DERIVATION OF MULTI-TEMPORAL SOIL SEALING MAPS USING HIGH RESOLUTION AIRBORNE THEMATIC MAPPER (ATM) IMAGERY AND AN EXAMINATION OF THEIR USEFULNESS IN TOWN PLANNING

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ABSTRACT

The main objectives of this project are to provide time-series information to define and locate the urban sprawl trends in sealing processes in Graz/Austria and to document the application and incorporation of sealing maps into planning purposes of the municipal building authority of the city of Graz (especially for the construction and renovation of sewage systems). Developments in soil sealing are largely determined by spatial planning strategies. Unfortunately, the effects of irreplaceable soil losses are often not taken into account sufficiently. Sealing of the soil causes significant (quantitative and qualitative) changes in groundwater recharging and in the water balance. These changes have to be recognized by the governmental authorities to construct appropriate drainage systems. Especially the heavy rainfall in August 2005 with more than 120 mm per day and extreme flooding and overload of the drainage system strengthen the importance of detailed planning of urban watersheds and drainage system of the municipality Graz by means of remotely sensed generated sealing maps.

Multitemporal sealing maps were generated by a digital classification of multispectral DAEDALUS Scanner data (1996 and 2004) and used for this study. Different methodologies and approaches of data analyses and their advantages and disadvantages for further applications in water management are documented in this paper.

INTRODUCTION

The urbanization process is a major factor of change in Central European cities, where urban settlements have grown rapidly over the past decades, especially since the 2^{nd} World War. Over the past 20 years, the extent of built-up areas in many western and eastern European countries has increased by some 20%. It by far exceeds the rate of population growth in the EU over the same period (6%). Due to economic and political pressures, several cities rapidly became regional centres or international nodes. Urbanization causes land cover changes, which can lead to deeper social, economic and especially environmental changes. Because of its negative effect on the soil water balance, microclimate, flora and fauna (destruction of habitats), noise and urban heating, monitoring in soil sealing provides basic indicators of urban ecology.

Around 5% of Austria's surface areas are building land or areas for transport purposes, and about 40% of these areas are sealed. About half of the new residential buildings in 2001 were single family dwellings or semi-detached houses which, in comparison to multi-family residences or other high-density structures, occupy a considerably larger surface area (1).

Sealing of the natural soil by construction has a number of negative effects on the ecosystem and the human habitat. In the following, the soil is considered sealed if it is covered with solid material. Sealed areas are categorised as either built-up or non-built-up sealed areas. In addition to structures and surfaces completely sealed with asphalt or concrete, surface sealed with more permeable coatings are also considered “sealed,” although, as in the case of grass paver blocks or wide-seamed pavement, they may still support reduced plant growth (2).

For mapping the sealing by field survey, each proportion of built-up, non-built-up impervious and pervious surfaces, green areas and open soils in every block was estimated. Here, open soil means naturally denuded land, which enables the rainwater to drain off 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 (3).

Sealing maps (sealed areas) can be generated by means of remote sensing in different ways. On the one hand, each single pixel can be attached in the range of 100 percentages from unsealed up to totally sealed. The amount of sealing can be analyzed with an automatic processing of multispectral information (including the infrared channel) of satellite image data (4,5,6) or with scanner data (7,8). A spatial less resolved elevation of the soil sealing is sufficient for city planning, urban environment observation and provision. A visual evaluation of the degree of soil sealing can be carried out for each urban block of residential buildings on the basis of relevant satellite or aerial images (7).

Monitoring the development of soil sealing can be done at different spatial resolutions. The mapping scale varies between 1:50,000 (e.g. megacities by means of medium resolution satellite images) and larger than 1:5,000 (aerial photographs and high resolution satellite images). A highly exact determination of the soil sealing (the plot must be seen clearly) is necessary within the framework of introducing splitted rainfall and waste water charges and has already been realised in some cities in Germany. This very complicated mapping of soil sealing is carried out on the basis of aerial image data on a scale of 1: 5,000 with manual mapping of built-up areas and completely or partly sealed grounds (9). A visual interpretation (mapping scale of 1:5,000) of the built-up areas in Graz was done by means of historical aerial photographs in 1952, 1956, 1968, 1984, 1990, 1997 and 2004 (10).

