01.12 Soil Functions 2020

Introduction

When the Federal Soil Protection Act came into force in 1999 (BBodSchG), soil as an environmental medium was protected by its very own specific law, as was already the case for water, air and nature conservation. This law aims at 'permanently safeguarding or restoring the functions of the soil'. For this purpose, 'precautions must be taken against adverse effects on the soil. In case of measures which impact upon the soil, impairment of its natural functions and its function as an archive of natural and cultural history should be avoided to the extent possible' (BBodSchG Section 1, translated from German). The Federal Soil Protection Act distinguishes the following functions of the soil:

1. Natural functions
   a) as the basis for life and habitat for people, animals, plants and soil organisms,
   b) as a component of the ecosystem, particularly with its water and nutrient cycles, and
   c) as a medium for decomposition, balance and restoration in response to material effects as a result of its filtering, buffering and substance-converting properties, in particular, too, for the protection of the groundwater.
2. Functions as an archive of natural and cultural history, as well as
3. Use functions
   a) as raw-materials storage,
   b) as land for settlement and recreation,
   c) as land for agriculture and forestry, and
   d) as land for other economic and public uses, such as transport, supply and waste disposal.

Human land use may impair or inhibit both the natural and archival functions of the soil. The main focus of sustainable soil protection (only in German) is thus on safeguarding these natural soil functions.

Targeted soil protection measures presuppose knowledge of the efficacy, protection level and sensitivity of soils and their functions. The assessment process of soil functions, i.e. the soils' capacity to fulfil their role in the ecosystem, will identify the soils in Berlin that require primary protection.

The functions addressed in Maps 01.12.1 through 01.12.5 were selected based on Table 1 and the functions listed in the Federal Soil Protection Act:

Soil function as per Section 2 BBodSchG	**Specific soil function** (Environmental Atlas Map number)	**Criteria for the practical implementation in Berlin**
A. Basis for life and habitat		
• for humans:	pollutant load	not assessed in this context due to a lack of comprehensive data
• for animals:	closely correlated with vegetation; no separate assessment	
• plants:	A. habitat for near-natural and rare plant communities (cf. Map 1.12.1) B. yield function for cultivated plants (cf. Map 1.12.2)	degree of naturalness and distinctive extreme sites typical of Berlin water supply and nutrient storage capacity
• soil organisms:	currently not assessable due to a lack of data	

B. Component of the ecosystem:		
• water balance:	water regulation function (cf. Map 1.12.4)	soil water exchange rate
• nutrient balance:	close connection to the habitat for plants (natural soil fertility); already covered there	
• decomposition, balance and restoration function:	buffering and filtering function (cf. Map 1.12.3)	substance-binding capacity and depth to groundwater
C. Function as an archive		
• for natural history	archival function for natural history (cf. Map 1.12.5)	distinctive landscape character and regional rarity
• for cultural history	currently not assessed from a soil science perspective	

Tab. 1: Soil functions as per the Federal Soil Protection Act (BBodSchG) and their assessment in terms of their specific functions for Berlin

Additionally, the cooling capacity (cf. Maps 1.12.7.1 through 1.12.7.4) is evaluated as another function of Berlin soils.

The assessment of the soil performance (Map 1.12.6) is an important criterion in considering preventive soil protection in urban development planning (only in German).

Methodology

The assessment of soil functions relied mainly on soil characteristic values extracted from the Soil Associations Map (cf. Map 01.01) and Grenzius' dissertation from 1987 (cf. Map 01.06). The quality of this initial data significantly impacts the quality and usefulness of the soil function assessment. Criteria (cf. Map 01.11) were derived from this information and other sources, enabling an assessment of soil functions (cf. Fig. 1). The assessment method originated from the development of a soil protection concept (Lahmeyer 2000) and later expanded to cover the entire city (Gerstenberg and Smettan 2001, 2005, 2009). The maps presented here are based on updated data and refined assessment methods (Gerstenberg 2017).

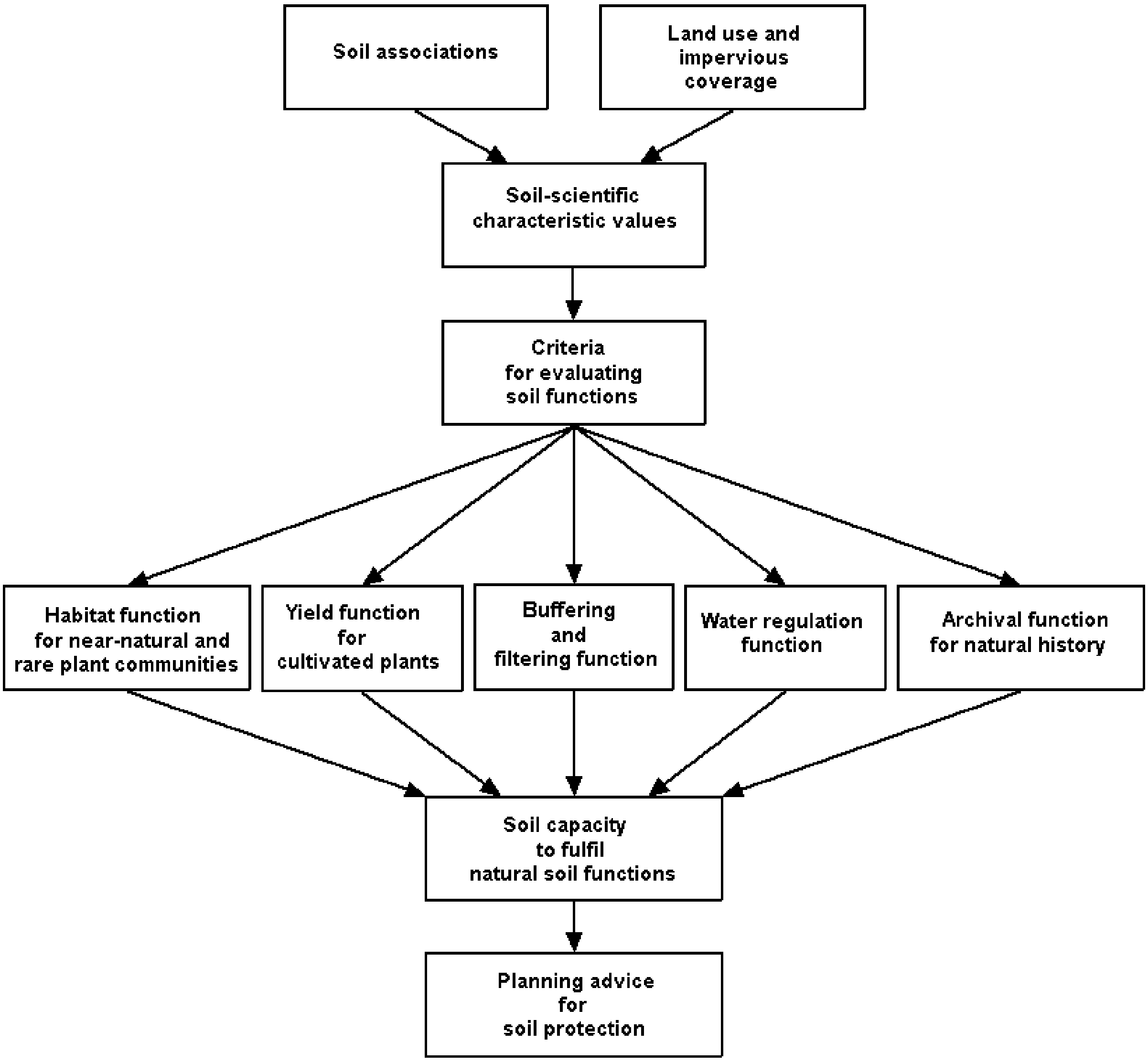

Fig. 1: Diagram for the evaluation of the soil functions

The Map of Soil Associations, scaled at 1 : 50,000, and consequently the maps for assessing soil functions, are general maps suited for state planning. Due to their scale, detailed information cannot be depicted on the map. This includes the intricate differentiation of soil categories, which are often ecologically relevant, and their functional assessments. The map can therefore not provide precise, lot-specific information, necessitating larger-scale mappings for such purposes. The present maps may however be used for an initial assessment.

The soil units depicted in the soil map describe soil associations, indicating how different types of soil are typically grouped together within specific landscape areas, defined by geological, geomorphological, hydrological, and land use characteristics. As a result, the ecological properties that are evaluated for these soils may vary widely within a soil association.

Soil associations are sometimes rated based on the presence of specific soil types, such as, when wet soils are identified as potential high-quality sites for vegetation. However, it is important to note that in some cases, these wet soils may coexist with drier soils or serve a secondary role within a soil association. The map scale does not allow for these ecological differences to be distinguished within a soil association.

Parameters are utilised to assess individual soil functions, which were determined as characteristic values rather than directly measured. This approach is commonly used in soil science and large-scale studies, as it allows for comprehensive assessments over broader areas. Key input variables for determining characteristic values include soil texture, humus content and pH value. These variables are available in sufficient detail in the characteristic values dataset linked to the Soil Associations Map.

The performance of soils for the five soil functions was evaluated using three categories: ‘low’, ‘moderate’, and ‘high’. Differences in evaluation that arise because soil associations often include various soil types with different pedological (soil-scientific) characteristics and functions, were simplified for analysis.

