Urban remote sensing

How can earth observation support the sustainable development of urban environments?

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1 Urban remote sensing

Cities are centres of economy, policy, society and culture and more than half of the world's population already lives in metropolitan areas. In the last decades the world has faced a constantly accelerating growth of urban areas - a development which is closely related to a tremendous increase of the urban population. In 2007 the amount of urban residents has outnumbered the rural population for the first time in history and by the year 2030 already two-thirds of the world's population is expected to live in cities (UNPP, 2008). Hence, urban and peri-urban environments show one of the highest dynamics in the context of global land use transformations. The constant urbanization and the rapid changes in urban environments involve considerable challenges with respect to the observation, analysis and understanding of the complex processes affecting and forming metropolitan areas. As a consequence, effective and sustainable urban management increasingly demands innovative concepts and techniques to obtain up-to-date and area-wide information on the characteristics and development of the urban system – regionally as well as globally. Currently, most of this information is collected by means of statistics, surveys and mapping or digitizing from aerial imagery. However, in consideration of stastistical information these approaches often show a comparably coarse spatial and temporal resolution while surveying and mapping is time consuming and cost-intensive - properties which significantly restrict periodic updates and regional, national or even global analyses.

Space- and airborne earth observation (EO) has become a promising tool to provide updated geoinformation on various aspects of built-up areas in manifold spatio-temporal dimensions (Bauer et al., 2004; Heiden et al. (2003); Henderson & Xia, 1998; Herold et al., 2003; Ji et al., 2006; Masek et al., 2000). Remotely sensed images represent an independent data source from which various layers of information can be derived area-wide, with a flexible repetition rate and in various scales ranging from spatially detailed analysis on single-building or building block level to global studies on continental scale. In combination with widely automated methods of data processing and image analysis, urban remote sensing provides multiple options to support decision makers such as resource managers, planners, environmentalists, economists, ecologists and politicians with accurate and up-to-date geoinformation. This paper introduces selected geo-information products derived from multisensoral remote sensing data. The products and the underlying remote sensing techniques were developed in the context of a joint research co-operation for urban applications between the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) and the Department of Remote Sensing at the University of Würzburg.

2 Earth observation in support of sustainable urban development

In this chapter we intend to demonstrate the applicability and benefits of different remote sensing data and image analysis techniques in terms of a monitoring and assessment of urban agglomeration. This includes the monitoring of urban sprawl (section 2.1), the mapping of imperviousness (section 2.2), the urban structure analysis for assessing local heating potential and modelling urban micro climate (section 2.3) and the assessment of vulnerability and risk (section 2.4).

2.1 Monitoring of urban sprawl

A first and at the same time basic demand for urban planning is information on the location, shape and development of built-up areas. The constant process of urbanization which is taking place in many countries involves a permanent and sometimes rapid change of the city footprints. Hence, even developed countries lack up-to-date information on urban sprawl. For the delineation of city footprints we have developed two semi-automated procedures that analyse either multispectral data and/or imagery recored by synthetic aperture radar (SAR) sensors.

The classification approach using multispectral data is based on an object-oriented hierarchical top-down methodology extracting the classes 'built-up areas' and 'water' for the time series of Landsat data (Taubenböck, 2008). The approach utilises spectral, shape and texture features as well as principal component analysis to extract urbanized, sealed areas from the Landsat data sets. In terms of monitoring urban sprawl, a post classification comparison was found to be the most accurate procedure and presented the advantage of indicating the nature of the changes (Mas, 1999). A comparative analysis of the individual land cover classifications for the available times performed independently was therefore implemented to monitor and analyse the development of urban areas. Pixelwise change detection was implemented checking the land cover classes individually for the available years. For it, all individual land-cover classifications are sampled up on the highest available geometric resolution of Landsat ETM. Figure 1 shows the result of the change detection displaying the spatiotemporal physical evolution of urbanised areas for the years 1973, 1989 and 2001 at the mega city Kolkata in India. Thus, a first result enables to calculate absolute areal growth or assess directions of urban sprawl. We assessed the accuracy of every classification result with 250 randomly distributed pixels. Due to missing ground truth data, we then assessed the accuracy visually by comparing classification results to the Landsat data. Thus, this assessment of accuracies already includes uncertainties. Even so, the high overall accuracies range from 86% to 93% correctly classified pixels.

Alternatively to the use of optical data, the semi-automated detection of built-up areas can also be based on SAR imagery (Esch et al., 2010). The corresponding technique includes a specific preprocessing of the SAR data and an automated image analysis procedure. The preprocessing focuses on the analysis of local noise characteristics in the SAR data in order to provide a texture layer that highlights built-up areas. In the context of the image analysis, this texture layer is used along with the original intensity information to automatically extract settlements. The technique was demonstrated on the basis of 12 scenes of the German SAR satellite system TerraSAR-X (TSX) covering representative urban agglomerations distributed throughout the world. Figure 1 (right) shows the urban footprint that was derived from TSX data for the area of Munich, Germany. Overall, accuracies between 76% and 96% for the derived city footprints showed the high potential of both the TSX imagery and the proposed analysis approach in detecting built-up areas.

