

01.02 Impervious Soil Coverage (Sealing of Soil Surface) (Edition 2007)

Overview

Data on impervious soil coverage are regularly used in the offices of the Berlin administration responsible for environmental protection and for urban and landscape planning. One main area of application is the use and processing in various models, such as urban climate and water balance, or in various evaluation methods, such as soil protection. But the documentation of the condition of the impairment of nature and the landscape due to impervious soil coverage is also of great significance. Finally, policy-makers increasingly require data on impervious coverage in high time resolution, in order to monitor and measure the success of environmental or urban-planning strategies.

Definition

The impervious coverage of natural soils has a number of negative effects on the ecosystem and on the human habitat. Impervious coverage means the paving of the soil with non-porous materials. The categories of impervious areas are: **built-up impervious areas**, i.e., buildings of all kinds; and **non-built-up impervious areas**, i.e., roads, parking lots, paved walkways, etc.

In addition to building complexes and surfaces completely imperviously paved with asphalt or concrete, more **porous paving types** are also considered impervious, although these often have very different ecological qualities. Such coverings as honeycomb brick or paving stones with wide seams still permit reduced plant growth, are partially permeable to water, and provide for a considerably more favorable microclimate.

The existing types of pavement were grouped into four **pavement classes**, with different effects on the ecosystem (cf. Table 1).

Tab. 1: Overview of Pavement Classes		
Pavement Class	Estimated effects on ecosystem	Type of pavement
1	extreme	Asphalt, concrete, paving stones with joint sealer or concrete substructure, synthetic surface materials
2	high	Artificial stone and plates (edge length > 8 cm), concrete-stone composites, clinker, medium and large-sized paving stones
3	medium	Small-stone and mosaic paving (edge length < 8 cm)
4	low	Grass trellis stones, water-bound pavement (i.e. ash, gravel or tamped ground), gravel lawn

Tab. 1: Overview of impervious pavement classes

[Examples: [Pavement Class 1](#), [Pavement Class 2](#), [Pavement Class 3](#), [Pavement Class 4](#).]

The Effects of Impervious Coverage on the Natural Balance

The effects of impervious coverage are felt primarily in cities and metropolitan areas, where a high proportion of the total area is impervious.

Among the various effects on the ecosystem is first of all the fact the impervious coverage contributes to the development of a specific **urban climate**. The air is heated by the high heat-storage capacity of buildings and asphalt streets. Especially in summertime, nighttime cooling is reduced (cf. Fig. 1).

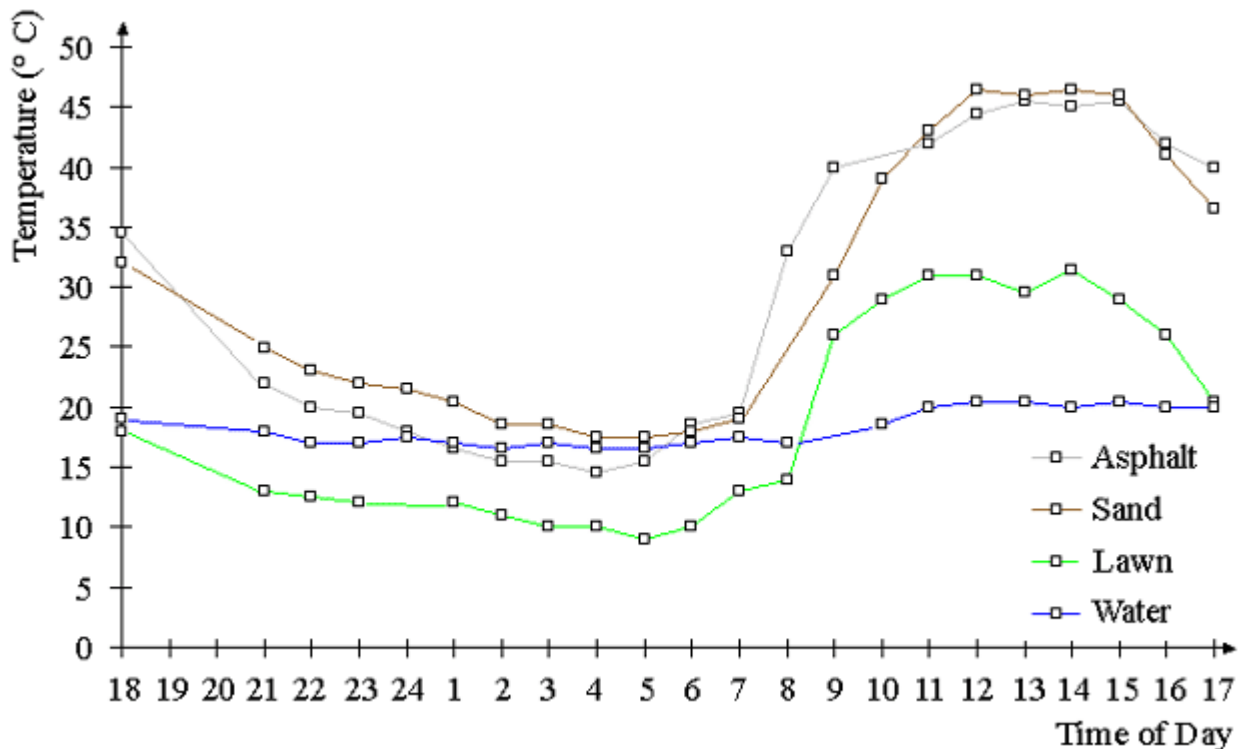


Fig. 1: Temperature curves over various surfaces (Kessler 1971 in: Mählenhoff 1989)

At the same time, the **relative atmospheric humidity too is reduced**, since vegetation-covered areas and the evaporation they generate is lacking. This can lead to the occurrence of **extreme values** which can impair human well-being considerably. In this context, pervious areas, such as parks, play a major role. Parks of even one hectare in size or more have a demonstrably positive climatic effects on human well-being. Vegetation-covered areas also have an effect on the dust and pollutant contents of the air, since, with their large leaf surfaces, they are able to **bind dust particles and other air pollutants**.

The effects of impervious coverage on the Berlin urban climate are described in detail in various maps of the chapter [04 Climate](#).

Impervious coverage of the soil also causes profound changes in the **water balance**, due to the loss of evaporation and seepage surfaces for precipitation. The rainwater runoff from impervious areas, heavily polluted by tire abrasion, dust, dog excrement, etc., is passed by via the sewage system either directly into the tributaries or into sewage-treatment plants (cf. Map 02.09, [Management of Rain and Waste Water](#)).

Impervious coverage and condensation moreover strongly disturb the **functions of the soil**. The blockage of the water and oxygen supply destroys most soil organisms. Since no more water can seep away, the pollutants introduced via the air and precipitation are no longer retained in the soil, and are washed into the surface waters.

The complete impervious coverage of the soil causes the complete loss of all **flora and fauna**, but even partial impervious coverage always means habitat loss. Biotopes are fragmented or isolated, while sensitive species are crowded out in favor of more adaptable species.

In addition to the above-described consequences for the ecosystem, the degree of impervious coverage in urban areas also has an immediate effect on the **human habitat**. A high degree of impervious coverage is usually associated with a disparity of open space per capita. Long rows of buildings, frequently interrupted only by asphalt or concrete surfaces, can have a depressing, monotonous effect on residents. Such factors of nature as the change of the seasons can no longer be experienced in the immediate residential environment. Increased dependence on nearby recreation areas at the outskirts of a city on the other hand generates traffic, which also has a negative effect on the environment.

Impervious Coverage and Land Consumption in Germany

In Germany, impervious areas account for approx. 6 % of the total area (Gunreben et al. 2007, not counting Saxony-Anhalt; 6.4 % UBA 2007). Given a total area of 35.7 million hectares, (Baratta 2003), this corresponds to an impervious area of 2.14 million hectares.

In the political debate, the **environmental indicator “land consumption”** is primarily cited, and has also found its way into the national sustainability strategy.

There, since 2002, the goal of reducing land consumption to 30 hectares per day by 2020 has been formulated. Daily land-consumption demand in Germany is 115 hectares (2004) (Umweltbundesamt 2008). This figure has been reduced in recent years due to the economic situation, the drop in new road building, and the impervious coverage regulations for new buildings (in 2000, it was 129 hectares/day); however, for the last five years, it has been stagnating.

Land consumption is calculated from the daily increase in **built-up and traffic areas**. This is not equal to the impervious area, since it also includes areas which are only slightly impervious, such as gardens in residential areas or green strips on roads, etc. (Gunreben et al. 2007).

The **reduction of land consumption**, which is a goal of the Sustainability Strategy, is to be achieved by space-reduced construction of buildings, densification of urban areas, concentration of infrastructure, provision of compensation areas, and the removal of impervious surfaces no longer used (space recycling). With the increase of the quality of the living environment in residential areas, concentrated housing in the city is to be reestablished as an alternative to the “home in the green suburbs” once again. (Bundesregierung 2007). Germany's states and municipalities are to realize these targets in the context of their spatial and construction planning.

Legally mandatory stipulations are also being used to reduce impervious coverage. The impervious-coverage removal requirement under §5 of the Federal Soil Protection Law (BBodSchG) of 1998 is designed to provide compensation for land consumption, by causing areas no longer used to be made pervious again, and thus regain their natural soil functions under §2 Sect. 2 BBodSchG. The law makes allowance for reasonable expense and burden (Oerder 1999, .p. 90 et seq.).

