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The urban environmental indicator "Biotope Area Ratio"—An enhanced approach to assess and manage the urban ecosystem services using high resolution remote-sensing

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ABSTRACT

The analysis of the environmental situation in urban areas is of higher importance than ever because of the altered urban ecosystem itself and its impacts on ecosystem services for the rapidly growing urban population. A major challenge remains in developing methods to assess and value ecosystem services and integrate them in urban decision-making processes. In this paper, the urban environmental indicator "Biotope Area Ratio" (BAR) is studied. We aim to analyse the benefits and limits of the BAR to assess and manage the urban ecosystem services using high resolution remote-sensing. We choose two urban environmental settings in Berlin and Seoul where the BAR has been already successfully applied. Results show that the BAR as is represents a valuable instrument and augments existing indicators but that there are modifications advisable to address recent challenges of ecosystem services in urban areas. For the successful implementation as a planning instrument we identify the legally required regulation in the planning process and the existence of reliable data as major challenges. The investigated high resolution remote-sensing based approach provides some advantages to map surface types of the urban environment for a first screening, monitoring and evaluation of implemented measures of the BAR and can therefore support existing field mappings. Insights from our study may stimulate developments of explicitly assessing and managing urban ecosystem services using aggregated indicators such as the BAR and may highlight the importance of a more adequate representation of the urban environment in decision-making processes in other cities in the future.

1. Introduction

The world population reached a landmark in 2008: for the first time in history the urban population exceeded the rural population (UN, 2008). The very high intensity and multi-functionality of land use in urban areas modify the local urban ecosystem to a large degree and lead to enormous stress for the urban biotic and abiotic subsystems (Grimm et al., 2008): fragmentation as well as loss of habitats of flora and fauna, soil and water pollution, modifications in the water cycle, and the urban heat island are characteristics of urban ecosystems (Alberti, 2005; Liu et al., 2007; Marzluff et al., 2008; Endlicher et al., 2011). The urban ecosystem vice versa affects the local living conditions of the urban population by environmental pollution and at the same time by the provision of ecosystem services, which are described as "the benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza et al., 1997). In one of the pioneer studies on urban ecosystem services Bolund and Hunhammar (1999) identify six local and direct ecosystem services relevant for a mid-latitude and developed European city: air filtration, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values. Whitford et al. (2001) stress in addition carbon sequestration as a regulatory service and biodiversity as a stabilizing element for the provision of ecosystem services. Following the categorization of the Millennium Ecosystem Assessment (MEA, 2005), regulatory and cultural ecosystem services are hence of particular importance in urban areas.

These recent approaches build upon and augment earlier approaches of urban ecology and urban environmental planning in some European countries such as in Germany to assess and manage urban ecosystem functions and services from the late 1970s (van Kamp et al., 2003; Sukopp, 2008; Werner, 1999; Breuste et al., 2008). In other regions of the world, such as in South Korea or China, assessing the urban ecological situation and

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associated ecosystem services has only recently gained importance (Ellis et al., 2006; Song and Mok, 2004). It is particularly the pressing environmental situation of urban areas in these rapidly developing urban areas which has to be faced (Grimm et al., 2008).

1.1. Indicators to assess urban ecosystem services

While urban decision-making and politics are increasingly aware of the importance of urban ecosystem services for human health and quality of life in cities, the question remains of how to assess and manage these. Within the framework of environmental impact assessment and management, different methods from qualitative to quantitative and monetary approaches have been developed (MEA, 2005; Boyd and Banzhaf, 2007). A well-established approach in environmental management is to use indicators as standardized tools which provide comparable and comprehensible information for a specific planning or management goal. Indicators hence depend on their specific application aims and scales, such as for measuring sprawl or monitoring small-scale urban development (Fricke and Wolff, 2002; Herold et al., 2002; Jaeger et al., 2009; Kasanko et al., 2006; Schwarz, 2010; Yang and Liu, 2005), for identifying large-scale landscape functions in semi-urban areas (Walz, 2008) or for detecting fine-scale land cover heterogeneity (Cadenasso et al., 2007).

One of the successfully and widely applied indicators in urban planning is the sealing degree describing the quantitative proportion of built-up or non-built-up sealed urban surface to the total surface. Since the impervious surface in urban areas heavily impacts ecosystem services, such as climate regulation, air filtering, ground water recharge, habitat of flora and fauna the indicator represents the environment to some degree (Scalenghe and Marsan, 2009). In densely built urban areas, however, where surfaces are frequently dominated by a very high degree of sealed surface an indicator is needed to augment the information on the provision of urban ecosystem services. More complex indicator approaches which try to integrate different aspects, are up to now focused on methodological development and have only rarely found their way into planning applications (Antrop, 2004; Antunes et al., 2002; Kain and Soederberg, 2008; Kleinschmit and Walz, 2006; Langanke et al., 2007; Lausch and Herzog, 2002; Schwarz, 2010; Whitford et al., 2001). Moreover, established indicators focus on assessing and monitoring the system's state while strategic purposes, such as measuring the present and target state on the level of properties, and benchmarking between different areas are only rarely addressed. It remains a challenge to efficiently assess and manage decentralized improvements of the environment on predominately private properties in urban areas (Repetti and Desthieux, 2006).

1.2. Remote-sensing to assess urban environmental information

To implement urban environmental indicators it is essential to assess the necessary information in a reliable, comparable, and affordable approach. Field-surveys to map the urban environmental situation are increasingly supported by remote-sensing based techniques due to their benefits of spatially explicit, area-wide and reproducible information (Carlson, 2003; Weng et al., 2008). The visual interpretation of high resolution color infrared aerial photos for assessing the urban environment was, among others, suggested in the late 1970's by the working group for urban biotope mapping (Sukopp, 1990) and is still being successfully applied (Cadenasso et al., 2007; Hodgson et al., 2003). However, spectral information content is limited in aerial photos and a time- and work-intensive predominately manual procedure is required for covering large areas.

