01.02 Impervious Soil Coverage (Sealing of Soil Surface)

Introduction

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 is defined as the paving (or covering) of the soil with solid materials. Impervious areas may be divided into **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 occurring types of pavement of non-built-up impervious areas have been grouped into **four pavement classes,** including their different effects on the ecosystem (cf. Table 1).

Tab. 1: Overview of the pavement classes of non-built-up impervious areas		
Pavement class	**Estimated effects on ecosystem**	**Pavement types**
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 the pavement classes of non-built-up impervious areas

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. Environmental

Atlas 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 Environmental Atlas Map "Nocturnal Cooling Rate between 10:00 p.m. and 04:00 a.m." (04.10.4)).

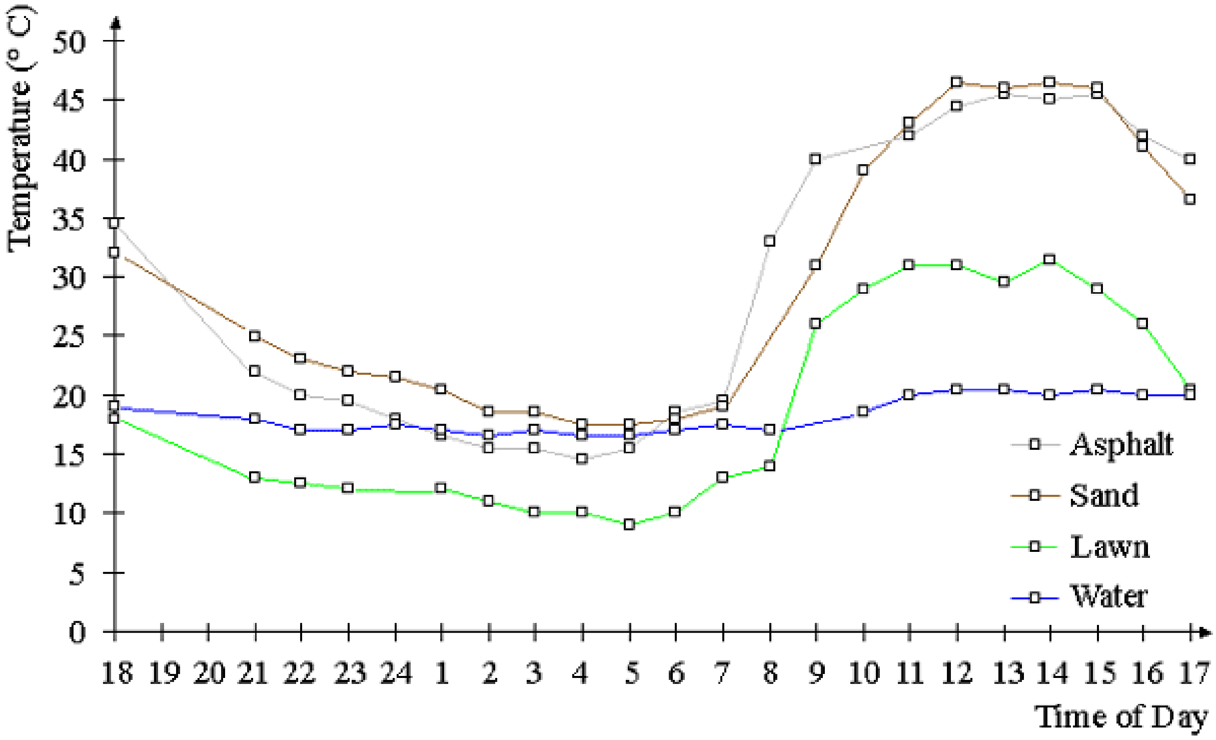


Fig. 1: Temperature curves over various surfaces (Kessler 1971 in: Mählenhoff 1989)

At the same time, the **atmospheric humidity** is also **reduced**, due to the lack of vegetation areas and the evaporation that emanates from them. This may lead to the occurrence of **extreme values** that may impair human well-being considerably. In this context, pervious areas such as parks play a major role. Positive climatic effects on human well-being may already be observed for parks as small as 1 ha in size. Vegetation areas also have an effect on dust and pollutant levels in the air, as their large leaf surfaces enable them 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 in the Climate section.

In addition to the effects on the ecosystem described above, the degree of impervious coverage of an urban area 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, may have a depressing, monotonous effect on residents. It becomes impossible to truly experience nature, such as the change of the seasons, in the immediate residential environment. Turning to the outskirts for recreation, however, generates traffic with equally negative impacts 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 evaluation methods, e.g. in soil protection. The documentation regarding the damage to nature and landscape due to impervious soil coverage is also of great importance. Policy-makers, too, are increasingly requesting frequent, regular updates on impervious coverage data, in order to monitor and measure the success of environmental or urban-planning strategies (cf. Reusswig et al. 2016, SenStadtUm 2016a, SenUVK 2019, AfS 2021).

Methods to Reduce Impervious Coverage and New Land Consumption

As part of the National Sustainability Strategy, the indicator **"new land consumption"** was developed for empirical studies and risk assessments on the impact of land consumption. New land consumption is calculated from the daily increase in **built-up and traffic areas.** This is not equal to the impervious area, since these also include areas which are only slightly impervious (gardens in residential areas, allotments, park facilities or green median strips on roads, etc.). The Federal Government's goal is to limit the average new land consumption to less than 30 ha per day by 2030. By 2050, the aim is to establish a closed-loop land-use regime, in which the total land consumption is reduced to zero, in net terms, by means of land recycling and a reduction in new land consumption (cf. Federal Statistical Office 2021). In the years from 2004 to 2019, the daily new land consumption decreased continuously from 131 ha to 45 ha. In the year 2020, however, it rose again to 58 ha per day. The 30-ha target originally set by the Federal government for 2020 was thus not met, despite a deceleration in new land consumption (Federal Environment Agency 2020).

At the UN Summit in New York in September 2015, the 2030 Agenda for Sustainable Development was adopted. The German Sustainability Strategy 2021 (The Federal Government 2021), based on the same, identifies the special need for sustainable soil protection as a resource against the background of increasing urbanisation and climate change (Sustainable Development Goal – SDG 15). Working towards the 2030 Agenda goal of a land and soil degradation neutral world, emphasises the crucial role that soil plays in biodiversity, climate protection and as carbon storage (The Federal Government 2021).

In a conurbation area such as Berlin, however, the increase in built-up and traffic areas as described above does not represent land consumption accurately (cf. Environmental Atlas Map "Open-Space Development"). For this reason, "soil imperviousness", which is indicator No 15.1 of seventeen core indicators for monitoring sustainability, was chosen to document 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 2021).

In 2005, the federal and regional-state soil conservation board (LABO) appointed a group of federal and state experts to develop a suitable assessment procedure for ascertaining the impervious soil coverage at the state level, in order to expand the sustainability indicator "new land consumption for residential and traffic areas" to include the component of impervious coverage.

The results of the experts' group were incorporated into the Environmental-Economic Accounting of the German States (EEAL), and documented in the report "Indikator Versiegelung", (the indicator "Impervious Coverage") (Frie & Hensel 2007).

LABO reports to the Environmental Minister's Conferences (UMK) document the development of new land consumption and the measures taken by the federal German states to reduce new land consumption (LABO 2020). According to the Environmental-Economic Accounting of the German States (EEAL), impervious areas in Germany accounted for 6.3 % of the total area in 2019. This corresponds to an impervious area of 2.2 million ha. In Berlin, impervious areas covered 34.7 % (approx. 30,894 ha) of the total area in 2019 (Statistical Offices of the German *States* 2021).

See also the Excursus Impervious Coverage Data 2005, 2011, 2016 and 2021, which compares the present results with those of the "Indikator Versiegelung" ("Impervious Coverage" indicator), by the Environmental-Economic Accounting of the German States (EEAL, Statistical Offices of the German States 2021).

The **reduction of land consumption**, which is a goal of the National Sustainability Strategy, shall be achieved through land-saving and compact construction, densification of inner-city areas, concentration of infrastructure, provision of compensation areas, and the rehabilitation of areas that are no longer used (space recycling). By improving the quality of the living environment in residential areas, dense housing in the city shall be reestablished as an alternative to the "home in the country" (The Federal Government 2021). Germany's states and municipalities shall realise 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 2021) 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 2022) and, in some cases, nature conservation legislation comprise pertinent regulations relating to soil as a subject to be protected. These include the "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, recording 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 2022), 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 offset.

With an increase in imperviously covered areas in the State of Berlin, there should be a qualitative assessment as to which soils are in use or need of extra protection. The Environmental Atlas Map "Planning Advice for Soil Protection" (01.13) and the summarised "Leitbild und Maßnahmenkatalog für den vorsorgenden Bodenschutz" (Catalogue of models and measures for precautionary soil protection in Berlin, SenStadt UVK 2021, only in German) serve this purpose.

