A NEW APPROACH TOWARDS MAPPING URBAN SEALING USING THE VERY HIGH-RESOLUTION SATELLITE DATA IN SEOUL METROPOLITAN AREAS

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ABSTRACT:

Sealed surfaces affect many environmental processes, including climatological and hydrological conditions, which have a direct impact on the quality of habitat and human life in a city. The sealing degree and the biotope area factor have been used as quantitative and qualitative indicators to measure the ecological values of urban surfaces. For this purpose, the advanced satellite remote-sensing offers a new potential with its geometrically, radiometrically and temporally improved high resolution. In this study, its possibilities and limits were tested in the urban area of Seoul. To deal with the particular situation of Seoul, a very densely and highly built-up metropolitan area, a new approach is needed for the satellite-data analysis and assessment because of large shadows and the oblique recording angle on buildings. This study therefore suggests a new concept for the comprehensive mapping of urban sealing. The very high resolution satellite data show large potentials for the detection of the sealing degree and the biotope area factor. The major benefits are the more or less automatically derived digital and objective information quickly to be up-dated and covering wide-range areas. However, the wholly automated remote-sensing based approach cannot fulfil the aims and requirements for the mapping of urban sealing as precisely and detailed as is desirable for urban-planning tasks. The visual interpretation of remotely sensed data or field surveying is still relevant. The best results can be achieved by combining the different methods. In future, these combined methods will be increasingly supported by high-resolution satellite data.

INTRODUCTION

The sealing of natural soils by man-made construction has caused negative consequences for the balance of ecosystems. Particularly in metropolitan areas, the amount of impervious surfaces is high, and its negative effects are very evident. The high proportion of the sealed surface changes urban climate conditions, causing the urban-heat island effect and leading to reduced evaporation. In addition, sealed surfaces prevent the draining of rainwater into the ground and, therefore, the regeneration of groundwater. As a consequence, the risk of high damage caused by floods has been increasing in urban areas, where a large amount of the rainwater is being channelled into municipal drainage systems. The increasing amount of impervious surfaces also causes a decrease of a useable habitat for numerous animals and plant species. The intensification of sealing also causes the isolation of green space which can alter biotic migration patterns (i). For all these reasons the sealing degree has been developed and applied as an indicator for environmental protection, e.g. urban soil protection, the water-balance model and urban microclimate simulation. However, an additional indicator is needed in highly sealed urbanized areas in order to comprehend the urban environmental situation more qualitatively (ii). The biotope area factor has been implemented as a qualitative indicator to measure ecological values of urban surfaces. Its definition is the amount of the ecologically effective surface area in relation to the total land area (iii). Various sealing types are evaluated according to their contribution to improve the microclimate and atmospheric hygiene to develop soil functions and water balance, to enhance the quality of habitat and to advance the residential environment.

In Seoul, the data on urban sealing were gathered during the urban biotope-type mapping, which was carried out by field surveying for the first time in 1999. The main problem was the surveyors' subjective opinion on the interpretation of sealed surfaces, because it is difficult to gain an overview on the whole surface on a site, particularly in highly built-up districts. Furthermore, some areas, such as private estates and military areas, were not always accessible. In this case, the estimations of the surveyors led to uncertain and irreproducible results. Park areas are very often assigned as a completely vegetation covered area in spite of the sealed surfaces in forms of ways, parking lots or squares. Therefore, the correction of this kind of errors and continuous updating, with regard to extremely fast changes on urbanized areas, are now an important task. For this purpose, the high resolution satellite remote sensing offers a new opportunity. In this study, its potentials and limits were studied with IKONOS satellite data.

STUDY AREAS

This study focuses on the development of the satellite remote-sensing based mapping method to be applied to the whole area. In order to represent various kinds of urban structures in Seoul, two study areas were chosen. The first one (Yeoido) is characterized by the highly built-up area, which is mainly composed of government office blocks, business blocks and apartment housing complexes. Fig. 1 shows a large-scale representation of park and green areas. In contrast, the second study area (near Ahyun- and Sogong-Dong) represents the relatively old neighbourhoods with very small-structured and heterogeneous land use in form of low-story housing residences, commerce, administration, education, traffic, park and forest.