With the current developments in remote-sensing technology, and in particular the availability of very high resolution data, new application fields for assessing the environment in urban areas arise (Hu and Weng, 2009; Antrop, 2004). The growing number of digital multispectral airborne systems, such as High Resolution Stereo Camera (HRSC), Airborne Digital Sensor or Digital Mapping Camera on the one side and satellite-borne systems, such as IKONOS, Quickbird, or GeoEye-1, on the other side offer a spatial resolution up to 1 m or even decimeters. The partly automatical differentiation of surface types and the fast, comparable, and reproducible processing of these digital, multispectral and very high resolution data on wide range urban areas highlight the potential for application in environmental management in urban areas (Herold, 2006; Weng and Quattrochi, 2007). To evaluate these new remote-sensing technologies in regard to their implementation potential in landscape ecological assessment and monitoring is a major challenge nowadays (Cadenasso et al., 2007; Herold et al., 2002; Lang and Blaschke, 2007; Langanke et al., 2005; Linden and van der Hostert, 2009; Lo, 1997; Mesev, 2005; Netzband et al., 2007; Walz, 2008; Weiers et al., 2004; Yang and Liu, 2005).

In this paper, we study an enhanced approach to assess and manage urban ecosystem services using high resolution remote-sensing. We focus on one of the few successfully applied strategic environmental indicators in large-scale urban planning, the Biotope Area Ratio (BAR), which has been particularly developed for highly sealed urban areas (Boetticher and Fisch, 1988). By analysing the implementation of the BAR in two different urban environmental settings, Berlin and Seoul, we discuss the benefits and challenges of the BAR to assess and manage urban ecosystem services and investigate the possibilities of high resolution remote-sensing to map the necessary information on the urban environment.

2. The Biotope Area Ratio

2.1. Development of the Biotope Area Ratio

The BAR was developed as an aggregated environmental indicator to measure the ecological value of highly sealed urban areas within the inner core of West Berlin, Germany in the late 1980s (Boetticher and Fisch, 1988). It was specifically designed to augment the well-established sealing degree by reflecting several ecosystem services in one quantitative indicator to provide a tool for decision-making in environmental planning and management. At that time in the late 1980s and early 1990s West Berlin was one major starting point for urban ecology within Europe and even beyond (Sukopp, 1990). This may be attributed to the isolated situation within the former German Democratic Republic, the presence of higher public funding and a rather specific social and political background of the inhabitants and decision-makers. Furthermore, the legal constitution of landscape planning for urban areas in Germany was established in 1976 with the proposed assessment of the urban environment in the German federal law of nature conservation (BNatSchG §1). Urban areas were explicitly included as one target area of landscape planning. Following this regulation a number of methods to assess the urban environment were developed, such as the method for urban biotope mapping developed in Berlin in the late 1970s (AG Methodik der Biotopkartierung im besiedelten Bereich, 1993). There was also the additional environmental data basis which was made available for different planning instruments in a web-based environmental information system in Berlin (Schneider et al., 2007). The particular interest in urban ecology, the available environmental data and the legally required urban environmental planning provided the ground for the development of the BAR in Berlin.

After more than a decade of experiences with the implementation in Berlin, the BAR – slightly modified to adapt it to local

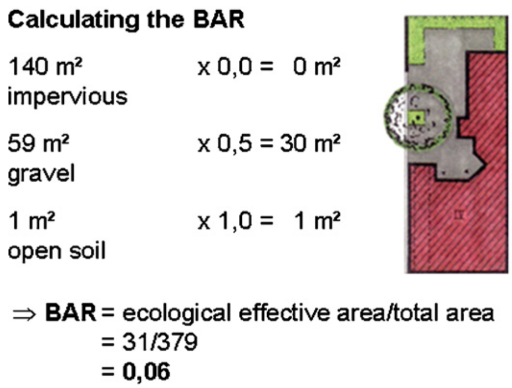


Fig. 1. Calculating the BAR – one example. Modified according to SenStadt (2011).

circumstances – was introduced to Seoul as an indicator for urban planning to support the environmental-friendly urban development in 2002 as well (Kim et al., 2002).

2.2. *An aggregated environmental indicator*

The BAR describes the amount of the ecologically effective surface area in proportion to the total land area (see Fig. 1). It thereby follows the principle of evaluating environmental functions, and services respectively, by assessing surface structures – the concept of landscape metrics or indices (Turner, 1989; Uuemaa et al., 2009). Since it focuses on single properties the BAR addresses the most disaggregated units for decision-making in urban areas.

The sum of the ecologically effective surface area is calculated by differentiating between surface types and assigning a specific weighting ratio according to their influence on the regulatory ecosystem services in terms of microclimate regulation, air filtering, groundwater recharge, rainwater drainage, on the cultural services in terms of residential and living condition, and on habitat for flora and fauna and biodiversity. Surfaces are categorized into ground surface, facades, and roof tops and are then differentiated according to their permeability and connectivity to the ground, and in Seoul furthermore according to water surfaces (see Table 1). The services are related to different surface types by applying a weighting ratio for each surface type. To transfer the BAR from Berlin to Seoul, surface types (e.g. water) and weighting ratios (e.g. greenery on rooftops and facades show lower weighting ratios) were slightly modified to account for relevant surface types and urban ecosystem services in different local settings (see Table 1).

3. Material and methods

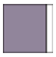
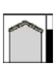
3.1. *The urban environmental settings*

The BAR is studied concerning its aims, methods of data acquisition and application in urban environmental planning in two different rapidly changing urban environments: in Berlin, the capital of Germany, and in Seoul, the capital of South Korea. Berlin on the one hand is one of the greenest cities in Europe, however also with large shares of densely built areas in the inner core. Seoul on the other hand belongs to the most densely built cities in the world. While Berlin has got a population of about 3,400,000 inhabitants/800 km^2, Seoul has got about 10,000,000 inhabitants/600 km^2. In both cities, the BAR has been implemented. Analysing these two different urban systems hence provides the chance to investigate the BAR and the high resolution remote-sensing approach in different urban environmental settings and planning systems. In the following both cities are described in more detail.