In its Environmental Report of 2020, the German Advisory Council on the Environment demands, among other things, that a duty of review be introduced to determine whether the impervious cover of an existing area may be removed, whenever a new area is rendered impervious (SRU 2020). In this context, a project is highlighted that systematically records areas that could have their impervious cover potentially removed 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 cover and the restoration of their soil functions (Environmental Atlas Map "Potential for the Removal of Impervious Soil Coverage (Soil De-sealing)" (01.16), SenSW 2021b).

Financial incentives for private individuals may also contribute to the reduction of impervious coverage. On January 1, 2000, Berlin introduced separate billing for rainwater and waste water charges. Splitting of the charges was introduced based on a ruling by the Federal Administrative Court (resolution of June 12, 1972) and the Higher Administrative Court of Lüneburg (rulings of June 14, 1968 and of April 10, 1980). It requires municipalities, in which the costs for the discharge of rainwater exceeds 15 % of the total costs of waste water disposal, to account for the charges separately. Thus, the rainwater charge is no longer proportionally linked to the waste water charge. It is calculated according to the proportion of the impervious area of the property from which rainwater is discharged into the sewage system (BWB 1998). Since 2000, owners have therefore been eager to keep impervious areas on their property as small as possible to save on sewage costs. Since the NWFreiV (Precipitation Water Exemption Ordinance, Ordinance on the exemption from permits for the safe percolation of precipitation water - NWFreiV of 24 August 2001) came into force, it has been possible to obtain a partial or complete exemption from the rainwater charge without a permit by allowing rainwater to percolate on one's own property (SenStadt 2001). Since 2018, construction projects have been required to take precautionary action to ensure rainwater management on the property in accordance with Section 29 (1) BauGB. If it is impossible to prevent the discharge of rainwater into the sewage system or directly into a body of water, the volume shall be reduced (BReWa-BE, SenUVK 2021).

Statistical Base

Data on impervious soil coverage has been available for Berlin in the Environmental Atlas since the early 1980s; initially only for the western part of the city. After the political turnaround, a database was established for all of Berlin and continually revised as part of a series of updates focusing on different key areas respectively.

In cooperation with the Technical University of Berlin, the Humboldt University and the company Digitale Dienste Berlin, a new survey method for recording impervious areas was developed for the 2005 dataset. The method applied since then enables a comparison of the degrees of imperviousness across the whole city for the years 2005, 2011, 2016 and 2021.The following expert information, geo-data and satellite-image data, were used:

- Urban and Environmental Information System (ISU5) – spatial reference and land use data (as of December 31, 2020),
- Official Real Estate Cadastre Information System – ALKIS (as of February 2022),

- NOT-ALKIS buildings (as of 2021),
- Map of Berlin 1 : 5,000 – K5 (as of May 2021),
- Orthophotos from 2020 and 2021 (as of August 2020 and February 2021),
- Impervious soil coverage data of the BWB (Berlin Waterworks, as of 2001),
- Road survey data (as of 2014),
- Multispectral Sentinel-2A scene of June 7, 2021.

In addition to the ALKIS building dataset, a classification of the 2020 DSM was carried out, facilitating the development of a NOT-ALKIS building dataset (SenSW 2020a, SenSW 2021a). The buildings thus determined were used to supplement the building data basis for selected area types (single-family homes, row houses and duplexes, villas, allotment gardens, weekend cottages and rental-flat buildings of the 1990s and later). Road traffic data collected by surveying the entire public road space in Berlin (primary and secondary road network including some paths in public parks) was used for the first time in 2014 to develop a differentiated map of the impervious soil coverage of Berlin's road space. The data contains information on 17 different materials, which was used to derive the degree of impervious coverage of the respective road surface (cf. SenUVK 2014).

Further information may be found in the final report of the impervious soil coverage mapping of 2021 (only in German).

Methodology

The impervious soil coverage mapping of the block (segment) areas and the road space was carried out separately based on two different methods. They were later combined to an overall evaluation of impervious coverage. Bodies of water were not included in this mapping.

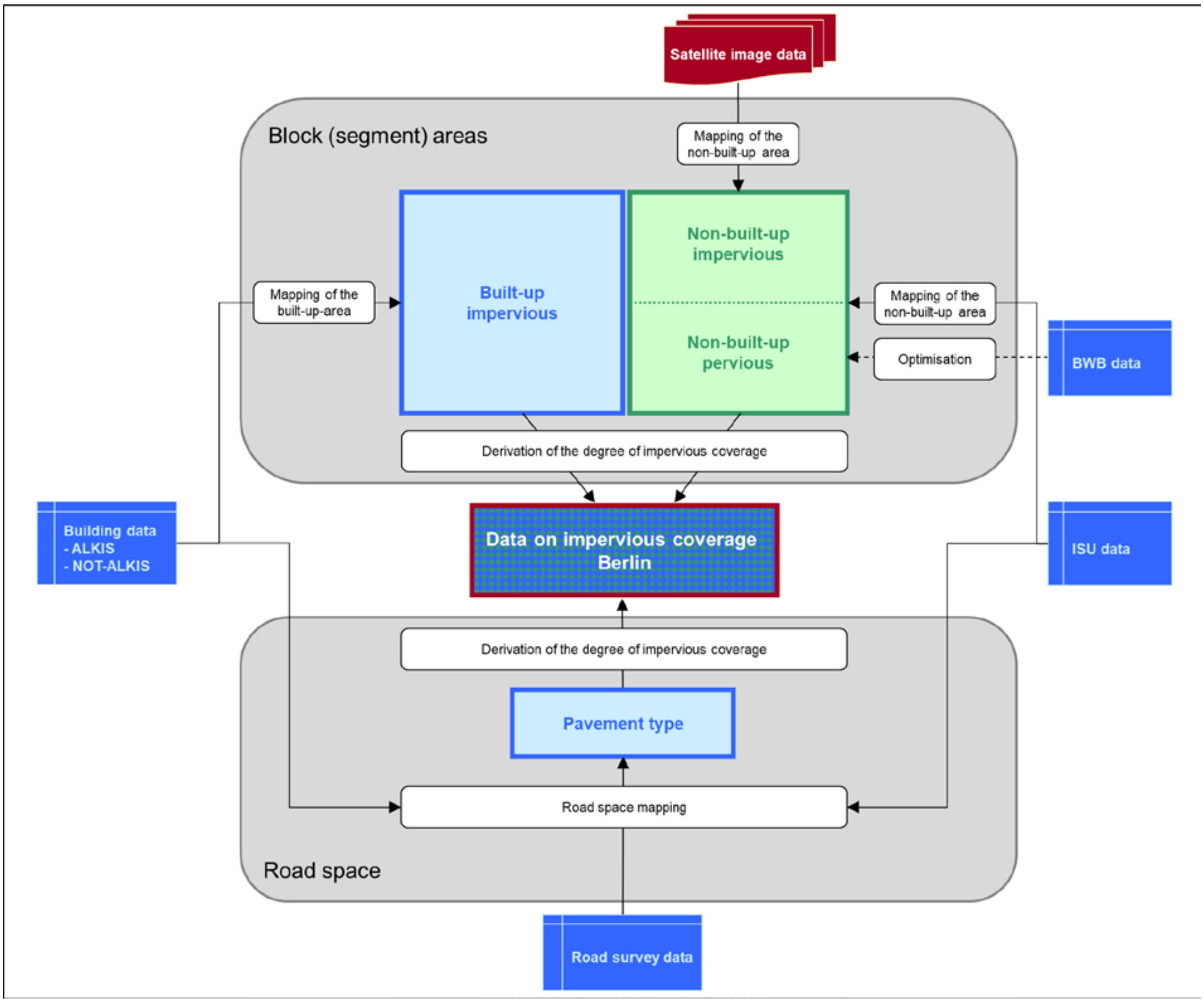


Fig. 2: Diagram of the hybrid mapping procedure

Degrees of Impervious Coverage of Block (Segment) Areas

The analysis process of the block (segment) areas 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** (cf. Figure 2).

A Sentinel-2A scene recorded on June 7, 2021 was employed. **Relevant information from the Environmental Atlas**, the Urban and Environmental Information System (ISU), and the already ascertained corrective factors, which were developed based on the **data of the Berlin Waterworks** (BWB data), were incorporated into the classification process. The mapping process is divided into three stages of analysis:

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

A detailed description of the methodological approach may be found in the final report on the impervious soil coverage mapping of 2021 (only in German).

The built-up impervious areas contained in the 2021 dataset were defined based on two data bases. This involved, on the one hand, the use of ALKIS building data. As it is incomplete, especially regarding allotments and newly built-up areas, NOT-ALKIS data was used in addition on the other hand (cf. Statistical Base). Integrating building data into the mapping process constituted the first component of the hybrid method approach. These areas were therefore not analysed with reference to the satellite-image data.

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

The evaluation of the satellite image focuses on the following evaluation criteria.