STUDY AREA AND DATASET DESCRIPTION

Graz is located in the south-eastern part of Austria. It is the second largest city in Austria (almost 290,000 inhabitants in 2008) behind Vienna and is the capital of the federal state of Styria (Figure 1). The total population of the agglomeration reaches half a million inhabitants and spreads from the south-eastern rim of the Alps to the alpine foreland. The town is settled in a wide basin of the Mur valley and on the tertiary ridges.

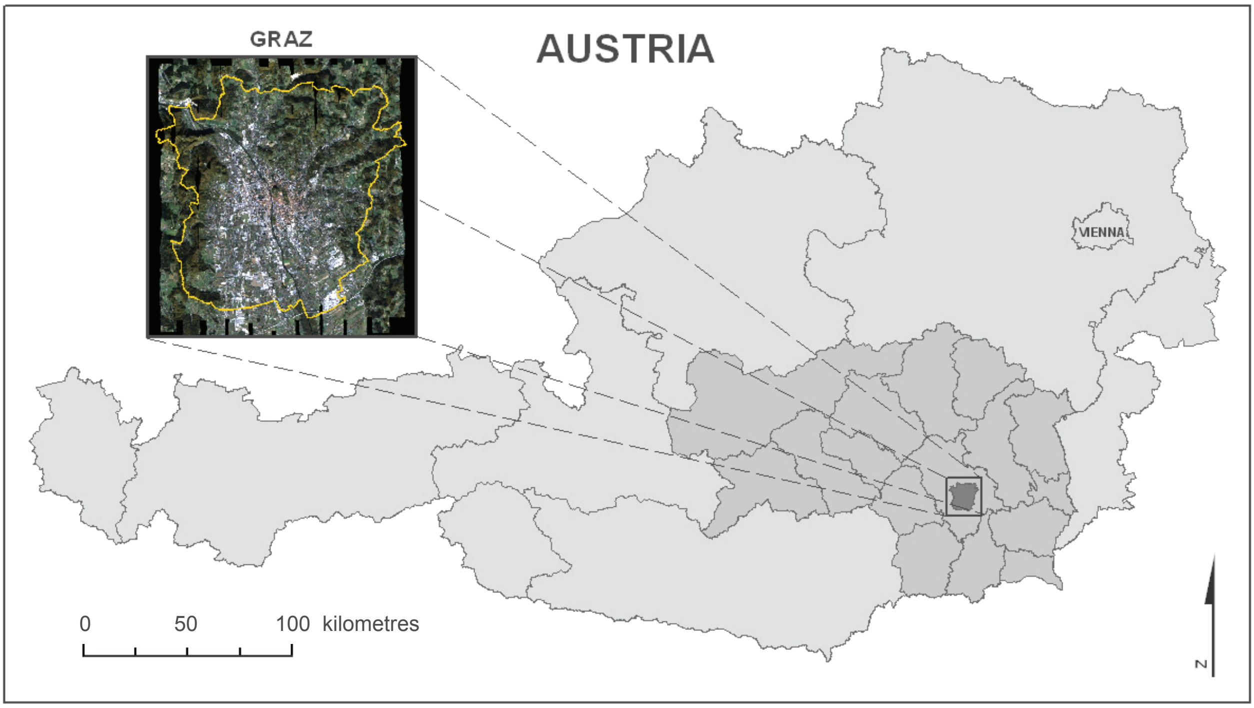

Figure 1: Location of the study area: Graz, capital of the federal state of Styria, Austria; Daedalus scanner data (4,3,2).

The investigation area covers the whole municipality and the accompanied settlements in the outer fringe (14 km × 15 km), where - especially in the flat southern part - mighty changes in land cover and land use have taken place over the past decades.

The city of Graz and the surrounding communities are covered by DAEDALUS scanner data. The DAEDALUS 1268 Airborne Thematic Mapper (ATM) was designed by DAEDALUS Enterprises Inc. in the early 1980ies, to acquire spectral information over a range identical to that of the LANDSAT Thematic Mapper (TM) satellite. The DAEDALUS ATM offers additional wavelengths and flexibility in spatial resolutions far in excess of the spaceborne TM. The scanner records in 12 bands broken down into 6 visible bands, 2 reflected near infrared (NIR) bands, 2 reflected SWIR bands, and 2 emitted thermal infrared (IR) bands, all at the same spatial resolution.