A further possible instrument for reducing impervious coverage is **financial incentives** at the individual level. For example, Berlin has since January 1, 2000, invoiced the charge for precipitate-water sewage separately. The introduction of this so-called **fee-splitting** is based on a ruling by the Federal Administrative Court (verdict of June 12, 1972) and the Superior Administrative Court of Lüneburg (verdicts of June 14, 1968 and of April 10, 1980). These rulings stated that in municipalities in which the cost of precipitate-water sewage disposal accounts for more than 15% of the total costs of sewage disposal, the fees must be invoiced separately, so that the fee for precipitate-water sewage disposal is no longer linked proportionally to the general sewage fee, but is rather charged according to the impervious share of the property from which waste water is fed into the sewage system (BWB 1998). Therefore owners have since 2000 endeavored to keep the impervious area of their property as low as possible, in order to save sewage fees. Since the new **Precipitate-Water Exemption Ordinance** of August 2001 came into effect (the Ordinance on Exemption from Requirement for Permission for Harmless Percolation of Precipitate Water – NWFreiV, 24 August, 2001), it is possible to obtain proportionate or full exemption from the precipitate-water sewage disposal fee (SenStadt 2001) via measures for relieving the rain water sewage system via-water percolation on one's own property, without permission.

Statistical Base

Data on impervious soil coverage for Berlin have been available in the Environmental Atlas since the beginning of the '80s. At first, this was true only for the western part of the city; since the political change in the East, a full-coverage data stock has been built up and maintained over the course of a number of shifts of emphasis and updates. However, this data base was no longer up-to-date, and was moreover based on non-uniform surveying methods.

In cooperation with the Berlin University of Technology, the Humboldt University and the company Digitale Dienste Berlin, a new data base has now been built up. Here, **a new mapping procedure** has been used, which was developed in the context of a preliminary study in 2005, and implemented generally in 2006.

The following specialized information and geo-data, as well as satellite-image data, have been used:

Urban and Environmental Information System, Block Map 1: 5000 (ISU 5) and Land Use Data

The spatial reference of the ISU is oriented toward the structure of the statistical **blocks** of the Regional Reference System (RBS) of the Berlin-Brandenburg Bureau of Statistics. However, each block may be further subdivided into homogeneous-use **block segments**. For each of the approx. 23,000 sections of the ISU 5 structure, there is a 16-digit key, to which a database is linked. In this database, information on both section size and use is stored.

A total of [63 section types](#) with homogeneous use and spatial structures are distinguished.

The ISU 5 was used for the impervious coverage maps current as of Dec. 31, 2005. The ISU data were used as follows in the evaluation process:

- The geometric data served to delimit blocks and distinguish streets and bodies of water. Sections outside the statistical blocks were not analyzed.
- The degrees of impervious coverage were calculated at the level of the ISU blocks and block segments.
- The ISU utilization data was used for the stratification of the municipal area, and were fed into the rule-based classification system.

Automated Map of Properties (ALK)

In Berlin, the lot-referenced factual and geometric data of the Register of Land Properties is maintained in the form of the Automated Book of Properties (ALB) and Automated Map of Properties (ALK). The data stock of the Berlin ALK covers the entire area of the State of Berlin and consists of approx. 1.5 million properties, largely fields and buildings.

The vector data of the ALK, current as of August 2006, were used for the **delimitation of buildings** within the ISU blocks, and for the specification of remaining areas as non-built-up block space and as analysis areas for satellite-image evaluation.

With regard to the integration of the ALK data into the evaluation process, it was ascertained that facilities on railyards and urban-rail stations, buildings in industrial and commercial areas, and also summer homes in allotment-garden areas were frequently missed.

Map of Berlin 1 : 5000 - K5

The map of Berlin by the State Mapping Agency at a scale of 1 : 5000 (K5) has been drafted by the Berlin boroughs on the basis the Berlin ALK. The above-ground railway lines shown in the K5 Map were used for the impervious-coverage maps current as of January 2006, to the extent that these were provided by the boroughs.

The lot-precise recording of **track beds** was used primarily for the mapping of the shaded railway lines in forests, such as that north of Müggel Lake.

Orthophotos

The full-coverage digital orthophotos used were taken from real-color aerial-photography material shot in August 2004. In the K5 sheet-line system, they are available in a resolution of 0.25 m, and were used for the following work steps:

- Geocoding of satellite photos,
- Ascertainment and delimitation of reference sections,
- Ascertainment and delimitation of sections to be corrected (e.g. water bodies not recorded).

Data on Impervious Soil Coverage of the Berlin Water Utility

For the ascertainment of correction factors for optimization of the evaluation procedure, the current impervious coverage information of the Berlin Water Utility (BWB) was consulted. Starting in January 2000, these data were collected in connection with the changed calculation of the **precipitate-water fees**. The BWB **aerial photography** and the **ALK** served for the initial recording of the impervious sections of the properties. Moreover, the checked information of the **property owners** was incorporated (WTE 2004). The lot-precise data was aggregated at the ISU block-segment level, and was available for evaluation, current as of 2001. Only the details on the non-built-up impervious sections were used. Lot-precise **local observation** and recording permitted a **very high degree of precision of data on impervious soil coverage** to be obtained.

The following restrictions had to be taken into account during the integration of the BWB data into the evaluation strategy:

- The BWB data were available only for properties with connection to the sewage system, particularly residential areas, not for all of Berlin.
- In traffic areas, parking lots, urban squares and promenades, green spaces, cemeteries, allotment gardens, areas with commercial or industrial use, areas with a low degree of built-up area, and supply and waste-disposal areas, the non-built-up impervious areas were often recorded only incompletely or not at all.
- The BWB definition of impervious coverage is different from that of the Environmental Atlas for some block types. While honeycomb-brick surfaces, or water-bound surfaces such as tamped ground and gravel surfaces are shown as 100% impervious in the Environmental Atlas, they are considered pervious in the BWB.

Multi-Spectral SPOT5 Scene

For the development of the procedure and the preparation of the impervious-coverage map, a multi-spectral SPOT5 scene (058/243) of September 5, 2005 was selected, and taken as a system-corrected data set. **The photo was free of clouds.** The analysis of the spectral bands showed only very low atmospheric impairment. The pan angle was approx. 1.9°, and tilts of buildings were negligibly low, so that in the context of this project, an “ideal” scene could be used. Due to the seasonal lighting conditions, the shaded areas were relatively large; however, they were in any case treated separately in the development of the procedure.

Methodology

The **Berlin University of Technology's** Institute for Landscape Architecture and Environmental Planning, in cooperation with the Geographical Institute of the **Humboldt University of Berlin** and the company **Digitale Dienste Berlin** were contracted to design and implement a **hybrid mapping procedure**, with the goal of developing a homogeneous city-wide database which would be current and precise enough to ascertain the impervious coverage situation and provide a means for changing it. After evaluation of a test area, the procedure was developed further and applied to the entire municipal area of Berlin. The evaluation procedure is based on the use of **ALK** (Automated Map of Properties) **data** for impervious built-up sections, and on the analysis of high-resolution multi-spectral **satellite-image data** for the impervious non-built-up sections.

The development of the procedure was carried out with a SPOT5 scene. Relevant information from the **Environmental Atlas**, the Urban and Environmental Information System (ISU) and the **Berlin Water Works (BWB data)** are incorporated into the classification process. The ISU statistical blocks serve as reference surfaces.

The mapping procedure consists of three evaluation steps:

- Mapping of impervious built-up sections,
- Mapping of impervious non-built-up sections,
- Ascertainment of the degree of impervious coverage.

The mapping of impervious coverage concentrates on the areas of the statistical blocks; transportation routes and bodies of water are not considered. The following illustration shows the use of the various data from the agencies and from geo and satellite image data in the Berlin mapping procedure for impervious sections.

The complete **Final Report of the Study** on the mapping of impervious coverage can be downloaded from the chapter Literature as a [PDF file](#) (in german).

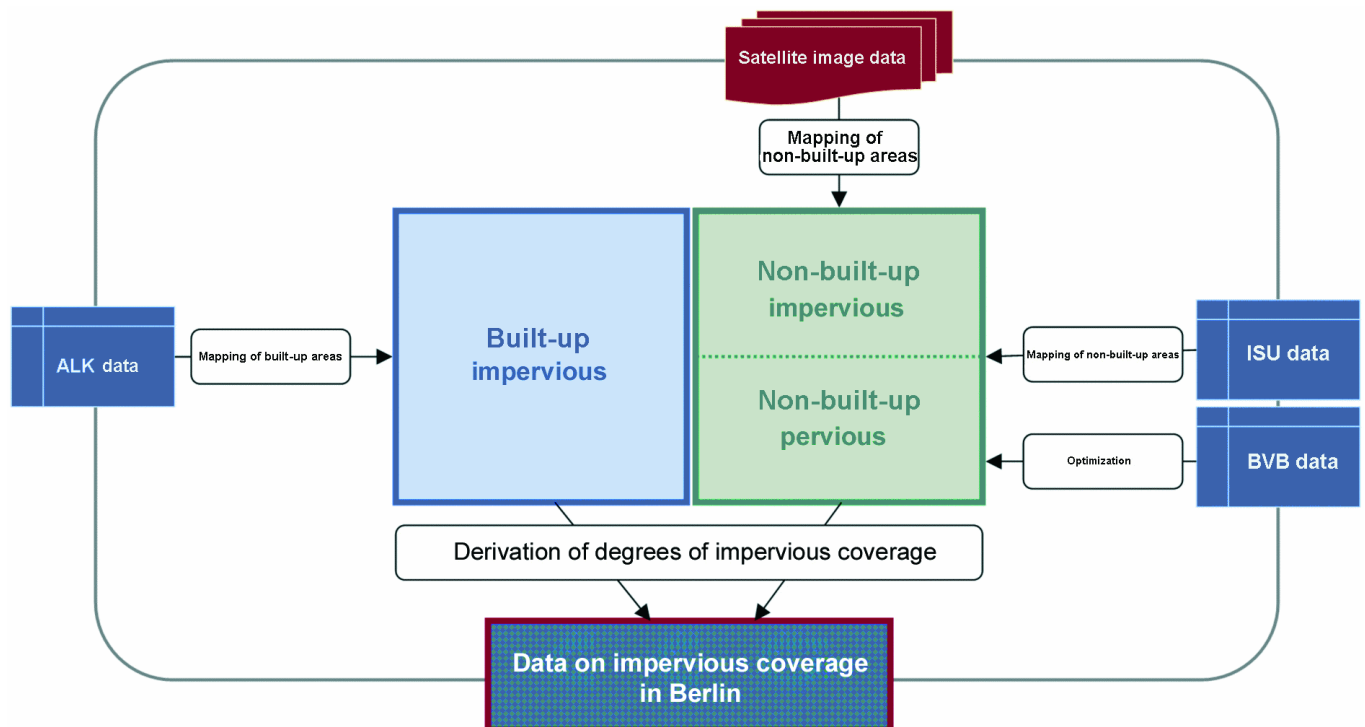


Fig. 2: Diagram of the hybrid mapping method

Mapping of Built-Up Impervious Sections

The delimitation of the built-up impervious sections was carried out exclusively on the basis of ALK data. Their integration into the mapping process constituted the first component of the hybrid method approach. For these sections, no evaluation has been carried out via satellite-image data.