Urban growth is characterised by complex diversity of spatial types. Growth may be laminar or punctual; it may increase density or it may sprawl; it may be mono- or polycentric. Furthermore, urban structure is very much scale-dependent. For a quantitative analysis of urban form and its changes over time different methods are implemented: We use gradient analysis defined by parameters like areal growth, urbanization rates, or built-up densities to assess on regional scale the diffencens in urban structure between the urban core and the periphery. In addition we chose landscape metrics (or spatial metrics) like the SHAPE index, patch density and largest patch index as quantitative indices to describe structures and pattern of the mega city. In general, spatial metrics can be defined as quantitative and aggregate measurements derived from digital analysis of thematic-categorical maps showing spatial heterogeneity at a specific scale and resolution (McGarigal, Cushman, Neel, & Ene, 2002; Herold et al., 2003). Figure 1 shows the change detection, the gradient analysis regarding built-up densities as weel as a spider charts showing landscape metrics quantitatively measuring the urban footprint of Kolkata in comparison to other cities.

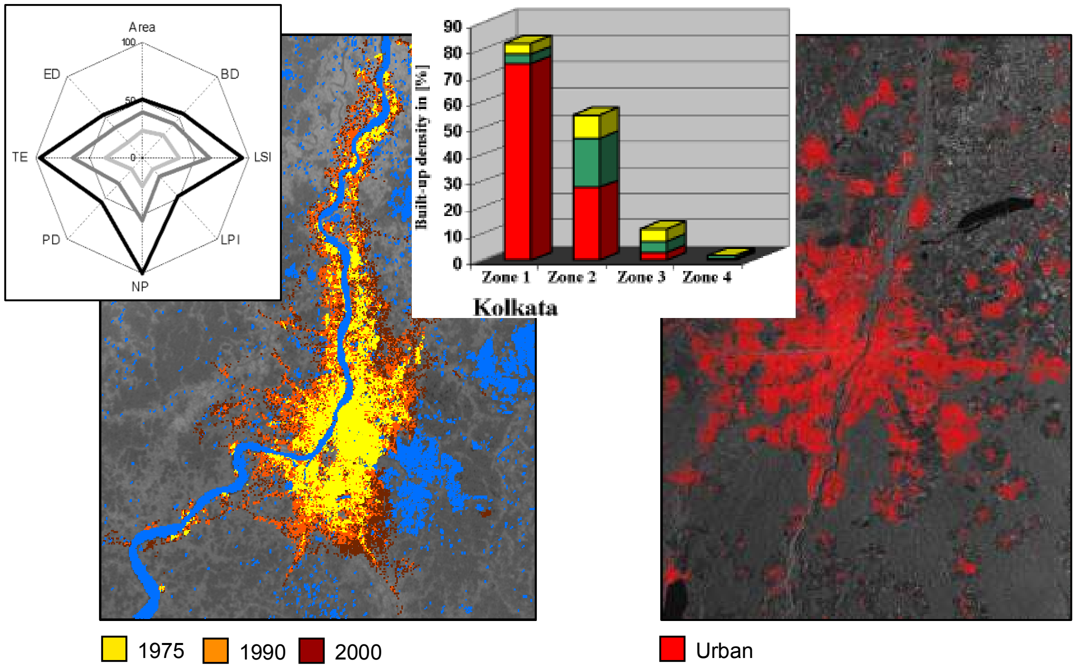

Fig. 1: Time series analysis of Landsat data for Kolkata, India (left), and urban footprint of Munich, Germany, derived from TerraSAR-X data (right). The spider diagram for Kolkata shows the development of different landscape metrics from 1975 – 2000.

2.2 Mapping of impervious surface

Most developed and emerging nations are confronted with a constantly increasing loss of land resources due to rapidly growing settlements and infrastructure. This development is closely associated with various negative consequences and therefore impervious surface (IS) is increasingly recognized as a key indicator for assessing the sustainability of land use changes due to urban growth. However, concepts and methods for a regional or state-wide quantification and assessment of IS in an accurate, fast and cost-effective way are still rare. Esch et al. (2009) presented a semi-automated approach towards a large-area assessment of IS based on an integrated analysis of single-date Landsat-7 images and geospatial vector data. The developed procedure includes three main steps: (1) the modeling of the percent impervious surface (PIS) based on Landsat-7 images, (2) the supplementation of the resulting imperviousness raster by line features providing information on small-scale infrastructure such as roads and railways and (3) the aggregation of the imperviousness layer to administrative boundaries of municipalities.