The used data were acquired by DLR (Deutsches Zentrum für Luft- und Raumfahrt) on April 20, 1996 and October 24, 2004 respectively (Table 1). Both flight campaigns were assigned by the municipality of the city of Graz to gain information about ongoing sealing processes and for climate/ecological purposes. In regard to the creation of sealing maps, the day of acquisition is an important factor for the usefulness of the dataset and subsequently for the accuracy of the results. In remotely sensed images it is often the case that sealed surfaces are entirely or partly covered by trees or bushes and so cannot be fully detected during classification. To avoid underestimation of sealed surfaces, the ideal time for data acquisition would be during off-growing season. Seeing that the data should be used not just for creating a sealing map, but also for a land cover / land use classification, one data set was acquired at the beginning of the vegetation period in April and the other one shortly before leaves fall late in October.

Table 1: Image data parameters of the DAEDALUS flights in 1996 and 2004

	1996	2004
Day of acquisition:	20.04.1996	24.10.2004
Time of acquisition:	11.00 am – 01.00 pm CET	12.00 am – 02.15 pm CET
Operating altitude (above ground):	1100 m	560 m
Heading:	west-east	north-south
Overlap:	30% - 40%	30%
Number of swaths:	12	21
Channels:	11	12
Image pixel size:	2.5 m × 2.5 m	1 m × 1 m

DATA PROCESSING AND CLASSIFICATION METHODS

Preprocessing and geometric correction

The aerial survey of 1996 was coordinated and processed by DLR. The data has been obtained by the city government of Graz and no further image preprocessing was necessary. In contrast to the data of 1996, the geometric processing of the 2004 data took place in cooperation with the Institute of Digital Image Processing (Joanneum Research). For the processing, the software package RSG (Remote Sensing Software Package Graz), which was developed at Joanneum Research, was used. Thereafter, the 21 georeferenced swaths were mosaicked into one image with ERDAS Imagine.

Shadow regions are often present in high spatial resolution images, particularly in urban environments. Due to its acquisition in late October, the 2004 image was seriously affected by shadow effects. Almost one third of the whole image contained shadow or at least penumbra effects. For this reason, the loss of information due to shadow effects had to be minimized. Therefore, the shadow areas were classified and extracted from the image. Then, the shadow-affected and non-affected areas were separated into vegetated and non-vegetated. In the following step, the histograms of every single band of the non-vegetated, shadow-affected areas were matched to the histogram of the non-vegetated, not shadow-affected areas. The same happened for the vegetated, shadow-affected areas. Finally, all parts of the image were merged together again (Figure 2).

(a) before shadow correction *(b) after shadow correction*

Figure 2: Comparison of the data before and after shadow correction.