With regard to the mapping precision of the built-up impervious sections, the familiar problems with regard to the topicality of ALK data must be considered. Particularly buildings on industrial and commercial areas as well as summer houses in allotment-garden areas are frequently missed, partially or entirely. In the future, there is a good chance that the data base can be completed.

Mapping of Impervious Non-Built-Up Sections

For the mapping of the impervious non-built-up sections, a classification approach was used in which satellite-image data (SPOT5) and geo-data (ALK, ISU) were incorporated and combined. The method took into account the following requirements:

- Mapping of the entire municipal area,
- Low expenditure of time and effort for the pre-processing of the satellite-image data:
 - use of geo-coded, system corrected data,
 - coverage of the municipal area with as few scenes as possible,
- Low expenditure of time for the analysis of the satellite-image and geo-data,
- Restriction of use of terrestrial photos, or controls to ensure they be kept to a minimum,
- Flexible sensor and scene selection,
- Realization of a high degree of automation,
- Integration of the mapping results into the ISU.

The satellite-image evaluation consists of the following five major evaluation focuses.

Categorization of Section Types Relevant for Remote Sensing

To improve the mapping results, a categorization of [ISU section types](#) according to the remote-sensing-relevant criteria building height, vegetation height, reflection quality, heterogeneity and relief, as well as the average degrees of impervious coverage (2001) was carried out. This permitted spatially separate segment classification, and optimized choice of methodology. Eighteen categories were defined (Table 2).

Tab. 2: Remote-Sensing-Relevant Section-Type Categories								
Section-Type Categories (KAT)		Mean Impervious Coverage [%] *			Effect Factors			
		Total	Built-up	Non-built-up	Buildings height	Vegetation-height	Spectral reflection	Heterogeneity
Densely built-up core, commercial and mixed areas; block structure	1	> 80 (> 66)	> 66	> 10 (> 33)	● / ●●	⊙	⊙	⊙ / ●●
Imperial-era block-edge buildings	2	> 66 (> 80)	> 66 (> 33)	> 10	●	●	⊙	●
Block edge buildings of the '20s/'30s, linear structure (no concrete-plate housing)	3	> 66	> 10	> 10	●	●	⊙	●
High buildings	4	> 66	> 10	> 10	●●	⊙	○	○
Low and village-type buildings with gardens, tree nurseries/ horticulture, water sports	5	> 10	> 10	> 10	○	●●	⊙	⊙
Traffic areas, urban squares/ promenades, sports facilities	6	> 66 (> 80)	> 10	> 66	⊙	○○ / ●●	○ / ●●	⊙
Public facilities/ special facilities (except traffic areas)	7	> 33	> 10	> 10	⊙ / ●	⊙ / ●	⊙ / ●	⊙ / ●

Forest	8	> 1	< 1	> 1	○○	⊙	○○	○○
Farmland	9	> 1	< 1	> 1	○○	○○	○	○
Parks, cemeteries, camp grounds	10	> 10	> 1	> 10	○○	●	⊙	⊙
Allotment gardens	11	> 10	> 10 (> 1)	> 10 (> 1)	○○	●●	⊙ / ●	●●
Fallow areas	12	> 1	> 1	> 1	⊙	⊙	●	●
Slightly built-up areas w/ primarily commercial/ industrial use	13	> 66	> 10	> 33	●	⊙	⊙ / ●	⊙
Schools	14	> 33	> 10	> 33	⊙ / ●	⊙ / ●	⊙ / ●	⊙
Sports facilities	15	> 33	> 1	> 33	○	○	⊙ / ●	○
Rail yards without track beds; Track beds	16	> 80	> 7	> 66	○○	○ / ●	●	○
Supply/ waste disposal areas	17	> 66	> 10	> 33	⊙ / ●	○○	⊙ / ●	○
Airports	18	> 80	< 10	> 80	○	○○	●	○

*) according to Environmental Atlas data as of 2001

Reduction of map precision	
○○	very low
○	low
⊙	medium
●	high
●●	very high

Tab. 2: Remote-Sensing-Relevant Section-Type Categories

Spectral Classification of Non-Built-Up Areas

The satellite-based remote-sensing data were further processed by means of a machine-based, automatic classification procedure.

First, the **degree of vegetation coverage** of non-built-up areas was ascertained via the **Normalized Differenced Vegetation Index (NDVI)**. This index is based on the fact that healthy vegetation reflects relatively little radiation in the visible spectral range (wavelengths of approx. 400 to 700 nm) and relatively much more in the subsequent near infrared range (wavelengths of approx. 700 to 1300 nm). In the near-infrared range, this reflection is strongly correlated with the vitality of a plant: the greater the vitality, the higher the increase of the reflection coefficient in this spectral range. Other surface materials, such as soil, rock or even dead vegetation, show no such distinctive difference in reflection coefficient for these two ranges. This fact can thus serve on the one hand to distinguish areas covered with vegetation from bare areas, and also to obtain information on photosynthetic activity, vitality and density of vegetation cover. This standardization yields a range of values between -1 and +1, where "an area containing a dense vegetation canopy will tend to positive values (say 0.3 to 0.8)" ([Wikipedia 2007](#)).

Particularly relevant surface materials, such as **sand, ash and tamped soil, railway-track gravel and artificial surfacing, as well as shaded areas**, which are frequently evaluated faultily, must continue to be examined with special care.

Fig. 3 shows the spectral classification procedure, which consists of 6 partial evaluations.

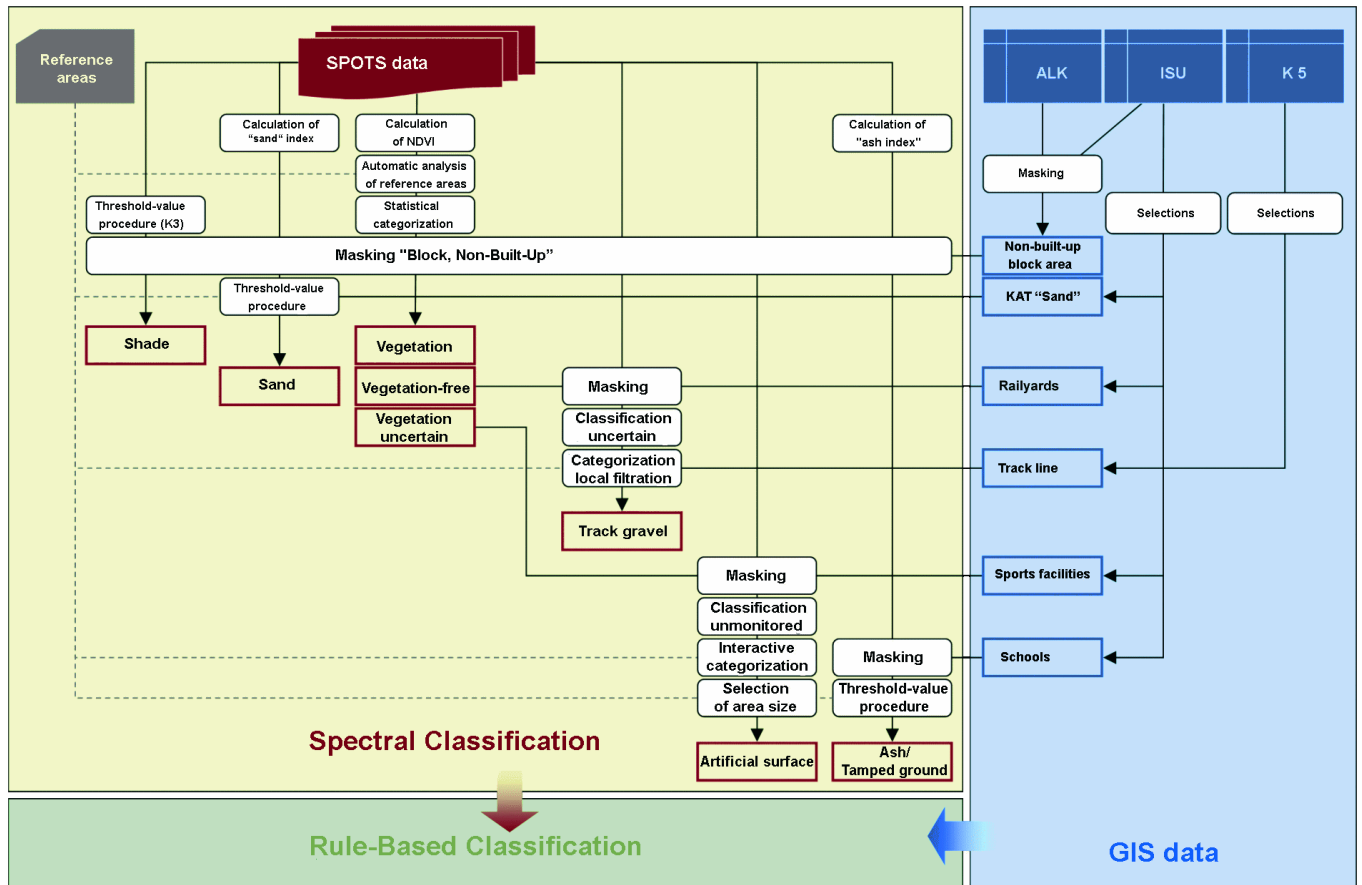


Fig. 3: Diagram of the Spectral Classification of Non-Built-Up Sections

The **degrees of impervious coverage** are obtained step-by-step from the **degrees of vegetation coverage** per pixel ascertained. The method is based on the following assumptions:

- There is a linear connection between NDVI and degree of vegetation coverage: the higher the NDVI value, the more vital vegetation will be present.
- There is a high negative correlation between degree of vegetation coverage and degree of impervious coverage.