Categorisation of Area Types Relevant for Remote Sensing

To improve the mapping results, the ISU area types were categorised according to criteria relevant for remote sensing, i.e. building height, vegetation height, reflective properties, heterogeneity and relief, as well as the average degree of impervious coverage of the existing data stock (2001). **Eighteen categories** were defined. This permitted spatially separated sub-classifications with an optimised methodological choice in each case.

Spectral Classification of Non-Built-Up Areas

The data collected by the satellite's sensor was further processed with the aid of an automatic classification system. First, the **degree of vegetation** of the non-built-up areas was calculated using the **Normalised Difference Vegetation Index (NDVI)** per pixel of 2.5 x 2.5 m².

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 much more, relatively, in the near infrared range (wavelength from about 700 to 1300 nm). Normalisation results in a range of values between -1 and +1, with positive values close to 1 indicating "many healthy, photosynthetically active plants per area" (e.g. Hildebrandt 1996).

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

- There is a linear connection between NDVI and the degree of vegetation: the higher the NDVI, the more (vital) vegetation is present.
- There is a high negative correlation between the degree of vegetation and the 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 healthy vegetation (**degree of vegetation: 100 %**), such as forests or grasslands are largely reflected by high to very high indices. These areas were classified as pervious.

The problem of local **obscuring by treetops of impervious areas** cannot be solved based on the evaluation of satellite-image data with its top view. To correct for this "error", **context-related correction**

factors were ascertained and implemented, with the aid of ISU data. Detecting and distinguishing between graduations of the degree of vegetation (degree of vegetation: >0 % and <100 %) proved to be methodologically complex. Medium index values predominated.

The current methodological development process addressed these differences: a nuanced approach was taken to evaluate NDVI values that indicated areas partially covered by vegetation (degree of vegetation >0 %). They were assigned to different degrees of impervious coverage in the **rule-based classification system, depending on the area type or area-type category.**

Based on this approach, 12 NDVI categories were established.

Drawing on the impervious coverage data, it should be possible to evaluate **track gravel** flexibly. In some contexts, these areas are considered impervious, in other contexts, they are considered to rather fall into the pervious area category. Therefore, "track gravel" was classed separately in the “railyard” category.

Due to their reflective properties, surface materials such as **sand, ash and tamped soil as well as artificial surfaces** were further separated into mappings based on objects. This step was taken to ensure a more targeted consideration of their impervious properties in the evaluation process and to minimise mapping errors.

The **classification components** were merged into a pixel-based data set, which formed the basis for the subsequent rule-based classification. Areas mapped as sand, ash or tamped soil, artificial surface or track gravel were aggregated with the impervious built-up building areas to form a **classified combined block area**.

The “Shade” class remained separated from the other classes and was addressed further when calculating the degrees of impervious coverage.

Rule-Based Classification

In the rule-based classification, the results of spectral classification were combined with ISU data (area types) to yield degrees of impervious coverage derived by pixel. For this purpose, an existing set of rules was initially repeated and applied as is, and a preliminary mapping was carried out for 2021.

In order to improve the comparability of two rule-based classifications derived using a mono-temporal approach, a second step was carried out involving a multi-temporal change analysis of satellite image data between 2016 and 2021.

The new rule-based classification of 2021 and the previous one of 2016 were thus available as an intermediate result. The objective was to obtain reliable information on changes in the degree of impervious coverage at block or block-segment level by linking these mappings with each other and with the current ISU5 of 2020.

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

- Recording of changed areas and automated 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 recording of suspected areas, indicating a change in impervious coverage, the existing satellite image data of 2016 and 2021 was analysed for the non-built-up areas on the one hand. For this purpose, relevant NDVI channels were compared with each other following normalisation and suspected areas were derived that indicate changes in impervious coverage. On the other hand, the building data was examined with regard to possible changes within the built-up impervious areas.

Another set of rules taken from the rule-based classification of 2016 and the intermediate result of 2021 were used to derive the final rule-based classification of 2021. For unchanged block (segment) areas, the 2016 classification was retained. The rule-based classification of 2021 was adopted in the following cases:

- Changed block (segment) areas (changes of the ISU area type, or major changes of block geometry),
- Suspected areas within unchanged block (segment) areas (changes in spectral properties, taking into account the phenology),
- Previously built-up areas, which, according to the current ALKIS building stock, no longer contain any structures (demolition).

The final **result of the rule-based classification system** of 2021 for the non-built-up area was also the final result of the satellite-image classification process. The category “non-built-up impervious area” has been described in the classification with the 12 **categories of the degree of impervious coverage**, a **Shade** class and a **Track-gravel** class (cf. Figure 3).

Figure 3 shows the 12 categories representing the degree of impervious coverage, the Shade and Track-gravel classes, and the built-up impervious areas from building data on a grid basis. Drawing on this intermediate result (grid data), the mean degrees of impervious coverage were then calculated by block area (cf. Calculation of the Degrees of Impervious Coverage). After final plausibility checks, any distinct pseudo changes were located, and relevant blocks were excluded from further analysis.

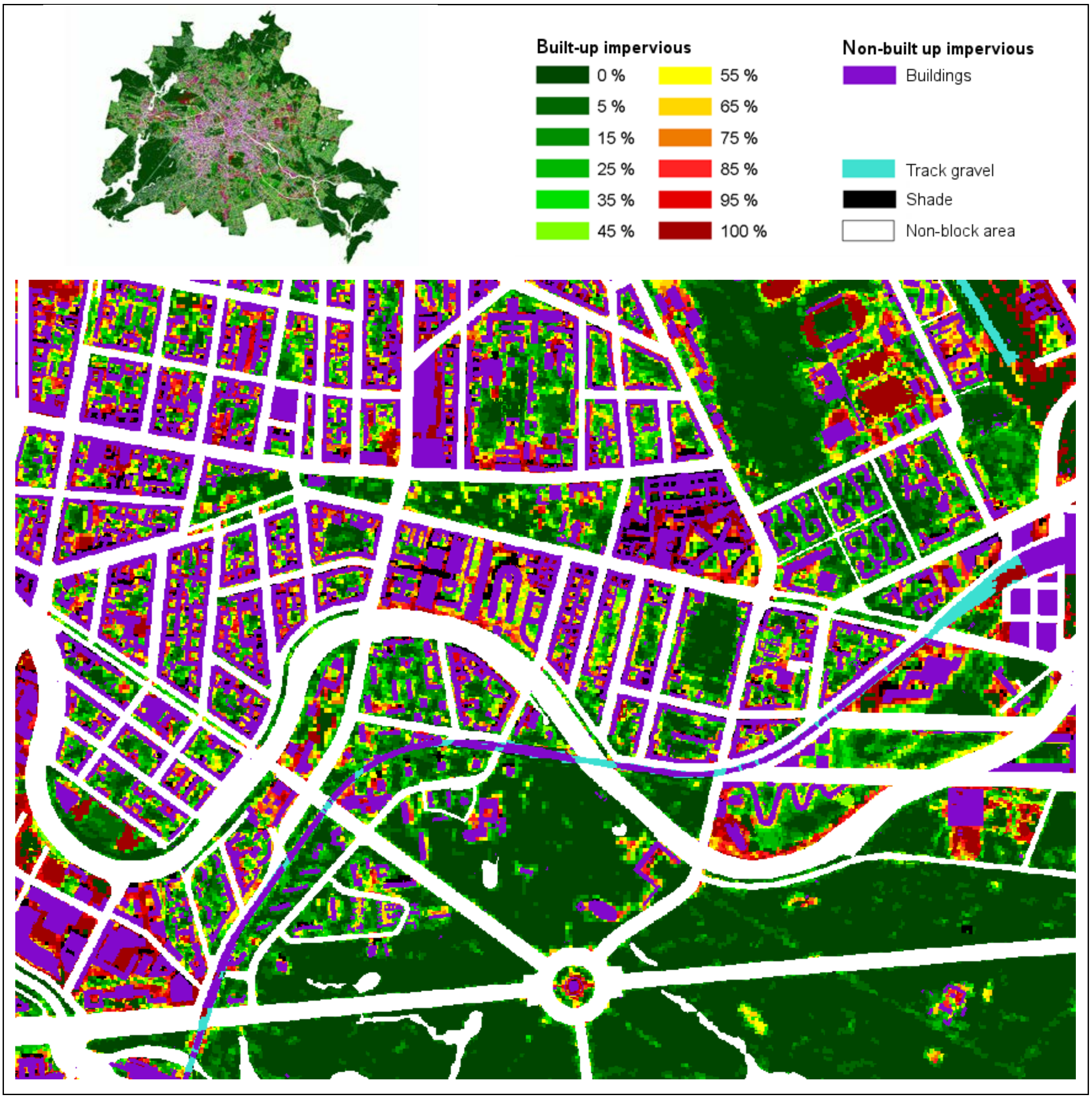


Fig. 3: Uncorrected degrees of impervious coverage of 2021 (grid data) - intermediate result of the rule-based classification

The intermediate result published in the FIS Broker as the 2021 [“Impervious Coverage Map (uncorrected degrees of impervious coverage, grid data)”] illustrates the distribution of impervious coverage within the block (segment) areas. The effect of shade in the various block (segment) areas is also presented. 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 2.5 m x 2.5 m, twelve classes representing the degree of impervious coverage 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.

