01.02 Impervious Soil Coverage (Sealing of Soil Surface) (Edition 2017)

Overview

The impervious coverage of natural soils by construction and non-porous materials has a multitude of negative effects on the ecosystem, the microclimate in the city and on the human habitat. The effects of impervious coverage are primarily noticeable in cities and metropolitan areas, where a high proportion of the total area is impervious.

Definition

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 grass trellis stones or paving stones with wide seams still permit reduced plant growth, are partially permeable to water, and provide for a considerably more favourable microclimate.

The existing types of pavement of non-built-up impervious areas are grouped into **four pavement classes,** with different effects on the ecosystem (cf. Table 1).

Tab. 1: Overview of impervious Pavement Classes

Pavement Class	Estimated effects on ecosystem	Types 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 (e.g. ash, gravel or tamped ground), gravel lawn

Tab. 1: Overview of impervious pavement classes

The Effects of Impervious Coverage on the Ecosystem and the Urban Climate

The complete impervious coverage of the soil causes the irreversible loss of natural soil functions.

Impervious coverage and densification moreover strongly impair the **water storage capacity of the soil that is available to plants**, as well as its buffering and filtration capacity. Obstructing the water and oxygen supply causes most organisms in the soil to die. Since no more water can seep down, the pollutants entering the soil via air and precipitation are no longer retained in the soil and are partially washed into surface waters. The formation of new groundwater is prevented or reduced.

Impervious coverage of the soil also results in changes in the **water balance** and the water composition**,** 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 “Management of Rain and Waste Water” (02.09)). The drainage of polluted rainwater after heavy rainfalls often causes the eutrophication of water bodies.

The complete impervious coverage of the soil consequently 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 favour of more adaptable species.

Pervious soils strongly impact the urban climate due to their capacity to store and supply water to plants. On the one hand, evaporation caused by plants and by the (pervious) soil surface leads to cooling of the air. On the other hand, the air is heated by the high heat-storage capacity of buildings, impervious areas and asphalt streets, contributing to the development of a specific **urban climate**. Especially in summertime, night-time cooling is reduced (cf. Fig. 1 and the Map “Nocturnal Cooling Rate between 10:00 p.m. and 04:00 a.m.” (04.10.4)).

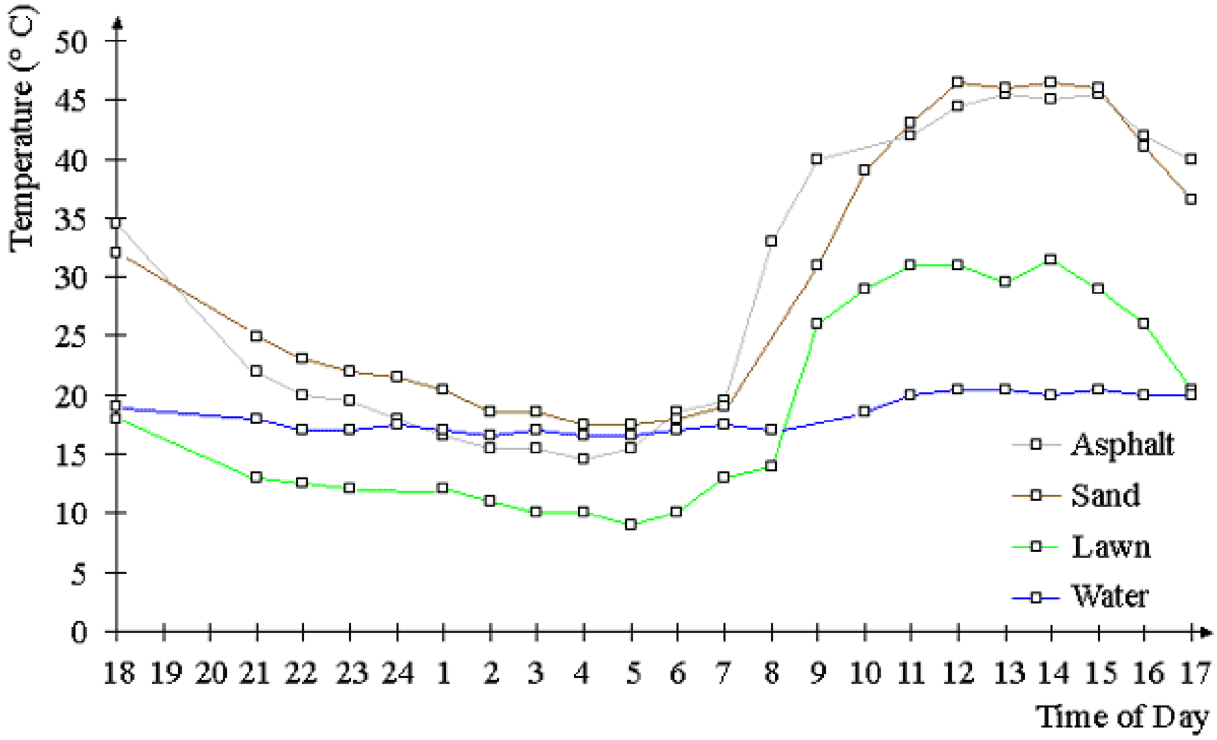

Fig. 1: Temperature curves over various surfaces (Kessler 1971 in: Mählenhoff 1989)

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 Climate.

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.

Data on impervious soil coverage is regularly used in important contexts for environmental protection, as well as urban and landscape planning. For example, this data is used and processed particularly often in various models (urban climate, water balance), or evaluating methods, e.g. in soil protection. Furthermore, the documentation indicating how strongly nature and the landscape are impaired by impervious soil coverage is also of great importance. Policy-makers, too, are increasingly requesting regular updates on impervious coverage data at a high chronological resolution, in order to monitor and measure the success of environmental or urban-planning strategies (cf. Reusswig et al. 2016, *Klimafolgenmonitoring* (Monitoring Climate Impacts) SenStadtUm 2016a).

Methods to Reduce Impervious Coverage and New Land Consumption

Since 2002, the goal of reducing new land consumption to 30 ha per day by 2020 has been formulated in the national sustainability strategy (The Federal Government 2002). Daily new-land-consumption demand in Germany for residential and traffic use currently amounts to 69 ha (2014) (UBA 2016). New land consumption has been reduced in recent years; however, it is still a long way from the target for 2020. Model calculations by the Federal Ministry of Transport, Building and Urban Development predict that new land consumption will level off at around 64 ha per day from 2015 (German Bundestag 2015).

At the UN Summit in New York in September 2015, the 2030 Agenda for Sustainable Development was adopted. The German Sustainability Strategy 2016 (The Federal Government 2016), based on the same, identifies the special need for sustainable soil protection as a resource against the background of increasing urbanization and climate change (Sustainable Development Goal – SDG 15). Working towards the 2030 Agenda goal of a land and soil degradation neutral world, emphasizes the crucial role that soil plays in biodiversity and climate protection (German Sustainability Strategy for Germany, 2016).

Within the framework of the national sustainability strategy, the indicator **“new land consumption”** was developed for empirical studies and risk assessments examining the consequences of land use. New land consumption is calculated from the daily increase in **built-up and traffic areas.** This is not equal to the impervious area, since they also include areas which are only slightly impervious (gardens in residential areas, allotments, park facilities or green median strips on roads, etc.). In a conurbation area such as Berlin, however, the increase in built-up and traffic areas is an unsuitable indicator for land consumption (cf. Map “Open Space Development” (06.03)). For this reason, “soil imperviousness”, which is indicator No 6 of sixteen core indicators for monitoring sustainability, is determined for documenting the economical use of soil as a resource from a sustainability perspective. Environmental Atlas data is also used to illustrate the development of the degree of imperviousness over time (Statistical Office for Berlin-Brandenburg 2014).

In 2005, the Federal-State Cooperative Association for Soil Protection (LABO) appointed a group of federal and state experts to develop a suitable assessment procedure for ascertaining soil impervious coverage at the state level, in order to expand the sustainability indicator “new land consumption for residential and traffic areas” to include the component impervious coverage.

The results of the experts’ group are incorporated into the Environmental-Economic Accounting of the German States (EEAL), and have been documented in the report “Indikator Versiegelung”, (the indicator “Impervious Coverage”) (Frie & Hensel 2007).

LABO reports to the German Conference of Environment Ministers in 2010, 2011 and 2012 document the development of new land consumption and the measures taken by the federal German states to reduce new land consumption. According to the Environmental-Economic Accounting of the German States (EEAL), impervious areas in Germany account for 6.17 % of the total area in 2014. This corresponds to an impervious area of 2.2 million ha. In Berlin, impervious areas cover 34.92 % (approx. 31,140 ha) of the total area in 2015 (Statistical Offices of the German States 2016).

See the Excursus impervious coverage data 2005, 2011 and 2016, which compares the present results with those of the “*Indikator Versiegelung*” (indicator impervious coverage), by the Environmental-Economic Accounting of the German States (EEAL, Statistical Offices of the German States 2016).

The **reduction of land consumption**, which is a goal of the national Sustainability Strategy, is to be achieved by space-reduced construction of buildings, densification of inner-city 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. (The Federal Government 2007). Germany’s states and municipalities are to realize these targets in the context of their spatial and construction planning. In March 2017, the amendment of the Building Code was adopted in the course of adapting urban planning laws to the Strategic Environmental Assessment (SEA) Amendment Directive. A key focus is the introduction of a new area category “urban area”, which is to enable a higher level of density of mixed uses while reducing land consumption (German Bundestag 2017).

With the federal soil protection legislation coming into effect, soil including all its functions was protected by uniform nationwide regulations for the very first time. The Soil Protection Law, however, does not provide any direct legal claim, in regard to use changes or land consumption by construction. Generally, the requirement of impervious-coverage removal under Section 5 of the Federal Soil Protection Law (BBodSchG 1998) represents an instrument for areas that are permanently no longer in use to be rendered pervious once again, and thus regain their natural soil functions, as per Section 2 Para. 2

BBodSchG (Oerder 1999). However, since costs and reasonableness are taken into account as additional criteria, this regulation has not proven its worth in practice.