Vegetation-free spaces (**degree of vegetation: 0%**) are reflected by low to very low index values. More detailed distinctions between impervious and pervious sections are not possible via NDVI.

Areas completely covered by green vegetation, such as forests or grasslands (**degree of vegetation: 100%**) are largely reflected by high to very high index values. These areas were classified as pervious.

The problem of the **local coverage of impervious areas by treetops** is not soluble via the evaluation of satellite-image data. To correct for this “error,” **context-related correction factors** were ascertained and used, with the aid of ISU data. The ascertainment and distinction process of the graduations of degrees of vegetation coverage (degree of vegetation coverage: >0% and <100 %) was methodologically demanding. Medium index values predominated. The fact that identical index values could result from different signature mixtures had to be taken into account.

The present procedural development made use of these differences: NDVI values which indicate partial vegetation coverage of sections (vegetation degree >0 %) were considered in a differentiated manner, and assigned to different degrees of impervious coverage in the **rule-based classification system, depending on section type or section-type category**.

Based on this approach, 12 NDVI categories were established (cf. Table 3).

In the future, it is to be possible to evaluate **track gravel** differently depending on the use of the data on impervious coverage. In some contexts, it is considered impervious, for others, they will be assigned to the “pervious sections” category. Therefore, they were classed separately within rail yards. A “track gravel” category was created, which can be assigned optionally to either of the two impervious coverage categories.

The spatial proximity of the materials iron, gravel and in some cases the wood of the rail ties yielded a largely characteristic reflection of track gravel. Here, ascertainment was more difficult, due to a category-typical spectral

heterogeneity. Particularly distinction from such impervious surfaces as streets was not always possible for certain. To avoid mis-mapping, the mapping of track gravel was carried out exclusively within the section-type categories "Railyards without Track Beds" and "Track Beds." Moreover, the K5 route network was used, which made it possible to detect tracks covered by treetops as well.

The corrected **classification components** were brought together into a pixel based data set, which formed the basis for the subsequent rule-based classification system. The mapped sand, artificial-surface and track-gravel sections were aggregated with the impervious built-up building sections from the ALK to form a **classified combined-block section**. The category "shaded" remained separated from the other categories.

Rule-Based Classification

Under rule-based classification, the results of spectral classification are combined with ISU data (section types) to yield **degrees of impervious coverage derived at the pixel level**. Figure 4 shows a schematic overview.

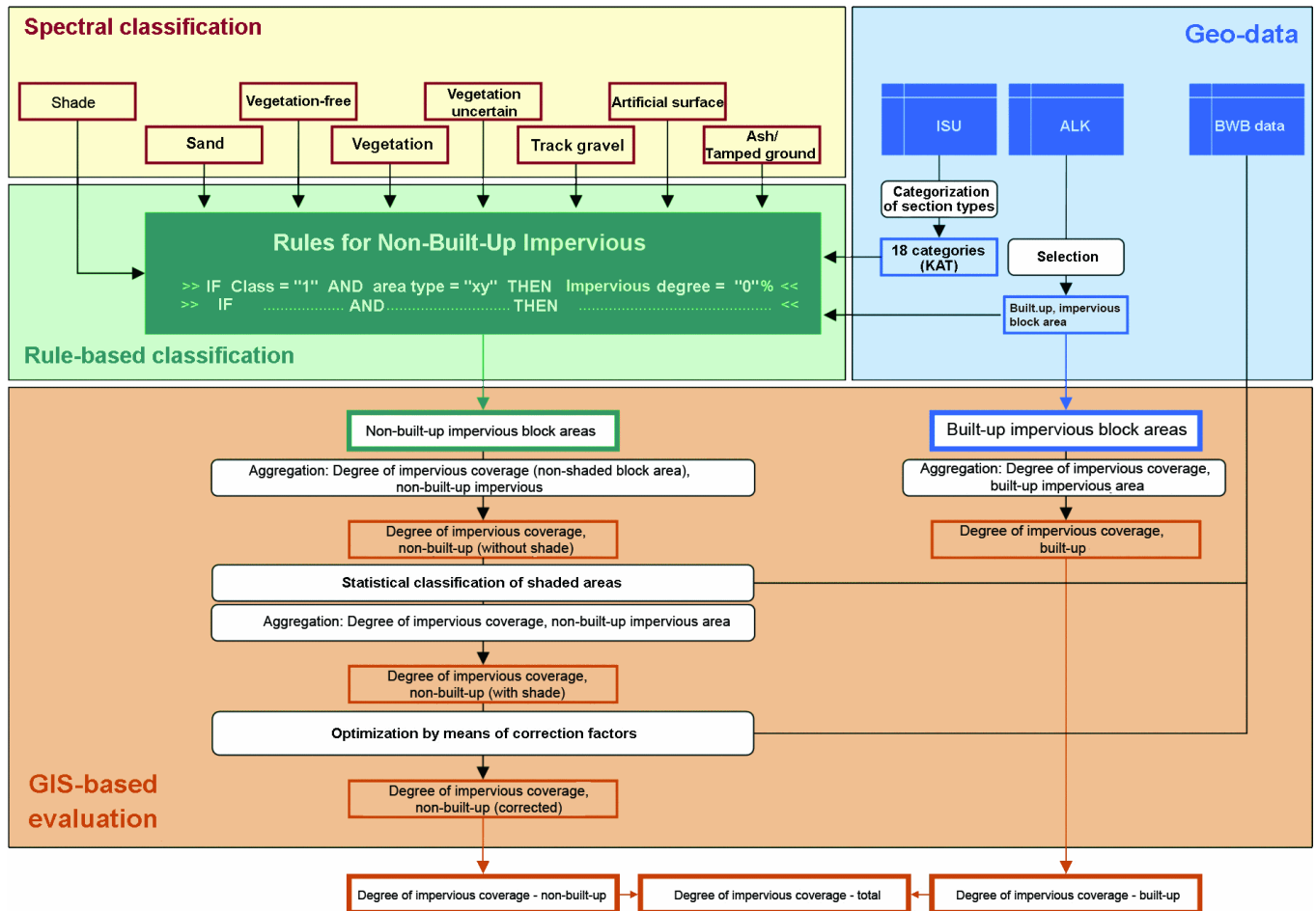


Fig. 4: Diagram of rule-based classification

The classes and the NDVI categories were then assigned to degrees of impervious coverage. A reliable delimitation of completely vegetation-free and completely vegetation-covered areas was achieved in the NDVI categories 1 and 12 (lowest or highest NDVI values, respectively). Corresponding **threshold values** were derived automatically by means of **reference sections**.

- NDVI Category 12 "Vegetation – Certain:" Under the rules, such sections were classified as 0 % impervious. This applied to all section-type categories.
- NDVI Category 1 "Vegetation-Free – Certain:" Vegetation-free spaces were only considered to be 100 % impervious once they had been determined to not be neither "Sand" nor "Track Gravel."

The range of values between these NDVI limits is broken down via interval scaling into 10 additional NDVI categories of "Vegetation – Uncertain." In order to obtain a reliable assignment of degrees of vegetation and impervious coverage, they had to be interpreted differently, by section-type category or section type. Thus, a total of 3 assignment variants were established (Table 3). For each NDVI and impervious coverage category, the mean percentage value (5 %, 15 %, ..., 95 %) was established as the conversion factor.

Recommendations from the concept study, the evaluation results of Haag 2006 and findings from aerial image interpretations and terrain inspections were incorporated. Also, results from the procedural validation process (cf. Validation) were taken into account for the iterative process optimization.

NDVI (categories and degree of vegetation)															
KAT	1	2	3	4	5	6	7	8	9	10	11	12			
%	0	5	15	25	35	45	55	65	75	85	95	100			
Degree of impervious coverage	%	100	0	0	0	0	0	0	0	0	0	0	A	Assignment variant	
	%	100	95	85	75	65	55	45	35	25	15	5	0		B
	%	100	100	100	100	100	100	0	0	0	0	0	0		C

Conversion factors for the calculation of pixel values: Degree of impervious coverage 100 % = 1.00; 95 % = 0.95 etc.

Tab. 3: Assignment variants: Degree of vegetation – Degree of impervious coverage

The assignment variants were oriented toward certain section types, which are characterized by the spatial interconnection and the proximity of certain surface materials and types of buildings.

- **Assignment Variant A: Vegetation and pervious vegetation-free sections.**

The intermediate stages of the degrees of vegetation coverage (5% - 95%) were interpreted as mixed signatures of vegetation and other pervious surface types. The corresponding sections were therefore classified as pervious.

Examples: Fallow areas, Forest, Farmland.

- **Assignment Variant B: Vegetation and impervious vegetation-free sections.**

The characteristic surface materials suggest a low share of vegetation-free pervious sections. Intermediate stages of the degrees of vegetation were therefore interpreted as mixed signatures of vegetation and impervious surfaces. The gradual increase in degree of vegetation per category thus corresponded to an adequate drop in degree of impervious coverage.

Examples: Allotment gardens, traffic areas, block-edge buildings.