For the impervious coverage map of the Environmental Atlas, the grid-level information was aggregated at block (segment) area level. It was then further processed and corrected where necessary. The black shaded areas presented here were assigned a degree of impervious coverage in a subsequent classification based on their immediate surroundings and their area types. The Environmental Atlas map “Impervious Soil Coverage” (01.02), on the other hand, illustrates the mean degree of impervious soil coverage by block (segment) 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. A distinction is made between three degrees of impervious coverage (IC):

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 block (segment) areas from the 2020 ISU5 block map**.** For this purpose, a summation by category of degree of impervious coverage was initially carried out for each block (segment) area, based on the grid-based intermediate result. Subsequently, a degree of impervious coverage was assigned to the **shaded areas** based on their immediate surroundings and their area types.

Correction factors were applied to individual **residential-land-use types characterised by greenery** in order to further improve the mapping results. For this purpose, the impervious coverage data of the BWB (Berlin Waterworks) was used, providing information on non-built-up impervious block areas and thus allowing for a look beneath the canopy cover.

The "**Track gravel**" class was maintained as a data field of its own, and could optionally be included in the calculations either as non-built-up impervious (100 %) or non-built-up pervious (0 %). This ensures that gravel is evaluated according to the subject matter at hand. In the map shown, track gravel is considered 100 % impervious.

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 using selected test areas. The results were then applied to all areas of the same area type. The pavement type distribution by area type was not updated for the current map but was adapted to the new ISU area types of 2020 (SenSW 2020b) instead. It is based on a survey from 1988 (AGU Arbeitsgemeinschaft Umweltplanung (Environmental Planning Working Group) 1988). The actual pavement types are not shown in the map; however, they may be displayed via the factual data display by block (segment) area in the Geoportal (only in German).

Tab. 2: Pavement classes of non-built-up impervious areas				
Area type	Share of pavement classes of non-built-up impervious areas			
	1	2	3	4
	%			
Residential area				
1 Dense block development, closed rear courtyard, 5-6 storeys	64	17	4	15
2 Closed block development, rear courtyard, 5-storeys	56	22	3	19
3 Closed and semi-open block development, decorative and garden courtyard, 4-storeys	62	27	10	1
6 Mixed development, semi-open and open shed courtyard, 2-4-storeys	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-storeys and more	15	67	7	11
10 Block-edge development with large quadrangles, 2-5 storeys	20	37	32	11
11 Row development with landscaped residential greenery, 3-6-storeys	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 storeys	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. 2: Pavement classes of the non-built-up impervious area by area type (Goedecke & Gerstenberg 2013)

Degrees of Impervious Coverage of Roads

For the first time, the impervious coverage mapping of the road space was carried out based on differentiated road survey data (as of 2014) (SenUVK 2014). This data set contains information on 17 different materials, which served as a basis for allocating the different road surfaces to the following seven different pavement classes:

Tab. 3: Overview of the pavement classes of road areas		
Pavement class	**Degree of impervious coverage**	**Pavement types**
0	pervious	Non-built-up, pervious
1	extremely high	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
5	n/a	Pavement unknown
6	track area	Tram track area in separate track bed
7	built-up	Developed

Tab. 3: Overview of the pavement classes of road areas

In the calculation of the degree of impervious coverage, pavement classes 1-4 are considered 100 % non-built-up impervious.

Areas with pavement class 5 “n/a” are not covered by the road survey data due to geometric deviations between the road survey data and the ISU5 road space. For those areas, the mean degree of impervious coverage of all areas included in the road survey data of the borough in question was used.

Areas with pavement class 6 "track area" are included in the calculation once as 0 % impervious and once as 100 % impervious, in line with the approach for block (segment) areas. These two scenarios allow an optional weighting of “track area” in the impervious coverage calculation, depending on the subject at hand.

All areas with pavement class 7, which were determined based on the ALKIS building data, represent the built-up impervious proportion. These built-up impervious areas are mostly building edges that are part of the road space, due to a scale-related imprecise delineation of the block (segment) areas.

The proportions of the different types of pavement and the total degree of impervious coverage were calculated for each individual road section. For this purpose, the road sections (approx. 32,000 sections) newly and systematically formed as part of the road space classification were used for the first time (LUP GmbH 2022).

See the final report of the impervious soil coverage mapping of 2021 (only in German) for more information.

Map Description

The map presents the **degree of impervious coverage**, i.e. the covering of the earth's surface with impermeable materials, as a **percentage of the reference area** (block (segment) area or road section). Generally, the degree of impervious coverage, especially that of block (segment) areas, decreases from the city centre toward the outskirts, as the building structure becomes less dense, and the areas on the periphery are either completely undeveloped (forest or farmland), or characterised by single-family homes. Exceptions to this are traditional borough centres, such as those of Spandau and Köpenick, which were separate cities prior to 1920. Their degree of impervious coverage is about 60 % in general, and higher than 90 % in their core areas. Extensive areas occupied by large estates on the outskirts, such as Marzahn, Hellersdorf and Hohenschönhausen, or Gropiusstadt in Neukölln and the *Thermometersiedlung* (“Thermometer Estate”) in Lichterfelde, are between 50 % and more than 80 % impervious. Commercial areas on the outskirts of the city, such as at Goerzallee in Steglitz or at Landsberger Straße in Mahlsdorf, also stand out due to a high degree of impervious coverage of more than 70 %. Table 4 presents the average degrees of impervious coverage of 2021 by area type in the following.

The area types "Dense block development, closed rear courtyard, 5-6 storeys" with 85.4 %, "Core area" with 85.7 % and "Commercial and industrial area, large-scale retail, dense development" display **the highest overall degrees of impervious coverage** at 88.4 %. **The lowest degrees of impervious coverage**, at below 1 % each, are listed for the area types "Forest", "Agriculture" and "Fallow area". A sharp increase in the degree of impervious coverage can be observed for the area type "Rental-flat buildings of the 1990s and later". In recent years, new building projects were completed in many of these blocks (e.g. in *Europacity*, north of the *Hauptbahnhof* (Berlin Central Station) or the *Rummelsburger Bucht* (bay along river Spree)).