The estimation of the PIS for each pixel of the Landsat image is performed by means of a training area covering a region of 15x10 km. The reference information for this training site is provided in form of a manually digitized map of impervious surfaces which was derived from aerial images. Based on this binary mask a regression model is calculated using the support vector regression (SVR) functionality of Support Vector Machines (Vapnik, 1998). Thereby, the spectral information of all Landsat bands is correlated with the PIS provided by the reference data set. By applying the resulting model to arbitrary Landsat images – each image covers around 185*185 km – the PIS can be estimated for an extensive area. In order to accelerate the analysis and – at the same time – improve the accuracy of the modeling, the analysis of the Landsat data is specifically focused on residential, industrial and transport areas. The information on the position and extent of the corresponding regions is provided by vector data of the German Official Topographic-Cartographic Information System (ATKIS). At the same time this vector data serves as a basis for the integration of linear infrastructure such as country roads or railway tracks which can not be detected properly by the Landsat data showing a ground resolution of 30*30 m per pixel. Hence, the impervious surface raster estimated on the basis of the Landsat data is combined with ATKIS vector information on linear infrastructure (object categories 3100 and 3200) (Fig. 2, right). Thereby each category is assigned with a specific width and PIS. By combining the impervious surface raster derived from the Landsat data with the vector information on linear infrastructure, the total IS can be calculated. In Figure 2 (left) this information is finally aggregated to the administrative units of the German municipalities. The validation of the impervious surface raster derived from the Landsat data based on reference data of different cities showed a mean absolute error between 15-20 % and a mean error between 0.5 and 1.0 %. For the PIS provided on a block by block basis for the city of Munich, reference data shows a mean imperviousness of 54 % whereas the modeled PIS came up to 50 %. The final product showing a combination of the impervious surface raster and the linear infrastructure (roads and railways) could be validated on the basis of reference data provided by the city of Passau. According to this reference 15 % of the municipality is covered by IS whereas the model-based estimation gave a value of 16 %.

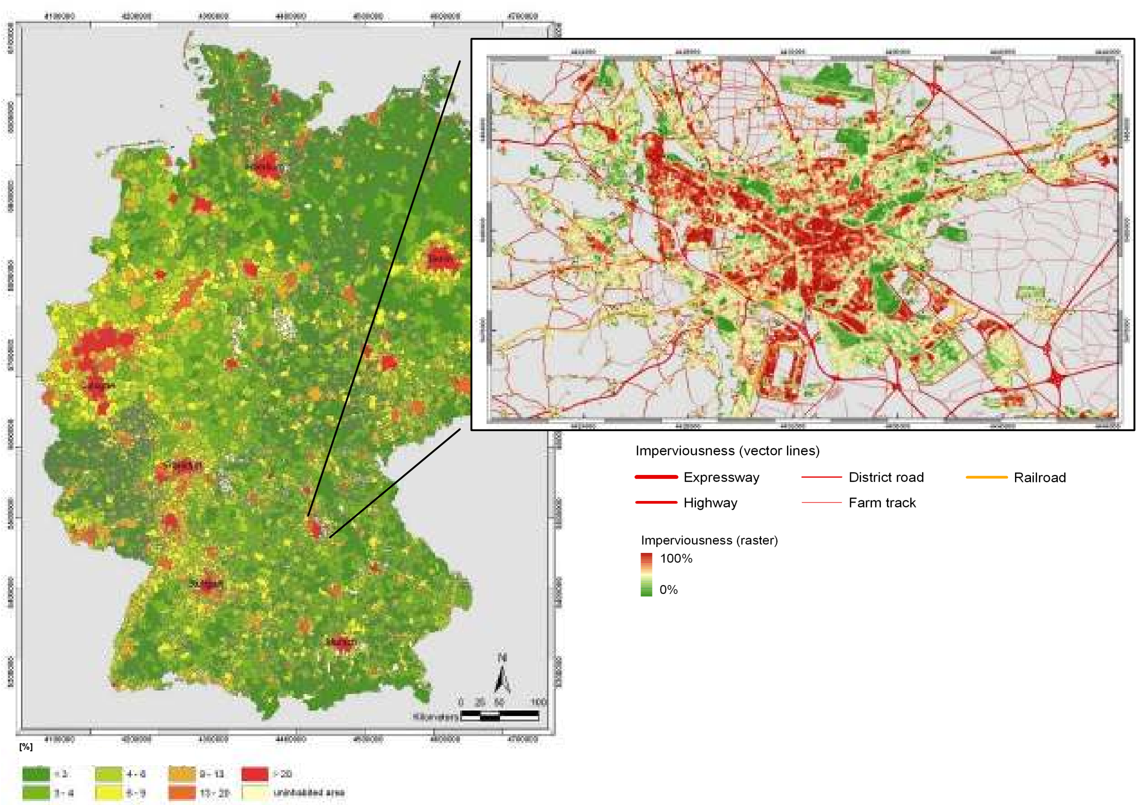

Fig. 2: Modeled percent impervious surface for the German municipalities (left) and subset of the underlying imperviousness data set (right), here showing the city of Nuremberg, Germany

