morphology and the socioeconomic characteristics of people residing there (Taubenböck et al, 2009b). Semantic classes are e. g. slums, suburbs, low (LC), middle (MC) or high class (HC) residential area. In conjunction with household surveys the hypothesis of correlating physical and socioeconomic parameters has been proven for certain parameters. The study was conducted using questionnaires for 1000 household samples.

The results for the sample parameter 'income' show that the classified slum areas as well as the classified suburb areas reveal lowest income values independent from their location within the

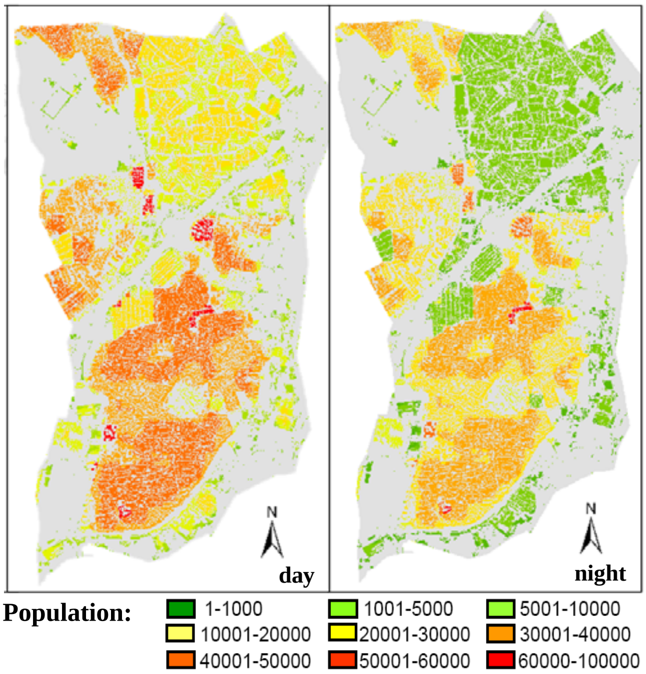

Figure 4.Time-dependent population assessment on building level

urban landscape. We also found consistently rising income levels to the semantic classes 'low class' and subsequently to 'middle class' areas. In the southern area of Padang we observe what was stated in the initial hypothesis – a rising income for the 'high class', while in the northern area we have lower incomes for this class. Thus, we resume that the physical urban morphology basically correlates with socioeconomic parameters of the people. The combination of area-wide available remotely sensed data enables to extrapolate the punctual survey data showing interdisciplinary value-adding.

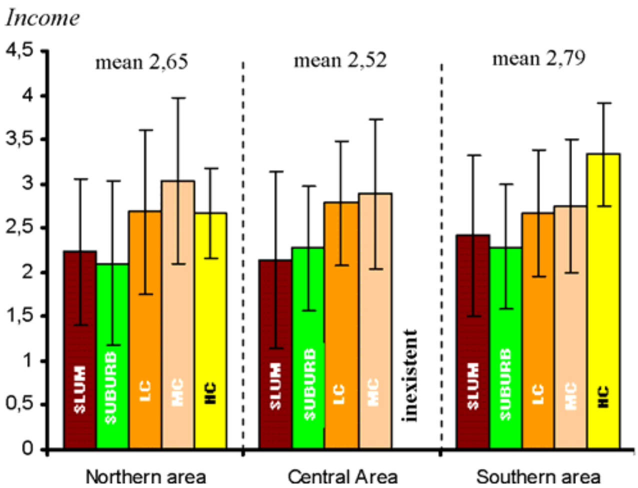

Figure 5. Location-based mean value correlation of semantic classes and the socioeconomic parameter income and their standard deviation

The multidimensional perspectives using spatial knowledge on urbanization over time, physical urban morphology on building level, urban pattern, land use, stability of buildings, population distribution and their socio-economic profiles enable a substantial information basis for a better understanding of urban systems and open up a wide field of applications. As natural interdisciplinary field remote sensing and urban planning can support each other substantially and develop new concepts. In trying to forecast the future, there can be no greater mistake than ignoring the burden of history (Hall, 2002). The first essential is to try to trace the main elements of causes and effects that have operated in the past as basis to forecast spatial urban development. Using the multidimensional results, modeling future urban growth can be based on manifold data. The more clearly future urbanization patterns can be anticipated, the greater our collective ability to undertake sound city, metropolitan, rural, and bioregional planning. One further example is evacuation modeling in case of a disastrous event (Lämmel et al, 2008). Thus, bottlenecks or evacuation time can be assessed as basis for future spatial planning or specific recommendations and thus for sustainable decision-making. This leads to the interdisciplinary approaches regarding risk assessment. Using information on the spatial impact of earthquakes, tsunamis, etc. enables to combine the hazard with the vulnerability of potentially affected systems. These multiple interdisciplinary capabilities provide useful means to improve the quantity and quality of data available for urban management.

3. STAKEHOLDERS PERSPECTIVE

Urban policymakers are struggling to balance massive urban growth in public and private investment with more sustainable forms of urban development. Questions regarding the shape, size, density and distribution of the city have become increasingly relevant for decision-makers / politicians, but are highly complex and politicized.