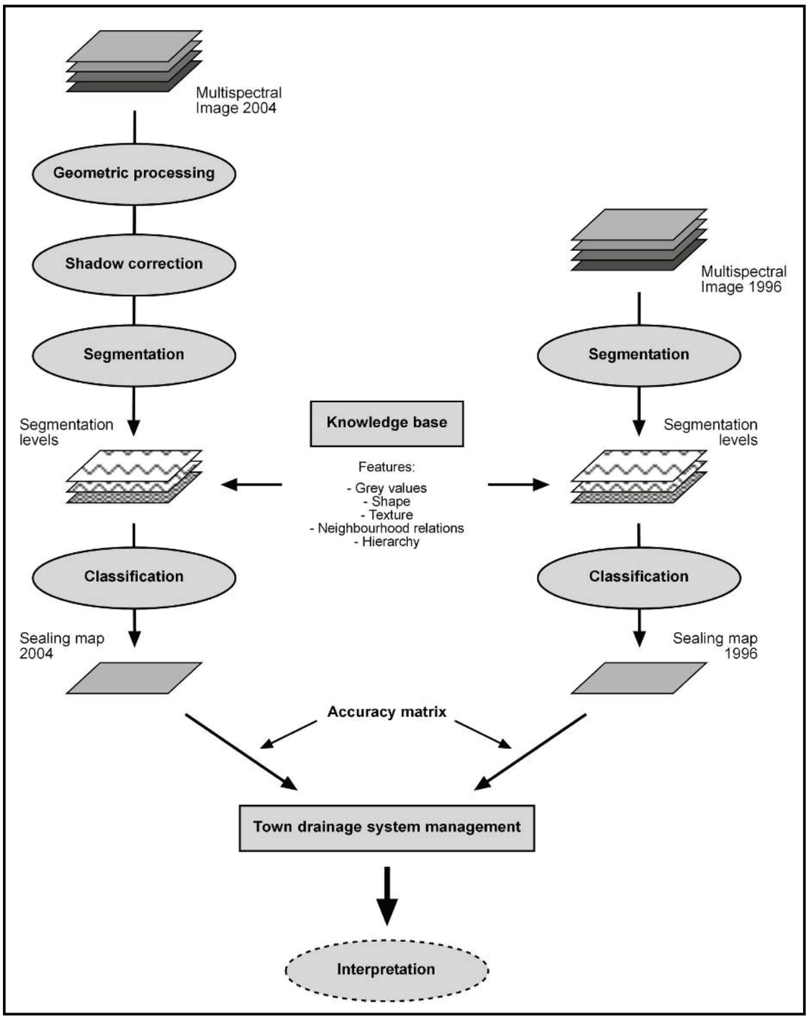

Figure 3: Workflow of the project.

Additionally, GIS data sets from the local governmental GIS data catalogue (digital cadastre, orthophotographs with a ground resolution of 0.25 m, DEM with 2 m, local geodetic GCP´s) were used in this study.

Object-based classification

Some of the twelve channels in the 2004 data set contained radiometric failures. In order not to negatively influence either the segmentation process or the subsequent classification, the channels 1, 5, 9 and 10 and the two thermal channels were eliminated. For segmentation and classification of the 1996 image, all channels besides the two thermal ones were in use.

Because of the high information content of the images, it was obvious to not only create a sealing map but also to perform a land cover/land use classification (11). Therefore, an object-oriented approach was developed using the Definiens Professional software.

The first step in object-oriented image analysis with Definiens Professional is a segmentation of the image. Since the accuracy of the classification results is very dependent on the results of the segmentation, it is very important that the segmentation represents every class of the subsequent classification as accurately as possible (12). Therefore, a hierarchical bottom-up network (13) consisting of three levels from fine to coarse was chosen for this project. Very small items such as trees or small houses were outlined by the segments of the bottom level. Whole buildings, smaller streets and green spaces were segmented at the medium level, while fields and groups of trees are represented on the coarsest level.

Table 2: Segmentation parameters used for the 1996 and 2004 images.

Level	Scale Parameter		Colour		Shape		Compactness		Smoothness	
	1996	2004	1996	2004	1996	2004	1996	2004	1996	2004
1	6	15	0.6	0.8	0.4	0.2	0.2	0.5	0.8	0.5
2	20	40	0.7	0.7	0.3	0.3	0.3	0.6	0.7	0.4
3	45	80	0.5	0.7	0.5	0.3	0.5	0.6	0.5	0.4

Table 3: Error matrix for the classification results 1996 and 2004.

User/ Reference Class	Wood		Green		Field		Sealed		Water		Quarry		Sum	
	´96	´04	´96	´04	´96	´04	´96	´04	´96	´04	´96	´04	´96	´04
Wood	180	360	7	18	0	1	5	8	0	0	0	0	192	387
Green	10	18	108	160	1	0	7	3	0	0	0	0	126	181
Field	0	0	0	4	47	65	0	1	0	0	0	0	47	70
Sealed	3	5	0	4	0	0	158	187	0	0	0	0	161	197
Water	0	0	0	0	0	0	0	0	4	4	0	0	4	4
Quarry	0	0	0	0	0	0	0	0	0	0	2	3	2	3
Sum	193	383	115	186	48	66	170	199	4	4	2	3	532	844
Producer %	93.3	94.0	93.9	86,0	97.9	98.5	93.0	94.0	100	100	100	100	Over all	Over all
User %	93.7	93.0	85,7	88.4	100	92.8	98.1	93.4	100	100	100	100	93.8	92.6

The class hierarchy was constructed for classification from the coarsest to the finest segmentation level. Level 1 has been selected to represent the final classification results. Segments have been analysed based on their mean grey values, shape, texture, neighbourhood relations and relations to segments of higher and lower levels. Membership functions were formulated for all levels. To improve the classification result, the classification rules of the finest level also contained sample image objects. Because of the minor occurrence of quarries and their spectral resemblance to sealed surfaces, they were classified manually.