Furthermore, the Federal Building Code (BauGB 2014) and, in some cases, nature conservation legislation comprise pertinent regulations relating to soil as a subject to be protected. These include the so-called soil protection clause according to Section 1a Para. 2 BauGB and the requirement of deconstruction and removal of impervious-coverage according to Section 179 BauGB. With the introduction of the Strategic Environmental Assessment in 2004, logging and describing soil functions became mandatory. As a result, measures to avoid, reduce and compensate for adverse effects must be described and assessed, and planning alternatives must be identified. According to Section 1 Para. 3 No. 2 of the Federal Nature Conservation Act (BNatSchG 2013), soils must be preserved in such a way that they can fulfil their functions within the ecosystem. According to Section 15 Para. 1 and Para. 2 BNatSchG, inevitable interventions in nature and landscape are to be balanced out or compensated.

With a growing impervious coverage in the state of Berlin, there should be a qualitative assessment as to which soils are in use or need of extra protection. The Map “Planning Notes for Soil Protection” (01.13) and the summarized “Catalogue of models and measures for precautionary soil protection in Berlin” (SenStadtUm 2015) serve this purpose.

In its Environmental Report 2016, the German Advisory Council on the Environment demands, among other things, that a duty of review be introduced to determine whether the impervious coverage of an existing area may be removed, whenever a new area is rendered impervious (SRU 2016). In this context, a project is highlighted that systematically records potential areas for the removal of impervious coverage developed by the state of Berlin. As part of nature conservation compensation measures, these areas could then be made available permanently to the ecosystem after the removal of their impervious coverage and the restoration of their soil functions (Map “Potentials for the Removal of Impervious Soil Coverage (Soil De-sealing)” (01.16), SenStadtUm 2016).

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 (resolution of June 12, 1972) and the Superior Administrative Court of Lüneburg (rulings 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. Thus, 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). Since 2000, owners have therefore endeavoured to keep the impervious area of their property as low as possible, in order to save on 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, August 24, 2001), it is possible to obtain proportionate or full exemption from the precipitate-water sewage disposal fee (SenStadt 2001) via measures for relieving the rainwater sewage system via 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.

In cooperation with the Berlin University of Technology, the Humboldt University and the company Digitale Dienste Berlin, a new procedure for ascertaining impervious coverage was developed for Edition 2007. It has been partially re-adapted and used for editions 2012 and 2017. The databases for impervious coverage of editions 1993 and 2004, which had existed previously had been based on non-uniform ascertainment methods, for which reason a direct comparison with these editions is not possible. The present reuse of this ascertainment method now permits an overall comparison of degrees of impervious coverage of the years 2005, 2011 and 2016.

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

The Urban and Environmental Information System, Block Map 1 : 5,000 (ISU5) and Land Use Data

The spatial reference of the City and Environment Information System (ISU) is oriented toward the structure of the statistical **blocks** of the "Regional Reference System" (RBS) of the Statistical Office for Berlin-Brandenburg. However, each block may be further subdivided into homogeneous-use **block segments**. Each of the approx. 25,000 areas of the ISU5 structure, is stored in a database, in which information on both area size and use is stored.

A total of 52 area types with homogeneous use and spatial structures are distinguished.

For the impervious coverage mapping, ISU5 (as of 31.12.2015) was used in the analysis process to delimit the areas that were examined. The use data was incorporated into the rule-based classification system of the satellite-image data.

Official Property Cadastre Information System - ALKIS

Since December 1, 2015, data of the Register of Land Properties has been recorded in the Official Property Cadastre Information System ALKIS and no longer in the Automated Book of Properties (ALB) and Automated Map of Properties (ALK) (SenStadtUm n.d.). Therefore, ALKIS data was used for the first time in mapping impervious coverage in 2016, replacing the ALK data used thus far. The following data was used dating from April 2016:

- All buildings above ground excluding underground parking from the layer "Area-like buildings and construction elements",
- A selection of building uses from the layer "Buildings areas".

The ALKIS layer "Sport, leisure, recreation" was also used for the first time to record artificial surfacing.

Non-ALK Buildings

As part of the "Ascertainment of Building and Vegetation Heights in the Area of the City of Berlin" (DLR 2013) commissioned by the Senate Department for Urban Development and the Environment, approximately 73,000 buildings were now included, which had not been part of the underlying ALK (i.e. "Non-ALK buildings"). For the impervious coverage mapping, a selection of this data base was therefore integrated into the analysis process in addition to the ALKIS buildings. The data current as of September 2009 and September 2010 improves the ALKIS building stock, especially in regard to allotment gardens.

Map of Berlin 1 : 5,000 - K5

The map of Berlin by the State Mapping Agency at a scale of 1 : 5,000 (K5) is drafted by the Berlin boroughs on the basis the Berlin ALK (now ALKIS). The above-ground railway lines shown in the K5 Map were used for the impervious-coverage maps current as of August 2014.

The lot-precise recording of **track areas** 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 RGBI orthophotos used were taken from material shot on April 2 and 3, 2016. They are available in a resolution of 0.20 m, and were used for the following work steps:

- Ascertainment and delimitation or review of reference areas,
- Ascertainment and delimitation of areas to be corrected (e.g. water bodies not recorded).

Data on Impervious Soil Coverage of the Berlin Water Utility

In the process of the evaluation, so-called corrective factors for ascertaining the degree of impervious coverage were used for certain area types. The purpose was to correct the view from the air, in which the impervious coverage is often largely obscured by trees, with certified information on impervious coverage. The ascertainment of corrective factors was carried out on the basis of the current impervious coverage information of the Berlin Waterworks (BWB). Starting in January 2000, this data was 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 areas 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 and block segment level, and was available for evaluation, current as of

2001. Only the details on the non-built-up impervious areas 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 corrective factors developed and tested in the 2007 mapping process were used again for the current mapping.

Multi-Spectral Sentinel-2A Scene

Multispectral data from the Sentinel-2A system were used for the first time in the impervious coverage mapping (Edition 2017). As part of the Copernicus Earth Observation Programme, the European Union (EU) and the European Space Agency (ESA) are developing a modern and powerful infrastructure for earth observation and geoinformation services. The aim is to provide current and reliable information based on earth observation data for decision-making processes in politics, the economy and science. The data is available free of charge (Copernicus n.d.)

Both the spatial and spectral resolution of the selected channels are comparable to the corresponding properties of SPOT5 scenes used in editions 2007 and 2013. For the preparation of the impervious-coverage map, it was possible to use a multi-spectral Sentinel-2A scene of May 2, 2016 as a data set. The original ground resolution of the scene is 10 m x 10 m and was refined to up to 2.5 m x 2.5 m during the analysis process. It was a more or less **cloud-free image**. The foliage is largely complete. The predominant phenology of the time of recording can be compared with that of the scene of the last impervious coverage mapping (Edition 2012). The proportions of shaded areas are also similar.

Methodology

The evaluation procedure was based on the use of **ALKIS and additional building data** for **impervious built-up areas**, and on the analysis of high-resolution multi-spectral satellite-image data for the **impervious non-built-up areas.**

A Sentinel-2A scene was used. **Relevant information from the Environmental Atlas**, the Urban and Environmental Information System (ISU), and the already ascertained corrective factors developed from the **data of the Berlin Waterworks** (BWB data) were incorporated into the classification process.

The mapping procedure consists of three evaluation steps:

- Mapping of impervious built-up areas,
- Mapping of impervious non-built-up areas,
- Derivation of the degree of impervious coverage.

The mapping of impervious coverage concentrates on block and block segment areas; 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 areas.

The complete **Final Report of the Impervious Coverage Mapping Procedure 2016** can be downloaded from the chapter Literature (Coenradie & Haag 2016) as a PDF file (only in German).

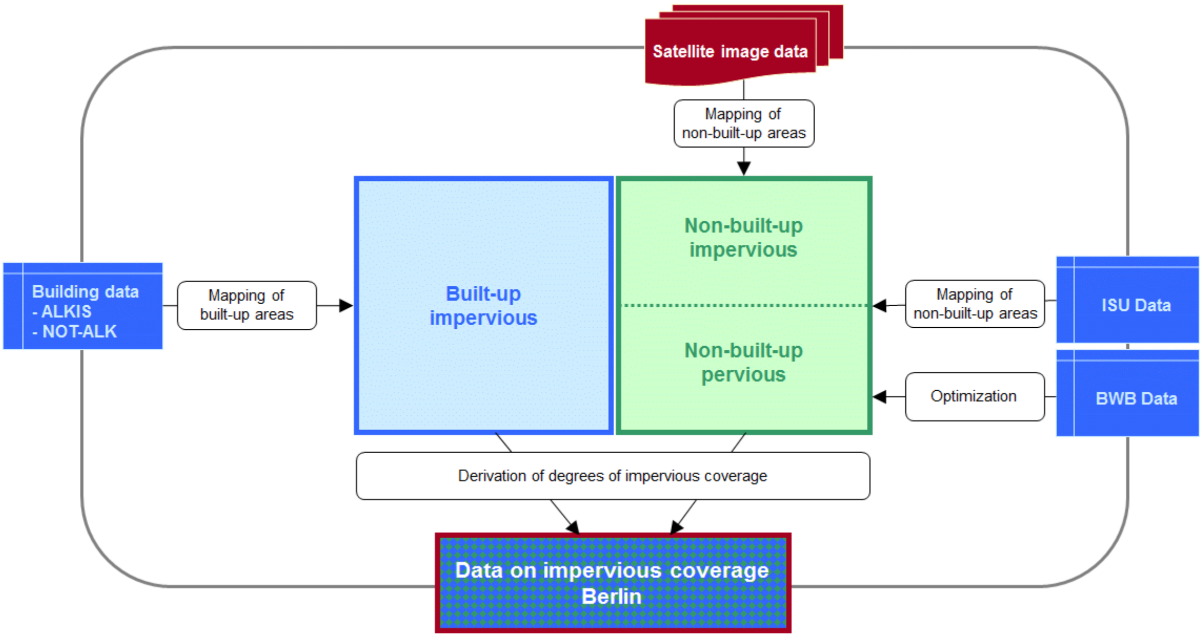

Fig. 2: Diagram of the hybrid mapping procedure

Mapping of Built-up Impervious Areas

In Edition 2017, the delimitation of the built-up impervious areas was carried out based on two data bases for the first time. On the one hand, the ALKIS building data was used. Since it contains gaps, especially regarding allotments, so-called Non-ALK data from the Environmental Atlas Map "Building and Vegetation Heights" (06.10, SenStadtUm 2014) was used on the other hand. Integrating building data into the mapping process constituted the first component of the hybrid method approach. For these areas, no evaluation has been carried out via satellite-image data.