In Berlin, the two different political and economical systems in East and West Berlin have led to unique urban structures which have faced major changes of urban land following the reunification in 1989. Nowadays, the city represents a heterogeneous mixture of building structures from the dense late 19th century's block-built structures, socialist architecture, single family housing, and new housing and commercial developments. In the inner city core large-scale and new developments such as the Potsdamer Platz can be observed while at the same time a high number of brown fields still exist. It is particularly the inner core of Berlin where a large amount of areas with a high sealing degree, only few green areas and high population numbers is prevalent. Habitats for flora and fauna are limited in size and quantity as well as in quality and are to a large degree restricted to private properties. In areas with densely built structures extreme hot summer days and heat waves are already prevalent and are expected to significantly increase in the future. Air quality has significantly improved within the last years and neither sulfur dioxide, carbon monoxide, benzol nor heavy metal require measures according to the German guidelines on air quality. However, in densely populated areas in the inner core with high traffic particulate matter (PM10) and nitrogen dioxide are still an issue of concern. High sealing rates are also important in regard to rainwater drainage and groundwater recharge because Berlin relies to a 100% on water supply from groundwater in the city area and its adjacent surroundings (Sukopp, 1990; Marzluff et al., 2008). To address such challenges of the urban environment in Berlin, different measures and instruments have been implemented, among others the promotion of facade and roof top greening and the transformation from impervious to pervious surfaces.

Seoul, the Korean capital for over 600 years, has developed as one of the largest metropolitan areas in the world within the last decades. The distinct expansion of built-up areas was accompanied by a strong increase in population and the large-scale city development as a result of rapid industrialization since the 1960s. Particularly in the 1980s, the urban structure of Seoul was modified from a single-centered to a multi-centered city by developing new apartment complexes in Gangnam, Yeouido, and Yeongdeungpo region, and by the urban growth beyond administrative boundaries into a metropolitan area. Since Seoul is surrounded by inner and outer mountains ranging from 111 to 836 m above sea level, its urbanization has been concentrated in basin areas and resulted in extremely high-density and high-rise development. Nearly the entire urban area is sealed by built-up and non-built-up urban facilities such as roads or parking lots. According to the biotope mapping in Seoul about 80% of the urbanized area is assigned into a sealing degree of more than 70% (Seoul, 2005). The metropolitan area still faces rapid modifications by the redevelopment of downtown areas and construction of new town housing complexes. From the view of urban ecology there are extreme urban environmental and climatic conditions in Seoul such as the urban heat island effect and the tropical night phenomenon. Furthermore, the risk of flooding during the monsoon season in the summer is significantly increased by the high degree of sealing. The mountainous topography and the large proportion of high-rise buildings result in a weak wind circulation and thus in an unfavorable condition for ventilation, leading to increasing emissions and smog. Air pollution by sulfur dioxide (SO_2) and carbon monoxide (CO) has gradually improved since 1980. The pollution by particulate matters (PM10) and nitrogen monoxide (NO_2) however, which is particularly caused by high traffic is still an unsolved problem. Within the last few years various measures have been carried out to improve the urban environment; e.g. revitalization of former stream covered by concrete roads (Cheonggae stream), roof greenery in the inner city area and transformation from built-up land use to open space such as public parks.

Table 1
The Biotope Area Ratio – weighting ratios (WR)[a] in Berlin and Seoul.

Surface type		WR Berlin	WR Seoul	Description of surface types
	Sealed surfaces	0.0	0.0	Surface is impermeable to air and water and has no plant growth (e.g., concrete, asphalt, slabs with a solid sub-base)
	Partially sealed surfaces	0.3	0.2	Surface is permeable to water and air; as a rule, no plant growth (e.g., clinker brick, mosaic paving, slabs with a sand sub-base)
	Semi-open surfaces	0.5	0.5	Surface is permeable to water and air; infiltration; plant growth (e.g., gravel with grass coverage, wood-block paving)
	Permeable pavement	–	0.3	Surface is permeable to water; no plant growth (e.g. gravel or sand paving on natural ground)
	Surfaces with vegetation, unconnected to soil below	0.5	0.5	Surfaces with vegetation on cellar covers or underground garages with less than 80 cm (Berlin), 90 cm (Seoul) of soil covering
	Surfaces with vegetation, unconnected to soil below	0.7	0.7	Surfaces with vegetation that have no connection to soil below but with more than 80 cm (Berlin), 90 cm (Seoul) of soil covering
	Surfaces with vegetation, connected to soil below	1.0	1.0	Vegetation connected to soil below, available for development of flora and fauna
	Rainwater infiltration per m^2 of roof area	0.2	0.2	Rainwater infiltration for replenishment of groundwater; infiltration over surfaces with existing vegetation
	Vertical greenery < 10 m (height)	0.5	0.3	Greenery covering walls and outer walls with no windows; the actual height, up to 10 m, is taken into account
	Greenery on rooftop	0.7	0.5	Extensive and intensive coverage of rooftop with greenery, regulation of the soil depth (≥10 cm) in Seoul
	Permeable water surface	–	1.0	Water area, water can run through the soil below (e.g. natural pond)
	Impermeable water surface	–	0.7	Water area, water cannot run through the soil below (e.g. artificial pond)

Source: SenStadt (2011), Seoul 2004.
[a] Weighting ratio multiplied by m^2 of surface type.

3.2. *Analysis of the BAR with a remote-sensing based approach*

The empirical analysis of the BAR regarding its implementation into planning was based on literature review, expert interviews, and a remote-sensing based GIS-analysis in the two cities. We applied high-resolution multispectral remote-sensing data and analysis methods to extract data on relevant surface types for assessing the BAR (see also Kim et al., 2005). Aerial scanner data (HRSC-AX: high resolution stereo camera–airborne extended) and satellite data (IKONOS and QuickBird) were investigated (see Table 2).