To determine the quality of the classification results, an error matrix was generated. For this purpose, a constant grid of 500 m × 500 m was used to select 532 test pixels in the 1996 classification and 844 in the 2004 classification. The difference in the number of test pixels arises from the fact that the 2004 image is larger in size than the one of 1996. The results of the error matrices are shown in Table 3. The overall accuracy of the 1996 classification results is 93.8% and the one of the 2004 classification is 92.6%. However, important for us were the classification results of the sealed areas, which can be considered good.

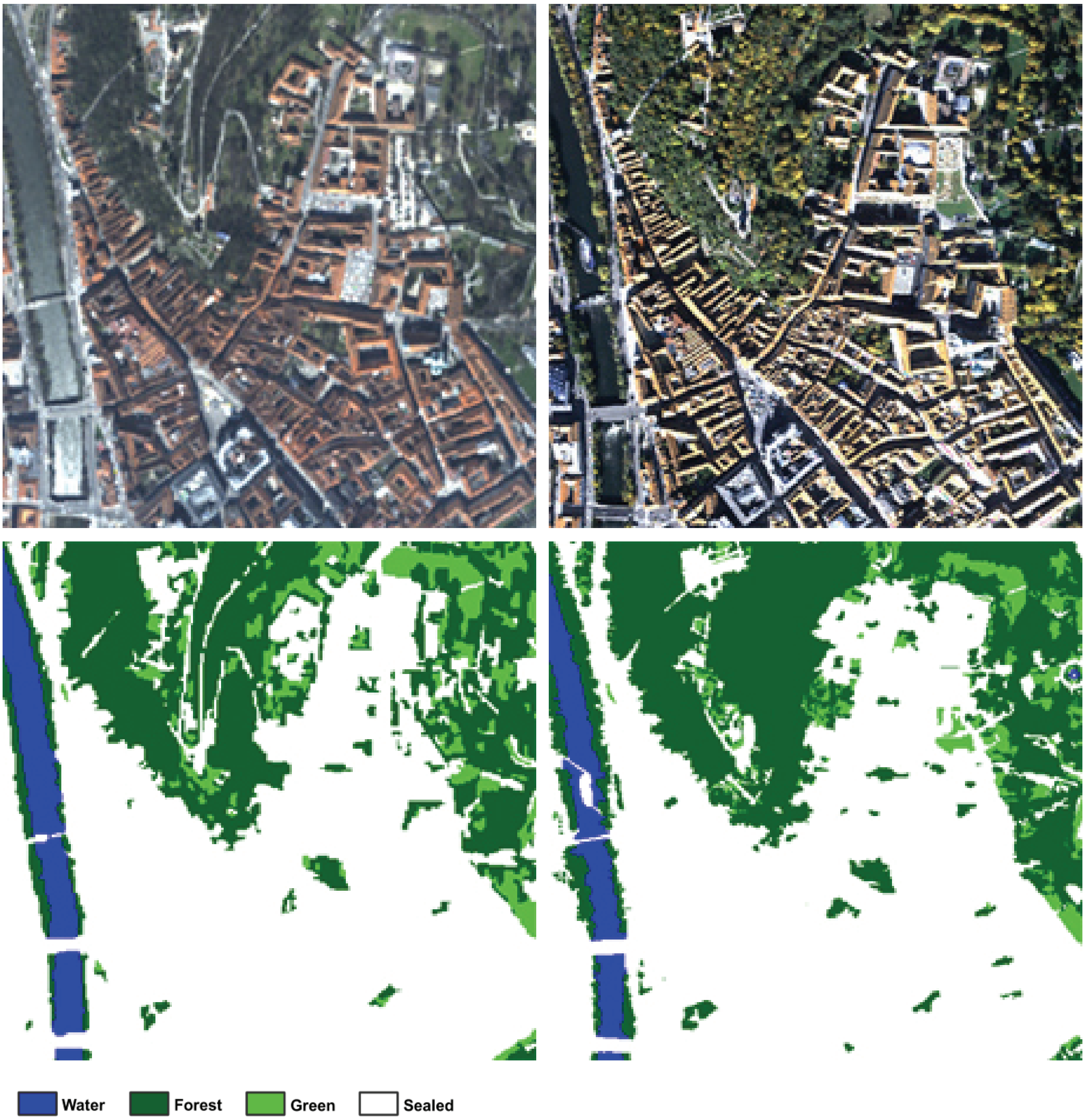

Figure 4: Comparison of the classification results (left 1996, right 2004).

RESULTS AND DISCUSSION