The use of additional building data (Non-ALK) also impacts upon the mapping of changes between 2011 and 2016 and is especially noteworthy. Based on the improved data base of the building stock, the proportion of the built-up area also changes for blocks that actually remain unchanged (**pseudo-changes**). This involves 718 blocks. Major changes in ISU block geometry affected 424 block and block segment areas between 2010 and 2015, resulting in area size changes of more than 10 %. Here too, pseudo-changes may occur in the impervious coverage mapping.

Mapping of Non-built-up Impervious Areas

For the mapping of the impervious non-built-up areas, a classification approach was used in which satellite-image data (Sentinel-2A) and geo-data (building data, ISU) were incorporated and combined.

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

Categorization of Area Types Relevant for Remote Sensing

To improve the mapping results, a categorization of ISU area 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 classifications, and an optimized choice of methodology respectively. **Eighteen categories** were defined.

Spectral Classification of Non-Built-Up Areas

The satellite-based remote-sensing data was 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 coefficients for these two ranges. This fact can thus serve 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 photosynthetically active vegetation canopy" will tend to positive values close to 1 (e.g. Hildebrandt 1996).

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

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

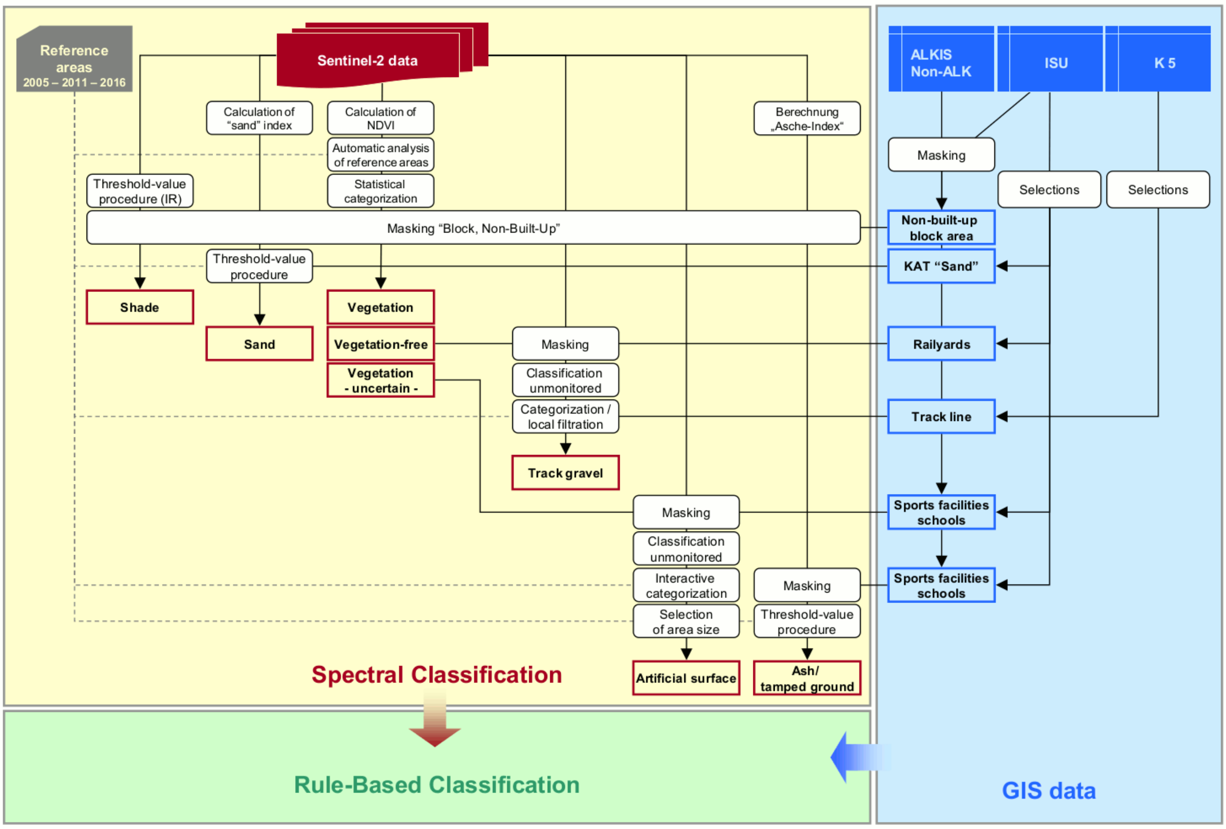

Fig. 3: Diagram of the spectral classification of non-built-up areas

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

The problem of the local **obscuring by treetops of impervious areas** 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 graduation 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 mixtures of signatures had to be taken into account.

The present procedural development made use of these differences: NDVI values which indicate partial vegetation coverage of areas (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 area type or area-type category.**

Based on this approach, 12 NDVI categories were established (cf. Table 2).

In the context of the process of the **mapping of changes**, the degrees of impervious coverage in 2011 are to be compared with those in 2016, for which purpose the spectral properties and phenological properties of the satellite image scenes have to be comparable. One advantage of the 2011 and 2016 impervious coverage maps is that both scenes were taken in May and are similar in their phenology. The satellite images of 2016 could thus be adapted both geometrically and radiometrically to the existing reference system of 2011, the so-called “master scene”.

Track gravel was to be evaluated differently in the context of the use of the data on impervious coverage. In some contexts, it is considered impervious, for others, it is assigned to the “pervious areas” category. Therefore, such areas were classed separately within railyards. 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 area-type categories "Railyards without track areas" and "Track areas". Moreover, the K5 rail route network was used, which made it possible to detect tracks secured 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 areas were aggregated with the impervious built-up building areas to form a **classified combined-block area**.

The category "Shade" remained separated from the other categories.

Rule-Based Classification

Under rule-based classification, the results of spectral classification are combined with ISU data (area types) to yield degrees of impervious coverage derived at the pixel level. For this purpose, we first proceeded by using the set of rules developed for the Edition 2007, and carried out a preliminary mapping process for 2016. Figure 4 shows a schematic overview.

In order to improve the comparability between two mono-temporally derived rule-based classifications, a second step was carried out involving a multi-temporal change analysis of satellite image data between 2011 and 2016.

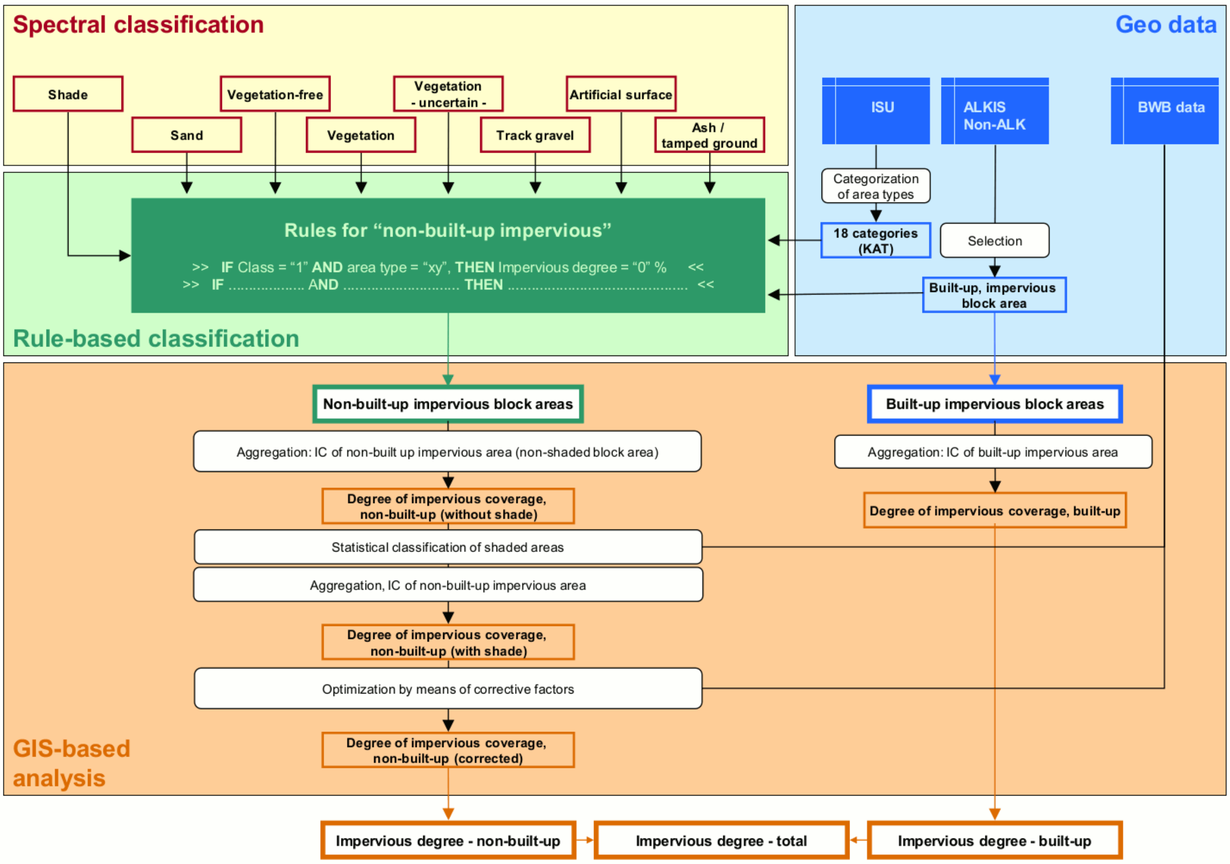

Fig. 4: Diagram of rule-based classification - preliminary mapping

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 and highest NDVI values, respectively). The corresponding **threshold values** were derived automatically by means of **reference areas**.