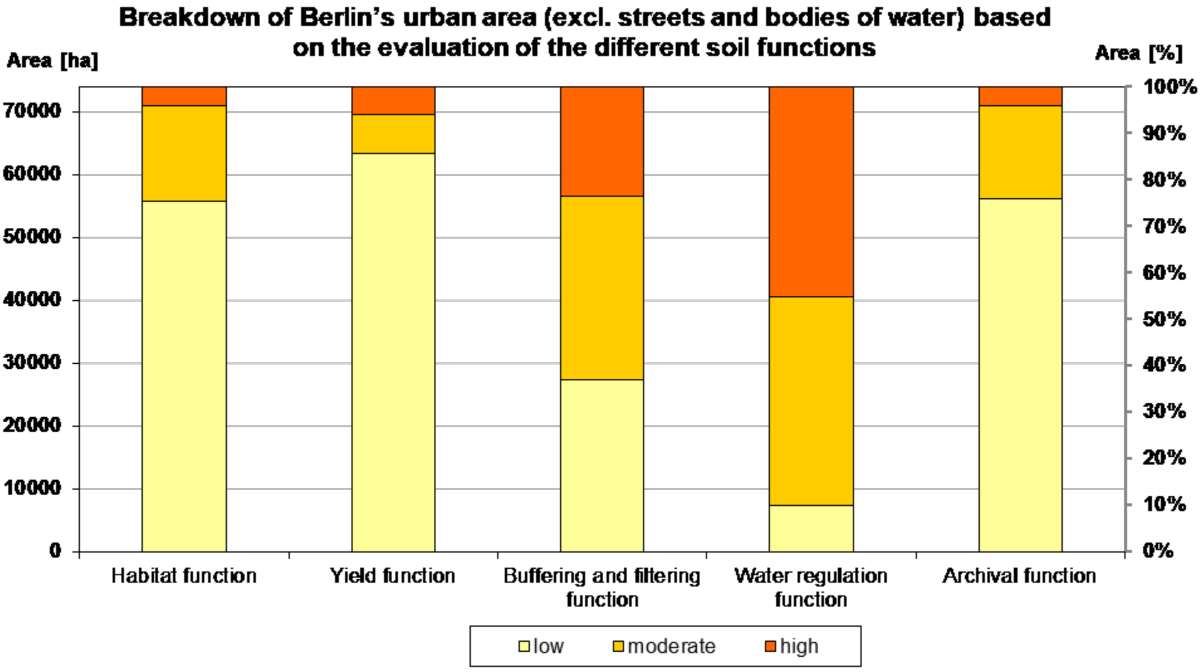

Fig. 2: Breakdown of Berlin’s urban area (excl. streets and bodies of water) based on the evaluation of the different soil functions

In summary, the areas are rated quite differently across the individual soil functions (cf. Fig. 2). These uneven proportions of soils with low, moderate and high capacities are directly linked to the nature of each function:

- With regard to the habitat function for near-natural and rare plant communities, the focus is commonly on protecting endangered biotopes, which are, along with their habitats, inherently rare.
- Natural soil fertility is generally rather low in Berlin.
- The buffering and filtering function is much more pronounced on Berlin’s plateaus. This differentiation and the regional frequency of the plateaus and valley sand areas are reflected in the distribution, with many areas rated as ‘moderate’ and ‘high’. In addition, many near-natural bog sites are included due to their high organic carbon content.
- The water regulation function is evaluated based on the soil water exchange rate, and the site’s resemblance to ‘natural’ drainage conditions, which are characterised by high evaporation and low percolation rates. This is the case in large parts of forest and agricultural areas, resulting in many areas being rated as ‘moderate’ or ‘high’, as these types of land use are rather widespread.
- The archival function protects primarily soil associations that are specific to a region and bestow a distinct or unique character upon the landscape. By definition, this is neither the ‘norm’ nor a common occurrence, so most areas here receive a ‘low’ rating.

These differences in evaluation are intentional because they correspond to the natural conditions of the landscape and reflect the varying importance of the functions.

Map 01.12.6 integrates the five individual maps to create the Capacity of Soils to Fulfil the Natural Soil Functions and the Archival Function Map.

01.12.1 Habitat Function of Soils for Rare and Near-Natural Plant Communities

Description

In general, most soils can naturally support plant growth, serving as potential habitats for diverse plant communities. Soil performance ratings vary based on the evaluation of potential vegetation that could grow on it, with plant species or plant communities categorised as ‘rare’ from a conservation perspective increasing the ratings.

When the soil undergoes changes like excavation, aggradation, and relocation, or experiences lowering groundwater levels and increased nutrient input, it often leads to more uniform site characteristics. This results in the loss of habitat for particularly rare specialist plant species. However, there are some exceptions, such as in the not uncommon case of poor and dry sites, where rare dry grasslands grow. Yet, even in these cases, their existence in the Berlin area is tied to minimal human interference.

The habitat evaluation, which builds upon Lahmeyer’s (2000) concept, classifies soil associations experiencing extreme hydrological conditions or rare soil associations as valuable. Rare and wet sites are identified as ‘special sites’, thus highlighting ecologically significant locations and potential habitats for floodplain associations, wet meadows and bog areas.

Extremely dry, nutrient-poor dunes, as well as anthropogenically created young soils, serve as potential sites for valuable dry grasslands. This type of area, considered a distinctive landscape, receives a ‘moderate’ rating, irrespective of its degree of naturalness.

Overall, the evaluation represents the potential of the soil to sustain specific types of vegetation and does not assess any current vegetation.

Methodology

The habitat function for near-natural and rare plant communities is evaluated using the following criteria: degree of naturalness (cf. Map 01.11.3), regional rarity of the soil association (cf. Map 01.11.1), site moisture (cf. Map 01.01 and 01.06.4) and nutrient supply (cf. Map 01.06.9) (cf. Fig. 1). Based on these criteria, ‘special sites’ can be identified.

Special sites include:

- areas where site moisture is classified as ‘wet’ or ‘moist’,
- areas where the regional rarity of the soil association is rated as ‘very rare to rare’, and
- areas with dry, nutrient-poor soils without construction site use (lowest nFK of the shallow-root zone < 20 mm; KAK_{eff} of the topsoil < 3.5 $cmol_c$/kg).

As shown in Table 1, the evaluation of the habitat function for near-natural and rare plant communities is carried out using three categories (‘low’ (1), ‘moderate’ (2), and ‘high’ (3)), while also considering the degree of naturalness. Rare and wet sites receive considerably higher ratings than dry soils, which are more capable of regeneration and therefore exhibit lower sensitivity. Dry locations are exclusively assigned a moderate potential for development, irrespective of their degree of naturalness. ‘Regular’ soils are only assigned a ‘moderate’ capacity if they are highly natural.

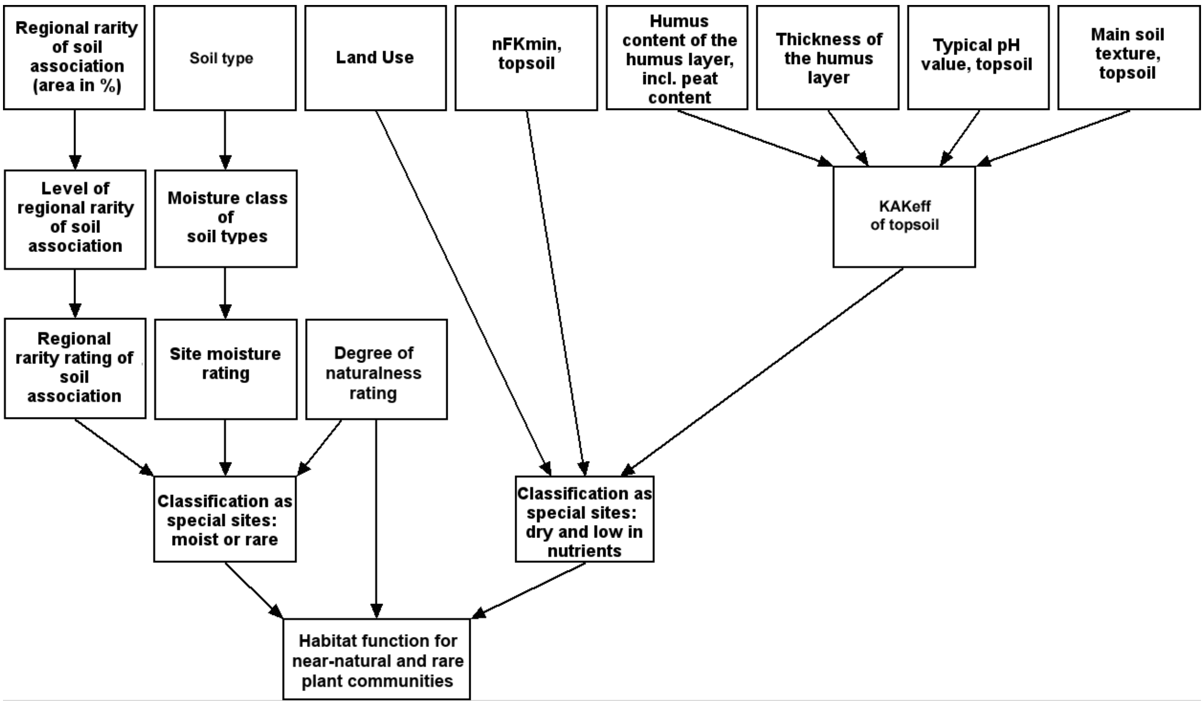

Fig. 1: Diagram for the evaluation of the habitat function for near-natural and rare plant communities

Special site	**Degree of naturalness**			
	high	**moderate**	**low**	**very low**
very rare to rare	high	moderate	low	low
moist	high	moderate	low	low
dry and nutrient-poor (excl. construction site use)	moderate	moderate	moderate	moderate
not a special site	moderate	low	low	low

Tab. 1: Evaluation of soils as habitats for near-natural and rare plant communities, based on their degree of naturalness, categorised by special sites and other sites (Gerstenberg 2017)

Map Description

Areas highly important for the habitat function for near-natural and rare plant communities are mostly found on the outskirts of Berlin. There are only a few areas in this category. These areas have soils characterised by high groundwater levels, such as soil associations featuring low-moor bogs, floodplains and gley soils located in meltwater channels, river lowlands and valley sand areas. Also notable are the lime-mud areas in Teerofen and the podzoluvisols (leached soils) with arenic dystric cambisol (wedged sandpit rusty-brown soil) on the boulder marl plateaus in Frohnau under forest cover. Since highly significant habitats for rare and near-natural plant communities are only found in highly natural areas, they are predominantly located within forests, with only a very few also found in cemeteries (cf. Fig. 2).