Figure 1. Study areas viewed from IKONOS satellite images (left: Yeoido, right: near Ahyun- and Sogong-Dong)

MATERIALS AND METHODS

In the mapping of the sealing by field surveying, each proportion of built-up, non-built-up impervious and pervious surfaces, green areas and open soils in every block was estimated. Here the open soil means the naturally denuded land, which enables the rainwater to drain away into the ground water. If a drainage system is constructed under the open soil, e.g. playgrounds at school, it was regarded as non-built-up impervious surface. The sealing degree was defined as the proportion of built-up and non-built-up impervious surfaces to the total area in each block.

In the urbanized areas of Seoul, there are hardly any naturally denuded lands because of the very high land-use intensity. According to the statistics (iv), the open soils amount to 3.9% of the whole area of Seoul but most of this area is under construction for a new residential or commercial use. The long-term naturally denuded lands only take up 0.03%. Also, because the non-built-up pervious surfaces take a very small amount of 1.1%, this study assumes that all the non-vegetation covered urbanized areas are completely impervious. Under this circumstance, the sealing degree can be replaced by the green proportion, e.g. the sealing degree of 70% corresponds to 30% of green proportion, and can be automatically gained by classifying non-vegetation areas from vegetation-covered areas. For the analysis, the IKONOS satellite image data recorded on November 27, 2000 were used.

Table 1. Characteristics of used IKONOS satellite image data

Product Type	Spatial Resolution	Spectral Resolution (nm)	Radiometric Resolution	Swath Width	(Orbit) Height	Repetition Rate (days)	Provider
CATERRA Geo	Pan: 1m MS: 4m	R: 450-520 G: 520-600 B: 630-690 IR: 760-900	11 bit	11 km	681km	3–5 (off-nadir), 144 (nadir)	SpaceImaging

So far many studies have ascertained that vegetation-covered areas can well be extracted automatically from non-vegetation areas by means of their clear spectral characteristics in satellite image data (v). In addition, the high spatial resolution of IKONOS has explicitly improved the visual interpretability of details on very heterogeneous as well as compact urban areas. But the strongly increased variations and noises within a thematic class or object cause other problems so that the traditional pixel-based classification leads to the so-called "salt and pepper effect" (vi). Also, by the object-based approach, segment boundaries cannot always be assigned to a thematically meaningful class(vii). Particularly in very heterogeneous urban areas like Seoul, incorrect segmentation occurs more often and, in general, can neither be reproduced nor improved to arrive at reliable results(viii). In this study, a combination of pixelbased and segmentbased classification was thus suggested in order to overcome these problems and to use the advantages of both approaches at the same time (Figure 2).

The panchromatic and multispectral channels of each data set were fused and then geometrically corrected with digital topographic maps at a scale of 1:1000. At first, every possible existing urban land-cover type was classified pixelbased by the maximum-likelihood method and then assigned to four classes of vegetation, non-vegetation, vegetation shadow and non-vegetation shadow / water. Because of the very simular characteristics on spectral channels, non-vegetation shadow and water could not be distinguished by the pixelbased classification. The problem of the "salt and pepper effect" was improved firstly by majority filtering and then by the objectbased approach taking into account the minimum area size and the spatial context. Furthermore, vegetation shadows were assigned to the vegetation considering their spatial location if they were located beside the vegetation. Water areas were separated from non-vegetation shadows according to the thematic data. Shadows can theoretically be further classified according to their context and texture information. As texture characteristics are not changed despite shading, the shadow sharing the same texture as its neighbourhood object can be assigned to the same land-cover type. But in this work, most of the shadows formed by high-rise buildings appear so dark, because the satellite data were recorded in the winter time with a strong oblique camera angle with the result that it was not successful to classify shadow areas into other land-cover types by their texture information. Hence the surface types were finally classified into green, impervious surface, shadow and water. The sealing degree was then calculated by the proportion of impervious surfaces in each block. This refers to the minimum value because shadow areas are not considered here. The maximum value of sealing degree supposes that all shadow areas are completely sealed by building or impervious pavement and can be gained by adding the proportion of impervious surfaces and shadow areas. On the assumption that the non-shaded area within the block represents the whole block, the mean value was defined by the proportion of impervious surfaces to the non-shaded block areas. As the surveyed sealing degree is problematic, the analogous aerial photos were visually interpreted for verifying these three classified values of the sealing degree.