- **Assignment Variant C: Vegetation and impervious vegetation-free sections – block type "Airports".**

A variety of impervious surfaces characterized this block type. Some materials, such as concrete, showed strong spectral coincidences with sand and open soil. Such blocks indicate runways, parking areas etc. Within the airport area; green spaces were largely delimited as separate blocks. To achieve certain separation, it has proved useful to classify sections with low degrees of vegetation as completely impervious (NDVI categories 2 through 6).

At the same time, the **result of the rule-based classification system** of the non-built-up blocks corresponded to the final result of the satellite-image classification process. The category non-built-up impervious sections has been described in the classification with the **12 impervious coverage-degree categories**, a **Shade** class and a **Track-Gravel** class.

Fig. 5 shows the result of the satellite-image evaluation and the mapping results of the built-up impervious sections. Both data sets were brought together, and in conclusion, the degrees of impervious coverage were calculated (cf. Calculation of the Degrees of Impervious Coverage).

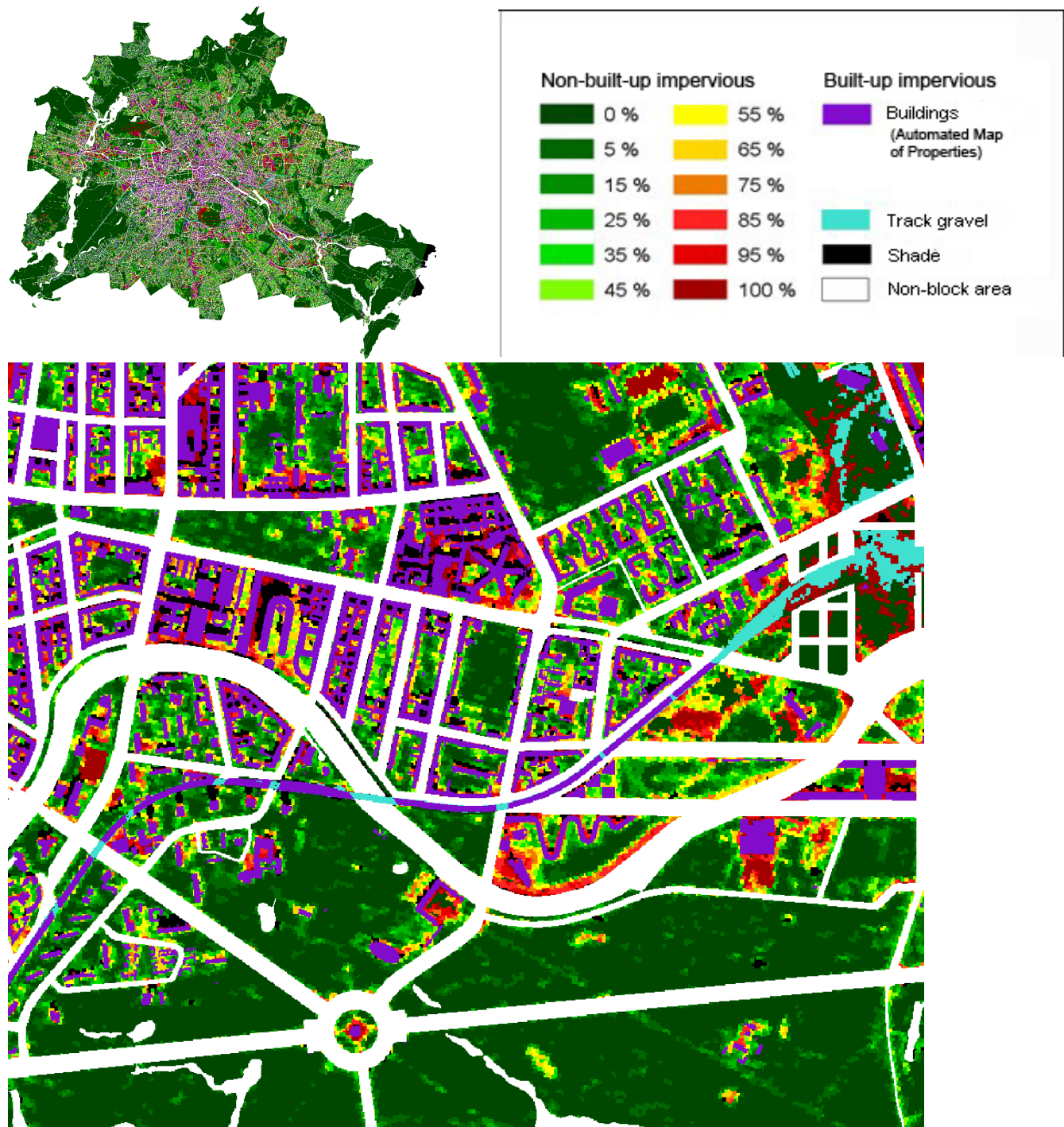


Fig. 5: Result of rule-based classification

Calculation of Degrees of Impervious Coverage

The goal of the impervious-coverage mapping process was the derivation of the **degrees of impervious coverage at block level**. The absolute and relative section information was calculated. Three degrees of impervious coverage (IC) were distinguished:

- IC "Built-up impervious sections" (calculated from the Automated Map of Properties/ ALK data),
- IC "Non-built-up impervious sections" (calculated from satellite data),
- IC Total (sum of the above).

For the calculations, the results of the **pixel-based satellite-image classification** were collated with the areas from the **block map ISU 5**.

First, a **summation by impervious coverage class and block areas** was carried out. Thus, the grid data of the classification system was no longer necessary for further analyses.

There were thus 15 section-referenced statements in sq. m. for each block and block segment:

- Built-up areas (from the ALK)
- 12 categories of degrees of impervious coverage – for non-built-up areas (corresponding to the NDVI categories)
- Track-gravel areas (optionally either 0 % or 100 % impervious), and
- Shaded area (unclassified).

For the further **improvement in the mapping results** the following additional calculations were carried out.

Optional Assignment of an Impervious-Coverage Value to Track-Gravel Areas

The class "Track Gravel" has been maintained as a data field of its own, and can optionally be included in the calculations either as an impervious non-built-up (100 %) or pervious built-up area (0 %). This ensures the different evaluation of gravel according to the respective question at issue. In the result map shown, track gravel is considered 100 % impervious.

Classification of Shaded Areas

Shaded areas have been assigned impervious-coverage values at block level in a follow-up classification procedure using ISU data or BWB data. The shaded areas were evaluated depending on **section type**. For section types with predominantly residential use and adequate BWB data, the latter were used for the classification of the shaded areas. For all other section types, shaded areas were classified in accordance with their block-specific surroundings.

Evaluation of Built-Up and Non-Built-Up Impervious Sections in the Category "Allotment Gardens"

For the category "Allotment Gardens," the data on impervious soil coverage usually showed only the overall degree of impervious coverage. Since the ALK hardly mapped any summer houses or cottages, the non-built-up impervious areas could only seldom be distinguished from the built-up impervious areas. Therefore, the degree of impervious coverage was ascertained almost entirely via satellite-image evaluation.

For this impervious-coverage map, the differentiation between built-up and non-built-up areas was carried out with the help of **average values** from the Urban Development Department, Section IC, Allotment Gardens. A degree of impervious coverage for built-up areas of 9.6 % for West Berlin and 8.6 % for East Berlin was assumed.

Introduction of Correction Factors

For the further improvement in the mapping results, so-called correction factors were introduced. The **BWB data on impervious soil coverage** was used for this purpose. The principle of section-type-referenced corrections is based on the following well-founded assumptions:

- the BWB data are still largely up-to-date at the time of processing,
- the BWB data are adequately precise, due to the ascertainment methods (terrestrial inspection, aerial-image interpretation, building-owner information),
- the one-time calculation of correction factors makes them transferable to future evaluations, since they describe systematic trends in a city-wide comparison.

Due to topicality, overlap problems, differing definitions of impervious coverage, and gaps in impervious coverage ascertainment of some types by the BWB, correction factors could be calculated only for **6 section types** (cf. Table 4).

The calculation of the correction factors was carried out on the basis of the non-built-up impervious areas. First, the sum of non-built-up impervious area was calculated for each selected section type from the BWB data and the classification result. If there was a **rectified systematic over or underestimate** of the impervious coverage degree, the **ratio** was incorporated into the system as the correction factor.

Tab. 4: Correction Factor by Section type				
	Section type (TYPE)	BWB data impervious non-built-up area	Classification result impervious non-built-up area	Correction- factor

		[sq. m]	[sq. m]	
21	Village type	447,806	598,469	0.75
22	Row house garden type	830,718	1,315,616	0.63
23	Gardens	4,129,760	6,349,315	0.65
24	Park-like gardens	1,353,980	1,411,935	0.96
25	Gardens, semi-private green space	1,133,823	1,367,805	0.83
26	Open residential buildings	1,024,595	2,186,389	0.47

Tab. 4: Correction factor by section type

Validation of the Satellite-Data Evaluation

A validation method was carried out within the context of the project, the results of which had already been taken into account during the development of the procedure. It quantified the general sensitivity and reproducibility of the procedure in case of transfer to other data sets and ascertainment times.

Two SPOT5 scenes were used for the validation process. The basic development of the procedure, including the calculation of the result, was carried out with the data from a **scene** from **2005**. This procedure was applied to a scene from **2006**, adaptations of the method carried out, and cross-scene sensitivity and reproducibility were examined and assessed.

Results and their Effects on the Hybrid Procedure

The basic data for the selection of the validation scene were purposely selected as highly contrary to those of the work scene, to maintain a high degree of **external influences**. Nevertheless, a good level of agreement of degrees of impervious coverage was ascertained for the reference block areas between the two points in times. **The developed methodology is thus well suited for extrapolations of the impervious coverage mapping procedure.**

The low number of absolute inaccuracies are of a procedure-specific nature, and are "transferred" for application to alternative points in times. Relative agreement is accordingly very good.