Tab. 4: Mean degrees of impervious coverage, 2021

				2021					
	Area type 2020	**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 [%]**
1	Dense block development, closed rear courtyard, 5-6 storeys	196	278	237	85,4	174	62,7	63	22,8
2	Closed block development, rear courtyard, 5-storeys	997	1.655	1.287	77,8	878	53,0	410	24,8
3	Closed and semi-open block development, decorative and garden courtyard, 4-storeys	433	648	425	65,6	270	41,7	155	23,9
6	Mixed development, semi-open and open shed courtyard, 2-4-storeys	103	196	122	62,2	68	34,6	54	27,5
7	De-cored block-edge development, post-war gap closure	484	841	558	66,3	350	41,6	208	24,8
8	Heterogeneous inner-city mixed development, post-war gap closure	113	278	185	66,4	110	39,4	75	27,0
9	Large estate with tower high-rise buildings, 4-11-storeys and more	724	2.390	1.076	45,0	515	21,5	561	23,5
10	Block-edge development with large quadrangles, 2-5 storeys	589	850	467	54,9	299	35,2	168	19,8
11	Row development with landscaped residential greenery, 2-6-storeys	866	2.468	1.027	41,6	540	21,9	487	19,7
12	Old school (built before 1945)	193	320	176	54,9	86	26,8	90	28,1
13	New school (built after 1945)	422	969	497	51,3	219	22,6	278	28,7
16	Sport facility, uncovered	428	1.612	551	34,2	97	6,0	453	28,1
17	Sport facility, covered	90	200	90	45,1	46	22,9	44	22,2
21	Village-like mixed development	114	394	150	38,2	94	23,9	56	14,2
22	Row houses and duplexes with yards	1.088	1.807	674	37,3	462	25,6	211	11,7
23	Detached single-family homes with yards	4.769	9.689	3.384	34,9	2.341	24,2	1.043	10,8
24	Villas and town villas with park-like gardens	703	1.526	547	35,9	374	24,5	173	11,3
25	Densification in single-family home area, mixed development with yard and semi-private greening	356	944	377	39,9	253	26,8	124	13,1
27	Cemetery	189	1.121	82	7,3	15	1,3	67	6,0
29	Core area	261	407	349	85,7	233	57,1	116	28,6
30	Commercial and industrial area, large-scale retail, sparse development	1.045	4.349	2.908	66,9	1.188	27,3	1.721	39,6
31	Commercial and industrial area, large-scale retail, dense development	222	939	830	88,4	473	50,4	357	38,0
32	Utility area	171	751	378	50,3	121	16,2	257	34,1
33	Non-residential mixed use area, sparse development	207	472	287	60,7	141	29,9	146	30,9
36	Tree nursery / horticulture	41	221	37	16,5	12	5,2	25	11,3
37	Allotment garden	727	3.108	828	26,6	339	10,9	489	15,7
38	Non-residential mixed use area, dense development	60	136	110	81,2	61	44,7	50	36,5
41	Security and order	101	582	227	39,0	92	15,8	135	23,2
43	Administrative	145	322	202	62,8	109	33,8	93	28,9
44	University and research	115	487	227	46,6	115	23,7	112	22,9
45	Culture	112	295	139	47,0	63	21,3	76	25,8
46	Hospital	74	565	227	40,2	121	21,5	106	18,7
47	Children's day care centre	174	205	68	32,9	29	14,0	39	18,9
49	Church	121	103	39	37,8	18	17,1	21	20,6
51	Other youth facility	76	172	34	19,9	15	8,9	19	11,0
53	Park / green space	1.319	3.417	345	10,1	22	0,7	323	9,4
54	City square / promenade	107	60	28	46,5	2	2,8	26	43,7
55	Forest	3.008	16.985	45	0,3	12	0,1	33	0,2
56	Agriculture	590	3.550	4	0,1	1	0,0	3	0,1
57	Fallow area	806	2.408	16	0,7	5	0,2	11	0,4
58	Camping ground	17	50	7	14,2	1	2,1	6	12,1
59	Weekend cottage and allotment-garden-type area	270	851	270	31,8	136	16,0	134	15,8
60	Other and miscellaneous public facility / special use area	285	885	353	39,9	148	16,7	205	23,1
72	Parallel row buildings with architectural green strips, 2-5 storey	286	635	280	44,1	166	26,2	114	17,9
73	Rental-flat buildings of the 1990s and later	743	1.166	749	64,3	390	33,4	359	30,8
91	Parking area	192	188	94	50,2	8	4,4	86	45,9
92	Railway station and railway ground, without track area	236	364	160	44,1	59	16,1	102	28,0
93	Airport	60	444	140	31,5	17	3,9	123	27,6
94	Other traffic area	571	207	52	25,1	3	1,2	49	23,9
98	Construction site	61	97	30	30,8	2	2,0	28	28,8
99	Track area	589	1.365	588	43,1	13	1,0	575	42,1
	Total excl. bodies of water and roads	**25.649**	**73.972**	**21.961**	**29,7**	**11.305**	**15,3**	**10.656**	**14,4**
100	Body of water	729	5.415						
	Total incl. bodies of water but excl. roads	**26.378**	**79.387**	**21.961**	**27,7**	**11.305**	**14,2**	**10.656**	**13,4**
	Roads		9.721	8.285	85,2	41	0,4	8.244	84,8
	Total excl. bodies of water but incl. roads	**25.649**	**83.694**	**30.246**	**36,1**	**11.347**	**13,6**	**18.899**	**22,6**
	Berlin total incl. bodies of water and roads	**26.378**	**89.108**	**30.246**	**33,9**	**11.347**	**12,7**	**18.899**	**21,2**

Track gravel is considered 100 % impervious both in the calculations and the map.
Discrepancies may occur due to rounding.
As of: June 14, 2022

Tab. 4: Mean degrees of impervious coverage by area type, 2021

For a better overview, the degrees of impervious coverage are also summarised for each **land-use type** (ISU land use categories) (cf. Table 5). Residential areas display an average degree of impervious coverage of 43.4 %. Core areas have the highest mean degree of impervious coverage, with 85.7 %, while “Forest” and "Farmland" indicate the lowest degree of impervious coverage.

Tab 5: Mean degrees of impervious coverage by land-use type, 2021										
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	11.760	24.062	10.452	43,4	6.601	27,4	3.851	16,0
21	Mixed-use area	1.071	2.310	1.490	64,5	885	38,3	605	26,2
30	Core area	261	407	349	85,7	233	57,1	116	28,6
40	Commercial and industrial area	1.267	5.288	3.738	70,7	1.661	31,4	2.077	39,3
50	Public service and other special uses	1.835	4.955	2.195	44,3	1.016	20,5	1.179	23,8
60	Utility area	171	751	378	50,3	121	16,2	257	34,1
70	Weekend cottage area	270	851	270	31,8	136	16,0	134	15,8
80	Traffic area	1.648	2.568	1.034	40,3	100	3,9	935	36,4
90	Construction site	61	97	30	30,8	2	2,0	28	28,8
100	Forest	2.742	15.634	8	0,1	6	0,0	2	0,0
121	Meadows and pastures	368	1.517	1	0,1	1	0,1	0	0,0
122	Farmland	222	2.033	3	0,1	1	0,0	2	0,1
130	Park / green space	1.729	5.246	382	7,3	28	0,5	354	6,7
140	City square / promenade	107	60	28	46,5	2	2,8	26	43,7
150	Cemetery	189	1.121	82	7,3	15	1,3	67	6,0
160	Allotment garden	727	3.108	828	26,6	339	10,9	489	15,7
171 bis 173	Fallow Area	662	1.930	15	0,8	5	0,2	10	0,5
190		518	1.812	641	35,4	143	7,9	498	27,5
200	Tree nursery / horticulture	41	221	37	16,5	12	5,2	25	11,3
	Total excl. bodies of water and roads	**25.649**	**73.972**	**21.961**	**29,7**	**11.305**	**15,3**	**10.656**	**14,4**
110	Body of water	729	5.415						
	Total incl. bodies of water but excl. roads	**26.378**	**79.387**	**21.961**	**27,7**	**11.305**	**14,2**	**10.656**	**13,4**
	Roads		9.721	8.285	85,2	41	0,4	8.244	84,8
	Total excl. bodies of water but incl. roads	**25.649**	**83.694**	**30.246**	**36,1**	**11.347**	**13,6**	**18.899**	**22,6**
	Berlin total incl. bodies of water and roads	**26.378**	**89.108**	**30.246**	**33,9**	**11.347**	**12,7**	**18.899**	**21,2**

Discrepancies may occur due to rounding.
As of: June 14, 2022

Tab. 5: Mean degrees of impervious coverage by land-use type, 2021

On average, 29.7% of Berlin’s block (segment) areas (excl. roads and bodies of water) are impervious. Of these, 15.3 % are built-up impervious areas, and 14.4 % are non-built-up impervious areas. **Including bodies of water and road land** in the calculation, **33.9 % of Berlin is impervious.** Of these areas, 12.7 % are built-up and impervious, while 12.0 % are non-built-up and impervious. Berlin’s urban area contains 9.3 % of impervious road space. This means that one third of Berlin’s total area is impervious. About one third of this total impervious area consists of buildings, one third of roads and one third of non-built-up impervious areas.

Impervious Coverage in the Boroughs

The borough with the lowest degree of impervious coverage is Treptow-Köpenick, with 22.4 %, while Friedrichshain-Kreuzberg and Mitte have the highest degrees, with 68.1% and 63.6 %, respectively. These two boroughs also have the highest shares of built-up areas, as a proportion of their total areas.