This paper is documenting one step within a long-term project. Results of the multitemporal comparison of two data sets will be pointed out; disadvantages and advantages of the above-mentioned methodology will be discussed and the integration of the provided sealing data set into the governmental sewage model will presented.

Comparison of the sealing maps

For comparison of the two data sets (1996 and 2004, Figure 4), the classification results of the data with the lower geometric resolution (1996, 2,5 m pixel size) was resampled to 1 m resolution. Due to different spatial extents of the images, a joint coverage area had to be defined for the analysis of change. Figure 5 presents a visual comparison. Furthermore, the results of the change analyses are listed in Table 4. Hence, the amount of sealing in the investigation area increased about 6% within 8 years.

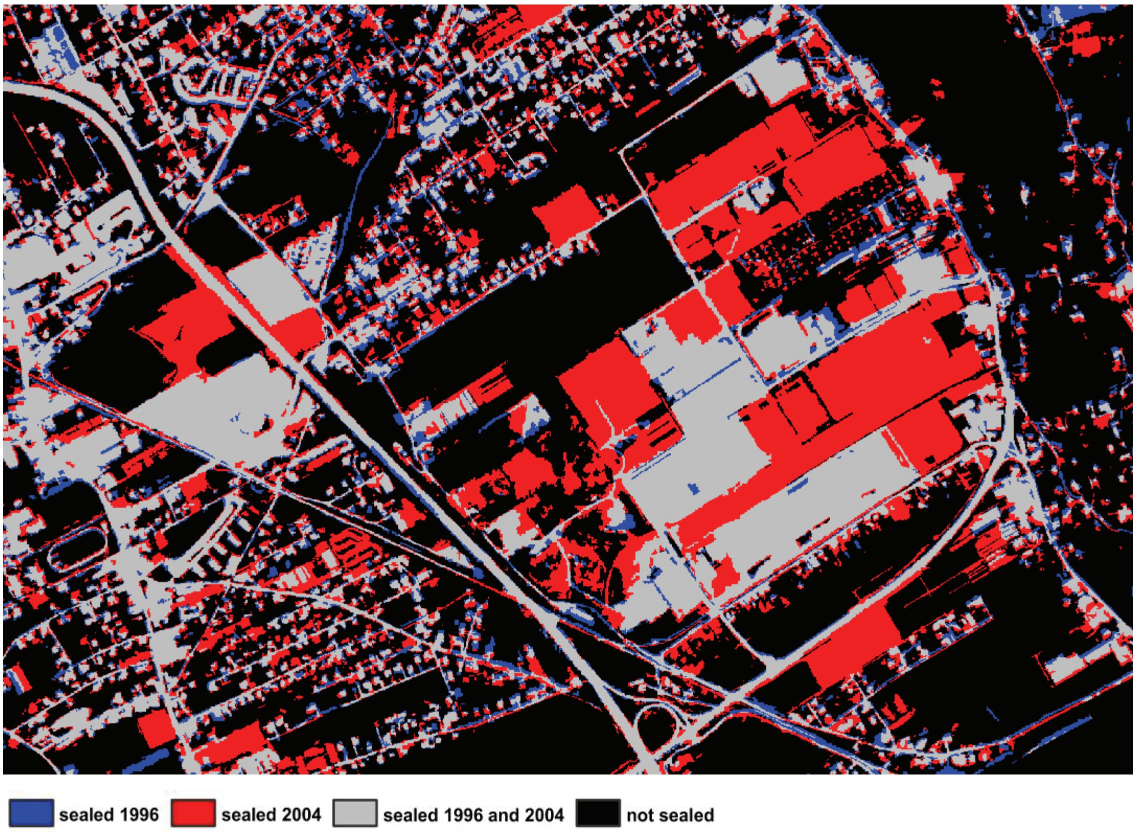

Figure 5: Comparison of sealed surfaces in the south-eastern part of Graz (1996-2004).

