ASSESSMENT OF URBAN LOCATION FACTORS FROM REMOTE SENSING

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ABSTRACT

Highly-dynamic, explosively and unmanageably growing megacities arise throughout the world. This rapid alteration within the urban environment often results in a lack of reasonable information for city planning, risk management or site selection. In urban areas conventional techniques for data collection through field work or census are too time-consuming and cost-intensive. Remote sensing of urban areas with a high spatial resolution has the potential to deliver up-to-date area-wide information about the urban morphology and to infer indirectly additional socio-economic parameters. This paper presents the workflow, from the original IKONOS imagery to a land cover classification and to a structuring of homogeneous zones within the city, based on similar urban morphology. Results show a 3-D perspective of alignments, structures and densities of urban areas. Supported by field work data the allocation of homogeneous zones serves for an area-wide computation of the population density distribution as an example for the inference of a socio-economic parameter. GIS-Layer of the built-up areas as well as census data are the basis for an accuracy assessment of the classification result and the population density. The collation of diverse location factors derived from remote sensing eventually leads to an assessment of a location at the test-site Üsküdar, a quarter on the Anatolian side of Istanbul, Turkey.

1. PROJECT OVERVIEW

In the context of the HGF-EOS (Helmholtz-Research-Network, Earth Observing System) project “Megacities and natural disasters” the overall goal of this study is the combination of value-added remote sensing products and results from ancillary data from building technology and insurance industry for a broader understanding of risk assessment. The first results show remote sensing methods for a differentiation of the city to infer standard data for the assessment of the spatial distribution of vulnerability.

Against the background of regular extreme natural events, catastrophes with dramatic consequences reveal considerable deficits hindering their effective management: Needs include systematic risk evaluation and assessment, a way to assess countermeasures, and a decision support system to be employed before, during and after crisis.

The primary objective of the overall study is to detect indicators of vulnerability using remote sensing and to analyse those data in a Geo-Information-System (GIS) to derive information critical for risk assessment. New methods aim at the assessment of vulnerability in its spatial distribution in highly structured endangered city areas.

2. INTRODUCTION

From a more general point of view, analysing the physical spatial distribution and inferring additional data from remote sensing imageries has a wide application potential. The paper shows possibilities of remote sensing to provide data to support site selection of companies, city planners and location consultants not only for assessment of vulnerability, but also for up-to-date, area-wide city management information.

Highly-structured urban areas are a complex entity of unequal location factors. Especially megacities in developing countries are growing rapidly, not only in terms of population but also in terms of economic importance. Application-independent, current spatial information is needed in order to make decisions concerning assessment, planning or management. High spatial resolution remote sensing data is capable of delivering information about locations within complex urban areas, for site selection support, city planning or risk management. This paper summarizes the workflow, from a high resolution satellite image to the urban land cover classification, to the derivation of homogeneous zones within urban morphology and to the final inference of location factors. As an example for an indirect inference or assessment of socio-economic data the computation of the population density distribution is presented. GIS-Layer and census data serve as basis for an assessment of the accuracy of the results.

Partial stages of methodologies have already been presented. Methodologies to classify high resolution remote sensing imageries with an object-oriented approach have already been shown by *BAATZ ET AL. (2000)* or *VAN DER SANDE ET AL. (2003)*. *BARR ET AL. (2004)*, *HOFFMEYER-ZLOYTNIK (2000)* and *WU (2003)* verified the assumption that urban pattern or morphology correlates with urban function as well as with a social-economic parameters. *ANAS ET AL. (1998)* defined homogeneous urban zones and *DONNAY ET AL. (2000)* connected an urban land cover product with population estimation.

The paper eventually lists location factors solely produced from remote sensing. This leads to a final assessment of a location at the test-site, Üsküdar, a quarter of the megacity Istanbul in Turkey.