The results of the study document that the proposed approach is qualified for an area-wide mapping of the PIS. The method provides spatially detailed and precise data on the characteristics and distribution of IS for large areas. The advantage of the presented technique lies in the ability of a fast, area-wide and at the same time spatially detailed and accurate mapping of IS – requirements that can not be met with existing reporting based on official statistics or survey. Moreover, the information on IS can be addressed at almost arbitrary spatial or administrative units. The approach also guarantees the mapping and assessment of IS by constant and objective rules - a key issue for regional or national surveys. The design of the developed approach facilitates the use of very high resolution data such as Ikonos and QuickBird imagery or aerial photographs instead of Landsat data. Thus, the level of detail can be further increased in order to meet the demands of municipalities with respect to the spatial resolution of corresponding analyses.

2.3 Urban structure analysis for local heating potential assessment and urban micro climate modelling

Remote sensing technology has not only the power to provide fundamental data for analysis on regional city level, but also to provide data in a very high level of spatial detail for local analyses. By integrating diverse information from various kinds of remote sensing sensors, a detailed characterisation of the complex urban landscape becomes possible. The identification of small single urban structure elements requires an appropriate geometrical resolution of the remotely sensed data. Spaceborne imagery has gained increased weight in the interpretation process since the sensors are able to dissolve objects with a size of one meter or less (Donnay et al., 2001). By means of these very high resolution optical satellite images, the components of urban landscape may be described. Open spaces, streets and individual buildings are the “bricks” of every urban environment. Classical thematic interpretation of monoscopic imagery allows the identification of these objects, but, despite indirect estimations (Hartl & Cheng, 1995), may not result in deeper, physiognomical information of the physical structures. However, characterisation of the three-dimensional urban landscape requires the integration of additional surface information. A digital surface model from the High Resolution Stereo Camera – Airborne Extended (HRSC-AX) as well as as IKONOS imagery is utilised for the derivation of a highly detailed 3-D city model. It is the basis for further urban structure analysis as well on single building as on block level. Additionally, it serves as input for local heating potential assessment and together with hyperspectral HyMAP data as input variables for modelling the urban microclimate.

The urban structure is a composition of single elements and may be mapped scale-dependantly. While for long-term spatio-temporal analysis the regional level is sufficient, analyses on the local level demand a very high geometrical resolution of the data sets. For the characterisation of the physical urban structure we developed a transferable, object-oriented workflow which can be applied on various urban areas. The result of the workflow is a 3-D city model with thematic representation of various landcover types and physiognomical characteristics of the single structure elements. The remote sensing data base for the presented workflow consists of very high resolution optical satellite imagery (IKONOS) and a digital surface model (DSM) derived by automatic photogrammetric analysis of HRSC-AX data (Scholten et al., 2003). A segmentation procedure is applied on the data with the result of a building mask, where each individual building is represented by a segment and an average height value. Hence, a physiognomical description of each individual building is possible due to its individual shape and size (area and height).

After derivation of the buildings, the optical data set is processed. This workflow follows a segmentation optimisation and landcover classification process which have been described by Esch et al. (2008), Taubenböck et al. (2010) and Wurm et al. (2010), resulting in a 3-D city model. This model includes individual buildings and various types of landcover such as ‘streets’, ‘sSealed areas’, ‘soil’, ‘trees/bushes’. ‘grass/meadow’ and ‘water’. Figure 3a represents a subset of the city center of Munich, Germany, in 3-D view showing various types of urban structures with different physiognomical characteristics as well as the “natural furnishing” of the city.

Information on the urban structures is also relevant for analyses in the context of local heating. The heat supply for residential buildings and for buildings of the public and private service sector is primarily based on the usage of fossil energy sources. These are often burned in old boilers with poor efficiency and high emissions. For a sustainable energy supply, which considers the finiteness of fossil resources as well as the drastic impact of an increasing emission of greenhouse gases, the usage of renewable energy resources and trigeneration is essential. In this context, small scale power grids are an important component for the technical heat allocation (Nitsch, 2008).