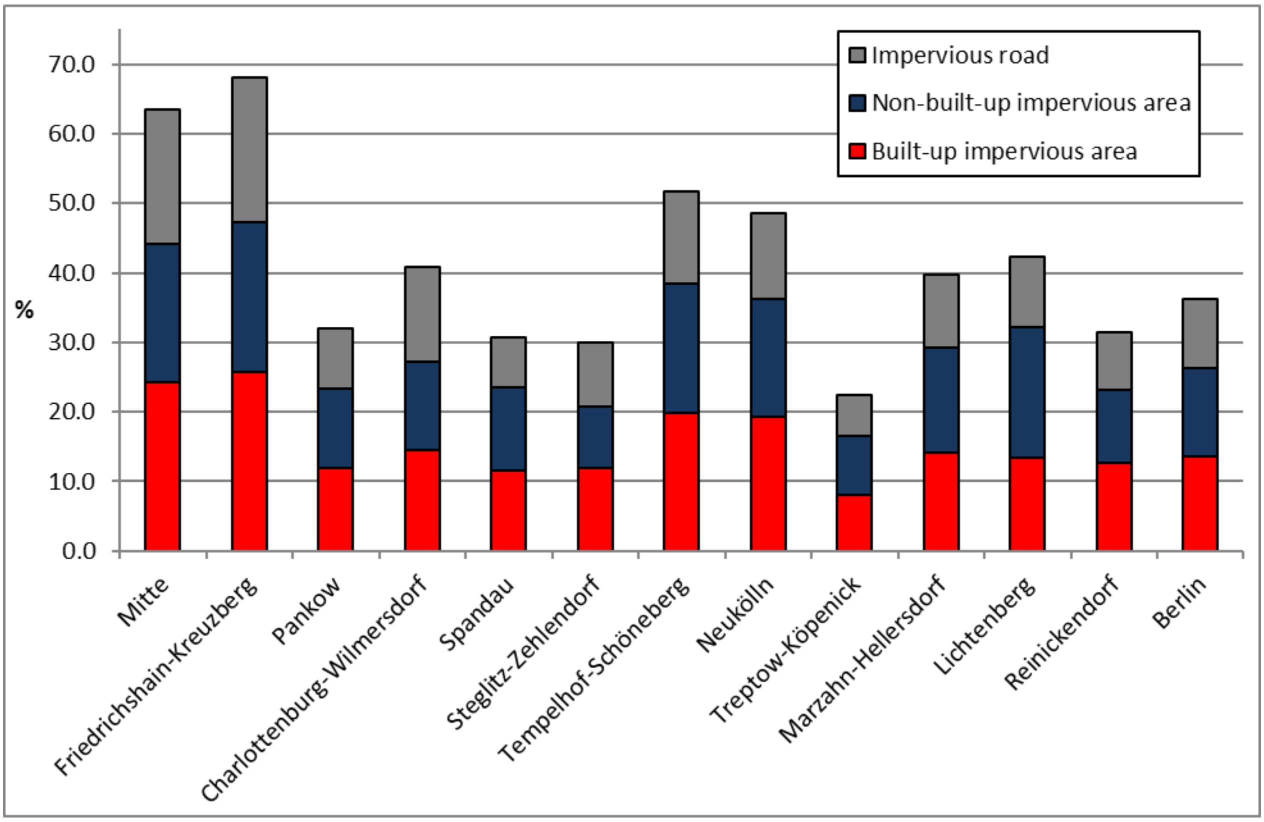


Fig. 4: Degree of impervious coverage of Berlin's 12 boroughs and in total (in % of the total area excl. bodies of water), 2021

The highly impervious road surfaces of pavement classes 1 and 2 (e.g. asphalt, concrete, plates and large-sized paving stones) occupy about two thirds (6,417 ha) of the total road space. Pavement types of groups 3 and 4 (e.g. small-stone and mosaic paving or grass trellis stones) that are slightly less impervious may only be found on about 11 % (1,110 ha) of the road space. Pervious road space, including traffic islands, green verges or pervious roads, allotment or forest paths, is represented by a percentage of 13.5 % (1,311 ha).

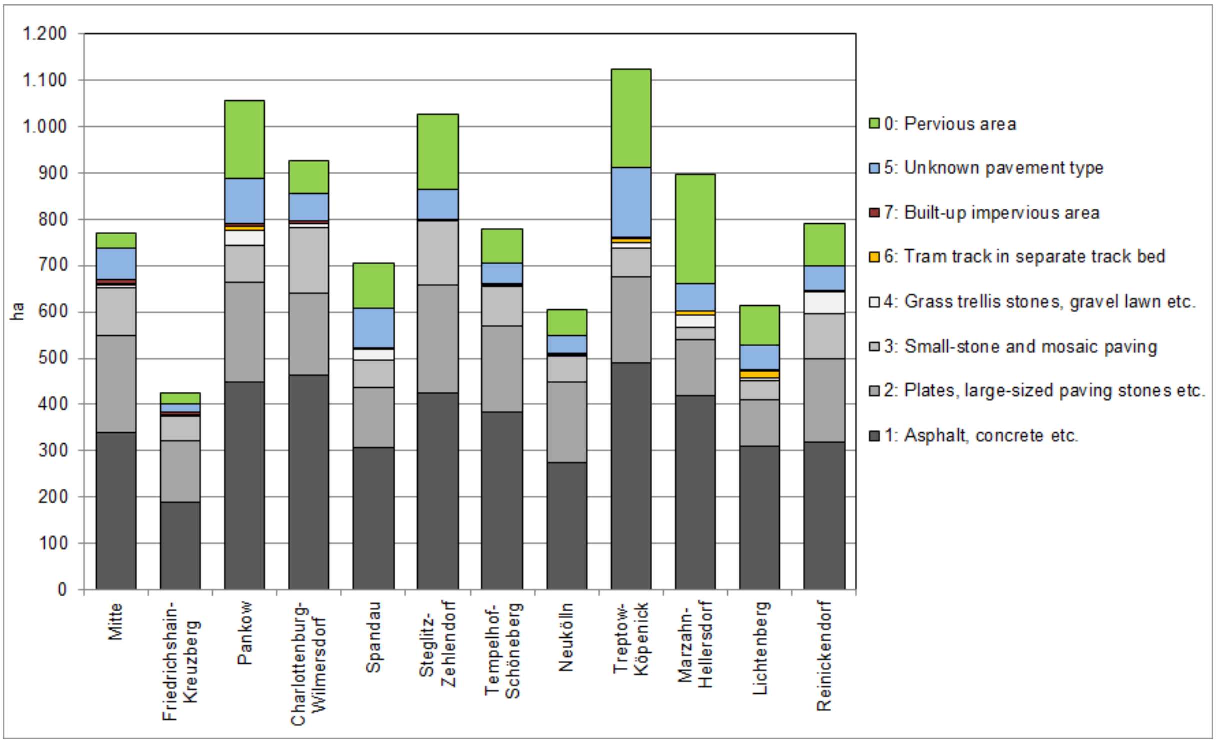


Fig. 5: Absolute area sizes of the road space pavement classes of Berlin's 12 boroughs

The road space in the inner city boroughs of “Mitte“, “Friedrichshain-Kreuzberg“ and “Charlottenburg-Wilmersdorf“ is particularly impervious. Pavement classes 1-4 (in shades of grey) occupy more than 85 % of the area.

With more than 10 %, the pervious green share of the road space is much greater in the outer boroughs of the city than in the inner-city areas. The borough of "Marzahn-Hellersdorf" stands out in particular here with a pervious share of more than 25 %. Wider roads, which are often accompanied by roadside greenery, and a larger number of pervious roads and footpaths as well as garden paths in the allotment gardens, concentrated on the outskirts of the city, may explain the large shares of pervious areas in the outer boroughs, if they are located outside the block (segment) area. The imperviousness of block (segment) areas is determined based on the method mentioned above.

Data on Impervious Soil Coverage of 2021 Compared with that of 1990, 2001, 2005, 2011 and 2016

Due to **different survey methods**, comparing the impervious coverage figures of the years 1990 and 2001 directly with those of 2005, 2011, 2016 and 2016 has its limitations. These figures are unsuitable for determining changes in the impervious area over the entire period of time (cf. Tab. 6).

In 2001, the degree of impervious coverage in amounted to 34.7 % in Berlin, including roads and bodies of water. This data is partially based on evaluations of satellite images as well as on other sources from the 1980s that only applied to West Berlin. In 1990, this mapping was extended to the area of East Berlin with the help of aerial photographs and topographic maps and partially updated in 2001. This also involved the use of flat-rate values for specific land uses. Overall, the survey method was inconsistent.

With the mappings of 2005, 2011, 2016 and 2021, data sets are now available that have been obtained using a uniform, automated and much improved procedure covering the entire area. Rather than presenting the impervious coverage numbers as they were determined at the time for each of those years, Table 6 presents **adjusted figures** for the first time. These were assigned retrospectively with reference to the improved data bases.

In 2021, Berlin’s degree of impervious coverage is **33.9 %** (30,246 ha). In absolute terms, it has therefore only increased by 54 ha compared to the figure published in 2016. This slight increase does not reflect the true development, however, and must be corrected in two respects.

On the one hand, a decrease in impervious road space was detected that does not actually exist, based on an improved data basis. On the other hand, the calculated increase in built-up impervious areas since 2016 also requires a correction, as only about half of these areas, i.e. around 230 ha, may be attributed to actual new construction. With these constraints, around 550 ha of area (approx. 230 ha are built-up and approx. 330 ha are non-built-up impervious) must be added to the total impervious area of the block (segment) areas. This means that, in total, the **impervious soil coverage actually increased by 0.5 % (approx.) between 2016 and 2021**.

In-depth information on the developments is presented in the following:

Above all, the number of **built-up impervious areas** has increased steadily since 2005. This development is mainly the result of construction activity. However, some of the built-up impervious areas that have been recorded since 2011 were also included because of the improved building stock data. Overall, this has resulted in a **more accurate delineation of shares** of built-up and non-built-up impervious areas.

Tab. 6: Results of impervious coverage mappings in Berlin from 1990 to 2021
(all information refers to the total area of Berlin incl. roads and bodies of water)

Year	Number of blocks	Total area evaluated [ha]	Impervious area [ha]	Degree of imp. cov. [%]	Built-up impervious area [ha]	Built-up impervious area [%]	Non-built-up impervious area [ha]	Non-built-up impervious area [%]	Road, impervious area [ha]	Road, impervious area [%]
1990	23.202	88.358	31.173	35,3	9.680	11,0	13.283	15,0	8.210	9,3
2001	24.505	89.317	31.021	34,7	9.629	10,8	13.058	14,6	8.334	9,3
2005	24.669	89.090	28.408	31,9	9.423	10,6	10.526	11,8	8.459	9,5
2011[1)]	24.961	89.095	28.892	32,4	10.174	11,4	10.432	11,7	8.286	9,3
2016[2)]	25.352	89.108	29.737	33,4	11.120	12,5	10.330	11,6	8.287	9,3
2021	26.378	89.108	30.246	33,9	11.347	12,7	10.656	12,0	8.285	9,3

Discrepancies may occur due to rounding.
The figures from 1990 and 2001 are based on different evaluation methods, which do not allow a comparison with the figures from 2005, 2011, 2016 and 2021.
1) adjusted figures, more accurate delineation between built-up and non-built-up impervious areas based on improved data from 2016, adjusted impervious coverage based on improved data from 2021.
2) 1) adjusted figures, more accurate delineation between built-up and non-built-up impervious areas, adjusted impervious coverage based on improved data from 2021.
As of: October 4, 2022

Tab. 6: Results of impervious coverage mappings in Berlin from 1990 to 2021 (all information refers to the total area of Berlin, incl. roads and bodies of water).