Near-natural soils of soil associations containing low-moor bog soils, floodplain soils or gley soils that are located in valley sand areas receive a moderate rating, as do dystric cambisols (rusty-brown soils) on ground, end, and push moraines, and gley soils in meltwater channels. The same applies to luvisols (para-brown soils) with arenic dystric cambisols (wedged sand-pit rusty-brown soils) on the loamy plateaus, and, to the former sewage-farm areas of Gatow, characterised by gleyic luvisols (gleyic para-brown soils) combined with gleyo-arenic dystric cambisols (wedged sand-pit rusty-brown gley soil). Dry sites are, as expected, found predominantly in the anthropogenically formed loose lithosols (raw soil of loose material) of the glacial spillway.

Most areas are of only minor significance as habitats for near-natural and rare plant communities. These are primarily inner city areas with anthropogenic aggradations, such as construction debris.

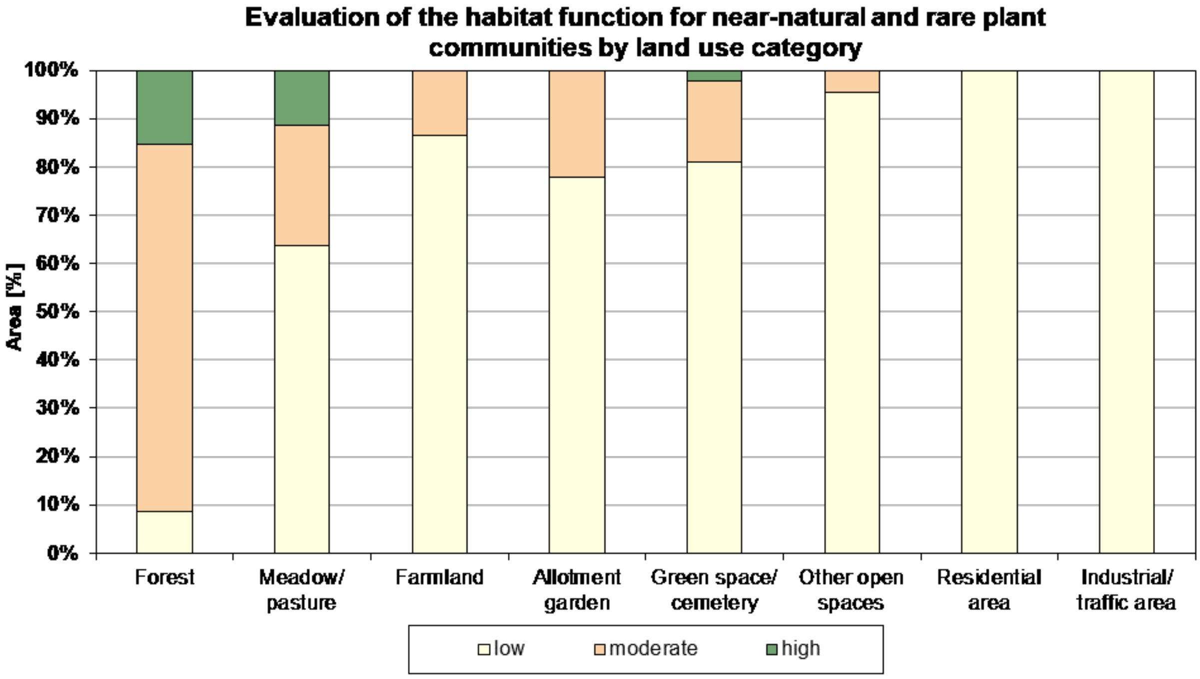

Fig. 2: Evaluation of the habitat function for near-natural and rare plant communities by land use category (incl. impervious sections, excl. streets and bodies of water, not all land uses are shown)

01.12.2 Yield Function of Soils for Cultivated Plants

Description

The yield function and performance of soils for growing cultivated plants reflect their suitability for agricultural and/ or horticultural use and production. The suitability of soils for forest use is not assessed here.

The yield function depends on the unique conditions of the soil at each site. These are mainly influenced by soil properties, especially the local water and nutrient balance. The water supply is determined by how much water the soil can hold and whether plants can access groundwater through capillary action. Loamy sites and/ or those near groundwater therefore have a water supply that is considerably better than that of sandy sites and/ or those remote from groundwater. The availability of nutrients is closely linked to the thickness of the humus layer, the organic matter content and the soil texture. A rich humus layer acts as a vital nutrient source of alkaline nutrients, including calcium, potassium and magnesium as well as nitrogen and phosphorus. Loamy soils contain more minerals than sandy soils and can retain them more effectively. The effective cation exchange capacity (KAK_{eff}) of the soils is analysed to look at this specific aspect, although it only reflects the base cations. In Berlin, root growth is not impeded by compacted soil horizons or solid rock layers. Distinguishing between different relief features was also not necessary since the Berlin area is characterised by largely homogenous terrain.

Methodology

A site's suitability as a habitat for cultivated plants is derived from the sum of the water supply and nutrient supply ratings available for the site (cf. Map 01.11.7 and Map 01.11.8). Each location is then rated 'low', 'moderate', or 'high', on a scale of 1 – 3, as illustrated in Table 1.

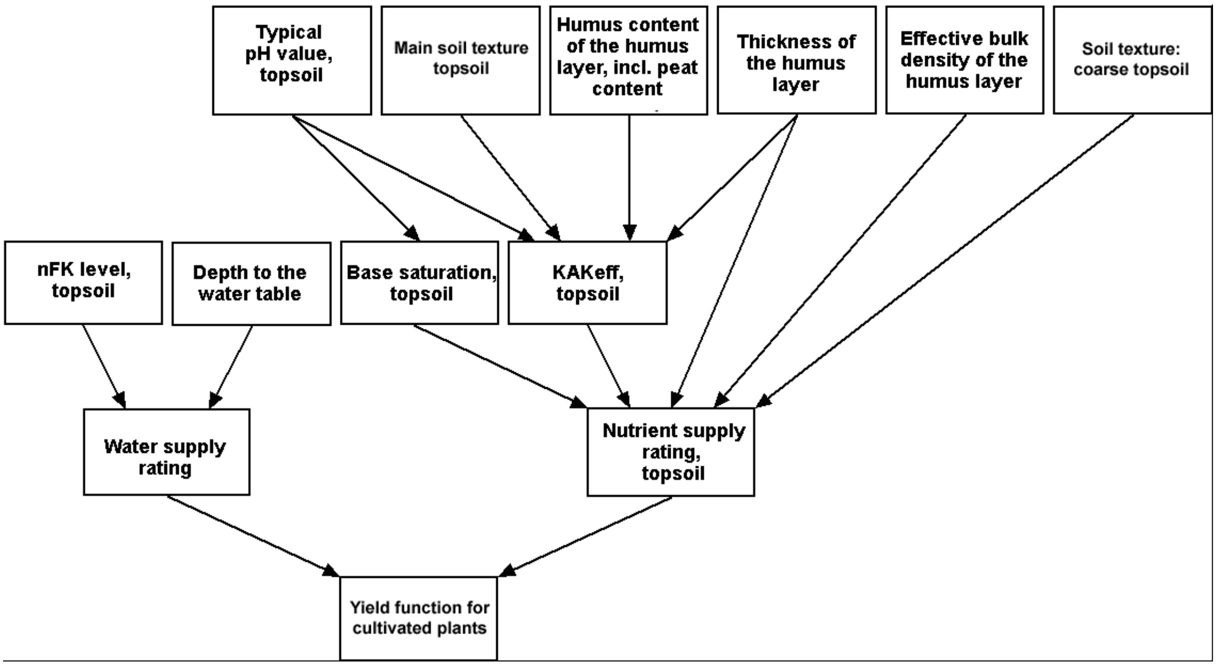

Fig. 1: Diagram for the evaluation of the yield function for cultivated plants

Sum of ratings for water supply and nutrient supply criteria	Yield function for cultivated plants	
	Rating	Designation
2	1	low
3		
4	2	moderate
5	3	high
6		

Tab. 1: Evaluation of the yield function for cultivated plants, based on the sum of ratings for water supply and nutrient supply (Gerstenberg 2017)

Map Description

The yield function of Berlin soils only reaches a ‘high’ rating in a few cases. These are primarily sites near groundwater with gleyic low-moor bog associations, featuring a high content of organic matter and a good water and nutrient supply. In addition, there are lime-mud soils and, on the plateaus, luvisol (para-brown soil) and arenic cambisols (wedged sandpit brown soil) that developed from boulder marl with embedded sands, provided that they have a high organic matter content. Since the humus levels vary depending on land use, the yield function for cultivated plants is also greatly influenced by it (cf. Fig. 2). There are no larger contiguous areas with uniform ratings.