To use the outlined perspectives for regional planning, economic decisions, and the search for best suited locations, a spatial model is needed. Previous models are limited by their spatial resolution (Fischedick et al., 2007) or can only be applied for selected reference model cities or cities with more than 20000 inhabitants (Lutsch et al., 2004). Our goal was to combine these requirements by analysing how potentials for local heating can be assessed with a high spatial resolution, area-wide processability as well as transferability.

Roth (1980) and Winkens (1984) show the relation of settlement structure and heat distribution systems and describe the associated specific costs. Fischedick et al. (2007) adapt this relation by identifying structural types that are relevant for local heating, with characteristic shares of building types, building usage, and period of construction, plus related costs for the infrastructure. This study is the basis for our assessment of potentials for local heating and gives reference values for several model parameters. A detailed description of the methodology is given in Geiss et al. (2010).

The main parameter of the model is the annual heat demand of the buildings. The heat demand correlates with the building volume and a specific heat demand coefficient. The heat demand coefficient in turn represents an idealised value, which is dependant on the building type and the age and usage of the building. The volume of a building is directly derived from the 3-D city model. The building type was determined by physiognomic characteristics. The usage of a building and period of construction can hardly be predicted solely using remote sensing data. Additionally, the economic costs of the necessary heat allocation infrastructure are estimated: costs for the small scale power grid, connections to the buildings, and transmission stations for every building. To quantify only the additional costs for local heating, costs for a conventional heat supply (oil or gas boilers) are subtracted. Typically small scale power grids are laid along streets. With a street network the length of the power grid and the connections to the buildings can be estimated.

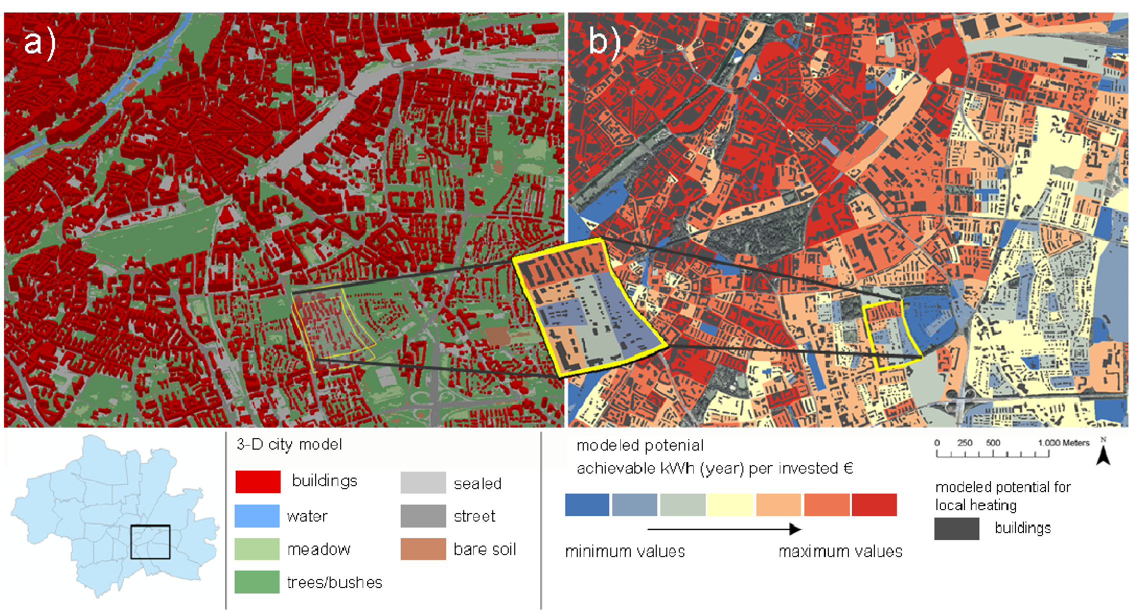

Fig. 3.: 3-D city model from the city center of Munich (a) and derived local heating potential (b)

With this information a specific value can be determined, which characterises the regional conditions for local heating on building block level. By dividing the annual heat demand of the buildings by the needed infrastructural investment costs, the achievable kWh/a per invested Euro can be quantified
Fig 3b shows the modelled potential for local heating for a subset of the city center of Munich, Germany. Remarkable is the decline of the potential values from central areas to outlying quarters. This is primarily due to above-average sized buildings in the centre, which causes, in combination with relatively short power grids and connections lengths, high potential values. Districts in the outskirts with a high share of detached houses have relatively low potential. This does not mean that these areas are generally not suited for local heating, but to be seen in the context of the shown area and the very favourable, alternative locations. Areas that are characterised by a heterogeneous building structure also show a high variability of potential values (see Fig 3, enlarged building blocks). The aim of this work is to show the surplus of the interdisciplinary combination of remote sensing and energy relevant questions. The developed method can be useful to identify suitable locations for local heating and determine the possibilities of local heating in general for several areas. Further research will focus on the improvement and enhancement of the used parameters and validate the accuracy of the predicted potentials with in-situ datasets.