For the **non-built-up impervious area**, the picture is somewhat different. The apparent decrease by 2.8 % between 2001 and 2005 may be due to the fact that flat-rate values were assigned to the non-built-up impervious shares of some green and open-space categories (e.g. Forest and Agriculture) on the old maps for. These values have been recognised as having been set too high since then. These areas constitute a large share of the urban area. The degree of impervious coverage was hence **overestimated for the non-built-up impervious areas in general**. On the other hand, due to the interpretation of the satellite data, **the new method rather underestimated** the non-built-up impervious area**.** This makes more sense than there having been an actual reduction in impervious areas in the urban area. Since 2016, the proportion of non-built-up impervious area has increased slightly, which may be attributed particularly to a higher degree of impervious coverage in commercial and mixed-use areas.

Regarding the recording of the **impervious road area**, the rough estimates available in 1990 could only be replaced by figures provided by the then road construction administration in 1997. These were also used for analysis in 2001. For the impervious coverage mappings of 2005 and 2011, the degrees of impervious coverage determined for roads by borough were applied to the entire city based on 2006 data (Gerstenberg & Goedecke 2013). It certainly seems plausible that underground construction projects may have contributed to the slight increase in the degree of impervious coverage, primarily in East Berlin. As part of the **2021** impervious coverage mapping, the **highly accurate area-specific road survey data** was used for the first time. This was done to record the impervious coverage of road pavement types differentiated by referencing the attribute of the recorded material. This methodological change explains why the degree of impervious coverage has decreased for the road space, which did not, in fact, actually decrease. The new mapping method, no longer based on the mean degree of impervious coverage provided by road statistics, reflects a much more nuanced picture of reality. In Table 6, the degrees of impervious coverage determined in 2021 were therefore retrospectively adopted for 2011 and 2016.

Change Mapping of Impervious Coverage between 2016 and 2021

The fact that the same procedure was used in 2021 also permits a comparison with the impervious coverage at block (segment) level. Figure 6 **maps the changes** between 2016 and 2021 (the resulting map is also available in PDF format). The map highlights block (segment) areas that saw a change in impervious coverage of more than 10 % during this period. The overall balancing of all areas as well as all evaluations, however, also take into account changes below 10 % (cf. Tables 4, 5, 6).

In the following, some notable examples are described that serve to highlight case-specific reasons of why the degree of impervious coverage of some areas was mapped differently between 2016 and 2021.

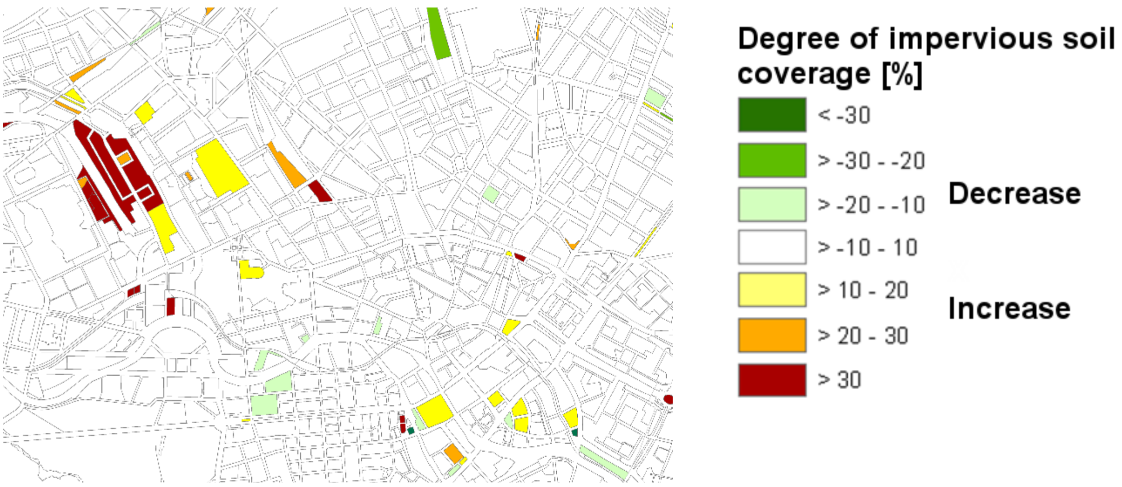
A change in the degree of impervious coverage of 10 - 20 % was recorded in 345 block (segment) areas. In many cases, this is due to the retrospective densification of existing buildings or the completion of large-scale construction projects that were already partially completed in 2016. The area types “Row houses and duplexes with yards” (22), “Detached single-family homes with yards” (23), “Commercial and industrial area, large-scale retail, sparse development” (30) and “Rental-flat buildings of the 1990s and later” (73) are frequently affected. Furthermore, it is apparent that about 50 areas of the type “Park / green space” (53) show an increase in the degree of impervious coverage of 10 - 20 %. Either, more impervious areas, e.g. playgrounds, were added to such green spaces (e.g. in the *Kierzpark Schönagelstraße* (park) in Marzahn or at Alarichplatz in Tempelhof). Or, based on less vital vegetation, the NDVI had changed to such an extent that it had an impact on the impervious coverage classes (e.g. *Park an der Spree* or at Lützowplatz).

A change in the degree of impervious coverage of more than 30 % usually indicates that a block (segment) area has either been redeveloped significantly or in its entirety. Notable large new construction projects include the aforementioned *Europacity* north of the *Hauptbahnhof* (Berlin Central Station), new commercial and residential developments in Mahlsdorf and Adlershof, the *Gartenstadt Karlshorst*, new rental-flat buildings at *Spandauer Seebrücke* or the *Tesla Center*. Newly constructed temporary buildings, such as the shared housing on Wollenberger Straße (borough of Lichtenberg), also exhibit an increased degree of impervious coverage, although these buildings are not listed in the building stock. Their non-built up impervious proportion has therefore increased.

A strong decrease in the degree of imperviousness of more than 30 % is usually also caused by construction activity, as the affected areas are temporarily completely uncovered and therefore pervious after demolition (e.g. *An der alten Gärtnerei* in Britz or Blockdammweg). If there is evidence of initial construction already on the aerial photograph, the non-built-up impervious area increases, as the new buildings are not yet listed in the building data base.

The following block (segment) areas are not included in the map due to limitations in comparability. The information may, however, be extracted from the factual data (564 areas):

- Pseudo change, non-block area share >10 %: the ISU block geometry of 36 areas changed drastically between 2015 and 2020, i.e. in 2015, more than 10 % of the 2020 area was still mapped as road space, leading to pseudo changes in the impervious mapping.
- Pseudo change, improved data base, buildings: the improved data base for the building stock (NOT-ALKIS) has not led to actual but to pseudo changes for 24 block (segment) areas. This mainly affects allotment garden facilities and areas characterised by single-family homes.
- Pseudo change, track: the improved data base for railway tracks (K5) as well as differences in the characteristics of the narrow track geometries between the grid analysis of 2016 and 2021 have led to pseudo changes in 234 block (segment) areas.
- Pseudo change, phenology: the satellite image scenes used for the impervious coverage mappings of 2016 and 2021 were not recorded on the same day, i.e. the vegetation was not at the same stage of development. For 2021, a scene recorded on June 7 was used in which the vegetation is more advanced in some places than in the scene from May 2, 2016. Since the degree of impervious coverage is derived from the NDVI for the non-built-up impervious areas of some area types, more developed vegetation is accompanied by a decreased degree of impervious coverage. This does not represent an actual use change and led to pseudo changes in 101 areas.
- Pseudo change, corrections of the 2016 analysis: mapping errors were detected in 28 areas of the 2016 analysis, which were corrected in the current mapping and led to pseudo changes for the areas in question.
- Pseudo change, 2015 land-use correction: for 106 areas, the use attributes were corrected without an actual change in use having taken place since 2015. A change in green-space use or area type then changed how the degree of imperviousness was assigned during the mapping process. For fallow areas, for example, all areas with a degree of vegetation of more than 5 % received a degree of impervious coverage of 0 % by default. For park areas, on the other hand, the degree of impervious coverage is assigned gradually, based on the degree of vegetation and how developed it is (cf. final report, NDVI categories, only in German).
- Pseudo changes, incorrect building data base of 2021: in 35 cases, there were pseudo changes due to the 2021 building data base containing errors, which was particularly the case for block (segment) areas with railway use. A reason for this is the fact that the ALKIS building dataset does not include all railway station buildings and that the NOT-ALKIS buildings are not applied for areas with railway use.