Fig. 2: Evaluation of the yield function for cultivated plants by land use category (incl. impervious areas, excl. streets and bodies of water, not all uses are shown)

Moderate ratings are assigned to small nutrient-rich fluvi-eutric histosols (river floodplain low-moor bog soils) in meltwater channels and some calcareous and nutrient-rich soil associations characterised by gley soils on valley-sand areas. On the boulder marl plateaus under near-natural land uses, this rating primarily applies to luvisols (para-brown soils) and podzoluvisols (leached soils), coupled with arenic cambisols (wedged sandpit brown soil), dystric cambisols (rusty-brown soils), and cambisols (brown soils).

The prevalence of areas with a low yield function can be attributed largely to a lack of nutrients and inadequate water supply in sandy soils, as well as limited water availability in loamy plateau soils distant from groundwater sources. For example, areas designated for forestry use are often characterised by sandy, nutrient-poor sites predominantly clustered on the outskirts of the city.

Soil associations in the city centre are usually characterised by soils aggraded by humans, resulting in a low yield potential.

01.12.3 Buffering and Filtering Function of Soils

Description

The buffering and filtering functions of the soil describe its ability to slow substances in the ecosystematic material flow (buffering function), or permanently remove them from this cycle (filtering function). This ability relies on soil’s capacity to capture or neutralise substances through physicochemical adsorption and reactions, and biological processes.

An essential aspect here is the soil’s capability to capture pollutants as they move through the soil into the groundwater. The evaluation is based on factors such as soil water permeability, heavy metal binding strength, nutrients and pollutants, and filtering distance to adjoining groundwater. Buffering counteracts soil acidification through the reaction of alkaline cations, while filtering mechanically removes solid substances from percolated water. These dissolved substances are primarily bound by humus and clay through sorption. This ability depends on soil’s physical, chemical and biological properties. Soil’s filtering and buffering capacities vary for different substances and substance groups, such as plant nutrients, organic compounds, acidifiers or heavy metals.

Soils with a high filtering and buffering capacity can accumulate large volumes of pollutants. These do not decompose but remain in the soil until its capacity is exhausted, at which point they are released into the groundwater. Pollutants continually entering the soil poses risks, such as the development of ‘pollutant sinks’. This may lead to soil pollution potentially inhibiting agricultural and horticultural uses.

Another aspect is the soil's capacity to store carbon as humus or peat. Soil disturbances and destruction, including decreased groundwater levels, lead to the loss of humus through soil respiration and decomposition. As a consequence, carbon dioxide (CO_2) or methane (CH_4) is released into the atmosphere. Bog soils, rich in carbon, play a crucial role in the organic carbon cycle's buffering and filtering functions.

Methodology

To evaluate the filtering and buffering function, the ratings for the following criteria are taken into account for each area: buffering capacity in the organic carbon cycle (cf. Map 01.11.11), nutrient storage capacity/ pollutant binding capacity (cf. Map 01.11.6), heavy metal binding strength (cf. Map 01.11.10), filtering capacity (cf. Map 01.11.9) and depth to the water table (cf. Map 02.07).

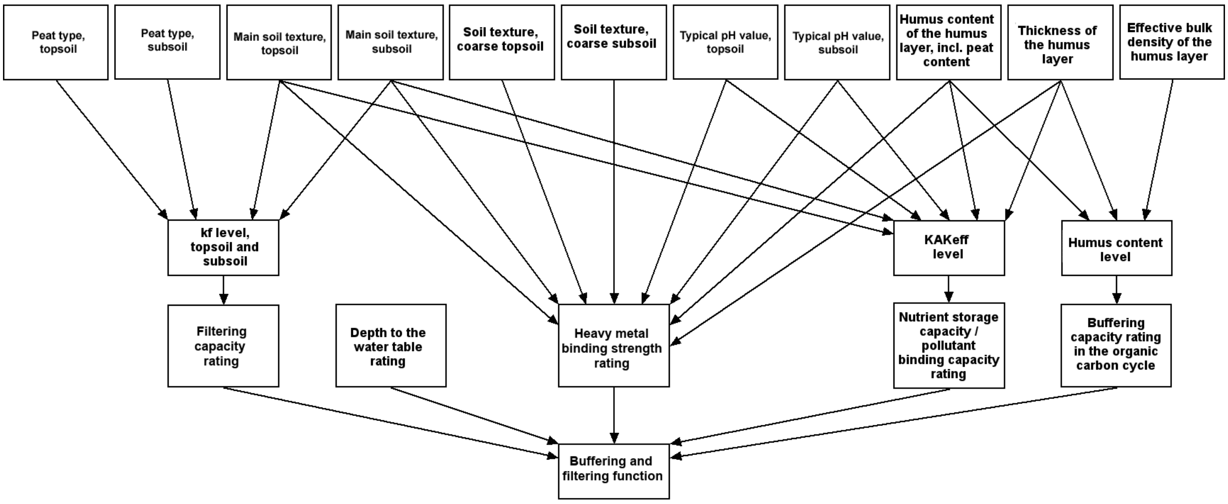

Fig. 1: Diagram for the evaluation of the buffering and filtering function (Gerstenberg 2017)

The buffering and filtering functions of soils are evaluated according to Table 1. The ratings for nutrient storage capacity/ pollutant binding capacity, heavy metal binding strength and filtering capacity of 1 (low), 2 (moderate) and 3 (high) are combined and corrected by the rating for the depth to the water table. Therefore, the filtration distance is considered in addition to the soil's ability to store substances, as pollutants enter groundwater faster the closer a location is to the water table.

Regardless of factors such as nutrient storage capacity/ pollutant binding capacity, heavy metal binding strength or depth to the water table, soil associations with the highest buffering capacity in the organic carbon cycle (3) receive a 'high' rating. Lower levels of these criteria have a negligible effect on the evaluation.

The total score for the buffering and filtering function is based on a three-point scale, 'low' (1), 'moderate' (2) and 'high' (3).

Sum of ratings of the criteria: filtering capacity + nutrient storage capacity/ pollutant binding capacity + heavy metal binding strength	Depth to the water table	Buffering capacity in the organic carbon cycle	Evaluation of the buffering and filtering function	
			Level	Designation
3 – 5	< 2 m		1	low
	2 – 5 m		1	low
	> 5 m		2	moderate
6 – 7	< 2 m		1	low
	2 – 5 m		2	moderate
	> 5 m		3	high
8 – 9	< 2 m		2	moderate
	2 – 5 m		3	high

	> 5 m		3	high
-	-	high	3	high

Tab. 1: Evaluation of the buffering and filtering function (Gerstenberg 2017)

Map Description

Loamy soils exhibit a high capacity for buffering and filtering due to their low water permeability and a pH level that tends towards neutrality or slight alkalinity, which in turn limits the movement of heavy metals. Additionally, these soils that are rich in clay and humus, coupled with a large depth to the water table, boast a high effective cation exchange capacity. These qualities are predominantly found in soils atop the Teltow and Barnim boulder marl plateaus. Typically, these soil associations are luvisol – arenic cambisol – podzoluvisol (para-brown soil – wedged sandpit brown soil – leached soil), characterised by near-natural land uses, undisturbed by materials aggraded by humans. They are often used for agricultural or allotment garden purposes (cf. Fig. 2).

Sandy soils originating from end and push moraines, as well as dune sands, receive a moderate rating. Such soils are part of the soil association cambisol – dystric cambisol – spodo-dystric cambisol (brown soil – rusty-brown soil – podzol brown soil) and subject to near-natural land use. Aggraded sandy soils formed during residential construction also receive a moderate rating. Despite their relatively high water permeability, the greater distance to groundwater increases the filtration path.

Conversely, sandy soils in the glacial spillway, channels and sinks, where pollutants have only a short distance to travel before reaching groundwater, display a limited ability to filter and buffer pollutants. These soils, whose development is closely tied to groundwater, include gley and bog associations used for near-natural purposes, or sandy, aggraded soils prevalent in the inner city area, characterised by the soil association: loose lithosol – regosol – calcaric regosol (raw soil of loose material – regosol – para-rendzina).

Soil associations with boggy soils under forest or grassland cover exhibit excellent buffering and filtering capacities in the organic carbon cycle. They are particularly prevalent in the glacial spillway and the meltwater channels.