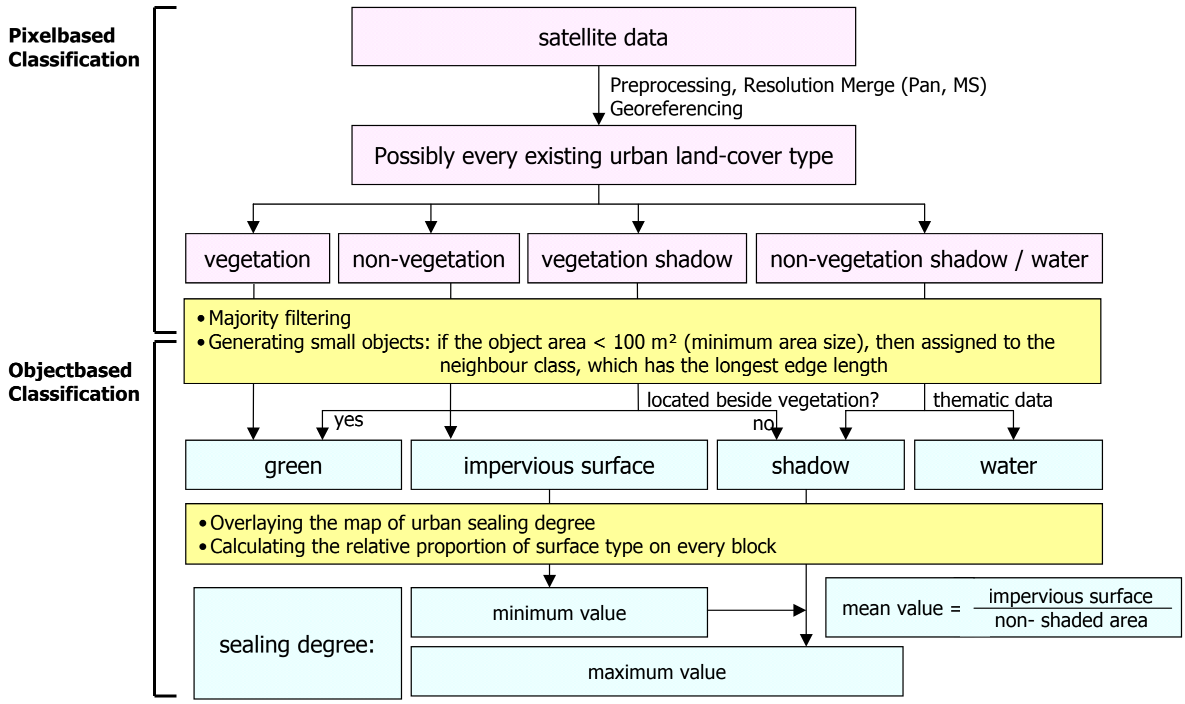

Figure 2. Analysis method

RESULTS AND DISCUSSION

As the terrestrial mapping of the sealing degree is not suitable for reference data because of the subjective interpretation by surveys, the accuracies of classified sealing degrees cannot be evaluated exactly but can be guessed by the results of the classification of surface types. This means that the better the impervious surfaces are classified, the higher the accuracies of classified sealing degrees. The accuracies of classification into green, impervious surface, shadow and water were 93.3 % on the first study area and 84.4 % on the second study area. Because of the very heterogeneous and compact physical structures in the second study area, the classification result showed a higher salt and pepper effect as well as misclassification.