- NDVI Category 12 "Vegetation - certain". Under the rules, such areas were classified as 0 % impervious. This applied to all area-type categories.
- NDVI Category 1 "Vegetation-free - certain". Vegetation-free areas 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 ten 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 area-type category or area type. Thus, **three assignment variants** were established (cf. Table 2), with the mean percentage value (5 %, 15 %, ..., 95 %) the conversion factor for each NDVI and impervious coverage category.

Recommendations from the concept study, the analysis results of Haag 2006 and findings from aerial image interpretations, and terrain inspections were incorporated, and results of the procedural validation process (cf. Validation, Edition 2007) were taken into account for the iterative process optimization.

NDVI (categories and degree of vegetation)

Degree of impervious coverage	CAT	1	2	3	4	5	6	7	8	9	10	11	12	Assignment variant
	%	0	5	15	25	35	45	55	65	75	85	95	100	
	%	100	0	0	0	0	0	0	0	0	0	0	0	A
	%	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. 2: Assignment variants: degree of vegetation - degree of impervious coverage

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

The new rule-based classification for 2016 and the previous one of 2011 were thus available as intermediate results. These sets of map data were interlinked, and also linked to the current ISU block map of 2015, in order to obtain reliable information on changes of degree of impervious coverage at block and block segment level.

Methodologically, the following aspects had to be taken into account in this process:

- Ascertainment of changed areas and elimination of pseudo-changes by means of multi-temporal change mapping,
- Comparability of the blocks in terms of geometry and area type category.

For the reliable ascertainment of suspected areas, which indicated changes in impervious coverage (see below), the satellite image data of 2011 and 2016 for the non-built-up areas were first of all analyzed, and secondly, the building data on possible changes in the built-up impervious areas were examined.

Figure 5 provides an overview of the derivation of the results of the 2016 rule-based classification:

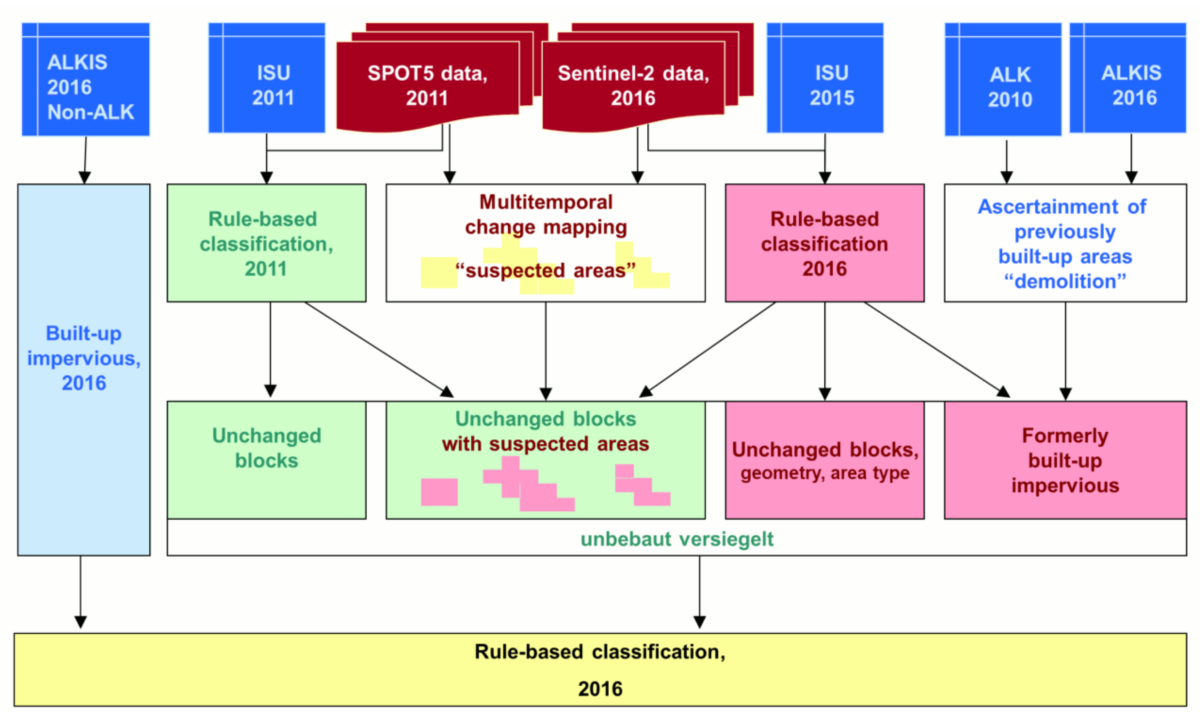

Fig. 5: Diagram of the 2016 rule-based classification

Using the procedure of principle component transformation (cf. Richards & Jia 1999, Coenradie 2003), the respective NDVI channels for 2011 and 2016 were analyzed, and suspected areas, i.e. those which, based on their NDVI values, indicated possible changes in impervious coverage, were statistically derived.

The conclusive rule-based classification in 2016 was derived from a set of rules from the rule-based classification of 2011, and from the 2016 intermediate results. For unchanged blocks, the 2011 classification was retained. The rule-based classification in 2016 was adopted in the following cases:

- changed blocks (changes of the ISU area type, or major changes of block geometry),
- suspected areas within unchanged blocks (changes in spectral properties, taking into account the phenology, ascertained by means of principle component transformation),
- previously built-up areas which, according to the current ALKIS building stock, no longer contain any structures (demolition).

The conclusive **result of the rule-based classification system in 2016** for the non-built-up blocks corresponded to the final result of the satellite-image classification process. The category “non-built-up impervious areas” has been described in the classification with the 12 **impervious coverage-degree categories**, a **Shade** class and a **Track-gravel** class.

Figure 6 shows the result of the 12 impervious coverage-degree categories, a Shade class and a Track-gravel class, and the built-up impervious areas from building data, on a grid basis. Based on this intermediate result (grid data), the mean degrees of impervious coverage per block area were then calculated (cf. Calculation of the Degrees of Impervious Coverage).

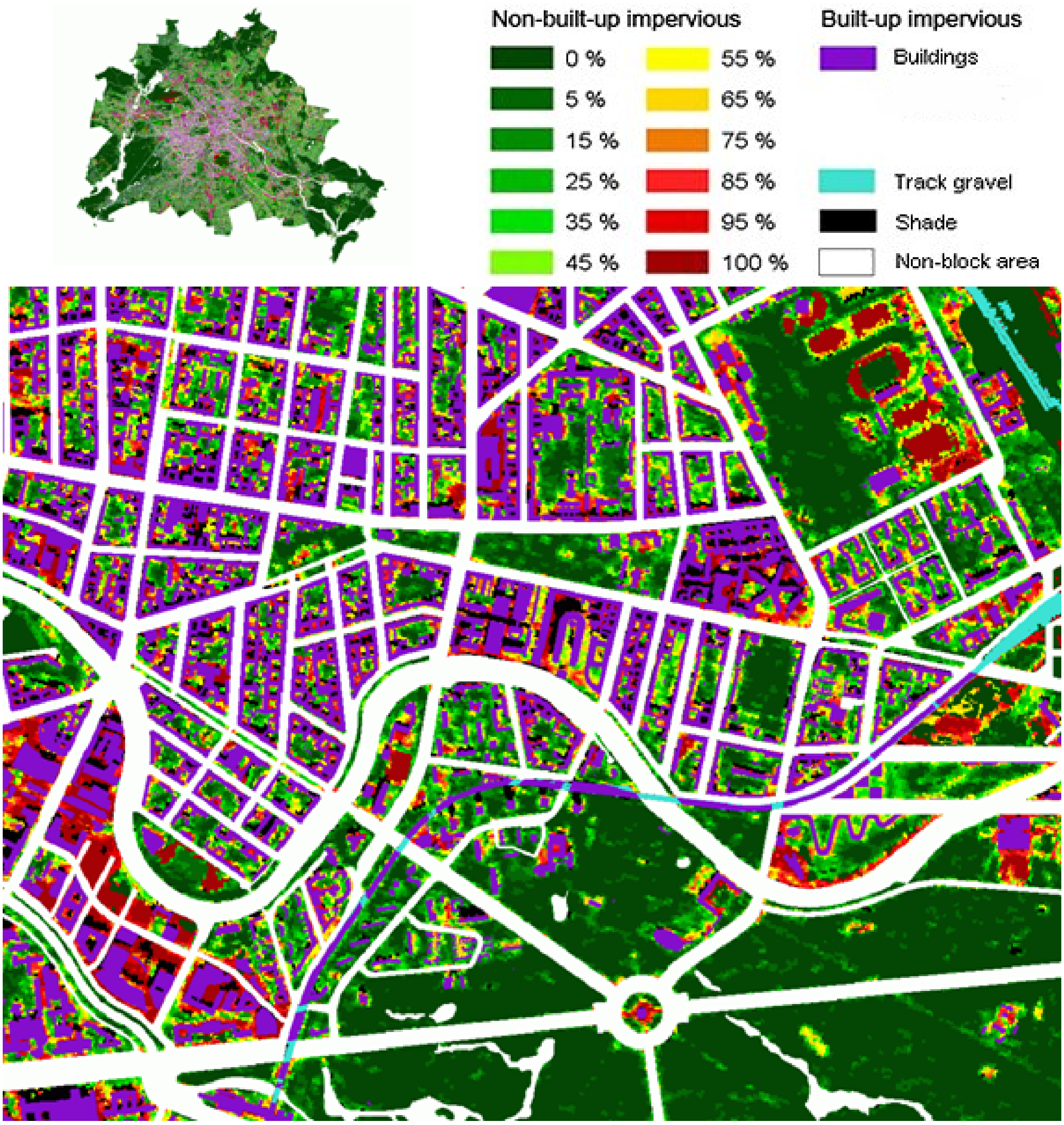

Fig. 6: Uncorrected degrees of impervious coverage (grid data) - intermediate results of rule-based classification

The intermediate result published in the FIS Broker as the 2016 "Impervious Coverage Map (uncorrected degrees of impervious coverage, grid data)" shows the distribution of impervious coverage within the blocks and block segments. The effect of shade in the various blocks can also be seen. However, it is both a grid map as well as an uncorrected intermediate result of the impervious coverage mapping, i.e. a satellite data result based on a rule-based classification. At the grid level of 2.5m x 2.5m, twelve impervious coverage-degree classes are displayed for the non-built-up area. Furthermore, the buildings are mapped based on various building data, i.e. built-up impervious areas, as well as track gravel and shaded areas. The grid level information was aggregated for the impervious coverage map of the Environmental Atlas at block area level and further processed and corrected in parts. The black shaded areas present here were assigned a degree of impervious coverage, e.g. based on their surroundings and their area types (see below).