3.2.1. *Berlin*

A literature review on the application of the BAR was supported by interviews following an interview guideline with experts from the Senate Department of Urban Development in Berlin as well as from the planning departments of the local boroughs in Berlin (for detailed information on expert interviews see Lakes, 2006). After a

Table 2
Characteristics of the investigated satellite and airborne data.

	HRSC-AX[a]	QuickBird	IKONOS
Geometric resolution (m)	Pan/MS: 0.20 DSM: 1.00	Pan: 0.61 MS: 2.44	Pan: 0.82 MS: 3.20
Spectral resolution (nm)	R: 642–682 G: 530–576 B: 450–510 NIR: 770–814	R: 450–520 G: 520–600 B: 630–690 NIR: 760–890	R: 450–520 G: 520–600 B: 630–690 NIR: 760–900
Radiometric resolution (bit)	8	11	11
Swath width (km)	0.8	16.5	11
(Orbit) height	Varying	450 km	681 km
Repetition rate (days)	Varying	1–3 (off-nadir)	3–5 (off-nadir)
Suited for map scales	Up to 1:500	1:25,000–1:5000	
Available since	2000	2001	2000
Price (€/km^2)		≥24	≥28
Provider	DLR	SpaceImaging	Digital globe

[a] Flying height of 4120 m.

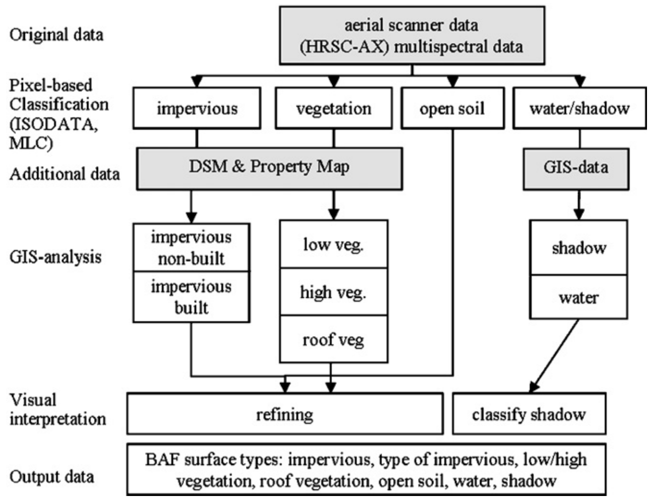


Fig. 2. Remote-sensing based workflow in Berlin.

Table 3
Target BAR in Berlin according to land use type and development type.

Modifications		New buildings
Degree of build area	BAR	BAR
Housing (residential without commercial use)		
<0.37	0.6	0.6
0.38–0.49	0.45	0.6
≥0.5	0.3	0.6
Commercial usage	0.3	0.3
Public usage		
<0.37	0.6	0.6
0.38–0.49	0.45	0.6
≥0.5	0.3	0.6
Schools	0.3	0.3
Kindergardens		
<0.37	0.6	0.6
0.38–0.49	0.45	0.6
≥0.5	0.3	0.6
Technical infrastruct.	0.3	0.3

Source: SenStadt (2011).

review of the available BAR-landscape plans, an in-depth analysis to investigate the potential of the remote-sensing data took place for the BAR-Landscape plan II-L-11 Tiergarten Sued, in the borough Mitte of Berlin, where lower air quality, increased summer temperature, higher sealing rates, and decreased groundwater recharge are particularly pressing. For the area covered by this plan, airborne scanner data (HRSC-AX) and additional environmental and property data was pre-processed and analysed. The panchromatic and multispectral data was acquired on a cloudless day on June, 7th 2003 with a spatial resolution of up to 20 cm. The additional digital surface model (DSM) was acquired on May, 3rd 2001 with a spatial resolution of 1 m. A semi-automatic pixel-based classification including an unsupervised ISODATA and a supervised maximum-likelihood classification enhanced by a visual interpretation of the data was applied to test the application of the scanner-data for extracting relevant information for the BAR (see Fig. 2).

In a first step, a pixel-based classification took place to roughly separate the classes of vegetation, open soil, water/shadow and sealed surfaces. The DSM was then applied to differentiate vegetation in low (grass) and high (bushes, trees) vegetation and sealed surfaces into low (impervious non-built-up) and high (built-up) by height. In addition, property information out of the real estate map was used to delineate high vegetation on built-up areas which could then be visually confirmed as roof top greening. An additional dataset on water bodies allowed to delineate these. Finally, the visual interpretation was used to refine the derived classes of open soil, sealed surface, sealed built-up, roof vegetation, high vegetation, low vegetation, water and shadow. To assess the classification and interpretation accuracy ground truth data was acquired by field mapping.

3.2.2. Seoul

To study the implementation of the BAR in planning practice in Seoul, discussions with planers and policy makers as well as a literature review were conducted. An inner city area located near the Seoul railway station representing the heterogeneous and compact urban land use with high sealing rates was selected to test the applicability of remote-sensing data for assessing the BAR. For this paper IKONOS (CATERRA GEO, recorded on November, 27th 2000) and QuickBird (Standard, recorded on February, 22nd 2002) satellite data were used and a combined approach of pixel- and segment-based classification methods was applied (see Fig. 3).

The pre-processing of the data included a resolution merge between IKONOS and Quickbird, the geometrical correction with ground control points, and the projection transformation. These data were then classified on a pixel-based level into possibly all existing land cover types by maximum likelihood classification and were reclassified into four classes of vegetation, non-vegetation, vegetation shadow and non-vegetation shadow/water. Problems by 'salt and pepper effects' were reduced by majority filtering. In addition, objects smaller than 100 m^2 were assigned to its neighboring object which had the longest common edge to avoid fragmentation of classification results. Due to very high land use intensity of Seoul hardly any pervious surfaces exist (Seoul metropolitan government, 2005), i.e. it is possible to assume that the urbanized areas except vegetation-covered open spaces are completely sealed by buildings or non-built-up pavement such as roads. Hence, the class of non-vegetation was classified into sealed surfaces. The objects of vegetation shadow were further classified according to their spatial context; if the objects were neighboring to the object of vegetation they were classified as vegetation, if not as shadow. The class of non-vegetation shadow/water was differentiated by using an additional thematic map, namely the biotope type map. Because the shadow areas and water surface have similar spectral characteristics in IKONOS and QuickBird satellite data, the automated differentiation of shadow from water was not possible. In result, four surface types were finally classified: vegetation surfaces, impervious surfaces, shadow, and water surfaces. For the validation of automated classification results aerial photos gathered on November 2000 were visually interpreted.