In order to find and correct the wrongly estimated sealing degree by the terrestrial mapping, the classified values of sealing degree were compared with the field-surveyed sealing degree. Since the real sealing degree should theoretically be higher than the classified minimum value and lower than the classified maximum value, the under or over-estimated blocks could be selected. The clear errors of the field-surveyed sealing degree were primarily found in the park areas, which were regarded as completely vegetation-covered areas (the sealing degree of 0 %; Figure 3a), and in hardly accessable areas such as one-family housing complexes (Figure 3b). In order to correct the false sealing degree, the classified minimum, maximum and mean values can be taken into consideration. For example, in the park block, the most shadowy areas are regarded as vegetation-covered green, so that the sealing degree can be replaced with the minimum value. However, some problems do remain. Firstly, because the digital sealing map boundaries (vector format) cannot always be correctly overlayed with satellite images (raster format), a neighbour block containing a part of green areas can be underestimated as regards its sealing degree. Secondly, the massively shaded areas are difficult to decide on because, on the one hand, the difference between the minimum and maximum values is large and because, on the other hand, the non-shaded area is hardly representative of the whole block.

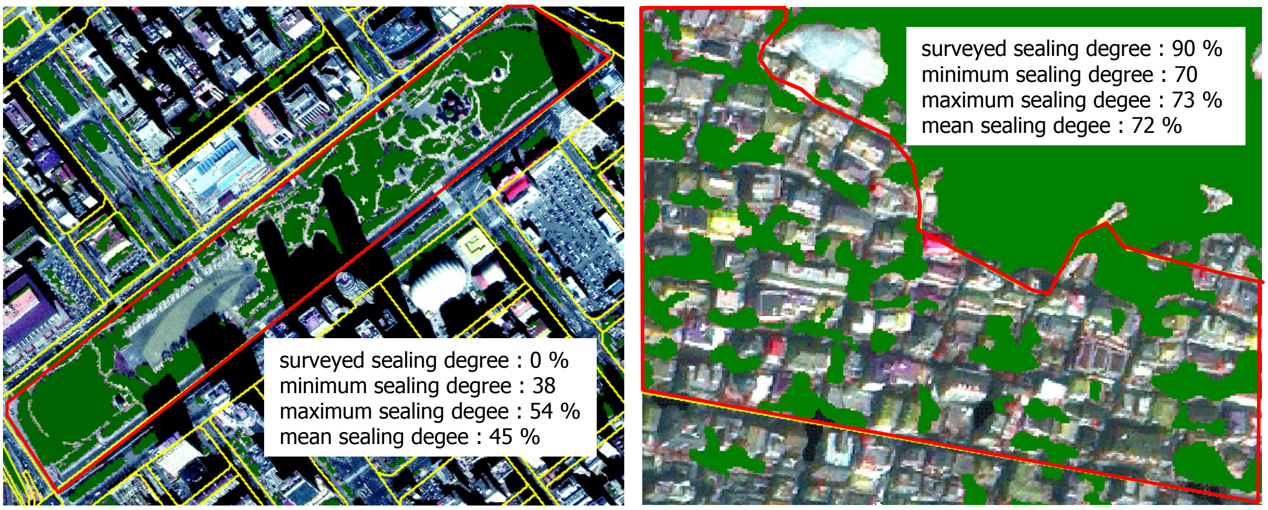

Figure 3. Examples of under or over-estimation of the sealing degree by field surveying(a: Yeoido, b: Ahyun- and Sogong-Dong)

Generally, the mean value of the sealing degree matches well with the visually interpreted sealing degree. But the visually interpreted sealing degrees using aerial photos are still problematic as reference data because there are the same problems of huge shadows and building facades. If the problem of shadows and oblique buildings is not avoidable in high-resolution remote-sensing data, the acceptable conditions for the analysis should be confined to the comprehensive mapping of the sealing degree in urbanized areas where the shadow proportion could be one of the criteria.