3. DATA

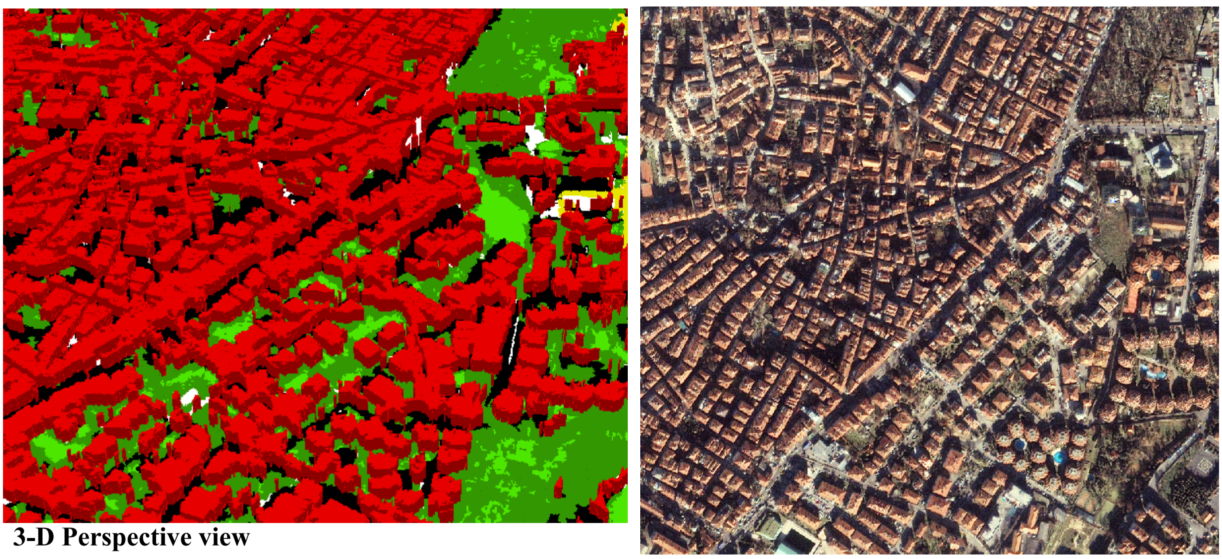
For a sufficient assessment of location factors within heterogeneous city structures high spatial resolution satellite images are necessary. IKONOS images feature a geometric and radiometric quality of 1-m panchromatic, 4-m multispectral and 1-m pan-sharpened imagery. For this study an IKONOS imagery taken on December 20th 2003 from the centre of Istanbul has been chosen as test site. Istanbul as a highly dynamic and rapidly developing megacity, located on the transition area between Asia and Europe with its estimated 14 million people, lives through enormous demographic, cultural and economic changes.

4. METHODOLOGY

The paper presents an overview of the workflow, from the original satellite image to the classification of land cover, to the structuring of homogeneous zones and to the calculation of the population density. It focuses on the correlation between homogeneous zones within an urban environment and the inference of the indirect location factor 'population density'. A sampling through field work provides the original data, which are converted from point information into area-wide data through spatial averaging in their particular homogeneous zone. The field work data as well as data census data are used for an accuracy assessment of the derived location factor 'population density'. Finally direct and indirect location factors are calculated at a test site for an assessment of this position within the urban environment.

4.1. Classification

To analyse urban morphology or urban pattern characteristics, the original IKONOS imagery has to be classified. An object-oriented approach has been implemented. For this purpose the first step contains a reasonable segmentation of real world structures. The segmentation concept is that important semantic information necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relationships *(BAATZ ET AL. 2001)*. Subsequently, the objects can be classified not only by spectral characteristics, but also by spatial and neighbourhood attributes. The classification result is the basis for a further analysis of city morphology. An accuracy assessment of the classification compared to a GIS-Layer of built-up areas resulted in a detection of 82% of the houses. Figure 1 shows a 3-D view of the urban land cover classification. Different alignments und structures within urban areas, densities of built-up areas and their transitions as well as open spaces are elaborated.