A confrontation of NDVI values for reference areas of both SPOT5 scenes clearly showed the affect of **phenology**. Compared with the ascertainment time in June 2006, the generally higher photosynthetic activity in August 2005 resulted in higher NDVI values.

After **calibration of the NDVI values** and their transfer to NDVI categories, a clear improvement in agreement could be obtained for both years. Thus, the phenological effect was largely compensated for by the use of the section-type categories.

The information gained on the reproducibility of the analysis, and on the spatial and temporal stability, can be used to **update the impervious coverage map** (monitoring). Of particular significance for the time of ascertainment was the affect of the position of the sun on the overall area affected by shade, and by the effect of the vegetation situation.

The result is that a period from the beginning of June to the end of July is recognized as preferable, in order on the one hand to minimize the shaded proportion of the graphical data and at the same time to be able to depict the vitality maximum of the vegetation.

Precision of the Results

After conclusion of the mapping process, an extensive precision analysis of the degrees of impervious coverage ascertained was carried out. The mapping of the non-built-up impervious areas was verified in a sample method by means of **aerial-image analysis**. The mapping of the impervious built-up areas was evaluated for how **up-to-date** the data used from the Automated Map of Properties (ALK) were, as well as for their section-type-specific **completeness**. The results of the partial mapping processes concluded with in an analysis of the **overall mapping** at the level of section types.

Mapping of Non-Built-Up Impervious Areas

The verification process concentrated on the precision analysis of the non-built-up block areas mapped by satellite remote sensing. **Statistical statements** were ascertained both for the level of section-type categories, and for the level of section types. As a basis for the derivation of independent verification data, digital aerial-image material (2004) was consulted.

For the entire urban area, verification areas were taken at random and evaluated via an aerial-image-supported **systematic random-sample grid**. Various analysis and evaluation methods were used for comparison of the mapping and verification data.

The **recording precision** of the non-built-up impervious areas depends to a large degree on **section type**. Approximately half of the section types show a high to very high absolute precision (> 90 %) rate (cf. Table 6).

The deviations and precisions for the various **residential building types** are very heterogeneous (very low to very high precision rates), and depend to a large degree on the use of the BWB data (shade evaluation, correction factors).

Section types for which **no block-specific shade evaluation** could be carried out by means of the BWB data are notable for very high absolute deviations, and thus **low precision rates**. One major reason for mis-mapping is the frequently very small-scale proximity of dwellings and garages with surrounding non-built-up areas.

A closer analysis of section types shows that while particularly those section types with a low mean degree of impervious coverage of non-built-up areas show very low deviations of percentage values (very high precision), they on the other hand show very high deviations in proportion to the degree of impervious coverage. This includes particularly the section types "Forest" (55), "Farmland" (56), "Fallow Areas" (57) and "Railyards without Track Beds" (92) and "Track Beds (exclusive)" (99). Nevertheless, the impervious coverage tendency is reflected fairly precisely by the maps in these **largely very extensive** block areas.

Section types in which **parking lots** predominate show high to very high absolute deviations. Parking lots are especially often included in the section types "Camp Sites" (58) and "Water Sports" (15), as well as in the public-utilities types. The area under the trees is usually overshadowed here, so that the **degree of impervious coverage is underestimated**.

Mapping of Built-Up Impervious Areas

For the recording of the **impervious built-up areas**, building data from the **ALK** were used exclusively. In view of how highly up-to-date they were, the ascertainment precision of the impervious built-up areas was generally assumed to be **99 %** for those section types which were covered completely by ALK data.

For the section types "Rail Yards without Track Beds " (92) and "Track Beds (exclusive)" (99) there was only fragmentary ALK information or none at all available, so that no precision assessment of the mapping results was undertaken for these areas, as was also the case for "Allotment Gardens" (section types 34, 35 & 37) for the built-up share of which a general area-wide value was assumed.

Area Weighting and Overall Precision

Since the ascertainment precision for the impervious built-up areas of most section types, 99 %, is very high, while that of non-built-up impervious areas depends on their section type and varies between 75 % and 98 %, the precision for impervious coverage generally lies between these values, and, to be specific, depends on the **relationship between built-up and non-built-up impervious areas** (cf. Table 6). An overview of the overall precision is shown in the last three columns of Table 6.

A four-step **evaluation plan** was used to **evaluate the precision levels obtained**. The distinction by "very low deviation" (very high precision), "low deviation" (high to medium precision), "high deviation" (low precision) and "very high deviation" (very low precision) took the spatial-geometric possibilities and the limits of the satellite sensors used (resolution: 10 m x 10 m) into account.

The evaluation of the precision was carried out by means of the so-called **absolute root mean squared error (RMSE)** of the degrees of impervious coverage (in % of the respective areas). This does not show the deviation of the mapping results from the verification value, which could be described via the **relative RMSE** of the impervious area (in sq. m), where the mapping result is placed in relation to the verification result (100 %), regardless of the size of the reference area.

Example: a mapped impervious coverage area of 1 hectare with a verification value of 1.5 hectares yields a difference of 0.5 hectares, for a relative RMSE of approx. 33 %. For the absolute RMSE, the same difference is referred to the block area: for a smaller block area of 10 hectares, an absolute RMSE of 5 % is obtained; for a larger block area of 20 hectares, it is 2.5 %.

Thus, in the context of the precision consideration, the following aspects have to be taken into account:

- If only the absolute RMSE is considered, the mapping of small impervious-coverage areas in very large block areas may yield an overly positive assessment.

- If only the relative RMSE is considered, the absolute area size remains undifferentiated, so that even slight differences between areas already describe extremely large errors, although in most cases, the impervious coverage characteristics will have been correctly recognized.

The Results of Precision Investigation

With the mapping method used, the overall result of the precision assessment of the **degree of impervious coverage of Berlin was ascertained with a mean precision rate of approx. 95%.**

An overview of the precision levels (cf. Table 6) shows that very densely built-up section types are necessarily mapped with **high or very high precision levels**, due to their ALK integration (>90 %). Altogether, precision levels of over 90 % are achieved for 49 of the 62 section types.

As expected, **lower precision levels** are primarily obtained for section types whose overall degree of impervious coverage mainly results from non-built-up areas. For ten section types, the mean precision levels are between 85 % and 90 %.

Very low precision levels were ascertained for three section types (less than 85 %). These were "Camp Sites" (58), "Parking Lots" (91) and "Other Traffic Areas" (94), and their results are due to the insufficient ascertainment of their non-built-up impervious areas. Since the blocks of these section types cover a total area of only approx. 374 hectares citywide, these errors are acceptable.

The overall picture of precision is that in the new **hybrid-procedure** approach integrating the use of both geo-data and satellite data, **the respective advantages of these two information sources are combined.**

On the one hand, the built-up areas are as a rule mapped very precisely by means of ALK. On the other, the regular combination of high-resolution satellite-image data with geo-data, the non-built-up impervious areas are ascertained with high precision in most section types.

The tendency to **underestimate the degree of impervious coverage of non-built-up impervious areas** is also a factor in the calculation of the overall degree of impervious coverage, and is methodologically inherent. Once this procedure has been used widely in the context of monitoring, this effect will be equalized, so that statements concerning changes will become possible at block level.

Adoption of the Surface Types from 2001

The surface types of the non-built-up impervious block segments (walkways, courtyard areas etc.) were grouped into four surface-type classes, from concrete to grass pavers. Their respective distribution was investigated via selected test areas, and the results transferred to all areas of the same section type. The type-specific surface type distribution was not updated for the current map, but is based on a survey from 1988 (AGU Arbeitsgemeinschaft Umweltplanung 1988). The surface types are not shown on the map; however, they can be shown via the factual data display by block area.

Tab. 5: Surface Classes of Non-Built-Up Impervious Areas				
Section type	Share of Surface Classes of Non-Built-Up Impervious Areas			
	1	2	3	4
	%			
Residential areas				
Courtyard	56	22	3	19
Decorative or garden courtyard	62	27	10	1
Preservation-oriented rehabilitation	62	17	8	13
Shed court	46	29	13	12
Post-war block-edge	41	27	4	28
Uncoordinated reconstruction	45	28	13	14
High-rise, large residential estate	15	67	7	11
'90s residential estate, compact (4-storey apartment houses)	20	60	10	10
'90s residential estate, expansive (single-family, duplex, row-houses; <4 storeys)	20	35	35	10
Large courtyard and linear buildings, '20s & '30s (in E. Berlin: only large courts)	20	37	32	11
Linear buildings, '50s	49	46	3	2

Row-houses w/ garden	25	65	3	7
Gardens	18	74	2	6
Park-like garden	15	60	12	13
Gardens w/ semi-private green	20	64	4	12
Open residential buildings	18	74	2	6
Village	21	39	22	18
Core area	50	34	9	7
Industrial/ commercial districts				
Mixed area II with sparse construction	48	38	1	13
Mixed area II with dense construction	74	20	1	5
Supply & Waste-Disposal Areas	31	56	1	12
Community Services				
Security and order	54	25	3	18
Postal service	54	25	3	18
Administration	41	42	15	2
Culture	41	42	15	2
Universities and research institutions	15	70	12	3
Hospitals	42	38	8	12
Schools	45	40	2	13
Sports facilities	18	28	1	53
Water sports	46	29	13	12
Churches	65	7	16	12
Day-care centers	7	42	5	46
Senior citizens' homes	4	62	18	16
Youth recreation centers	4	62	18	16
Green and Open Spaces				
Allotment gardens, general	5	31	4	60
Cemeteries	14	27	5	54
Tree nurseries/horticulture	35	45	9	11
Parks, green spaces	30	20	5	45
Urban squares/promenades	50	20	10	20
Forest	5	5	0	90
Farmland	10	10	0	80
Fallow areas	20	10	0	70
Camp sites	20	20	0	60
Weekend house areas	11	43	2	44
Traffic Areas				
Parking lots	31	53	7	9
Railway facilities	5	5	0	90
Airports	85	10	0	5
Other traffics areas	42	32	19	7

Tab. 5: Impervious coverage classes in non-built-up impervious areas

Map Description

In the map, the **degree of impervious coverage**, i.e. the coverage of the earth's surface with impermeable materials, is represented in **percent of the reference area** (statistical block or block segment). Generally, the degree of impervious coverage declines from the center toward the outskirts, since the building structure toward the outskirts is less dense, and the outskirts areas are either completely undeveloped (forest or farmland), or characterized by detached homes. The exceptions to this are the traditional centers of boroughs like Spandau and Köpenick, which were separate cities prior to 1920. There, impervious coverage degree is about 60 %, and more than 90 % in their core areas. The large new development areas at the outskirts, such as Marzahn, Hellersdorf and

Hohenschönhausen, or Gropiusstadt in Neukölln and the "Thermometer Estate" in Lichterfelde, are between 50 % and over 80 % impervious.