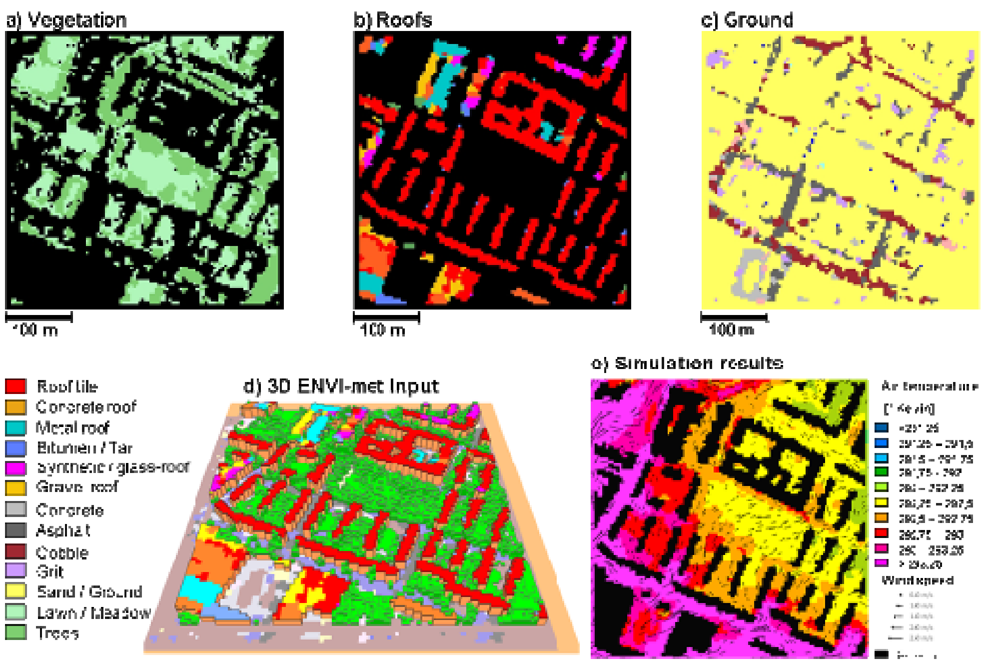

Fig. 4: Input variables for ENVI-met derived from HyMAP and HRSC data and simulated air temperature.

The urban area itself - and finally also the single urban structure - is responsible for different climatic characteristics in contrast to its surroundings. Densely built-up areas, reduced vegetation, emission of air pollutants and waste heat lead in cities to a higher average temperature, lower humidity and less wind speed. The local climate is influenced by the city on several scales. On the regional level an urban heat island effect can be identified. The urban structures, their alignement and their surface characteristics have influence on the local climate conditions in terms of air temperature, wind, humidity and air quality (Kuttler, 1998). Hence, these characteristics influence the climatical well-being of inhabitants and are therefore important for urban planning. By means of micro-climate models various planning-scenarios can be simulated regarding their influence on the urban microclimate (Bruse & Fleer, 1998).

For measuring effects on the local climate, area-wide information is needed. Traditionally, these data have been collected by field trips, being a very laborious and cost-intensive work. With airborne hyperspectral mapping, an objective and fast method is available for the retrieval of information on surface materials. These indicators serve asinput variables for the ENVI-met microclimate-simulation model developed by the University of Mainz. On the basis of numerical models, climate parameters like air temperature, humidity, wind direction and wind speed are calculated as well as the predicted mean vote (PMV), which is a measure of comfortness (Fanger, 1970). First, a spatial description of the study area is implemented. Location and height of individual buildings as well as vegetation is represented in a threedimensional raster. Based on that, various vegetation characteristics, thermal and hydrological characteristics, soil type characteristics and specific roof characteristics are integrated. The corresponding information is derived from interpretation of hyperspectral HyMAP imagery. Fig.4 presents model input parameters and a result of a 24h climate simulation for a test area in Munich, Germany. While differences in the absolute temperature are marginal, the shielding influences of building structures in the lower left corner are obvious. Additional information about this study can be found in Heldens & Heiden (2010).

2.4 Assessment of vulnerability and risk

The past decade proofed the vulnerability of the urban areas acrros the world to natural hazards. Examples are the dramatic impacts of hurricane “Katrina” in New Orleans 2005, of the earthquakes in Sichuan 2008 or Haiti 2010. Risk results from a future interplay of a hazard and an environment, which is characterized by various components – physical, demographic, socioeconomic, etc. – defining the vulnerability. Problems associated with hazard and vulnerability identification, risk assessment, and developing mitigation solutions are inherently spatial in nature (Taubenböck et al. 2008). Especially urban environments are characterized by a small-scale heterogeneous morphology and a highly complex and dynamic pattern (cp. Fig 3). According to this, risk and vulnerability changes spatially with subject to a plurality of location factors or rather indicators. Remote sensing enables both the assessment of indicators related to the hazard and the assessment of indicators related to vulnerability and thus serve as a powerful instrument for decision makers in disaster management (Taubenböck et al. 2009b).