4. Results

4.1. Implementation of the BAR in planning

The analysis of the BAR pointed out that it was initially developed in Berlin as an instrument to manage the urban environment by defining ecological minimum standards for surfaces on the planning site when rebuilding or new construction works occur. Even though it was mainly intended to define a target-state it has since then increasingly been used as a means to assess the present state. Target states were defined according to type of land use, existing degree of built area, and to type of development (alterations/extensions vs new development) as described in Table 3. The highest target BAR is prescribed for residential housing, public usage and kindergardens with a ratio of 0.6 for the lowest degree of built area. Commercial areas instead are rather low with a target

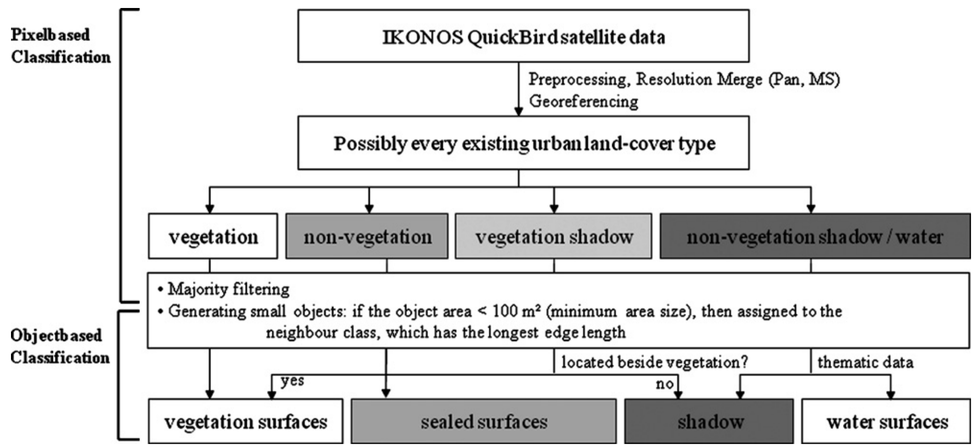


Fig. 3. Remote-sensing based workflow in Seoul.

BAR of only 0.3. For all new developments always the highest ratio of the modification is chosen (see Table 3).

The BAR is implemented for large-scale planning, such as the environmental impact assessment or the preparation of landscape plans in highly sealed urban areas on a scale of about 1:10,000 in Berlin (see Fig. 4). Hence, as an urban ecological indicator the BAR can be compared to the indices of legally binding land use planning regulating the area and size of built area, such as "build area in proportion to total property area" (Grundflaechenzahl) and "build area to live on in proportion to total property area" (Geschossflaechenzahl). While the latter ones are legally required to be considered for built-up structures in the hierarchical system of comprehensive spatial planning (Federal building code on a country-wide and Berlin building law on a Berlin-wide level), landscape planning is regulated complementary by the Federal law of nature conservation and the Berlin law of nature conservation respectively. Since the 1990s the target-BAR specifications for single properties had been legally binding in Berlin landscape-plans. Interviews revealed that the BAR-landscape plans are widely seen as an efficient instrument of landscape planning to address the urban environmental situation on private properties as well. Especially in the highly sealed inner core of Berlin where urban ecosystem services face a strong pressure BAR-landscape plans have been implemented so far (see Fig. 4a).

In case of a planned development project within the area of the BAR-landscape plan, a legal advice of the responsible local nature conservation administration has to be asked for. The following steps need to be addressed then: (1) the identification of the envisaged land use type, (2) the identification of existing buildings, (3) the assessment of the target-BAR, and (4) the development of measures according to the local circumstances until the target BAR is reached (see Fig. 4b). In order to achieve the required target-BAR of 0.6, for example, different measures such as planting vegetation or greening of facades can be developed and implemented. A major challenge remains the evaluation of the implemented measures, which is according to the interview up to now restricted to on-site building supervision that is originally meant to control only the building works on the property and not the BAR. This means that necessary ecological expert knowledge of the surveyors is frequently missing and not all environmental measures have been realized at that point of stage. A control of the realized environmental measure at a later stage is most often canceled due to time and cost-efforts.

Compared to the complementary levels of landscape and land use planning in Germany, South Korea holds an integrated spatial planning system, in which the environmental regulations are included in land use planning on all spatial scales. In result, the BAR can be integrated into the "urban district unit plan" (1:5000–1:10,000) according to the "National Land Planning Act" for urban districts where new development projects are assigned to or where a change of land use takes place. In 2004, the Seoul Metropolitan Government formalized the implementation of the BAR as ordinance for the following public urban development projects: (1) urban infrastructure installation and maintenance projects, (2) district unit projects, (3) urban development and maintenance projects, and (4) civil architecture projects (Seoul

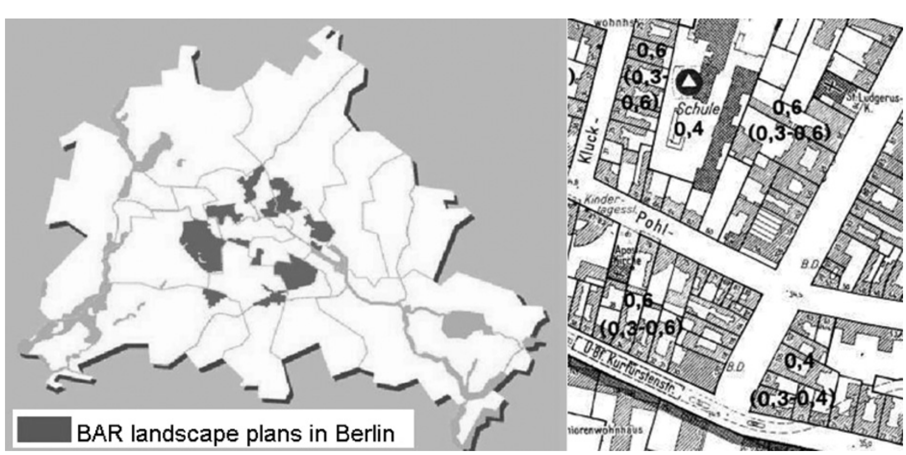


Fig. 4. BAR-landscape plans in Berlin. *Source*: SenStadt (2011).