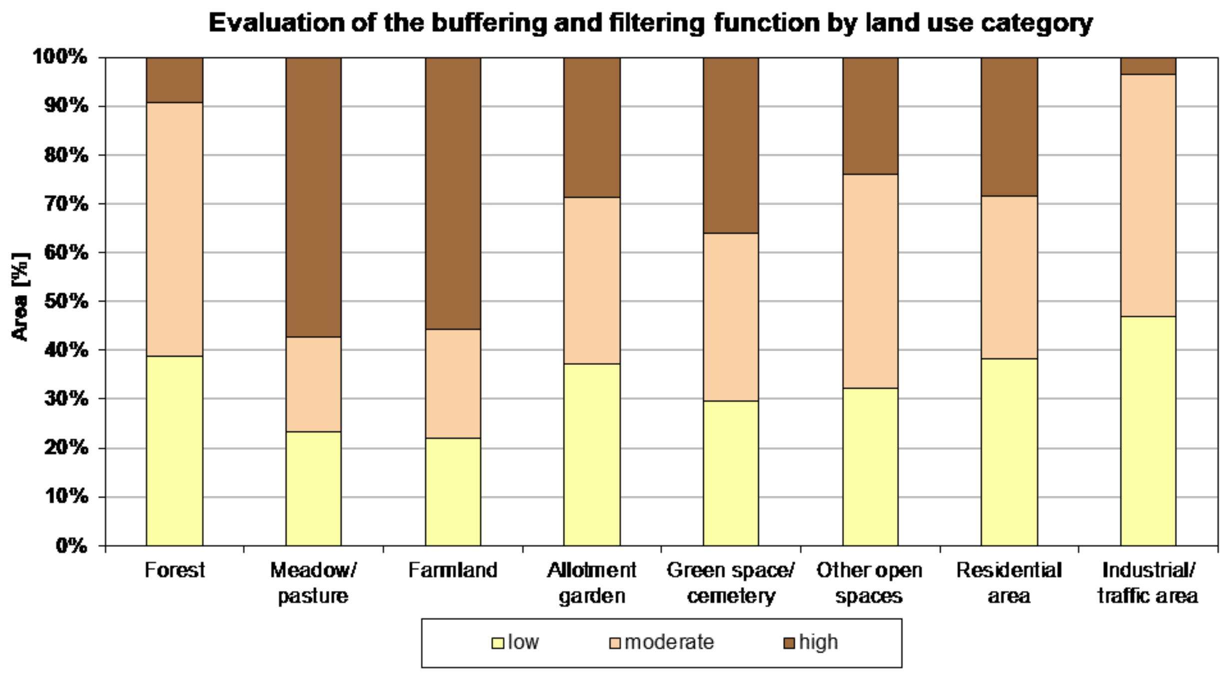

Fig. 2: Evaluation of the buffering and filtering function by land use category (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

01.12.4 Water Regulation Function of Soils

Description

The water regulation function depends on the soil's capacity to store or retain water, which influences both groundwater and surface-water runoff. The soil water exchange rate is used to assess this soil function (cf. Map 01.11.4). When water exchanges infrequently, it remains in the soil for longer periods, leading to a higher volume of retained water – a favourable condition for maintaining the landscape's water balance. Prolonged retention of water also enhances the decomposition of substances introduced into the soil, thereby improving the quality of percolating water. The rate of groundwater replenishment is low when the soil has a high water storage capacity and low frequency of water exchange, as precipitation mainly remains in the soil and is absorbed by plants.

Methodology

The water regulation function is directly determined by the soil water exchange rate (cf. Map 01.11.4), assessed on a three-point scale: 'low' (1), 'moderate' (2) and 'high' (3). Referring to Table 1, the regulation function receives a 'high' rating when water exchanges very infrequently, a 'moderate' rating for infrequent to moderate exchange rates, and 'low' for frequent to very frequent exchanges.

Soil water exchange rate per year	Water regulation function	
	Rating	Designation
< 1	3	high
1 – < 3	2	moderate
≥ 3	1	low

Tab. 1: Evaluation of the water regulation function, based on the soil water exchange rate

To calculate the soil water exchange rate, percolation (irrespective of impervious soil coverage) was used as a measure (cf. Map 02.13.4). The percolation rate is not only influenced by precipitation and soil conditions, however. It is also significantly affected by evaporation, which depends on vegetation and, consequently, land use. When interpreting the map, it should therefore be noted that areas with the same soil associations may receive different ratings due to variations in vegetation affecting percolation rates.

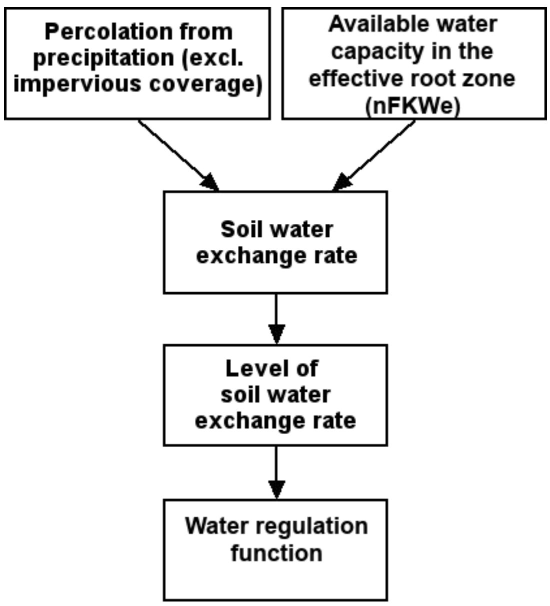

Fig. 1: Diagram for the evaluation of the water regulation function

Map Description

Many near-natural soil associations receive a high rating for their regulatory function, when their soil water exchanges less than once a year. This category includes all groundwater-influenced soil associations with low-moor bogs and gley soils, which maintain a constant water supply throughout the year in the surface layer of the soil (1 metre thickness). Due to the high evaporation rate of vegetation, the percolation from precipitation is minimal here, especially under forest cover (cf. Map 2.13.2). In some cases, groundwater depletion even occurs, resulting in very infrequent soil water exchanges. Another group comprises plateau soils primarily composed of boulder clay and boulder marl. They have a large storage capacity and can effectively retain precipitation, due to their low permeability. Dune sites with fine sand as their main soil texture, akin to loamy soils, also possess a great storage capacity and fall into this category.

Near-natural soils distant from groundwater sources, where soil water exchanges occur once to twice a year, receive a moderate rating. These primarily include dystric cambisols (rusty-brown soils) found on end and push moraines, arenic cambisols (wedged sandpit brown soil) located on the boulder marl plateaus with embedded sands, and dystric cambisol – eutro-gleyic cambisol (rusty-brown soil – gleyic brown soil) associations in the valley-sand areas. Soils that also receive moderate ratings are those formed from aggraded and relocated natural substrates, such as sands and loams, from which regosol – calcaric regosol – hortisol soil (regosol – para-rendzina – horticultural soil) associations have developed. Soils with a soil water exchange rate of three to four times a year receive a low rating. They are concentrated in the inner city, industrial areas, and track facilities (cf. Fig. 2). Coarse aggraded material, such as construction debris and track gravel, ensures a high permeability of the soil, facilitating swift percolation of precipitation.

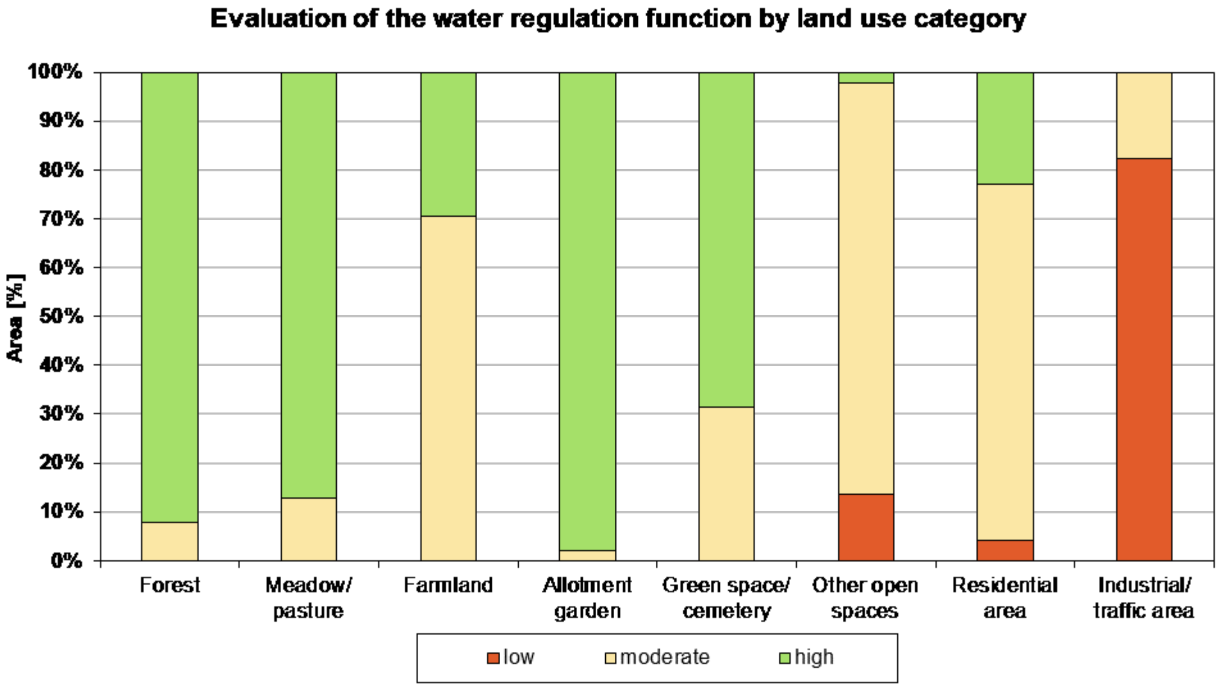

Fig. 2: Evaluation of the water regulation function by land use category (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

01.12.5 Archival Function of Soils for Natural History

Description

Soil types are shaped by environmental conditions such as rock, climate, and time. As a result, soils can reflect the historical landscape conditions of their formation era in their profile features, provided their structure remains undisturbed by human activity. These soils serve as valuable archives or sources of information on landscape history. In the Berlin area, soils reflect both the glacial conditions during formation and the postglacial bog formations. The archival function is defined by natural features such as kettle holes, push moraines and the regional rarity of soil associations. The highest ratings are given to very rare and geomorphologically unique soils as well as soils with a high buffering capacity in the organic carbon cycle.