The Map "Impervious Soil Coverage" (01.02) by contrast, shows the mean degree of impervious coverage per block area.

Calculation of Degrees of Impervious Coverage at Block and Block Segment Level

The goal of the impervious-coverage mapping process is the derivation of the **degrees of impervious coverage** at block and block segment level in absolute and relative area numbers. Three degrees of impervious coverage (IC) were distinguished:

1. IC - built-up impervious area (calculated from building data),
2. IC - non-built-up impervious area (calculated from satellite data),
3. IC - total (sum of 1 and 2).

For the calculations, the results of the **pixel-based satellite-image classification** were collated with the areas from the **ISU5 block map** 2015**.**

First, a **summation by category of degree of impervious coverage and block (segment) area** was carried out. Thus, the grid data of the classification system was no longer necessary for further analyses.

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

- Built-up area (from building data)
- 12 categories of degrees of impervious coverage of the non-built-up area (corresponding to 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 subject matter at hand. In the 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 at block (segment) area level using ISU or BWB data.

For this, the shaded areas were analyzed depending on **area type**. For area types with predominantly residential use and adequate BWB data, the latter was used for the classification of the shaded areas. For all other area types, shaded areas were classified in accordance with their block-specific surroundings.

Evaluation of Built-Up and Non-Built-Up Impervious Areas in the Category "Allotment Garden"

Due to the improved data base for buildings, it was possible to record the built-up impervious area share more accurately than was the case still for the 2005 and 2011 mappings. However, as there are still gaps in the building data, especially in this category, e.g. due to unmapped cottages and sheds, shares of the non-built-up impervious area were also counted as part of the built-up area in the current impervious coverage mapping, based on the mean values laid down in the *Bundeskleingartengesetz* (Federal Allotment Garden Law) and those specific to Berlin (SenStadtUm, I C 2009). A degree of impervious coverage for built-up areas of 9.6 % for West Berlin and 8.6 % for East Berlin was assumed.

Application of Corrective Factors

To further improve the mapping results, so-called corrective factors were employed. The **BWB data on impervious soil coverage** was used for this purpose. The principle of area-type-referenced corrections is based on the following well-founded assumptions:

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

Due to a lack of topicality, overlap problems, differing definitions of impervious coverage, and gaps in impervious coverage ascertainment of some use types by the BWB, corrective factors could be calculated only for **5 area types** (cf. Table 3).

Corrective factors were only applied to non-built-up areas.

Tab. 3: Corrective factor by area type

	Area type (TYPE)	BWB data non-built up area impervious [sq. m.]	Classification result non-built-up area impervious 2005 [sq. m]	Corrective factor
21	Village-like mixed development	447,806	598,469	0.75
22	Row houses and duplexes with yards	830,718	1,315,616	0.63
23	Detached single-family homes with yards	4,129,760	6,349,315	0.65
24	Villas and town villas with park-like gardens	1,353,980	1,411,935	0.96
25	Densification in single-family home area, mixed development with yard and semi-private greening	1,133,823	1,367,805	0.83

Tab. 3: Corrective factor by area type

Adoption of the Pavement Types from 2001

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

Tab. 4: Pavement classes of non-built-up impervious areas					
	Area type	Share of pavement classes of non-built-impervious areas			
		1	2	3	4
		%			
	Residential area				
1	Dense block development, closed rear courtyard, 5-6 storey	64	17	4	15
2	Closed block development, rear courtyard, 5-storey	56	22	3	19
3	Closed and semi-open block development, decorative and garden courtyard, 4-storey	62	27	10	1
6	Mixed development, semi-open and open shed courtyard, 2-4-storey	46	29	13	12
7	Closed and semi-open, de-cored block-edge development, post-war gap closure	41	27	4	28
8	Heterogeneous inner-city mixed development, post-war gap closure	45	28	13	14
9	Large estate with tower high-rise buildings, 4-11-storey and more	15	67	7	11
10	Block-edge development with large quadrangles, 2-5 storey	20	37	32	11
11	Row development with landscaped residential greenery, 3-6-storey	49	46	3	2
21	Village-like mixed development	21	39	22	18
22	Row houses and duplexes with yards	25	65	3	7
23	Detached single-family homes with yards	18	74	2	6
24	Villas and town villas with park-like gardens	15	60	12	13
25	Densification in single-family home area, mixed development with yard and semi-private greening	20	64	4	12
60	Other and miscellaneous public facility / special use area	36	42	5	17
72	Row development with architectural green strips, 2-5 storey	20	37	32	11
73	Estates of the 1990s and later	20	60	10	10
29	**Core area**	50	34	9	7
	Industrial / commercial area				
30	Commercial and industrial area, large-scale retail, sparse development	48	38	1	13
31	Commercial and industrial area, large-scale retail, dense development	74	20	1	5
33	Mixed use area, mainly small trade and small business, sparse development	48	38	1	13
38	Mixed use area, mainly small trade and small business, dense development	74	20	1	5
32	**Utility area**	31	56	1	12
	Public service				
41	Security and order	54	25	3	18
43	Administrative	41	42	15	2
44	University and research	15	70	12	3
45	Culture	41	42	15	2
46	Hospital	42	38	8	12
47	Children's day care centre	7	42	5	46
49	Church	65	7	16	12
51	Other youth facility	4	62	18	16
12	Old school (built before 1945)	57	32	4	7
13	New school (built after 1945)	38	44	2	16
16	Sport facility, uncovered	59	24	1	16
17	Sport facility, covered	5	71	24	0
	Green and open spaces				
37	Allotment garden	5	31	4	60
27	Cemetery	14	27	5	54
36	Tree nursery / horticulture	35	45	9	11
53	Park / green space	30	20	5	45
54	City square / promenade	50	20	10	20
55	Forest	5	5	0	90
56	Agriculture	10	10	0	80
57	Fallow area	20	10	0	70
58	Camping ground	20	20	0	60
59	Weekend cottage and allotment-garden-type area	11	43	2	44
	Traffic area				
91	Parking area	31	53	7	9
92	Railway station and railway ground, without track area	5	5	0	90
93	Ariport	85	10	0	5
94	Other traffic area	42	32	19	7
99	Track area	5	5	0	90

Tab. 4: Pavement classes in non-built-up impervious areas by area type (Goedecke & Gerstenberg 2013)

Degrees of impervious coverage of roads

The degree of impervious coverage of roads is based on the evaluation of road statistics from the Senate Department for Urban Development and the Environment, *Grundsatzangelegenheiten der Straßenbautechnik und der Straßenerhaltung, Tabelle Fahrbahndecken und Beläge der Straßen und Gehwege in der Baulast Berlins* (Policy matters of road construction technology and road maintenance, table of road surfaces and pavement types of roads and walkways subject to maintenance by Berlin) (as of January 1, 2016), covering 8,950 ha of roads excluding motorways (SenStadtUm 2016b). The data for these statistics is available for each borough. The degree of impervious coverage per borough resulting from these statistics was assumed to be valid for all road areas within the respective boroughs.

Map Description

In the map, the **degree of impervious coverage**, i.e. the coverage of the earth's surface with impermeable materials, is represented as a **percentage of the reference area** (block or block segment area). Generally, the degree of impervious coverage declines from the city centre 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 centres of boroughs like Spandau and Köpenick, which were separate cities prior to 1920. There, the impervious coverage degree is about 60 %, and more than 90 % in their core areas. The extensive areas determined by large estates on the city outskirts, such as Marzahn, Hellersdorf and Hohenschönhausen, or Gropiusstadt in Neukölln and the “Thermometer Estate” in Lichterfelde, are between 50 % and over 80 % impervious.

In the following, Table 5 shows the average degrees of impervious coverage per **area type** in 2016.

The highest overall degrees of impervious coverage are shown for the area types "Dense block development, closed rear courtyard, 5-6 storey" with 85.6 %, “Core area” with 84.4 % and "Commercial and industrial area, large-scale retail, dense development" with 88.3 %. **The lowest degrees of impervious coverage**, with below 1 % each, are listed for the area types "Forest", "Agriculture” and “Fallow area”. A sharp increase in impervious coverage can be observed in the area type “Rental-flat buildings of the 1990s and later”. In recent years, many of these blocks have seen a lot of subsequent densification (e.g. the Beuth-Höfe at Spittelmarkt, Havelschanze in Spandau).