Table 4
Target BAR according to civil architecture types.

Civil architecture types	BAR
Regular housing (development area < 660 m^2)	≥0.2
Public housing (development area ≥ 660 m^2)	≥0.3
Regular architecture (business, commercial, industrial, etc.)[a]	≥0.2
Public facilities and architecture[b]	≥0.3
Educational facilities (schools, universities, etc.)	≥0.4
Green area facilities and architecture	≥0.5

Source: Seoul 2004.
[a] Excluded: industrial area discharging environmental pollution material.
[b] Excluded: facilities with more than 20% roads, underground as well as air facilities.

metropolitan government, 2004). However, the compliance of the BAR is not strictly sanctioned, so that development projects conducted by private investor do not fall under this regulation. Up to now, no management plan, such as the BAR-landscape plan in Berlin, for regulating the BAR has been implemented in Seoul. In order to get an overview over the present state of BAR values, which should be used to prescribe the target values, the representative areas of each land use type in Seoul were studied. The government published the present BAR representatively based on field mapping of 43 urban blocks and 20 lots in the metropolitan area Seoul (Seoul metropolitan government, 2007). Based on this study the Seoul Metropolitan Government regulates the target values of BAR either depending on civil architecture types as shown in Table 4 or on urban zoning area types; according to the regulation based on zoning area types, the BAR should be higher than 0.3 in exclusive and regular residential areas, which are assigned to secure a good residential environment, and above 0.2 in high-densely developed areas such as semi-residential or commercial districts.

4.2. BAR data acquisition by a remote-sensing approach

The tested high remote-sensing approaches allow differentiating urban surface types which can then be used for further calculating the BAR on a property or even city-wide level. Automatic classification of the following surface types by their spectral characteristics was feasible for the aerial scanner data in Berlin: impervious surface, open soil, vegetation, and water/shadow with an overall classification accuracy of 79%, however, also showing a significant amount of misclassification of the heterogeneous urban surface types on such a high spatial resolution. Following an iterative approach enhanced by surface height information, additional datasets and visual interpretation it was possible to differentiate even more classes and with higher accuracies. Results are summed up in Table 5 and exemplified by the outlined property of the real estate map within the city center of Berlin the BAR (see Fig. 5).

The additional benefit of HRSC-AX data is the digital surface model which enabled to separate surface types according to their height into high sealed surfaces (buildings) from low sealed surfaces (ground), as well as high vegetation (trees) from low vegetation (bushes, grass). This information also allowed automated detection of greenery on house roofs to a far degree including property outlines as well. However, limits were not only obviously due to the remote-sensing inherent perspective from above which means that surfaces beneath trees for example are covered, but also in high-dense areas where shadows did not allow a proper identification of the surface type. Above all, the highest level of detail of information for the BAR, however, can be acquired by visual interpretation of the multispectral scanner data with the help of the interpreter's context and local knowledge (see Table 5). The differentiation of surface types at a very detailed level e.g. partially impervious or semi-permeable was if at all only then feasible. Above all, a large benefit of the multispectral airborne scanner data was the high spatial accuracy within the range of cm which enables the overlaying of auxiliary geo-data, such as the real estate map to derive built structures and property outlines or additional environmental information such as on water bodies. While airborne scanner data allows in general higher spatial resolution than satellite borne systems, the disadvantage that goes along with it is the low coverage, the limited availability and the unknown repetition rate determined by funding.

Table 5
Benefits and challenges of the evaluated remote-sensing data to assess the BAR.

	HRSC-AX	IKONOS/QuickBird
Data characteristics		
Benefits	• Multispectral data • High geometric accuracy • Additional DSM	• Multispectral data • High repetition rate • Large coverage • Relative low costs
Challenges	• Large data amount • Color shifts, processing errors • Limited availability • High costs • Shadows, covered surfaces	• Off-Nadir-Mode: representation of facades, large shadows • High costs • Covered surfaces
Applicability of classification methods		
Visual	• Very good	• Good
Pixel-based	• Problematic ("salt and pepper effect")	• Problematic ("salt and pepper effect")
Segment-based	• Mostly favorable	• Better than pixel-based • Ambiguous segmentation process

The automated classification of surface types using the pan-sharpened IKONOS and QuickBird satellite data allowed a coarse classification into vegetation, impervious surface, water and shadow with the overall classification accuracy of 86.7%. However, the dark shaded areas of high buildings could not be satisfactorily classified into these surface types. Detailed classification of pavement types such as partially impervious or semi-open surface by spectral characteristics with an automated approach was not successful because of improper spatial as well as spectral resolution. In the inner city non-built-up surfaces such as pedestrian ways, parking lots are either very narrow or small and are sometimes shaded by building mass. In result, it is very difficult to find statistical significance among their spectral values to ensure reliable and stable classification accuracy. Furthermore, since there was no detailed urban surface model available in Seoul, the automated differentiation of buildings and ground, or high and low vegetation was not possible.