3-D Perspective view

Thematic classes:

built-up areas **shadows** **lawn** **trees/brushes** **main roads**

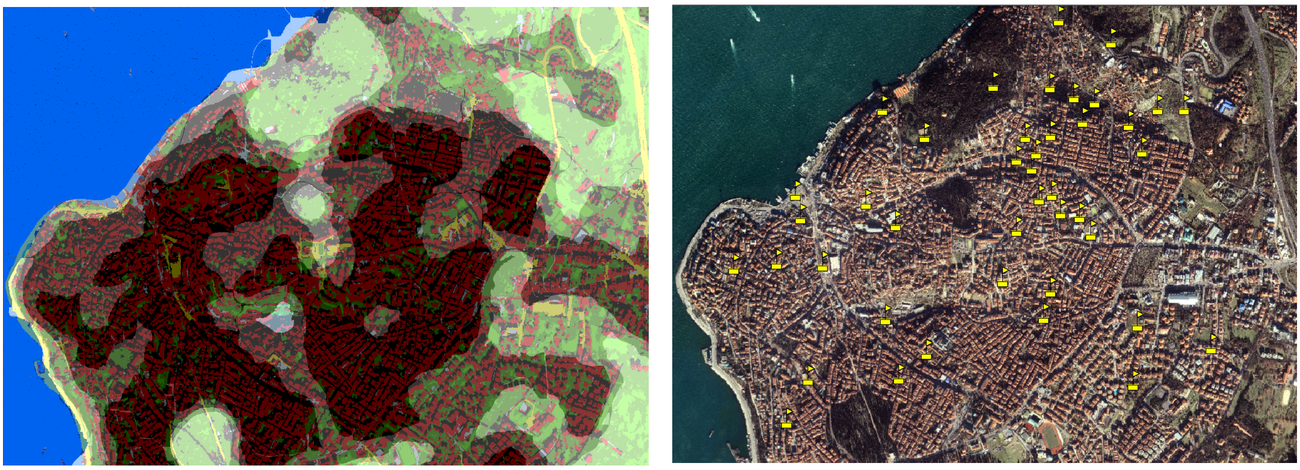
Figure 1: 3-D view of alignments, structures and densities of urban areas compared to IKONOS imagery.

4.2. City structuring

The distinction of homogeneous zones within the complex urban morphology enables the spatial projection of standard parameters to assess location factors. Therefore, the challenge consists in detecting internal characteristics of the urban agglomeration and constructing spatially continuous socio-economic data sets that can be combined with the digital remotely sensed value-added product. To classify homogeneous zones the rules of grouping or zoning are, according to *ARNHEIM (1954)* and *WLODARCZYK (2005),* based on similarities like size, orientation, location, shape, configuration, colour, material, texture and function. These might be the factors which facilitate the distinction. The city structuring in this paper has been computed by different physical parameters derived from the land cover classification. The built-up density, vegetation rate and the location proportional to main infrastructure and the city centre have been calculated for an allocation of homogeneous zones within the city. The calculated density values have been segmented for an object-oriented approach to derive homogeneous density areas. Figure 2a shows the result of the statistical calculation of density parameters and the allocation of homogeneous zones within a complex urban morphology. Most of the applications in the field of zoning urban areas with remote sensing still rely on ancillary data for pre-defined borders like, for example, a road-layer from GIS-data pools or the use of an artificial grid pattern to generate quadrants to compare urban morphologies. The advantage in this approach is that homogeneous zones have been created from solely remote sensing data.

4.3. Field work

The allocation of homogeneous city morphology zones gives the opportunity to assess area-wide location factors indirectly. Therefore, a questionnaire has been carried out in pre-defined city structures of Üsküdar, a quarter on the Anatolian central side of Istanbul, to investigate if homogeneous city structures correlate with certain location factors like for example 'population density'.



Built-up areas: High density; Dense; Loose; Open space

Area shown in Figure 1; Sampling distribution

Figure 2: Homogeneous city zones computed with physical parameters
a) Automated density distribution *b) Distribution of field work data acquisition*

A quadrant sampling method in the central part of Üsküdar has been realized, to spatially represent the pre-defined homogeneous city zones. This sampling methodology enables an equal sampling distribution in the case area. Data about day and night time population have been acquired, as well as other socio-economic factors like household income level. Figure 2b shows the sampling and the spatial data collection distribution.

The determination of the spatial distribution of population densities is a mandatory location factor for any management and planning operation. Consequently, there is a need for an alternative, fast, area-wide, inexpensive and reliable source of demographic information, to which remote sensing can contribute. A method for estimating population density has been presented by *DONNAY ET AL. (2000)*. The approach is based on the hypothesis that population density can be estimated from homogeneous housing areas, and that those areas showing nearly similar housing conditions will have homogeneous social and demographic characteristics. A similar land area density technique has been presented by *PAULSSON (1992)*. Various types of residential land use areas are multiplied by average population densities for each type.