Tab. 5: Mean degrees of impervious coverage, 2016									
				2016					
	Area type 2015	Number of blocks	Block area [ha]	Impervious area [ha]	Degree of impervious coverage [%]	Built-up impervious area [ha]	Built-up impervious area [%]	Non-built-up imper-vious area [ha]	Non-built-up imper-vious area [%]
1	Dense block development, closed rear courtyard, 5-6 storey	184	258	221	85.6	168	65.0	53	20.7
2	Closed block development, rear courtyard, 5-storey	1,018	1,708	1,345	78.7	947	55.4	398	23.3
3	Closed and semi-open block development, decorative and garden courtyard, 4-storey	469	729	484	66.4	316	43.3	168	23.1
6	Mixed development, semi-open and open shed courtyard, 2-4-storey	105	202	129	63.5	76	37.5	53	26.0
7	De-cored block-edge development, post-war gap closure	468	836	562	67.2	360	43.0	202	24.2
8	Heterogeneous inner-city mixed development, post-war gap closure	89	229	155	67.5	91	39.8	63	27.7
9	Large estate with tower high-rise buildings, 4-11-storey and more	710	2,379	1,091	45.9	533	22.4	558	23.5
10	Block-edge development with large quadrangles, 2-5 storey	581	837	469	56.1	313	37.4	156	18.7
11	Row development with landscaped residential greenery, 2-6-storey	878	2,528	1,073	42.4	587	23.2	486	19.2
12	Old school (built before 1945)	187	312	175	56.2	89	28.4	87	27.8
13	New school (built after 1945)	406	983	500	50.9	229	23.3	271	27.6
16	Sport facility, uncovered	459	1,718	593	34.5	124	7.2	469	27.3
17	Sport facility, covered	61	115	57	49.6	33	28.8	24	20.8
21	Village-like mixed development	112	403	142	35.3	81	20.0	61	15.2
22	Row houses and duplexes with yards	1,020	1,762	587	33.3	368	20.9	219	12.4
23	Detached single-family homes with yards	4,703	9,646	3,014	31.3	1,913	19.8	1,102	11.4
24	Villas and town villas with park-like gardens	709	1,554	526	33.8	334	21.5	192	12.3
25	Densification in single-family home area, mixed development with yard and semi-private greening	346	933	347	37.2	217	23.3	129	13.9
27	Cemetery	181	1,122	93	8.3	17	1.5	76	6.7
29	Core area	285	464	391	84.4	259	55.9	132	28.5
30	Commercial and industrial area, large-scale retail, sparse development	1,104	4,773	3,119	65.4	1,321	27.7	1,799	37.7
31	Commercial and industrial area, large-scale retail, dense development	185	765	676	88.3	400	52.3	276	36.0
32	Utility area	132	608	267	43.8	96	15.8	170	28.0
33	Non-residential mixed use area, sparse development	163	411	251	61.0	126	30.6	125	30.4
36	Tree nursery / horticulture	55	263	51	19.2	15	5.8	35	13.4
37	Allotment garden	757	3,223	880	27.3	420	13.0	461	14.3
38	Non-residential mixed use area, dense development	46	116	90	77.6	53	45.5	37	32.1
41	Security and order	90	552	223	40.5	92	16.8	131	23.7
43	Administrative	161	398	231	58.1	125	31.5	106	26.6
44	University and research	102	495	226	45.6	115	23.2	111	22.4
45	Culture	96	261	132	50.6	62	23.7	70	26.9
46	Hospital	87	712	284	39.9	152	21.3	132	18.6
47	Children's day care centre	173	217	81	37.2	36	16.8	44	20.4
49	Church	122	115	41	35.7	19	16.7	22	19.0
51	Other youth facility	81	194	42	21.6	19	9.7	23	11.9
53	Park / green space	1,281	3,372	341	10.1	27	0.8	314	9.3
54	City square / promenade	103	57	26	44.7	2	4.2	23	40.6
55	Forest	2,871	16,951	57	0.3	16	0.1	41	0.2
56	Agriculture	496	3,595	4	0.1	2	0.1	3	0.1
57	Fallow area	783	2,690	23	0.8	12	0.4	11	0.4
58	Camping ground	11	46	8	16.7	1	2.0	7	14.6
59	Weekend cottage and allotment-garden-type area	253	820	242	29.5	102	12.4	140	17.1
60	Other and miscellaneous public facility / special use area	158	640	250	39.0	104	16.2	146	22.7
72	Parallel row buildings with architectural green strips, 2-5 storey	252	541	253	46.8	159	29.3	95	17.5
73	Rental-flat buildings of the 1990s and later	482	797	467	58.6	223	28.0	244	30.6
91	Parking area	195	192	99	51.8	10	5.2	89	46.6
92	Railway station and railway ground, without track area	235	360	178	49.6	60	16.7	118	32.9
93	Airport	56	444	140	31.4	18	4.0	122	27.4
94	Other traffic area	553	282	131	46.5	31	10.9	100	35.6
98	Construction site	26	75	28	36.9	6	7.7	22	29.2
99	Track area	575	1,349	657	48.7	15	1.1	642	47.6
	Total without bodies of water and roads	**24,655**	**74,033**	**21,450**	**29.0**	**10,890**	**14.7**	**10,560**	**14.3**
100	Body of water	697	5,388						
	Total with bodies of water but without roads	**25,352**	**79,421**	**21,450**	**27.0**	**10,890**	**13.7**	**10,560**	**13.3**
	Roads		9,687	8,741					
	Total without bodies of water but with roads	**24,655**	**83,720**	**30,192**	**36.1**	**10,890**	**13.0**	**10,560**	**12.6**
	Berlin total with bodies of water and roads	**25,352**	**89,108**	**30,192**	**33.9**	**10,890**	**12.2**	**10,560**	**11.9**

The area of roads constitutes the difference between the total area of Berlin (according to the ISU) and the area of all blocks and bodies of water.

The degree of impervious coverage of roads is based on the analysis of road statistics from the Senate Department for Urban Development and the Environment VII D 41, Grundsatzangelegenheiten der Straßenbautechnik und der Straßenerhaltung, Tabelle Fahrbahndecken und Beläge der Straßen und Gehwege in der Baulast Berlins (Policy matters of road construction technology and road maintenance, table of road surfaces and pavement types of roads and walkways subject to maintenance by Berlin) (as of January 1, 2016), covering 8,950 ha of roads excluding motorways. The degree of impervious coverage per borough resulting from these statistics was assumed to be valid for all road areas within the respective boroughs.

Track gravel is considered 100 % impervious both in the calculations and the map.

Discrepancies may occur due to rounding.

As of December 31, 2016

Tab. 5: Mean degrees of impervious coverage per area type, 2016

For a better overview, the degrees of impervious coverage are also summarized for each **land-use type** (ISU categories) (cf. Table 6). Residential areas have an average degree of impervious coverage of 41.4 %. Core areas have the highest mean degree of impervious coverage, with 84.4 %, while “Forest” and "Farmland" have the lowest.

Tab. 6: Mean degrees of impervious coverage by land-use type									
Use		Number of blocks	Block area [ha]	Impervious area [ha]	Degree of impervious coverage [%]	Built-up impervious area [ha]	Built-up impervious area [%]	Non-built-up impervious area [ha]	Non-built-up impervious area [%]
10	Residential area	11,367	23,690	9,814	41.4	6,021	25.4	3,794	16.0
21	Mixed-use area	967	2,177	1,389	63.8	841	38.6	549	25.2
30	Core area	286	466	393	84.4	260	55.9	133	28.5
40	Commercial and industrial area	1,289	5,539	3,795	68.5	1,721	31.1	2,074	37.5
50	Public service and other special uses	1,674	4,925	2,193	44.5	1,043	21.2	1,150	23.3
60	Utility area	132	608	267	43.8	96	15.8	170	28.0
70	Weekend cottage area	253	820	242	29.5	102	12.4	140	17.1
80	Traffic area	1,614	2,627	1,206	45.9	134	5.1	1,072	40.8
90	Construction site	26	75	28	36.9	6	7.7	22	29.2
100	Forest	2,652	15,611	12	0.1	9	0.1	2	0.0
121	Meadow s and pastures	281	1,375	3	0.2	1	0.1	2	0.1
122	Farmland	215	2,219	2	0.1	1	0.0	1	0.0
130	Park / green space	1,611	5,230	388	7.4	34	0.6	354	6.8
140	City square / promenade	103	57	26	44.7	2	4.2	23	40.6
150	Cemetery	181	1,122	93	8.3	17	1.5	76	6.7
160	Allotment garden	757	3,223	880	27.3	420	13.0	461	14.3
171 to 173	Fallow Area	672	2,172	22	1.0	11	0.5	10	0.5
190		520	1,833	650	35.4	157	8.5	493	26.9
200	Tree nursery / horticulture	55	263	51	19.2	15	5.8	35	13.4
	Total without bodies of water and roads	**24,655**	**74,033**	**21,450**	**29.0**	**10,890**	**14.7**	**10,560**	**14.3**
110	Body of w ater	697	5,388						
	Total with bodies of water and without roads	**25,352**	**79,421**	**21,450**	**27.0**	**10,890**	**13.7**	**10,560**	**13.3**
	Roads		9,687	8,741				8,741	90.2
	Total without bodies of water and with roads	**24,655**	**83,720**	**30,192**	**36.1**	**10,890**	**13.0**	**19,301**	**23.1**
	Berlin total with bodies of water and roads	**25,352**	**89,108**	**30,192**	**33.9**	**10,890**	**12.2**	**19,301**	**21.7**

The area of roads constitutes the difference betw een the total area of Berlin (according to the ISU) and the area of all blocks and bodies of w ater.
The degree of impervious coverage of roads is based on the analysis of road statistics from the Senate Department for Urban Development and the Environment VII D 41, Grundsatzangelegenheiten der Straßenbautechnik und der Straßenerhaltung, Tabelle Fahrbahndecken und Beläge der Straßen und Gehw ege in der Baulast Berlins (Policy matters of road construction technology and road maintenance, table of road surfaces and pavement types of roads and w alkw ays subject to maintenance by Berlin) (as of January 1, 2016), covering 8,950 ha of roads excluding motorw ays. The degree of impervious coverage per borough resulting from these statistics w as assumed to be valid for all road areas w ithin the respective boroughs.
Discrepancies may occur due to rounding.
As of December 31, 2016

Tab. 6: Mean degrees of impervious coverage by land-use type, 2016

The block and block segment areas of Berlin (without streets and bodies of water) are 29.0 % impervious, on average. Of this, 14.7 % are accounted for by impervious built-up areas, and 14.3 % by impervious non-built-up areas. **Including bodies of water and streets, Berlin is thus 33.9 % impervious.** Of this, 12.2 % is accounted for by impervious built-up areas, and 11.9 % by impervious non-built-up areas. Impervious streets account for 9.8 % of the Berlin area. Berlin is thus one third impervious. The total impervious area in turn consists of roughly equal parts of buildings, streets, and non-built-up impervious areas (one third each).