The aim is to highlight soil associations and soil properties that uniquely characterise Berlin's landscape or are special because of their own rarity or that of their properties. Such soils are particularly deserving of preservation and protection.

Methodology

The archival function for natural history was evaluated based on two criteria. Firstly, the soil association's regional rarity, for which soil associations covering less than 0.4 % of the urban area (excl. streets and bodies of water) were classified as level 2 (very rare to rare), while the remaining soil associations were classified as level 1 (moderate to very common) (cf. Map 01.11.1). Secondly, soil associations with a distinctive landscape character (level 1) based on their geomorphological conditions were also considered in the assessment (cf. Map 01.11.2). These ratings were then combined to evaluate the archival function. A sum of 3 indicates a 'high' importance as an archive, 2 represents a 'moderate' importance and 1 reflects a 'low' importance (Gerstenberg 2017).

Additionally, a moderate or high rating of the buffering capacity in the organic carbon cycle also leads to a medium or high rating of the archival function.

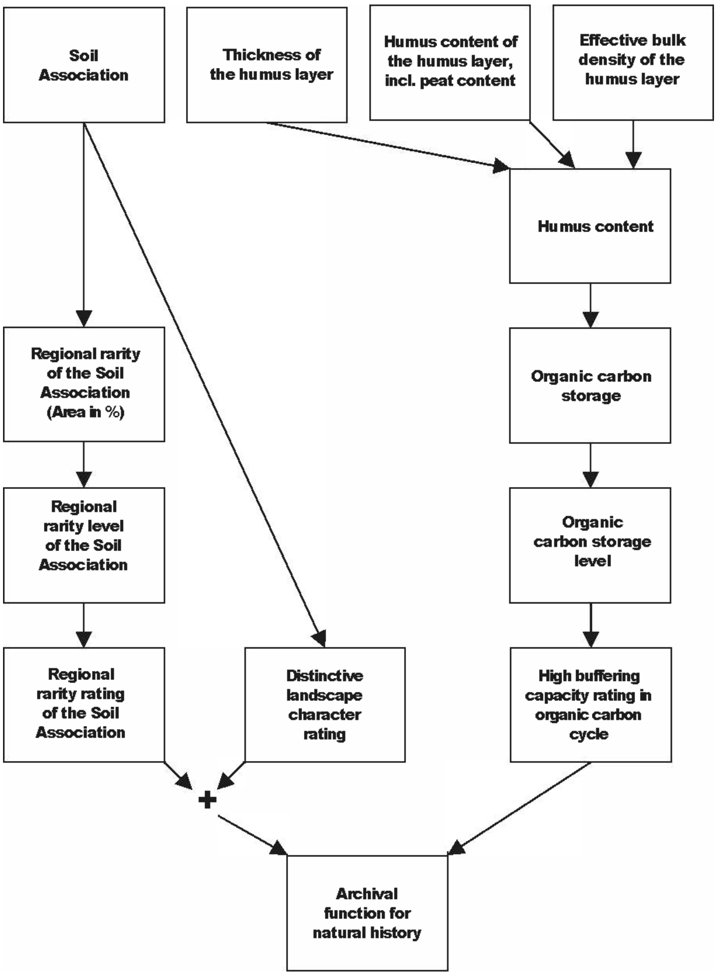

Fig. 1: Diagram for the evaluation of the archival function for natural history

Map Description

In the Berlin region, only a few areas truly stand out in their archival function for natural history. These areas are typically found on the outskirts of the city and are limited to near-natural soils.

Particular significance is attributed to lime-mud areas, low-moor bog associations and histo-humic gleysols (peaty half-bog gley soils) found in river floodplains and kettle holes. The same applies to calcic gleysols (limey gley soils), dystric gleysols (brown gley soils) and calcaro-dystric histosols (lime slope bog soils) on the push and end-moraines. Preserved arenic dystric cambisols (wedged sandpit rusty-brown soils) and gley arenic dystric cambisols (wedged sandpit rusty-brown gley soils) that can be observed on the boulder marl plateaus in Gatow and Frohnau are equally important.

Low-moor bog soils and groundwater soils located in meltwater channels, sinks, and certain valley-sand areas play a moderate archival role. Similarly, podzolised soils in dune landscapes, dystric-cambisol (rusty-brown soil) associations on moraine hills and on end and push moraines fall into the same category. On the plateaus, arenic dystric cambisols (rusty-brown soils) and gley arenic dystric cambisols (wedged sandpit rusty-brown gley soils) of boulder marl stand out in this context in particular.

The remaining soil associations, which have often been significantly altered by human activity or are the result of aggradation, play a minor archival role.

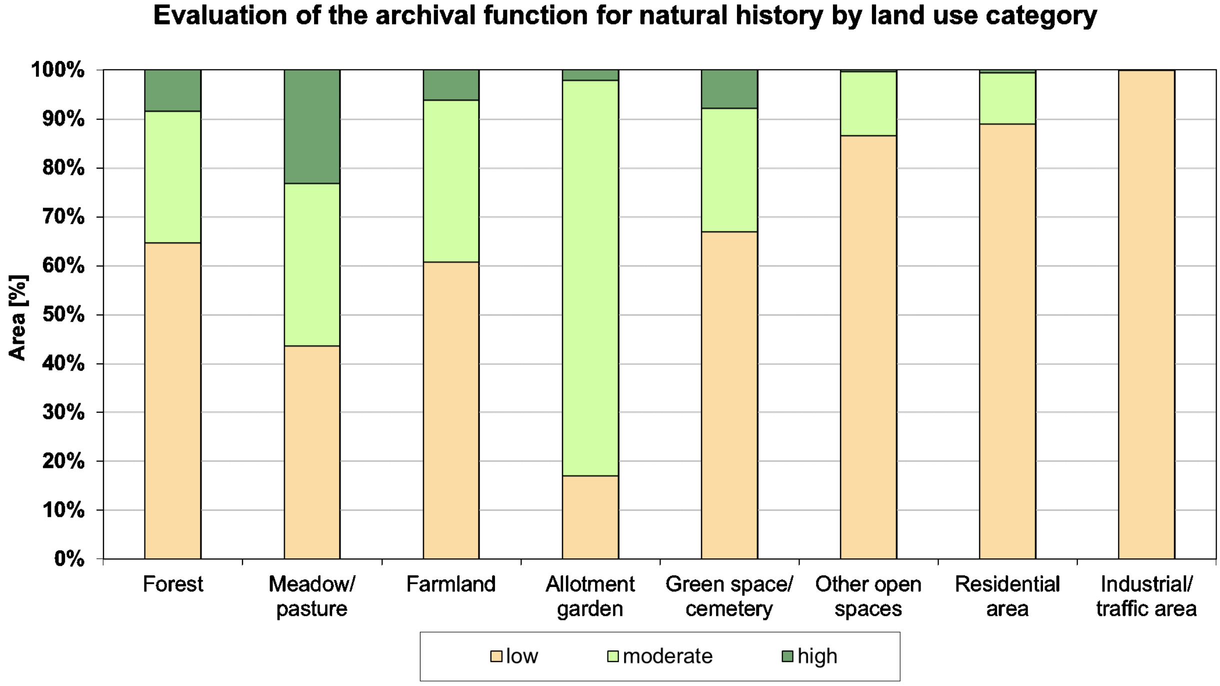

Fig. 2: Evaluation of the archival function for natural history by land use category (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

01.12.6 Capacity of Soils to Fulfil the Natural Soil Functions and the Archival Function

Description

The evaluation provided by maps 01.12.1 through 01.12.5 sheds light on how soils perform in their natural functions and their archival role. Using this assessment, soils can be gauged at a local level to prevent or mitigate any negative impacts on their performance. For a comprehensive consideration of soil protection in broader spatial planning, it is beneficial however, to consolidate these evaluations into a single assessment. The goal of the present map is thus not only to evaluate soil functions individually but also to grasp the overall soil performance. This approach aims to highlight areas crucial for soil protection due to their significant performance and functionality.

Methodology

A challenge arises when consolidating all five soil functions because similar soil properties often have different or opposing impacts on different functions. For instance, extreme sites such as those that are moist or wet, highly natural or rare score ‘high’ for their function as a habitat supporting natural vegetation. At the same time, they often receive a ‘low’ rating for their yield function for cultivated plants. Moreover, while dry dune sites may excel in their archival function for natural history (‘high’ rating), they might perform poorly in filtering, buffering, water balance regulation, and yield functions (‘low’ ratings).

Another problem is that due to the evaluation methodology chosen for the individual functions, areas that differ greatly in size received the same 'moderate' or 'high' rating for a particular function (cf. Fig. 1). For example, while large parts of the urban area scored 'high' with regard to their buffering and filtering function, only a few areas exhibited a 'high' performance regarding their role as an archive. As a result, while all five soil functions contribute equally to the final evaluation on paper, certain functions, particularly the water regulation function and the buffering and filtering function, have a stronger practical influence than the other functions.