The following table shows the average degrees of impervious coverage and the mean precision levels per section type.

The highest overall degrees of impervious coverage are shown for the section types "Closed Courtyard" with 83 %, and "Airport" with 86 %. **The lowest degrees of impervious coverage**, with 0 % each, are listed for the section types "Forest" and "Farmland."

Tab. 6: Mean degrees of impervious coverage and mean precision of ascertainment per section type

										Mean precision of ascertainment		
	Section Type	No. of Blocks	Block sect. [ha]	Imperv. sect. [ha]	Degree of imperv. cov. [%]	Built-up imperv. sect. [ha]	Built-up imperv. sect. [%]	Non-built-up imperv. sect. [ha]	Non-built-up imperv. sect. [%]	Total imperv.	Built-up imperv.	Non-built-up imperv.
1	Closed Courtyard	172	244	202	83	148	61	54	22	96,2	99,0	88,7
2	Courtyard	993	1672	1274	76	848	51	426	25	94,9	99,0	86,8
3	Decorative or garden courtyard	524	849	530	62	331	39	199	23	92,4	99,0	81,4
4	De-coring rehabilitation	84	168	102	61	63	37	40	24	93,6	99,0	85,1
5	Preservation-oriented rehabilitation	110	225	164	73	108	48	56	25	96,1	99,0	90,5
6	Shed court	126	252	148	59	81	32	67	27	95,0	99,0	90,1
7	Post-war block-edge	343	604	382	63	239	40	142	24	94,2	99,0	86,1
8	Uncoordinated reconstruction	44	108	71	65	41	38	29	27	93,3	99,0	85,2
9	High-rise, large residential estate	523	1921	858	45	387	20	471	25	93,0	99,0	88,0
10	Large courtyard and linear buildings, '20s & '30s (in E. Berlin: only large courts)	836	1436	711	50	448	31	263	18	93,4	99,0	84,0
11	Linear buildings, '50s	882	2699	1082	40	561	21	522	19	94,8	99,0	90,3
71	Concrete-plate buildings, '80s & '90s	90	252	130	51	54	21	76	30	95,4	99,0	92,9
72	Linear buildings, '20s & '30s (in E. Berlin only)	129	210	101	48	57	27	44	21	93,9	99,0	87,3
73	'90s residential estate, compact (4-storey apartment houses)	250	398	226	57	110	28	116	29	97,0	99,0	95,1
74	'90s residential estate, expansive (single-family, duplex, row, <4 storeys)	116	223	105	47	40	18	65	29	88,4	99,0	81,6
29	Core areas	281	479	371	77	232	48	139	29	92,0	99,0	80,3
54	Urban squares/ promenades	182	88	35	39	3	4	31	36	86,7	99,0	85,3
21	Village	132	450	151	34	80	18	71	16	94,0	99,0	88,5
22	Row-houses w/ garden	643	1200	345	29	211	18	134	11	97,8	99,0	95,8
23	Garden	2949	6209	1767	28	1092	18	675	11	95,9	99,0	90,8
24	Park-like garden	664	1492	458	31	279	19	179	12	97,3	99,0	94,6
25	Gardens w/ semi-private green	356	946	324	34	195	21	128	14	94,8	99,0	88,3
26	Open residential buildings	1564	3196	734	23	451	14	283	9	97,7	99,0	95,7
12	Schools, old buildings (before '45)	144	247	134	54	67	27	67	27	87,9	99,0	76,7
13	Schools new buildings (after '45)	422	1010	483	48	198	20	285	28	85,5	99,0	76,1
14	Schools	12	18	8	42	3	16	5	25	94,1	99,0	90,9
15	Water sports	58	128	43	33	20	16	23	18	88,1	99,0	78,4
28	Sports facilities	410	1552	555	36	100	6	455	29	88,8	99,0	86,6
41	Safety & order	88	597	232	39	89	15	143	24	87,9	99,0	80,8
42	Postal service	20	67	42	63	16	24	26	39	88,7	99,0	82,2
43	Administration	182	542	295	54	154	28	141	26	94,6	99,0	89,9
44	Universities and research institutions	91	376	183	49	98	26	85	23	95,2	99,0	90,8
45	Culture	68	180	90	50	44	24	47	26	91,1	99,0	83,4
46	Hospitals	116	852	306	36	161	19	145	17	96,2	99,0	93,0
47	Day-care centers	254	373	134	36	56	15	78	21	94,3	99,0	90,9
49	Churches	88	93	33	36	16	18	17	18	94,4	99,0	89,9
50	Senior citizens' homes	18	38	17	45	9	23	9	22	96,1	99,0	92,9
51	Youth recreation centers	39	87	19	21	9	10	10	11	92,2	99,0	86,0
60	Community services	40	93	36	38	11	11	25	27	94,0	99,0	91,8
59	Weekend house areas	77	214	47	22	20	9	27	13	95,9	99,0	93,6
58	Camp sites	24	90	8	9	1	1	7	8	81,2	99,0	78,5
30	Commercial areas with sparse construction	960	4361	2773	64	1127	26	1646	38	93,4	99,0	89,4
31	Commercial areas with dense construction	153	854	685	80	333	39	352	41	90,4	99,0	82,3
39	Mixed area I (e.g. restaurants)	14	24	9	36	4	17	5	19	94,4	99,0	90,2
38	Mixed area II with dense construction	29	53	42	79	29	54	13	25	94,6	99,0	85,1
33	Mixed area III with sparse construction	119	296	178	60	86	29	91	31	90,8	99,0	83,0
27	Cemeteries	190	1154	89	8	14	1	75	7	96,1	99,0	95,6
36	Tree nurseries/horticulture	176	654	191	29	70	11	121	19	93,3	99,0	90,0
37	Allotment gardens, general	543	1954	541	28	194	10	346	18	88,0	-	88,0
34	Allotment gardens with low service area share	255	818	176	22	35	4	141	17	88,1	-	88,1
35	Allotment gardens with high service area share	186	1247	235	19	46	4	189	15	90,3	-	90,3
53	Parks, green spaces	1504	3924	371	9	52	1	318	8	93,6	99,0	92,7
55	Forests	2629	15827	14	0	13	0	1	0	99,3	99,0	99,5
56	Farmland	419	3736	13	0	12	0	2	0	99,0	99,0	98,7
57	Fallow areas	1294	4308	98	2	53	1	45	1	98,0	99,0	96,6
91	Parking lots	161	164	83	50	9	6	74	45	78,0	99,0	75,5
32	Supply & waste-disposal	158	931	472	51	151	16	321	34	94,5	99,0	92,4
92	Railway facilities	226	331	194	59	33	10	161	48	95,6	-	95,6
99	Rail lines	470	1248	546	44	9	1	537	43	99,7	-	99,7
93	Airports	14	294	252	85	19	7	232	79	86,0	99,0	84,9
94	Other traffic areas	335	134	48	36	2	1	47	35	77,8	99,0	77,1
98	Construction sites	14	21	6	27	1	2	5	24	-	-	-
Total, w/o waters & streets		23993	74212	19949	27	9423	13	10526	14	95,2	99,0	92,4
100	Bodies of water	676	5388	0	0	0	0	0	0			
Total, w/ waters, w/o streets		24669	79600	19949	25	9423	12	10526	13			
Streets			9496	8465	89	0	0	8465	89			
Total, w/o waters, w/ streets			83708	28413	34	9423	11	18990	23			
Total Berlin, w/ waters & streets			89096	28413	32	9423	11	18990	21			

The area of streets was ascertained as the difference between the total area of Berlin (according to information from the ISU) and the combined area of all blocks and bodies of water.

The impervious coverage degree of the streets is based on the evaluation of road statistics of Department of Urban Development VI C which, however, covers only 8,790 hectares. The degree of impervious coverage ascertained from these statistics was assumed to apply as well to the remaining street area.

Track gravel is considered 100% impervious for purposes of calculation of the map, but it was considered pervious for purposes of the precision assessment.

The precision of the ALK is not given for the five section types 34, 35, 37, 92, 99, so that the overall level of precision for non-built-up impervious areas is assumed to apply.

The overall precision was calculated via the area share of each section type. The five section types 34, 35, 37, 92, & 99 were not included in determining the overall level of precision of the impervious built-up area.

The section type Construction sites was not used for calculating the precision of ascertainment.

Differences due to rounding may occur.

As of: Dec. 31, 2005

Tab. 6: Mean degrees of impervious coverage and mean precision of ascertainment per section type

For a better overview, the degrees of impervious coverage are also summarized for each land-use type (ISU categories). Residential areas have an average degree of impervious coverage of 38 %. The core areas have the highest mean degree of impervious coverage, with 77 %, while "Forest" and "Farmed fields" have the lowest.