As most shadows in urbanized areas are caused by high-rise buildings, a high shadow proportion signifies indirectly the highly built-up urban block. And normally in built-up blocks, huge facades are formed more or less by oblique recording on high-rise buildings. In this case, the calculation of the sealing degree can be affected by building facades because they are classified as the non-vegetation area. Moreover, the possible green spaces hidden by building facades cannot be included in the analysis. Consequently, the higher the proportion of shadow the higher, also, the potential of a wrong estimation of the sealing degree. In contrast, the low shadow proportion areas show less problems by distortion of buildings, so that the classified minimum, maximum and mean values are similar. The sealing degree in this case is reliable as far as the impervious surfaces are well classified.

Regarding the biotope-area factor (Table 2), IKONOS satellite data can only be applied to a certain extent to the detection of urban surface types, i.e. sealed surfaces can be distinguished automatically as well as visually very well from non-sealed or vegetation-covered areas. However, it is not sufficient to identify very detailed pavement types, e.g. partially sealed surface or semi-open surface despite the explicitly improved spatial resolution. The planting on rooftops can be classified but cannot be distinguished automatically from vegetation on the ground. A digital surface model can be helpful for the automatic classification. If there is no digital surface model available, the planting on rooftops should be differentiated by visual interpretation. The vegetation types related to soil characterics, if, for example, natural or artificial ground with a certain soil depth, and the vertical greenery, such as plantings on building facades, cannot be detected with satellite image data. In addition, water surfaces can hardly be differentiated automatically from shadow areas.

Table 2. Biotope-Area Factor in Seoul (ix*)*

Surface Type	Biotope-Area Factor	Description of surface types
sealed surfaces	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	0.2	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	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	surfaces with vegetation on cellar covers or underground garages with less than 90 cm of soil covering
surfaces with vegetation, unconnected to soil below	0.7	surfaces with vegetation that have no connection to soil below but with more than 90 cm of soil covering
surfaces with vegetation, connected to soil below	1.0	vegetation connected to soil below, available for development of flora and fauna
rainwater infiltration per m² of roof area	0.2	Rainwater infiltration for replenishment of groundwater; infiltration over surfaces with existing vegetation
vertical greenery up to a maximum of 10 m in height	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	0.5	Extensive and intensive coverage of rooftop with greenery
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)

CONCLUSION

The remote sensing based method suggested in this study can be applied to the comprehensive mapping of the sealing degree and type in urbanized areas. This method is primarily suitable for the correction or updating of falsely surveyed or possibly changed areas as well as for a pre-mapping in order to get an overview on the study area. The main advantages of the remote-sensing based approach are fast up-to-dateness, simultaneous recording of a wide-range area, the digital format and direct integration into a geographic information system. Furthermore, the short revisit frequency of the IKONOS satellite system up to 3 days appears very profitable for the purpose of constant data updating. But in this case, because IKONOS allows off-nadir recording up to about 30°, the problem of shadows and distortion of high-rise buildings cannot be denied. It restricts its application for automatic analysis and assessment. In order to avoid problems by shadows or distortion of high-rise buildings, true-nadir recorded data are required. Then the repetition rate is very long, i.e. up to 144 days. If the weather is cloudy or rainy on this specific day, then it is even more difficult to get acceptable data restricting, in turn, the application. Hence, if off-nadir recorded data are used for urbanized areas, the acceptable conditions for automated classification or analysis should be defined, e.g. a certain shadow proportion in built-up areas. For the highly built-up areas, the results of classification or analysis must be verified and improved by field surveying. In addition, due to the extreme high heterogeneity of urban structures, the visual interpretation based on expert knowledge plays is still very significant for satellite-data analysis and assessment. Field surveying is also still needed for the mapping of urban sealing as precisely and detailed as possible. Therefore, the best results of comprehensive mapping of urban sealing can be achieved by combining the different methods. These combined methods will be increasingly supported by high-resolution satellite data in the future.

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