Impervious Coverage in the Boroughs

The borough with the lowest degree of impervious coverage is Treptow-Köpenick, with 22.3 %, while Kreuzberg-Friedrichshain and Mitte have the highest degrees, with 69.7 and 63.5 %, respectively. These two boroughs also have the highest shares of built-up areas, as a proportion of their total areas.

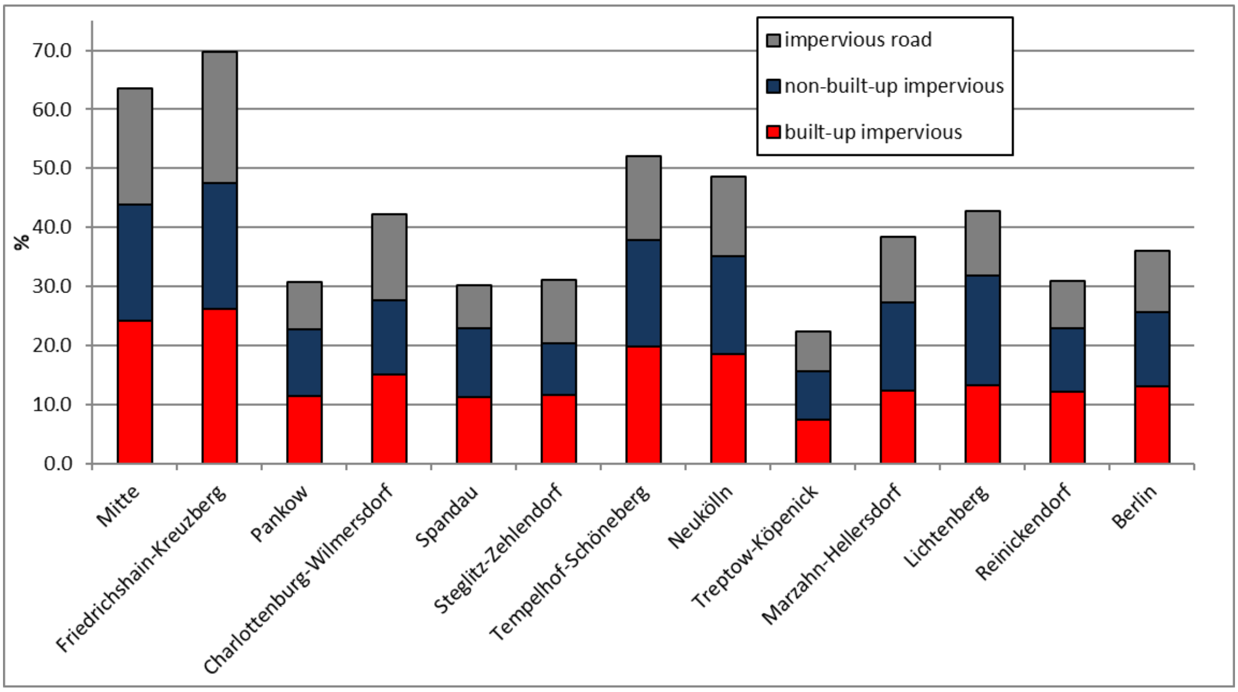

Fig. 7: Degree of impervious coverage by borough (in percentage of total area without bodies of water)

Data on Impervious Soil Coverage in 2016 Compared with 1990, 2001, 2005 and 2011

Due to **different ascertainment methods**, a direct comparison between the impervious coverage values of 1990 and 2001 on the one hand with 2005 and 2011 or 2016 on the other hand is possible only to a limited degree. No change in the impervious area over the entire period of time can be ascertained from these figures.

In **2001**, the degree of impervious coverage in Berlin amounted to **34.7 %**, including streets and bodies of water. This data is to some extent based on evaluations of satellite images and other sources from the '80s and only applied to West Berlin. This mapping material was 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 mapping projects of 2005, 2011 and 2016 now provide a data set gain from a uniform, completely automated and considerably improved procedure. The result is that the degree of impervious coverage in **2016** amounts to **33.9 %** (30.192 ha), and is thus approx. 1.1 % higher than the value for 2011.

The numbers show a major increase in **built-up impervious areas** to reach 10,890 ha. However, this is only partly the result of construction activities; the improved building stock data base was the main cause for the newly recorded built-up impervious areas. Areas that had been recorded as non-built-up impervious in 2011, were now mapped as built-up impervious. Furthermore, this explains the decrease in non-built up impervious areas. According to a qualitative GIS-technical estimate of these built-up areas, the changes amount to approx. 600 ha due to the improved data base. Thus, a **considerable growth** of approx. 700 ha **of impervious area** was recorded in these five years. Hence, new construction accounts for just over half of the increase in built-up impervious areas.

Tab. 7: Results of mapping of impervious coverage in Berlin, 1990 to 2016										
	Impervious coverage		Built-up impervious area		Non-built up impervious area		Roads		Total area analyzed	No. of blocks
	ha	%	ha	%	ha	%	ha	%	ha	
1990	31,173	35.3	9,680	11.0	13,283	15.0	8,210	9.3	88,358	23,202
2001	31,021	34.7	9,629	10.8	13,058	14.6	8,334	9.3	89,317	24,505
2005	28,408	31.9	9,423	10.6	10,526	11.8	8,459	9.5	89,090	24,669
2011	29,190	32.8	9,574	10.7	11,032	12.4	8,584	9.6	89,095	24,961
2016	30,192	33.9	10,890	12.2	10,560	11.9	8,741	9.8	89,108	25,352

Discrepancies may occur, due to rounding

Tab. 7: Results of mapping of impervious coverage in Berlin, 1990 to 2016 (all information refers to the total area of Berlin, incl. streets and bodies of water). Due to changed evaluation methods, no change can be concluded for the entire period of time. The values for 1990 and 2001 are based on different evaluation methods, which do not permit any comparison with the values for 2005, 2011 and 2016. However, a comparison between 2005, 2011 and 2016 is possible.

For the **non-built-up impervious area,** the picture is somewhat different. The apparent decrease by 2.8 % between 2001 and 2005 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 Agriculture) were assigned estimated values for their non-built-up impervious portions, values which we today recognize as having been set 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 actually took place in the municipal area. The decrease in the non-built-up impervious area by 0.5 % between 2011 and 2016 is not due to an actual decline in impervious coverage but due to an improved building stock data base. Overall, the **proportions** of built-up and non-built-up impervious areas have been **identified more precisely**.

With regard to the ascertainment of the **impervious road area**, the roughly estimated values available in 1990 could not be replaced by values from the Road-Building Authority until 1997. These were used for the evaluations in 2001. For the impervious coverage mapping projects in in 2005 and 2011, degrees of impervious coverage for streets, recorded by borough based on 2006 data, were obtained for the entire city (Gerstenberg & Goedecke 2011). A slight increase in the degree of impervious coverage attributable to the road category and caused by road-building measures, primarily in East Berlin, certainly seems plausible. Similarly, the degree of impervious coverage of roads, as of 2016, were applied by borough for the 2016 analysis (SenStadtUm 2016b, Goedecke & Gerstenberg 2013 method).

Change Mapping of Impervious Coverage between 2011 and 2016

The multiple use of the procedure in 2016 also permits a comparison with the impervious coverage at block and block segment level. Figure 8 **maps the changes** between 2011 and 2016. Blocks with changes of greater than 10 % of the degree of impervious coverage are shown. However, in the overall accounting of the impervious coverage in the total area and at the level of area types, smaller changes have also been incorporated.

- For 424 areas, the block geometries changed considerably by more than 10 % of the previous area size between 2010 in 2015, causing pseudo-changes to appear in the impervious coverage map.
- The improved data base for the building stock and railway tracks led to pseudo-changes rather than actual changes for 718 block and block segment areas. This is the case predominantly for allotment gardens and the area type “Track area”.

In the following, some striking examples are described that serve to highlight the - at times - very case-specific reasons for differences in mapping the degree of impervious coverage for areas between 2011 and 2016.

The decrease in impervious coverage in the commercial area on Blankenburger Straße in Pankow stands out. There has been no actual change here. However, large sandy areas created in 2011 during construction activities are meanwhile overgrown, whereby a decreased impervious coverage was mapped.

Upon analysis of the orthophotos from 2016, the significant decrease in impervious coverage at Schöneweide station can be attributed to the extensive dismantling of tracks and an increased degree of vegetation coverage of the track gravel.

The similarly striking (apparent) decrease in impervious coverage around the Tempelhofer Freiheit is due essentially to the total area being divided into several block segment areas. As a result, the areas overgrown with vegetation are more prominent compared to the mean value of the former total area in the 2010 block map. A change in impervious coverage is effected by areas of formerly impervious runways and storage areas that are gradually becoming overgrown. These changes are detected by the satellite sensor and are thus mapped as partially impervious areas. New residential areas are also clearly visible in the change mapping of the overall impervious coverage. In addition to the rural town of Gatow, the two residential areas at Oskar-Helene-Heim station stand out in particular.