Tab. 7: Mean degrees of impervious coverage by land-use type									
Use		No. of Blocks	Block area [ha]	Imperv. sect. [ha]	Degree of imperv. cov. [%]	Degree of imperv. cov. [%]	Built-up imperv. sect. [ha]	Built-up imperv. sect. [%]	Non-built-up imperv. sect. [ha]
10	Residential areas	10586	22518	8549	38	5040	22	3509	16
	Mixed areas	1102	2511	1500	60	888	35	612	24
30	Core areas	283	487	376	77	235	48	142	29
40	Commercial & industrial areas	1072	5087	3395	67	1450	29	1945	38
50	Community services & special uses	1605	4760	2108	44	956	20	1152	24
60	Supply & waste-disposal areas	154	874	468	54	149	17	319	36
70	Weekend house areas	76	213	47	22	20	9	27	13
80	Traffic areas	929	1365	851	62	63	5	788	58
90	Construction sites	13	19	4	22	1	3	4	19
100- 102	Forests	2634	15913	24	0	17	0	7	0
121	Grassland (meadows & pastures)	56	349	4	1	3	1	0	0
122	Farmed fields	366	3396	10	0	9	0	1	0
130	Parks, green spaces	1523	3958	378	10	53	1	325	8
140	Urban squares/ promenades	185	88	38	43	4	5	34	38
150	Cemeteries	190	1154	89	8	14	1	75	7
160- 162	Allotment gardens,	999	4049	962	24	276	7	686	17
171- 174	Fallow areas	1588	5216	420	8	71	1	349	7
180	Camp sites	24	90	8	9	1	1	7	8
190	Sports facilities / outdoor pools (incl. water sports, tennis, riding etc.)	432	1509	526	35	104	7	423	28
200	Tree nurseries/ horticulture	176	654	191	29	70	11	121	19
	Total, w/o Waters & Streets	23993	74212	19949	27	9423	13	10526	14
110	Bodies of water	676	5388	0	0	0	0	0	0
	Total, w/ Waters, w/o Streets	24669	79600	19949	25	9423	12	10526	13
	Streets		9496	8465	89	0	0	8465	89
	Total, w/o Waters, w/ Streets		83708	28413	34	9423	11	18990	23
	Total Berlin, w/ Waters & Streets		89096	28413	32	9423	11	18990	21

The area of streets was ascertained as the difference between the total area of Berlin (according to information from the ISU) and the combined area of all blocks and bodies of water. The degree of impervious coverage of the streets is based on the evaluation of road statistics of Department of Urban Development VI C, but covers only 8,790 hectares. The degree of impervious coverage ascertained from these statistics was assumed to apply for all remaining street areas as well. Differences due to rounding may occur
As of: Dec. 31, 2005

Tab. 7: Mean degrees of impervious coverage by land-use type

The statistical blocks and partial blocks of Berlin (without streets and waters) are 27 % impervious, on the average. Of this, 13 % are on the impervious built-up areas, and 14 % on the impervious non-built-up areas. **Including bodies of water and streets, Berlin is thus 32 % impervious.** Of this, 11 % are on the impervious built-up area, and 21 % on the impervious non-built-up area. Berlin is thus one third impervious. The impervious area in turn consists of roughly equal parts of buildings, of streets, and of non-built-up impervious areas.

Impervious Coverage in the Boroughs

For the **borough-referenced evaluation**, the average degree of impervious coverage of the road surfaces was calculated. For this purpose, statistics on the pavement and road surfacing of Berlin's streets, bicycle paths and sidewalks were evaluated (SenStadt 2006).

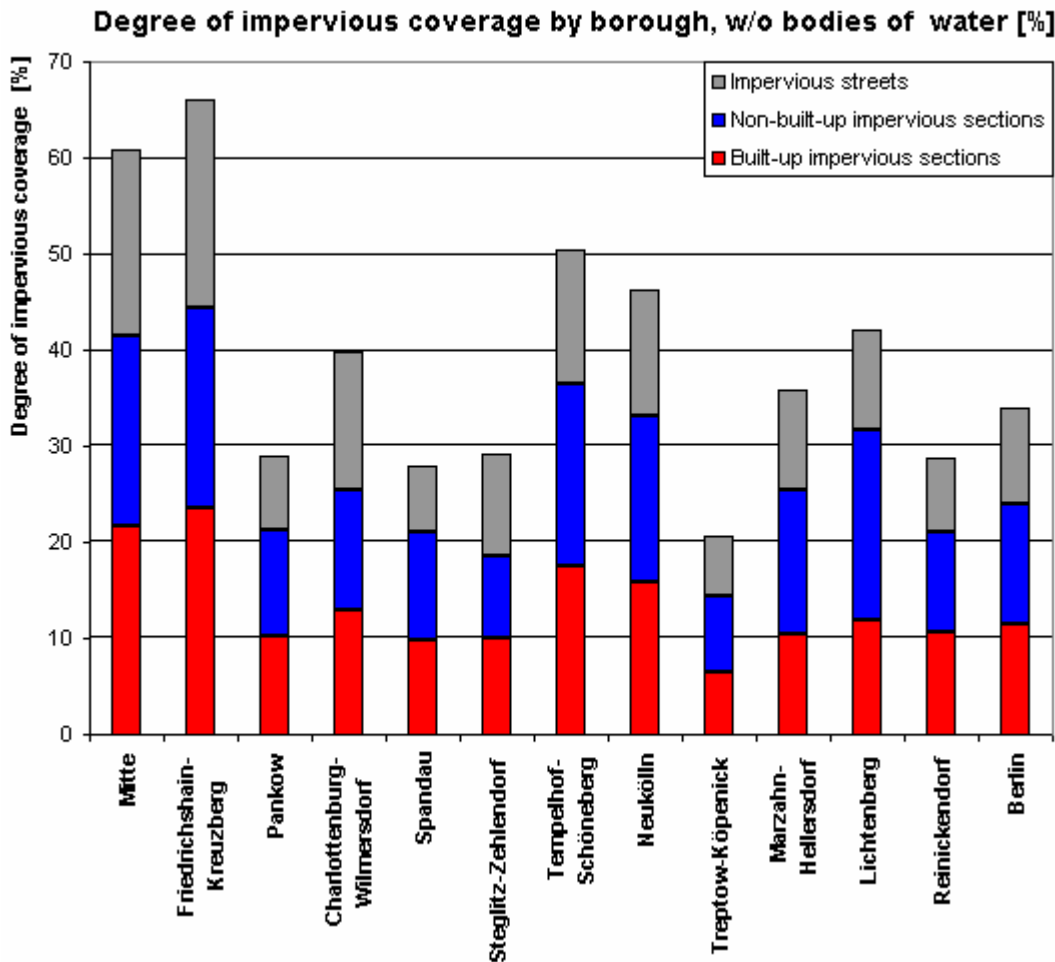


Fig. 6: Degree of impervious coverage by borough (in percent of total area w/o bodies of water)

The borough with the lowest degree of impervious coverage is Treptow-Köpenick, with 21 %, while Kreuzberg-Friedrichshain and Mitte have the highest degrees, with 66 and 60 %, respectively. These two boroughs also have the highest shares of built-up areas, as a proportion of their total areas.

Data on Impervious Soil Coverage in 2005 Compared with 1990 and 2001

Due to **different ascertainment methods**, a direct comparison between the impervious coverage values of 2001 and 2005 is possible only to a limited degree. **No change in the impervious area over the course of this period of time can be ascertained from these figures.**

In 2001, the degree of impervious coverage in Berlin amounted to **34.7%**, incl. streets and bodies of water. These data are to some extent based on evaluations of satellite images and other sources from the '80s (only in West Berlin). These mapping system were expanded to include East Berlin in 1990, and partially updated, in 2001 by means of aerial photography and topographical maps of the area. Here, use-specific flat values were assumed in some cases. Overall, the ascertainment methodology was non-uniform.

The current set of maps now provides a data set obtained according to a considerably improved methodology which is uniform and completely automated. The result is that the degree of impervious coverage in 2005 amounts to **31.8%**, and is thus approx. 3% below the values of 2001. **However, this does not under any circumstances imply any reduction in impervious area.**

Tab. 8: Results of Impervious Coverage Maps in Berlin, 1990 to 2005

	1990	2001	2005
Total impervious	31.0	34.7	31.8
Built-up impervious	10.1	10.8	10.6
Non-built-up impervious	10.8	14.6	11.7

Streets	10.1	9.3	9.6
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Tab. 8: Results of mapping of impervious coverage in Berlin, 1990 to 2005.

No change of the impervious area can be seen from the results of impervious coverage maps (all information refers to the total area of Berlin, incl. streets and bodies of water).

These figures do not indicate any reduction in impervious coverage over the course of this time period.

It is notable that the values ascertained for the impervious built-up area over the years are **almost identical**. This indicates that the old ascertainment methods yielded values that were quite good on the average, since the ALK survey in 2005 can be considered very precise.

For the **non-built-up impervious areas**, the picture is somewhat different. Here, the values ascertained have **decreased** by 3 percentage points compared with 2001. This may on the one hand be due to the fact that on the old maps, some green and open-space categories (e.g. Forest and Farmland) were assigned flat values for their non-built-up impervious portions, values which we today recognize as too high. Since these areas constitute a major share of the municipal area, the degree of impervious coverage was **overestimated for the non-built-up impervious areas** overall. On the other hand, due to the problems mentioned above regarding the interpretation of the satellite data, the non-built-up impervious areas **were more likely to be underestimated under the new method**. These assumptions are rather more plausible than the supposition that any reduction in impervious areas has actually taken place in the municipal area.

With regard to the ascertainment of **impervious roadways**, the roughly estimated values available in 1990 could be replaced by values from the Road-Building Authority only in 1997. These were used for the evaluations in 2001 and updated in 2005. A slight increase in the degree of impervious coverage caused by roadways, due to road-building measures, primarily in East Berlin, certainly seems plausible.

In case of a future **repetition of the procedure**, e.g. in the context of a **monitoring process**, the new method will now permit the ascertainment of changes relevant at the block level, and then their incorporation into a city-wide balance sheet.

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