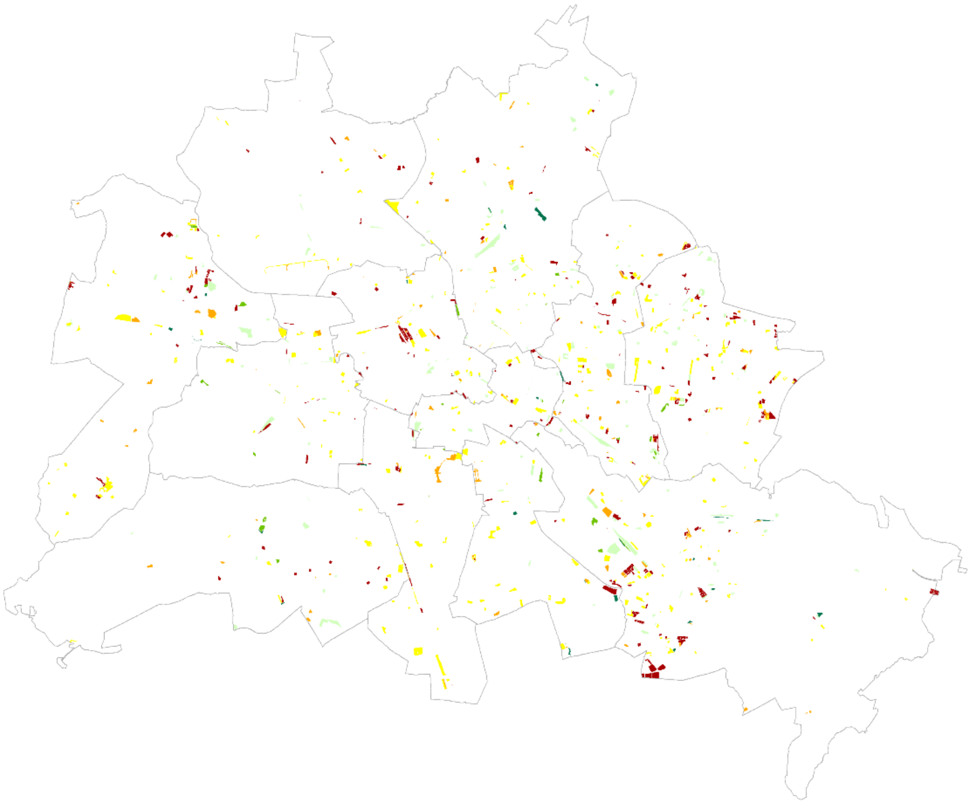


Fig. 6: Map of changes of impervious coverage between 2016 und 2021, top left section: area around the Hauptbahnhof (Central Station) with Europacity (the result is also available in PDF format, only in German)

Excursus

Comparison of the Impervious Coverage Data of 2005, 2011, 2016 and 2021 with the “Impervious Coverage” Indicator of the Environmental Economic Account (EEA) of the German Federal States

In the following, the impervious coverage value of the Environmental Economic Account (EEA) of the German federal states, developed for Berlin by the federal and regional-state soil conservation board (LABO) based on the sustainability indicator “land consumption for residential and traffic areas”, is compared with the results of the Environmental Atlas.

The data collection of the degrees of impervious coverage by federal state is based on the official land statistics. In this process, flat-rate degrees of impervious coverage are assigned to each land use category of residential and traffic areas, which are adjusted to the residential density of the areas, and then used as a factor in calculation. Therefore, impervious coverage data is created for the whole of Germany every year. The data on the development of impervious coverage in the federal states is updated annually (Statistical Offices of the German States 2021).

According to this, the impervious coverage share of Berlin’s total area rose from 34.24 % to 34.7 % between 2000 and 2019. It thus increased by 0.46 % in 19 years, or by 0.02 % per annum. In 2012, an increased impervious coverage of 35.10 % was recorded, which has been declining slightly since then.

Therefore, the absolute increase in impervious coverage, amounting to approx. 30,912 ha, was 385 ha in nineteen years (Statistical Offices of the German States 2021).

Figure 7 shows the rate of impervious coverage of the Environmental Atlas in 2005, 2011, 2016 and 2021, compared with the annually generated data of the EEA of the German federal states.

Neither approach ascertains impervious coverage with 100% accuracy; both work with different methods and different goals, and, to a certain extent, with estimates and assumptions.

While the EEA approach indicates that the overall impervious coverage of Berlin was 34.7 % in 2019, only 33.9 % of the city were mapped as impervious in the Environmental Atlas in 2021.

For the Environmental Atlas, the built-up impervious area was derived directly from a number of different building stock data sets (in 2005 and 2010 exclusively from ALK, in 2016 and 2021 from ALKIS and NOT-ALKIS building data), and hence has a very high degree of accuracy, while the non-built-up impervious area, as described above, is determined using satellite images. Methodological error sources must be considered as a possibility here.

By contrast, the EEA approach operates from the outset with estimates for the individual use classes, which are also the same nationwide and hence disregard any regional particularities. For instance, the removal of the area of Tempelhof Airport from the category of traffic areas would have changed the statistics, without any actual change in the degree of impervious coverage. When looking at the entire period, there is a trend towards the two values converging.

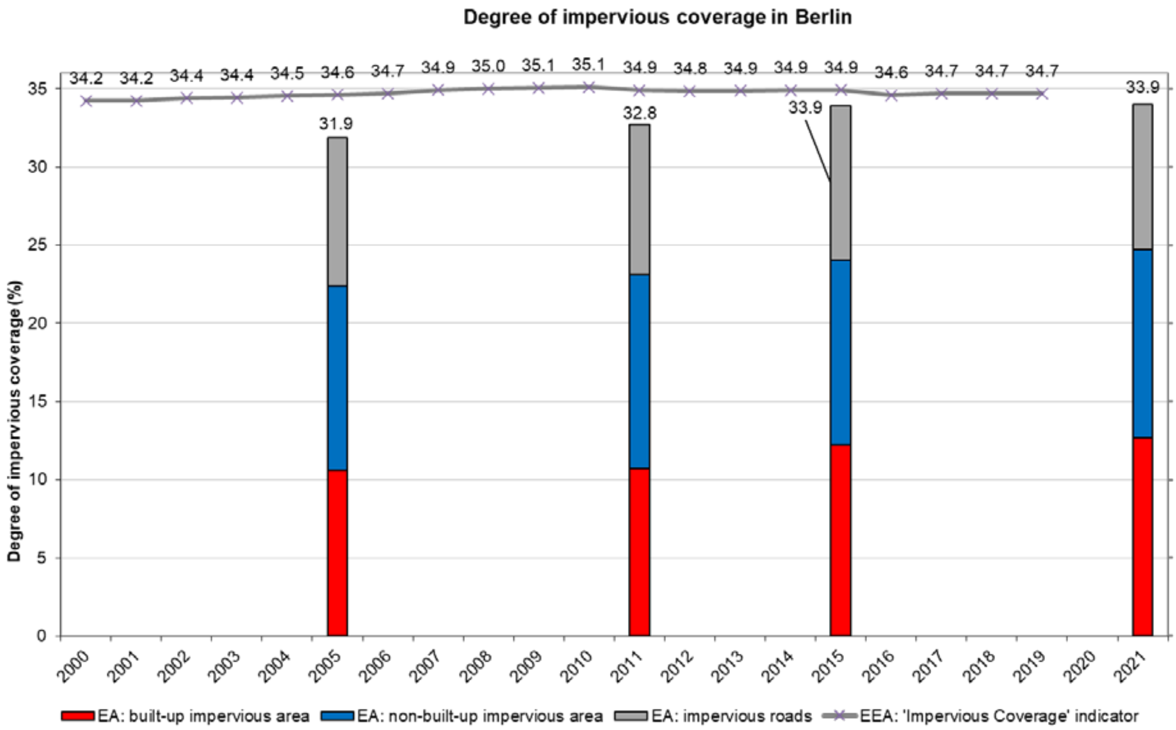


Fig. 7: Degrees of impervious coverage shown in the Environmental Atlas (EA), of 2005, 2011, 2016 and 2021, compared with the annually generated data of the EEA of the German federal states (up until 2019)

Both monitoring systems may be used for political decisions (cf. Amt für Statistik Berlin-Brandenburg (Statistical Office for Berlin-Brandenburg) 2021). The impervious coverage data of the EEA of the German federal states is collected annually using a standard method that is comparable throughout the country. It is thus best suited for comprehensive monitoring which is exactly what it was developed for. By differentiating between built-up impervious areas, non-built-up impervious areas, and impervious road areas, the figures of the Environmental Atlas complement and differentiate the EEA data. For built-up impervious areas, the maps of the Environmental Atlas provide a very high degree of accuracy.

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