5. Discussion

5.1. Does the BAR as an indicator successfully assess and manage urban ecosystem services?

Results have shown that the BAR does resemble a successful strategic environmental indicator to assess and manage ecosystem services in large-scale urban planning with high rates of impervious surface. It clearly augments established indicators such as the amount of sealed surface or built-up (Scalenghe and Marsan, 2009) by including different ecosystem services in an aggregated indicator approach (Whitford et al., 2001). Taking into account roof and facade greening for example allows differentiating urban surfaces in their 3D relevance for the urban environment and can hence resemble the local characteristics of providing ecosystem services to a far better degree (see Table 1). We sum up the following benefits of the BAR to assess urban ecosystem services:

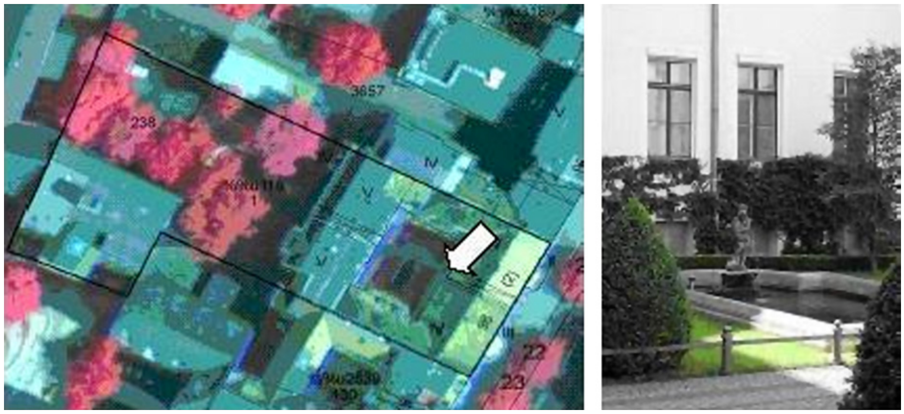


Fig. 5. Insights into one BAR-property in Berlin: high resolution aerial scanner data.

- The BAR addresses the urban environmental situation on the level of properties which quickly represent changes in urban land use and are the most disaggregate and decentralized level of decision-making.
- The cartographic precise demarcation of areas allows the integration of the BAR into existing planning instruments and provides a joint basis for decision-makers as well as property owners.
- The legal implementation is of the most decisive challenges for a successful application of the BAR in the planning processes. While the implementation in the landscape plans can be rated as a well-working approach, recent changes in the German federal building code may result in a less effective BAR-instrument which could limit the BAR application more or less to the goodwill of the property owner. In Korea, on the other hand, further expansion of the BAR to public and private urban developments and the implementation in district plans is still under discussion.
- The BAR resembles an aggregated indicator assessing surface structures which indicates some of the most important ecosystem services in urban areas, such as groundwater recharge, climate and air pollution regulation, and cultural services according to Bolund and Hunhammar (1999).
- Relying on surface structures to indicate processes allows assessing urban ecosystem services in an approximate, however, manageable and cost-efficient approach following the fundamental concept of landscape metrics or indices (Turner, 1989; Uuemaa et al., 2009).

Furthermore, our comparative results in Berlin and Seoul have outlined that the BAR also fulfills the requirements of comprehensibility, flexibility, and modularity due to its methodically and systematically structured, transparent and easy understandable approach. Modularity and flexibility allow modification and adaptation of the BAR to local settings, as was the case in Seoul where additional surface types were introduced, namely open water, and weighting factors and target BAR were adjusted, namely reduced to account for the higher degrees of impervious surfaces in the city and hence lower possibilities to reach high BAR values.

Overall, the BAR does already provide an aggregated view on the local provision of different ecosystem services, however, the major focus was up to now on climate regulation, air pollution filtering and rainwater drainage. This is underlined by higher weighting ratios of the relevant surface types and particularly by taking the permeability and connection to the ground into account in Berlin and giving more weight to water bodies in Seoul (see Table 1). Possible modifications to address recent challenges in urban areas could be firstly, the cultural ecosystem services in terms of health, for example including the perception of density, greenery, accessibility and the socioeconomic value (Tyrvaeinen et al., 2006) which is of growing importance in urban planning, secondly the issue of biodiversity (Loefvenhaft et al., 2002) and thirdly, carbon sequestration (Whitford et al., 2001). However, balancing is needed between a further differentiation of more distinct surface types, vegetation types for example, and the simplicity to guarantee successful implementation in the planning process (see also Loefvenhaft et al., 2002; Repetti and Desthieux, 2006). To sum up we suggest a number of modifications regarding the structure and definition of the BAR in the following:

- Modification of the surface type categories is recommended for Berlin and Seoul derived from the comparative analysis, namely introducing open water areas in Berlin and introducing a new approach to indicate groundwater recharge in Seoul, where frequently even below impervious land underground infrastructure is established (such as parking lots, underground railway, commercial buildings).
- To address the present urban environmental problems of air pollution and heat effects, particularly in the summer, the differentiation of surface types and weighting ratios of the BAR for the purpose of urban climate regulating services should be addressed in more detail in both cities. One possibility would be to assess and value different vegetation types to account for atmospheric purification (Jo and Ahn, 2001) and moderation of urban climate (Heidt and Neef, 2007), In order to efficiently manage urban ecosystem services in a local setting of urban areas, the target BAR can be defined by overall criteria, such as type of land use and development, but should also consider local settings, such as the existing degree of built area in Berlin (Lee et al., 2007; Mok and Kim, 2005; Oh and Kim, 2006).
- A future perspective could be to address recent questions of carbon sequestration (Whitford et al., 2001) and living quality in urban areas which would mean a revision of the existing approach. Vegetation types could provide important information in this regard (see also Loefvenhaft et al., 2002).

While the BAR does provide important insights as is for urban planning, there may exist trade-offs between different surface types for respective services, e.g. the proposed transformation of impervious to pervious surfaces to enable rainwater drainage, which can be critically reviewed because of findings on increasing pollution in the groundwater (Scalenghe and Marsan, 2009). In both urban environmental settings, interrelations and correlations, respectively, between different criteria, such as vegetation and open soil have not been explicitly addressed nor are they reflected in a multicriteria approach nor has the BAR been validated up to now – major recent challenges of managing ecosystem services by indicator approaches in urban areas (see also Kain and

Table 6
Assessment of indicators for urban ecosystems by remote-sensing techniques.