Nevertheless, a direct comparison of both sealing maps cannot be made without qualifications. Some of the reasons are listed below:

One of the core reasons is that the two flights took place in different seasons. While the 1996 image was taken when the vegetation period just started, the vegetation period in the 2004 image was almost over. In April, agricultural fields were at least partially vegetated, but greening-up of deciduous forest and semi-natural vegetation had not started yet. On the other hand, crop harvesting and leaf fall was in progress in October. Hence, the sensor recorded considerably less possible sealed surfaces in 2004 than in 1996, because many of them were covered by the leaves of trees. Another result is a 15% decrease of green space from 1996 to 2004; at least one third of the former green space became sealed within that time period.

Moreover, the sun elevation is already low in late October and extensive shadows occur. The image taken in October 2004 contains about 60% more shadow than the image of April 1996. During classification, surfaces under shadow sometimes got mixed up with other types of objects which have similar spectral signatures as shadows. In our case, sealed surfaces affected by shadows were often misclassified as forest. This fact also explains a 10% increase of wooded areas from 1996 to 2004.

Vegetation changes not only during seasons but also over time. Trees are growing, parkways and woods become denser and thereby cover more and more sealed surfaces. The two images have different spatial resolutions. The 1996 image has a ground resolution of 2.5 m × 2.5 m, while the 2004 image has a resolution of 1 m × 1 m. Details which were recorded in the 2004 data could not be captured in 1996.

Due to the two different geometric correction routines the geometric accuracy and overlay of both images do not fit perfectly.

Table 4: Comparison of sealed surfaces 1996-2004 (total investigation area).

	Hectares	1996	2004
2004	1056.5	X	1056,5
1996	844.7	844.7	X
No change	2510.5	2510.5	2510,5
Total area	X	3355.2	3567,0

Application of sealing maps in town planning

Sealed areas are important indicators of urbanization (a major component of urban infrastructure and an indicator of human activities) and an essential environmental index (model run-off volume and monitor water quality). The main proposed effort of the sealing maps is their integration into the town drainage/sewage system management of the governmental office of Graz. The objective of the presented study is about to map the currently sealed urban area in the city for calculating the amount of sewage of each single catchment area. This knowledge and the figures of rainfall and waste water from households will help to estimate the amount of water, which flows into the channel system (cf. also 14).

Ground check of single plots in different places (allotments) proves that the accuracy of the sealing map is sufficient for the governmental requirements.

Figure 6: Sealing map with drainage system (whole area, left); catchment area and sealed areas (subset; right).

CONCLUSIONS

The generation of detailed sealing maps of an urban environment and their integration into the analyses of the local sewage system of Graz have been documented in this paper.

The analyses of multitemporal aerial scanner campaigns are still ongoing. The historical data of 1986 are still in process. The next scanner mission is proposed in 2009/2010. With these data, the city government of Graz owns a detailed homogenous data set over a time period of more than 25 years. For ecologically sensitive regions on the fringe of the town, detailed information about the actual extent of the sealing process and the rate of changes is very important to obtain relevant information of the ongoing and future sealing processes. During heavy rainfall, evidences like in August 2005 with more than 120 mm per day and extreme flooding and overload of the drainage/sewage system show the importance of detailed planning of urban watersheds and drainage systems by the municipality Graz. Remotely sensed generated sealing maps are one important step amongst others to avoid floods by a severe prediction of natural evidences (rain), land use/land cover and technical infrastructure. Generating sealing maps and integrating them into sewage analyses is only a small part of the whole project, which also includes a lot of ecological and planning driven analyses of the scanner data.

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