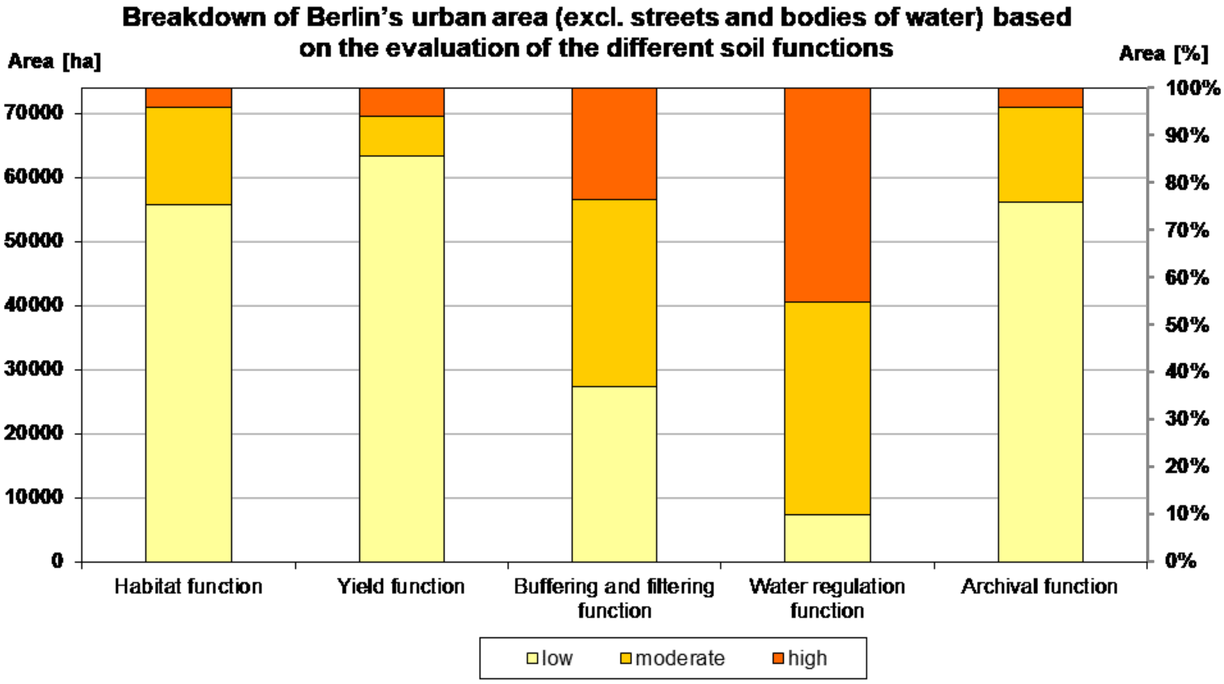

Fig. 1: Breakdown of Berlin's urban area (excl. streets and bodies of water) by ratings for the individual soil functions

The final assessment is based on the evaluation of each function according to a three-point scale. Each area within the city has a rating for each soil function, ranging from 'low' (1) to 'moderate' (2) to 'high' (3). Various methods were explored for evaluating the soils' capacity to fulfil natural soil functions.

The adopted method takes into account both the frequency of the highest rating (level 3) and the total rating sum in the overall assessment (cf. Tab. 1). All soil functions carry equal weight in the overall evaluation; a weight function was not applied.

Criteria	Soil capacity	
	Rating	Designation
Low capacity across all five soil functions on average (total of individual ratings < 9 and no 'high' capacity in any function)	1	low
Medium capacity across all five soil functions on average (total of individual ratings 9 to 10 or 'high' capacity in only one function)	2	moderate
Above-average capacity across all five soil functions on average (total of individual ratings > 10 or 'high' capacity in more than one function)	3	high

Tab. 1: Evaluation of the soil capacity to fulfil natural soil functions and the archival function

This method aims to mitigate the drawbacks and shortcomings of the other potential approaches. It reduces the prominence of the water regulation function and the buffering and filtering function. Even if an area scores ‘high’ (3) for only one soil function, it can still achieve the highest rating level if the sum of the individual ratings is high.

Map Description

Areas with an overall high capacity predominate on the plateaus in the north and south, the Spandauer Forst and the Gosener Wiesen. Conversely, heavily populated areas that are far from natural exhibit a low to moderate capacity. The dominance of the water regulation function and the buffering and filtering function is particularly evident on the plateaus.

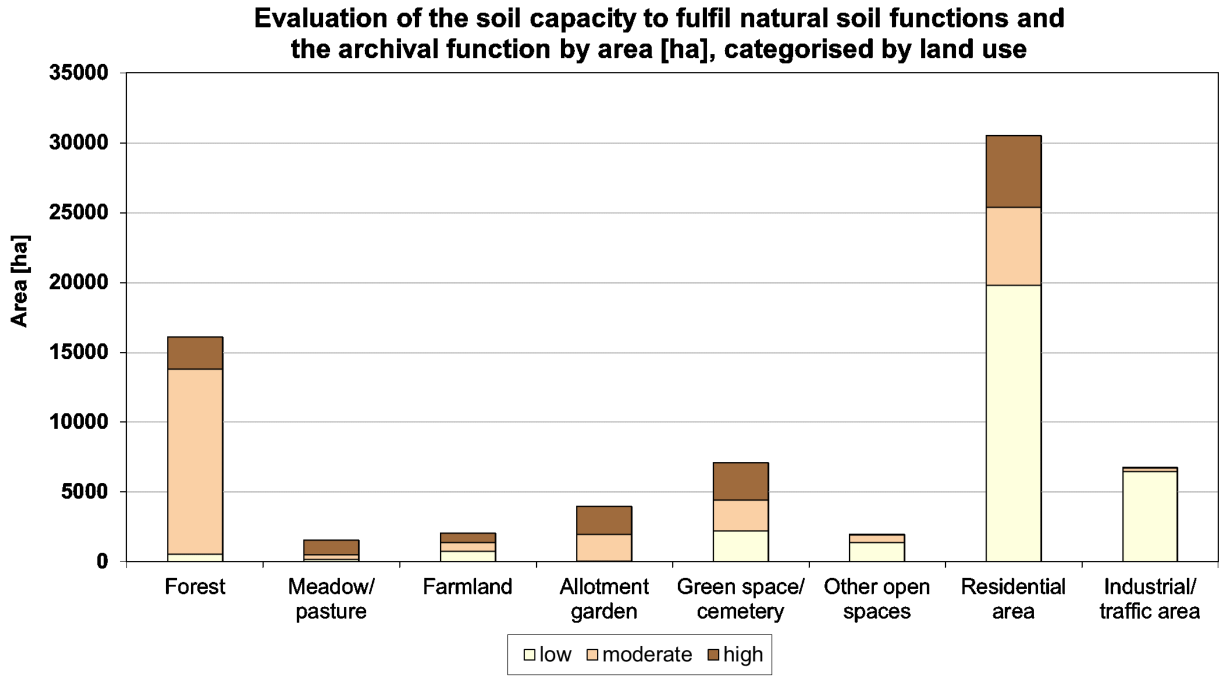

Fig. 2: Evaluation of the soil capacity to fulfil natural soil functions and the archival function by area, categorised by land use (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

Soils that are particularly valuable because of their high capacity are primarily located in forests, allotment gardens and agricultural areas. Additionally, some loosely built-up residential areas, where it is presumed that some near-natural soils still exist, demonstrate high capacities (cf. Fig. 2). However, a portion of these areas is impervious due to land use.

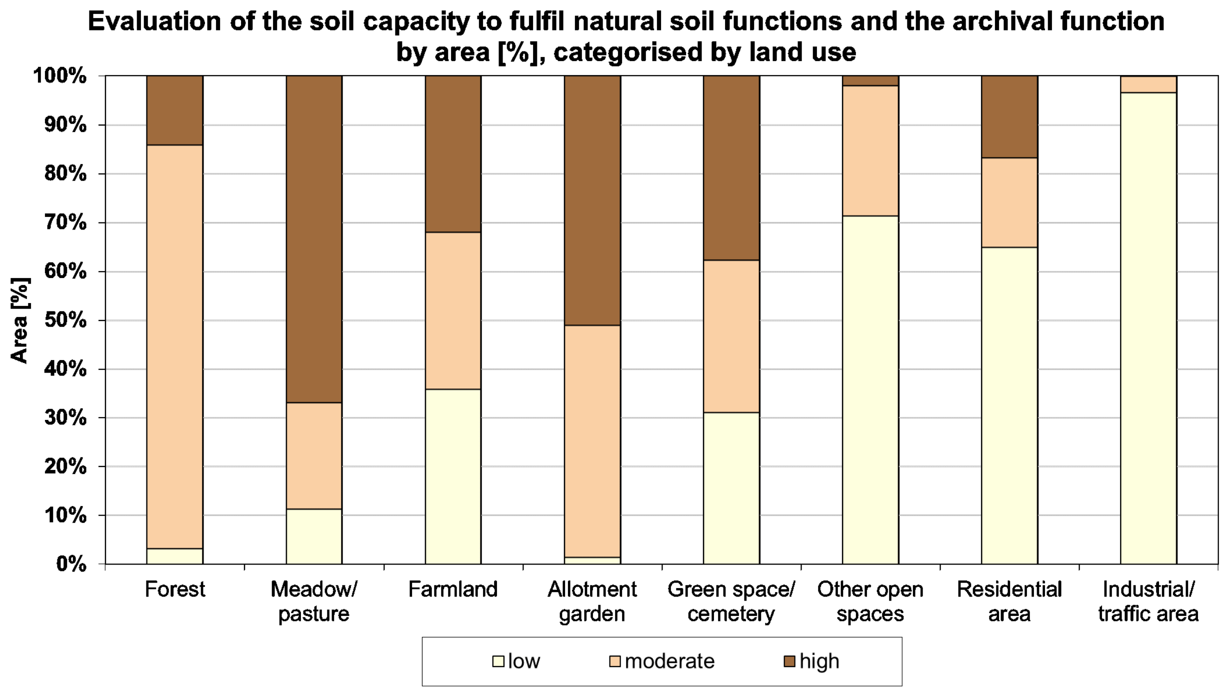

Fig. 3: Evaluation of the soil capacity to fulfil natural soil functions and the archival function by area [%], categorised by land use (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

However, in relation to their total area, high proportions of allotment gardens, meadow/ pastures, farmland and green spaces/ cemeteries receive 'high' capacity ratings (cf. Fig. 3).