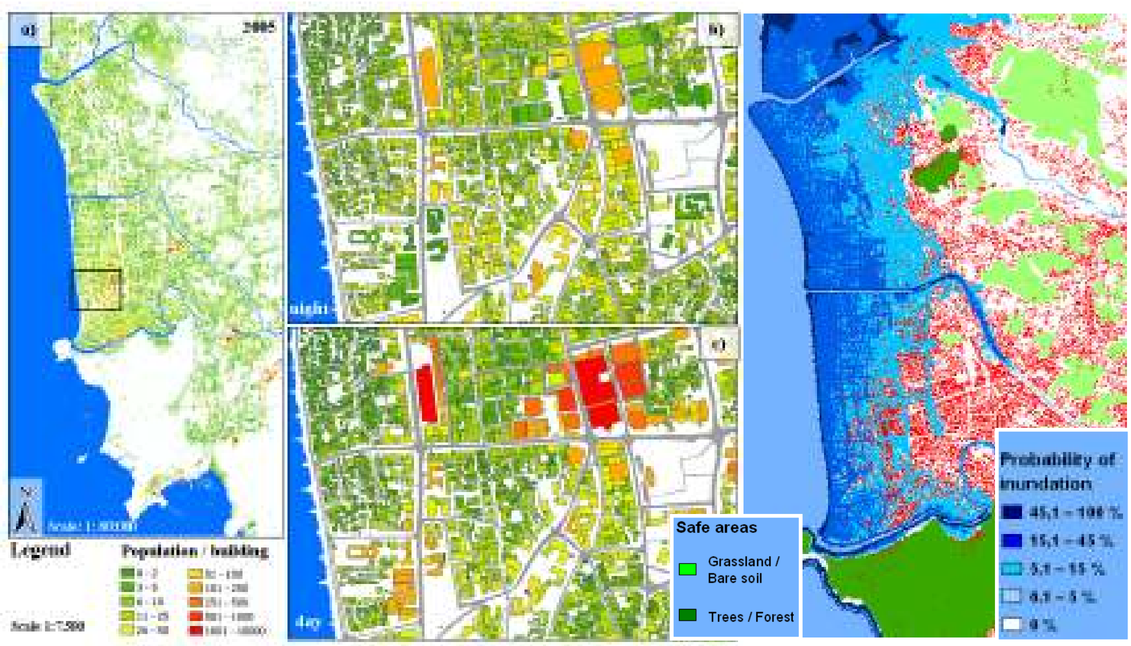

Fig. 5: Building mask, nighttime population distribution, inunadation modelling and derivation of safe areas

Assessing risk and vulnerability on highest resolution the small-scale urban structure defined by the heterogeneous physical alignment and characteristics of buildings, streets and open spaces is derived from high resolution satellite data. We integrate the third dimension, assessing building heights using a digital elevation model. These data can be generated by airborne LaserScanning or in our case by an airborne Multi Functional Stereo Camera (MFC). Thus a three-dimensional city model has been derived (Taubenböck et al, 2009b). Furthermore, knowledge of the physical structure of urban morphology can be utilized to indirectly derive further parameters crucial for risk management. The basic idea behind inferring the population distribution is based on a correlation between the structural characteristics of the urban environment and its population. In combination with land use knowledge the capabilities of remote sensing enable to calculate dynamic behavior of urban population (Taubenböck et al. 2007). Inunadation modelling (Goseberg et al, 2009) combined with the e. g. the building mask or the population distribution allows quantifying houses at risk or vulnerable people (Fig. 5). Thus it allows the identification of safe areas and the derivation of the the main street network is basis to model evacuation scenarios (Lämmel et al. 2008) or analyze bottlenecks for accessibility.

3 Conclusions and outlook

The constantly increasing availability and accessibility of modern remote sensing technologies has provided new opportunities for a wide range of urban applications such as mapping and monitoring of the urban environment (land cover, land use, morphology, urban structural types), socio-economic estimations (population density), characterization of urban climate (microclimate, human health conditions), analysis of regional and global impacts – (ground water and climate modelling, urban heat islands) or urban security and emergency preparedness (sustainability, vulnerability). The objective of the joint research initiative between DLR and University of Würzburg in terms of urban applications is to address issues of needs and the potential of remote sensing technologies and data for diverse stakeholders dealing with issues in environmental protection, urban and regional planning or resource management.