In this context knowledge refers to the activities of monitoring, analyzing and evaluating which are needed to increase our understanding of what is happening in our cities. But, scientific results are valueless if they do not transform into practical value. Thus, transdisciplinary integration of stakeholders is of crucial importance. Solutions have to be developed along the stakeholders needs. The results must be scientifically robust, plausible and communicable to a multiple stakeholders, yet sensitive to the needs of the political leaders and decision makers. The data and results have to be easily available. Examples are WebGIS applications with the capability to visualize and calculate results specific to the individual needs of particular stakeholders. This intends to lead to actions; tasks of integrating, planning, and executing which are the main components of any management process (Masser, 2001).

As one concrete example the 'Urban Age' network developed bringing together professionals from a variety of different disciplines and backgrounds. Sociologists, geographers, economists and political scientists join practitioners such as planners, architects, developers, transport experts and engineers in a dialogue with political decision makers (Urban Age, 2009). Thus, science can take crucial influence into the development of strategies or political will.

4. AN URBAN OUTLOOK

Urban planning was subject to severe criticism for its failure to be effective in the management of urban development and the creation of high quality, sustainable living environments, both in developed and less developed countries (Sliuzas, 2008). One of the main reasons for unreliable combination of strategic and action planning is the lack of spatial data available. Especially in a time when a new kind of city is emerging: globalized (connected to other cities in global networks); quaternized (dependent almost entirely for its economic existence on advanced services); 'informationalized' (using information as a raw material); and polycentric (dispersing residences and decentralizing employment into multiple centres or 'edge cities') (Hall, 1997). Managing urban growth has increased in both scope and complexity and has become one of the most important challenges of the 21st century.

This study provided a broad overview on up-to-date and area-wide multi-scale results derived from multi-sensoral remotely sensed data to overcome the lack of data problem. Thus, future intentions may transform scientific knowledge to political will for sustainable development.

REFERENCES

S. L. Barr, Barnsley M. J., Steel A. "On the separability of urban land-use categories in fine spatial scale land-cover data using structural pattern recognition", Environment and planning B: Planning and Design, volume 32, pages 397 – 418. 2004.

G. C. Bruna, "The Sao Paulo region" In R. Simmonds & G. Hack (Eds.), Global city-regions: their emerging forms (pp. 107–119). London and New York: SPON Press. 2000.

B. Cohen, "Urban Growth in Developing Countries: A Review of Current Trends and A Caution Regarding Existing Forecasts", World Development, Vol 32, No. 1, pp. 23-51, 2004.

EEA Report, "Urban sprawl in Europe – The ignored challenge", No. 10, 2006, ISSN 1725-9177.

P. Hall, "Planning: millennial retrospect and prospect", Progress in Planning, 57, pp. 263-284, 2002.

P. Hall, "Modelling the Post-industrial city". Futures, vol. 29, issues 4-5, pp. 311-322. 1997.

G. Lämmel, et al, "Emergency Preparedness in the case of a Tsunami - Evacuation Analysis and Traffic Optimization for the Indonesian city of Padang". In: Proceedings of the Pedestrian and Evacuation Dynamics Conference, Wuppertal, 2008. pp.12. 2008.

I. Masser, "Managing our urban future: the role of remote sensing and geographic information systems", Habitat International, vol. 25, issue 4, pp. 503-512, 2001.

J. C. Münich, Taubenböck, H., Stempniewski, L., Dech, S., Roth, A. "Remote sensing and engineering: An interdisciplinary approach to assess vulnerability in urban areas", First European Conference on Earthquake Engineering and Seismology. Geneva, Switzerland. pp. 10. 2006.

A. Roth, Hoffmann, J. & Esch, T. "TerraSAR-X: How can high resolution SAR data support the observation of urban areas?", Proceedings of URBAN 2005 & URS 2005, Tempe, AZ, USA, CD-ROM, 2005.

R. Sliuzas, "Improving the performance of urban planning and management with remote sensing systems", In: EARSeL Cenference, Bochum, Germany, pp 1-13, 2008.

H. S. Sudhira, Ramachandra, T. V. & Jagadish, K. S. "*Urban sprawl: metrics, dynamics and modelling using GIS*". In: International Journal of Applied Earth Observation and Geoinformation. vol 5(1), pp 29-39. 2004.

H. Taubenböck, Roth, A. & Dech, S. "Linking structural urban characteristics derived from high resolution satellite data to population distribution". In: Urban and Regional Data Management. In: Coors, Rumor, Fendel & Zlatanova (eds). Taylor & Francis Group, London, ISBN 978-0-41544059-2. S. 35-45. 2007.

H. Taubenböck, "Vulnerabilitätsabschätzung der Megacity Istanbul mit Methoden der Fernerkundung". PhD Thesis. Universität Würzburg; p. 178. ISBN-10: 3639083180. (Online-Publication: http://www.opus-bayern.de/uni-wuerzburg/volltexte/2008/2804/). 2008.

H. Taubenböck, Roth, A. & Dech, S., "Mega cities: Hints on risk management using EO data". In: Gamba, P. & Herold, M. (eds.): Global Mapping of Human Settlements: Experiences, Data Sets, and Prospects. Taylor and Francis. pp. 197-221. to be published. 2009a.

H. Taubenböck et al, "Integrating Remote Sensing and Social Science – The correlation of urban morphology with socioeconomic parameters". In: Urban Remote Sensing Joint Event, Shanghai, China. 2009b.

United Nations, "World Urbanization Prospects - The 2007 revision". New York. 2007.