4.4. Population density spatial averaging and its accuracy

Spatial averaging comprises the calculation of the average number of inhabitants per unit in a special homogeneous zone. The outcome will be calculated for the whole area of the homogeneous zone. This gives an assessment of the absolute number of inhabitants in this part of the city.

Starting point for the calculation of population density is the computation of an area of a homogeneous zone and its proportion of areas classified as houses. An average determination of the size of the houses in the particular zone has been assessed by a sampling of the classified IKONOS imagery. The average inhabitants living per house has been acquired by the described field work. From the quantity of houses and the average population densities, area-wide zone computation of inhabitants has been computed.

$$\textbf{Inhabitants / Zone} = \frac{\textbf{Area of houses per zone [m}^2\textbf{]}}{\textbf{Average size of houses [m}^2\textbf{]}} \; \textbf{* Population per house}$$

The outcome of the population assessment is for the central high dense built-up area in Üsküdar a population density of 36,000 inhabitants per km², in dense built-up areas 26,000 inhabitants per km² and in low dense built-up areas 6000 inhabitants per km².

Remote sensing is not able to deliver absolutely accurate census data. In fact, the question is, if the assessment of the example population density matches the dimension of the real world. An accuracy assessment is difficult because of a lack of reliable data. A census in 2000 in the whole quarter Üsküdar in Istanbul resulted in a population density of 12,837 inhabitants per km². For this analysis, only the central old part of Üsküdar was part of the sampling of the field work because the IKONOS imagery from 2003 displayed only this area. In this central high dense areas of old Üsküdar the result from the remote sensing analysis are 17,000 inhabitants per km². This seems to be a close approximation to the real values due to an expected higher population density in this central part with higher building density and lower portions of open spaces then in the peripheral areas of the quarter.

4.5. Assessment of location factors

From the physical zoning of the city described above, the location factors built-up density, vegetation rate, location and open space analysis are directly computed from the high resolution remote sensing IKONOS imagery. In addition, a DEM (Digital Elevation Model) from the SRTM Radar Mission has been used to analyse the terrain situation. Socio-economic data sets are equally important for any application in the fields of city planning and managing. Based on the physical zoning an indirect derivation of the socio-economic parameter population density has been taken into account. As an example a laminar projection of the population density has been computed. An example location (shown in Figure 3) from the test site Üsküdar has been chosen to demonstrate the assessment of location factors derived from remote sensing in table 1.

Location factors	For example location in Üsküdar (Figure 3)		
Densities	Homogeneous Zone	Vegetation rate	Built-up rate
	Central high dense built-up area	5 %	50 %
Population	Inhabitants/km²	Absolute number of inhabitants in 2.5 km ring	Day population/km²
	17,000	161,000	10,000
Location	Distance to centre of Üsküdar	Distance to superior road	Distance to CBD Istanbul
	0 km	2,2 km	5 km
Terrain	Height	Inclination	
	58 m	3 %	
Open spaces analysis	Portion of open spaces in 2.5 km ring	Proportion from open spaces < 10 % slope	
	16 %	60,2 %	

Table 1: Location factor assessment for an example location in Üsküdar from remote sensing.

The listing of the assessed location factors is supported by a visual presentation.