In this paper we have introduced a selection of applications and example products which have been developed in the context of this initiative in order to provide additional and innovative data that might support day-to-day decision-making of local and state governments. We could show that one basic challenge of an (semi-)operational analysis of urban agglomerations by means of remote sensing techniques and data respectively is related to their spectral heterogeneity and morphological complexity. The spectral heterogeneity originates from the enormous diversity of different materials forming the urban landscape. Thereby, some land cover types such as vegetation, bare soil or water are also found in non-urban environments. Moreover, certain surfaces – for instance bare soil and specific construction materials of buildings or pavements – can hardly be differentiated from each other through their spectral signature. Regarding the morphological complexity, urban areas are characterized by structural elements featuring diverse scales and shapes. In order to accurately capture the morphological properties of urban objects a very high spatial resolution of the sensor system and images respectively is required. However, although an increased spatial resolution certainly expands the spectrum of urban application this development comes along with new challenges in terms of an automated image analysis. On the one hand the observable heterogeneity within the specific object types increases significantly since many local, but often non-relevant characteristics appear – e.g. roof lights and chimneys on top of building or cars, street furniture and sign-postings on streets. On the other hand urban features are hence formed by a group of pixels with a similar spectral signature. To address the mentioned challenges arising from an improved spatial resolution recent studies have increasingly used object-oriented analysis approaches. Compared to the established pixel-based approaches these techniques facilitate an improved consideration of spectral, geometric and textural, contextual and hierarchical characteristics.

The previous remarks regarding urban remote sensing stress that the appropriate approach, technology and data are highly dependent on the thematic focus and the spatial scale of the analysis. Medium resolution multispectral data – e.g., Landsat, Spot, IRS - are best suited for regional analyses since they cover areas of up to 32,000 km^2 with one image ensuring cost-effective analyses. At the same time the spatial resolution is still sufficient to discriminate built-up areas from non-urban regions based on spectral and textural characteristics. Due to their direct link to morphologic properties high and medium resolution SAR images provide particularly robust features for the detection of settlements. However, the applicability of SAR data for local analysis of the urban structures is still limited since the complex geometrical and physical characteristics of metropolitan areas and the varying appearance and visibility of objects subject to the line of sight (LOS) lead to significant distortions of and ambiguities in the resulting radar images.

To cope with the entire heterogeneity and complexity of urban areas very high resolution multispectral systems such as Ikonos or QuickBird are required. Their sensors provide images in four spectral bands featuring a ground resolution of 4 m (Ikonos) and 2.44 m (QuickBird) supplemented by a panchromatic channel with a geometric resolution of 1 m (Ikonos) and 61 cm (QuickBird). A drawback of this data is the limitation of the spectral resolution to four bands – only facilitating a very rough reconstruction of the spectral signature – and the limited spatial coverage of a few hundred square kilometers by one image. Hence, analyses of complete metropolitan areas, major or mega cities demand a data volume which significantly increases the complexity and expense for image processing and classification. The immense spectral resolution of hyperspectral sensor systems enables thematically comprehensive and spatially detailed characterizations of the urban environment. However, current hyperspectral sensor systems showing a spatial resolution which is useful for urban applications are limited to airborne platforms. The first high resolution hyperspectral satellite sensor – EnMAP - is supposed to be launched by 2012. This system will feature a spatial resolution of 30 m and cover the spectral range of 420-2450 nm with about 200 bands (Kaufmann et al., 2006).

The synchronism and coexistence of economic activities, environmental threats, infrastructural deficits, poverty and population growth mark a significant challenge to urban planning. Therefore future research has to focus on integrated interdisciplinary studies to understand the multi-dimensional and complex interactions of urban systems and to analyze and assess the effects of plans, actions and concepts. An important step towards the improvement of the generated information products and their acceptance by decision makers consists in the adaption to holistic approaches on complex urban systems. Hence, the according concepts have to integrate and correlate multiple analysis tools (image analysis software, GIS), data types (satellite images, vector data and statistics) and data sources (EO, survey, census). The synergetic use of various data sources and their combined analysis increases the quality and information content of the resulting products, opens new levels of information and enhances the possibilities of integrating the resulting data and information into existing systems and concepts. First prototypes of such interdisciplinary approaches are presented in this paper – e.g. by combining results from remote sensing with data from civil engineering or demographic census. However, in view of regional, national or even global monitoring tasks there is still some effort needed with respect to the availability and accessibility of remote sensing data and the operationalization of image processing and analysis in order to allow for cost- and time-efficient analyses and a rapid provision of the required information. Thereby new sensor systems such as RapidEye and Geoeye will improve the capabilities of urban remote sensing application, particularly in terms of providing detailed time series of multispectral imagery.

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