Indicator	Urban ecosystem services	Suggested remote-sensing approach	Additional information
Sealing	Groundwater recharge, climate regulation	Sealed surfaces can be detected to a far degree (except: shadow, covered surfaces)	Field assessment
Sealing type	Groundwater recharge	Can be differentiated to a limited degree by visual interpretation	Field assessment
Vegetation	Climate regulation air quality regulation habitat for flora and fauna	Can be detected, but no information to connection to soil	Field assessment, biotope map
Roof veg.	Climate regulation air quality regulation habitat for flora and fauna	Can be identified by combining multispectral and DSM or property map, no information on connection to soil	Field assessment, biotope map (Berlin)
Facade greening	Climate regulation air quality regulation habitat for flora and fauna	Not possible	Field assessment, biotope map (Berlin)
Groundwater recharge	Groundwater recharge	Not possible	Integration of data from water/engineering companies
Vegetation type	Carbon sequestration human well-being	Vegetation types (e.g. trees, grass. . .) possible, 3D data would allow vegetation volume information	Field assessment

Soederberg, 2008; Liu et al., 2007; Repetti and Desthieux, 2006). A systematic evaluation of the implemented measures by using the presented remote-sensing approach for example could give new insights on the efficiency of the BAR.

5.2. How can a remote-sensing approach enhance the assessment of the BAR?

While the BAR as an aggregated indicator to assess and manage urban ecosystem services is being widely appreciated from decision-makers in the investigated study areas, results showed that the successful implementation is partly limited due to the available data on the present BAR and on the realized measures according to the target BAR. Our analysis of remote-sensing techniques showed the benefits of high resolution remote-sensing data to identify urban surface information for the BAR.

The very high geometrical resolution and the multispectral information of new remote-sensing data lead to an improved recognition and identification of different surface types, namely, sealed, vegetation-covered or water surfaces. The main advantages are furthermore fast up-to-dateness, comparable data, less subjective, simultaneous recording of wide-range and non-accessible areas, digital format and direct integration into geo-information system (Herold, 2006). In the case of the airborne multispectral sensor HRSC-AX different urban surface types at large scales of up to 1:1000 could be derived. It was also the digital surface model which provided an important additional information source for differentiating different sealed surfaces and vegetation types. The investigated satellite borne systems in contrast, IKONOS and QuickBird sensors, provide area-wide coverage and regular repetition rates and allow the differentiation of surface types at small scales of up to 1:3000. In addition to the fully automated approaches, visual interpretation will clearly add even more information and will allow further differentiation of surface types and correct for misclassifications for example in shadow areas.

Of course, remote-sensing techniques to assess the urban surfaces for the BAR are limited to some degree, such as shadows and multi-storey elements limit the sight on the ground, vertical elements such as facades cannot be mapped, heterogeneous urban surfaces are difficult to separate according to their spectral signal. In result, remote-sensing analysis needs to be combined with additional geo-data and field assessments (Mesev, 2005), which we sum up in the following Table 6 for data acquisition for the respective ecosystem services of the BAR. For the identification of size of sealed surface as well as for vegetation on ground and on roof tops, remote-sensing provides reliable information. Additional field assessments may correct for in-depth information on these three surface types. For information on groundwater recharge and facade greening, however, field assessments still remain the only data source, perhaps in some cases, such as in Berlin, additional data from water and engineering companies may be available. In addition, we add a new category of vegetation type which could address the above proposed modification of the BAR by including additional ecosystem services: carbon sequestration and human well-being. In this regard, a remote-sensing approach could provide reliable information on vegetation types and, if available, even vegetation volume information derived from elevation and surface models.

Overall, the results of our study hence suggest that remote-sensing based data assessment can provide a valuable method for data acquisition for the BAR at different stages: a first screening, a monitoring of existing BAR data and a focused control for the realization of BAR measures, that means if the target BAR was achieved. Screening and monitoring of the present BAR would allow new insights in the city-wide distribution and benchmarking of the BAR for the first time and may rely on a coarse classification of the BAR by using the presented automated approaches to start with. The control of the realized BAR measures on the other hand would have to be on a far higher level of detail, where remote-sensing based information could allow first insights and may be, if necessary be augmented by additional field mapping.

6. Conclusions and outlook

In this paper we studied one of the few well-established aggregated indicators for environmental urban planning, the BAR. It has been successfully applied in the two urban settings to assess and manage urban ecosystem services by implementation in local planning instruments. We conclude that firstly, the BAR augments existing indicators of spatial planning such as the proportion of built surface by calculating the ecologically effective area of a property including those ecosystem services which are of importance in urban areas. This allows dealing with present challenges of urban ecosystems on the most decentralized level of decision-making in urban areas – the level of single properties.

Secondly, the proposed remote-sensing approaches may augment existing techniques of assessing the BAR or similar indicators and could be particularly valuable for screening and monitoring of BAR-data and would hence allow first insights on the distribution of urban ecosystem services on a city-wide level.

Thirdly and finally we want to conclude with stressing the importance of future studies on the development, evaluation, and transfer of new indicators to assess urban ecosystem services. Up to now, only few studies address the systematic development and evaluation of environmental indicators in urban areas (Loefvenhaft et al., 2002). There remains a high need to exchange experiences not only about up-to-date technologies but also about implementations of indicators as a planning instrument across national boundaries. After all, the management of urban environmental situation and in particular urban ecosystem services by means of indicators such as the BAR is a future task of high importance in all countries, particularly in rapidly developing urban areas with an increasingly pressing environmental urban situation. Only if we face the present situation of the environmental condition in cities, define goals and exchange about instruments of how to reach these goals we can meet the challenges of urban ecosystem services in present and future cities.

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