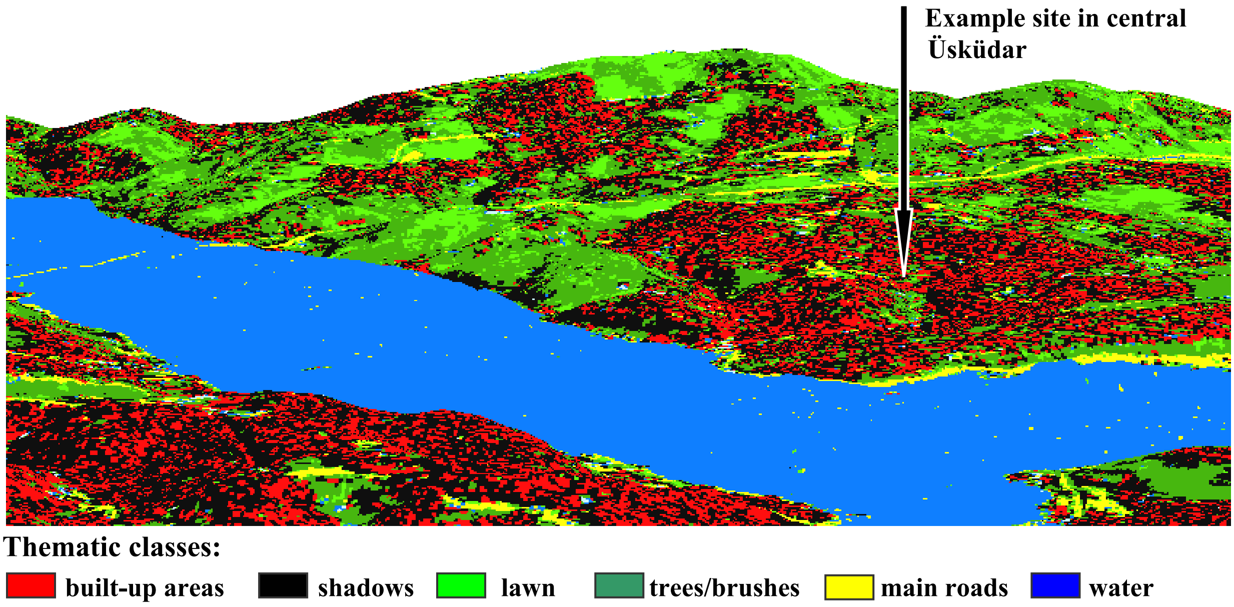


Figure 3: Visual simulation of location factors – View across the Bosporus to the quarter Üsküdar.

Figure 3 shows a view over the Bosporus to the hilly Anatolian side of Istanbul and its quarter Üsküdar. It emphasises the importance of the inclusion of a DEM and shows the distribution of built-up densities and its decrease with an increase of distance to the centre.

A fast, area-wide assessment of location factors can support the site selection as well as information management for city development. A location decision is determined by high complexity and uncertainty (*Taubenboeck et al.* 2005). Therefore, a prospective settling of a company has to withstand certain decision criteria, but for a lot of possible locations, especially in explosively growing megacities, the information for a substantiated decision is missing. The analysis of the example site highlights that it is a high dense built-up area with a high population density. Besides, its central location appears to be highly accessible through the main highway and the waterway and contains a high customer potential. Although it is a high density living area, open spaces within the urban environment are within a small range. Depending on the individual importance criteria of a company, location factors like location, accessibility or population density can be balanced for a reasonable location decision.

Further indirect inferences can now be performed. For example, the location factor difference in Üsküdar between day population and inhabitants indicates that the area is predominantly a central residential area. In addition to this, *Wu (2003)* shows the importance of an open space analysis for development and attractiveness of a city. The analysis of residential housing prices consistently reveals an inverse relationship between housing prices and distance to urban environmental amenities *(Wu, 2003)*. This shows one direction of the assessed physical location factors from remote sensing for further analysis steps.

5. Summary and Conclusion

The workflow from a high resolution satellite image, the urban land cover classification process, the derivation of homogeneous zones within urban morphology and the final inference of location factors has been summarized. The result shows capabilities of high spatial resolution remote sensing imagery for the assessment of location factors. Independent of the application, these location factors is considered to be central information, useful for city planning, risk management or site selection. The fast, up-to-date and area-wide capability of remote sensing is an essential part for a city effectively managed, and therefore seminal for urban development. The assessment of location factors has been realized exemplary for a site in the quarter Üsküdar on the Anatolian side of Istanbul. The result is a listing of information for an application-dependent individual analysis of the area.

In terms of the HGF-EOS project “Megacities and natural disasters” an accurate assessment of location factors especially in explosively developing urban areas, where data are mostly inexistent, remote sensing can contribute important spatial information. The future research will concentrate on the identification of vulnerability indicators from the presented location factors and the indirect inference of additional socio-economic indicators for an overall risk assessment.

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