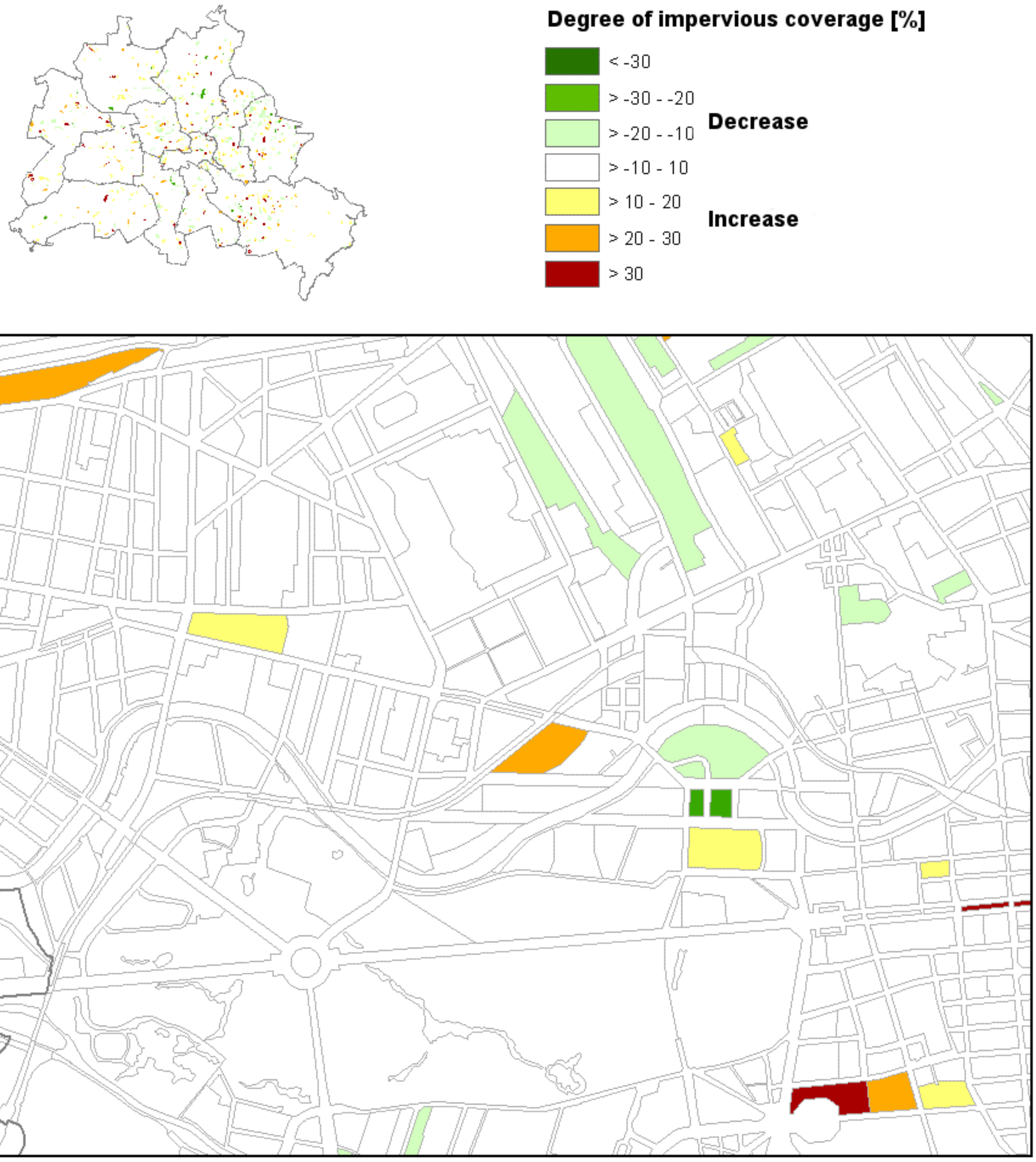

Fig. 8: Map of changes in impervious coverage between 2011 and 2016 (the result is also available as a PDF-Document)

Excursus

Comparison of the impervious coverage data for 2005, 2011 and 2016 with the “Impervious Coverage Indicator” of the Working Group on Integrated Environmental and Economic Accounting of the German States (EEAL)

The impervious coverage value for Berlin of the Working Group on Integrated Environmental and Economic Accounting of the German States (EEAL), developed by the Federal-State Commission on Soil Protection (LABO) on the basis of the sustainability indicator “land consumption for residential and traffic areas”, is juxtaposed to the results of the Environmental Atlas.

The data survey of degrees of impervious coverage by state is based on official land statistics, in which estimated degrees of impervious coverage are assigned to various use categories of residential and traffic areas, modified in accordance with residential density of the areas, and then used as a factor in calculation. In this way, impervious coverage data can be generated on an annual basis. The data on development of impervious coverage in the states are updated annually (EEAL 2016).

Accordingly, the proportion of impervious coverage in the total area of Berlin rose from 34.24 % in 2000 to 34.92 % in 2015, and thus increased by 0.68 % in 15 years, which comes to an annual rate of increase of 0.05 %. The increase of impervious coverage to reach 35.10 % by 2010, has seen a slight backward trend over the last five years.

The absolute increase in impervious coverage, amounting to approx. 31,140 ha, was thus 770 ha in those fifteen years.

Figure 9 shows the rate of impervious coverage of the Environmental Atlas in 2005, 2011 and 2016, compared with the annually generated data of the EEAL.

Neither approach ascertains impervious coverage precisely; both work with different methods and different goals, and, to a certain extent, with estimates and assumptions.

While the EEAL approach gives the current (2015) overall impervious coverage of Berlin as 34.92 %, the Environmental Atlas mapped only 33.9 % of the city as impervious in 2016.

Under the procedure of the Environmental Atlas, the built-up impervious coverage area was derived directly from a number of different building stock data sets (ALK only for the years 2005 and 2010), and hence has a very high degree of precision, while the non-built-up impervious coverage area, as described above, is determined from satellite imagery. Hence, the above-mentioned error sources must be methodologically taken into account.

By contrast, the EEAL approach operates from the outset with estimates for certain use classes, which are moreover nationally uniform, and hence do not take regional particularities into account. For instance, the elimination of the area of Tempelhof Airport for the category of traffic areas at the time of its closure would have led to a change in the statistical situation, in spite of the fact that the degree of impervious coverage did not actually change.

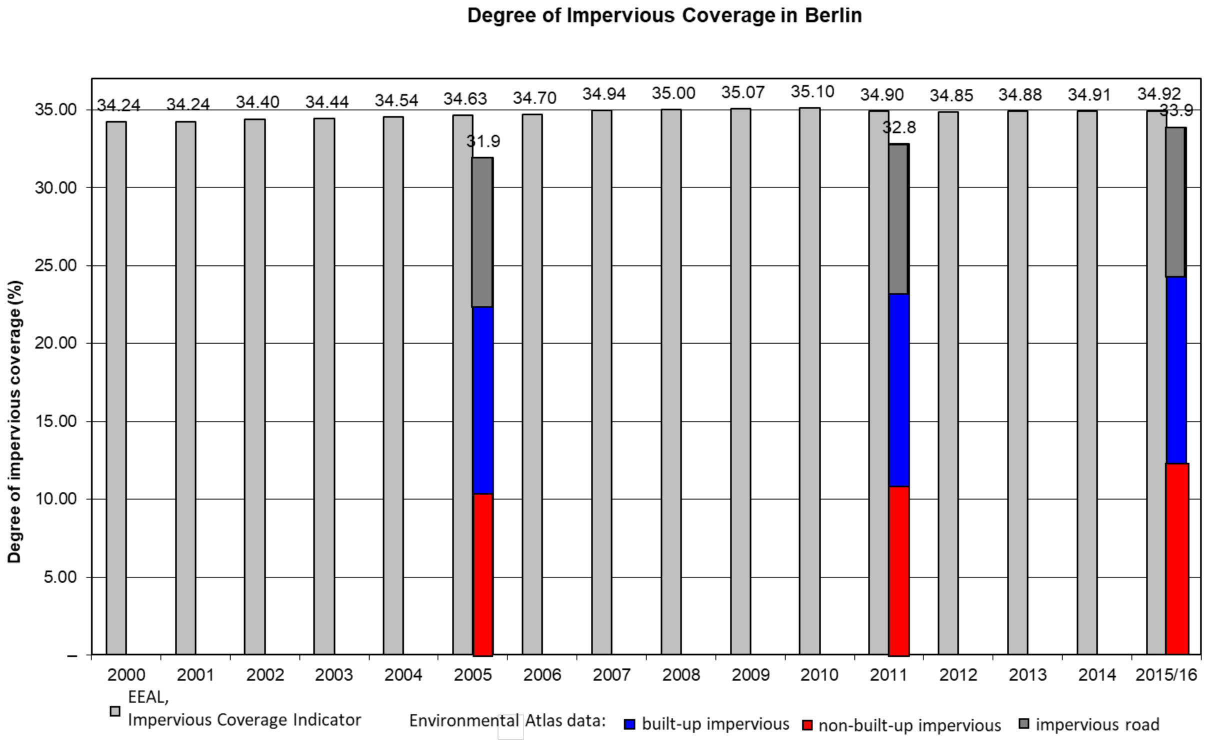

Fig. 9: Degrees of impervious coverage shown in the Environmental Atlas, editions 2005, 2011 and 016, compared with the annually generated data of the EEAL

For political decision-making, other impervious coverage data can also be used (Amt für Statistik Berlin-Brandenburg (Statistical Office for Berlin-Brandenburg) 2014). The impervious coverage data of the EEAL is collected annually according to a fixed, nationally uniform comparison method, and is thus best suited for monitoring, and ultimately, too, has been developed precisely for that purpose. Due to the ability to differentiate between built-up impervious areas, non-built-up impervious areas, and impervious road areas, the Environmental Atlas figures complement and modify the figures of the EEAL data. For built-up impervious surfaces, the maps of the Environmental Atlas provide a very high degree of precision.

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