01.12.7 Soil Cooling Capacity

Description

In cities, intense sunlight causes significant heating due to factors such as impervious surfaces, increased surface runoff, few green spaces, and lowered groundwater levels. Pervious surfaces, however, help counteract the formation of urban heat islands, as water is able to evaporate from them (evapotranspiration). During evaporation, solar energy transforms water from liquid to gas, storing it as latent heat in the surrounding environment, which is imperceptible and does not increase the ambient temperature (Damm, 2013, LANUV 2015, 22). As soil both stores and supplies water, it plays a pivotal role in regulating the urban climate. The aim is therefore to quantitatively capture and evaluate the soil cooling capacity based on its physical properties, land use, and vegetation cover. This assessment is based on three thematic maps: one estimates the soil evaporation potential qualitatively, considering soil physical properties and distance to the water table (Map 01.12.7.1), while the other two illustrate the evaluation of the soil cooling capacity with and without the impact of impervious surfaces (Maps 01.12.7.2 and 01.12.7.3).

01.12.7.1 Soil Evaporation Potential Based on Soil Properties

Description

The soil's potential to evaporate water depends on land use, its soil physical properties, the water balance, and the proportion of impervious surfaces. This identified evaporation potential serves as a gauge for the potential cooling capacity of Berlin's soils. Evaluating this potential draws on the concept outlined for estimating and quantifying Berlin's soil cooling capacity (Deiwick et al. 2020). It is derived from factors such as the available water capacity in the effective root zone and depth to the water table (Maps 01.06.4 and 02.07). Map 01.12.7.1. The Berlin Environmental Atlas depicts the evaporation potential without factoring in impervious areas. Thus, the map illustrates the evaporation potential based solely on the soil properties and water balance, irrespective of any effects impervious soil coverage may have.

Methodology

The methodology is based on Deiwick et al. (2020). The input data includes the available water capacity of the effective root zone (nFKWe), derived from soil texture, humus content, peat content (cf. methodology for Map 01.06.4), and depth to the water table (Map 02.07) based on the soil association and land use category. The evaluation, based on the method developed by Deiwick et al. (2020) was adjusted to match the levels outlined in the Soil-Scientific Mapping Guidelines (Bodenkundliche Kartieranleitung, 2023) for the nFKWe. This assessment involves six levels ranging from 'very low' to 'extremely high'. The nFKWe levels were adopted for this purpose. If the depth to the water table is ≥ 2 m, the rating is lowered by one level, and if the groundwater level is < 0.5 m, the highest level ('extremely high' evaporation potential) is assigned (cf. Tab. 1).

Depth to the water table [m]	nFKWe [mm]	nFKWe Level	Evaporation Potential	
			Rating	Designation
≥ 2	< 50	very low	1	very low
	50 – < 90	low	2	low
	90 – < 140	moderate	3	moderate
	140 – < 200	high	4	high
	200 – < 270	very high	5	very high

	≥ 270	extremely high	6	extremely high
≥ 0.5 – 2	< 50	very low	2	low
	50 – < 90	low	3	moderate
	90 – < 140	moderate	4	high
	140 – < 200	high	5	very high
	200 – < 270	very high	6	extremely high
	≥ 270	extremely high	6	extremely high
< 0.5	-	-	6	extremely high

Tab. 1: Evaluation of the evaporation potential without the impact of impervious soil coverage, estimated from the nFKWe and depth to the water table

Map Description

Areas with a very high to extremely high evaporation potential include the Tegeler Fließ, parts of the Bogenseekette landscape conservation area and the Lietzengrabenniederung in Buch as well as the Neuenhagener Mühlenfließ (Erpe), the Müggelspreewiese, the Gosener Wiesen landscape conservation area, and Seddinsee in Treptow-Köpenick. This is primarily due to very shallow groundwater levels. Similarly, areas with a very high to high evaporation potential include the Spandauer Forst, Tegeler Forst, and Treptow-Köpenick. Moderate evaporation potential is prominent in regions surrounding the Müggelsee, Grunewald, Tempelhofer Feld, Tiergarten as well as the eastern and southern outskirts of the city. Areas characterised by ground moraines generally exhibit a lower evaporation potential due to depths to the water table exceeding 2 metres. Likewise, sandy areas in the glacial spillway typically demonstrate a lower evaporation potential due to a low available water capacity.

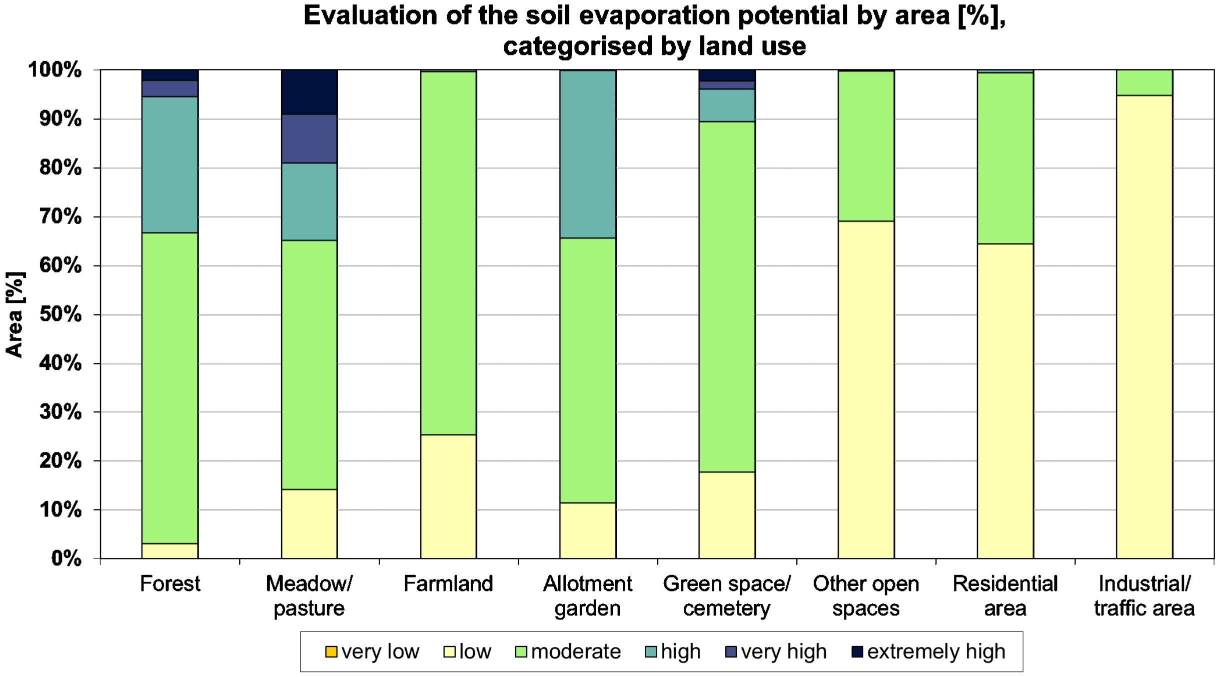

Fig. 1: Evaluation of the soil evaporation potential by area [%], categorised by land use (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

01.12.7.2 Soil Cooling Capacity Without the Impact of Impervious Soil Coverage

Description

The soil cooling capacity refers to the soil's ability to convert solar energy into latent heat through the evaporation of stored water within it. This transformation of solar energy into latent heat means it no longer contributes to heating the air (Damm 2013, LANUV 2015). The more water stored in the soil and evaporated directly by plants and through the soil, the less the air temperature rises due to solar radiation. Thus, soil and climate protection, as well as climate adaptation, are closely intertwined. The soil cooling capacity holds particular significance in cities and provides an important ecosystem service, as these areas are largely impervious.

The cooling capacity depends not only on climatic conditions but also on soil properties and the degree of impervious coverage. It is derived from the actual evapotranspiration of pervious block portions calculated using the ABIMO water balance model while also considering irrigation. The soil cooling capacity without the impact of impervious soil coverage (Map 01.12.7.2) represents the cooling capacity expected on fully pervious areas with the same land use.

Methodology

The calculation of the soil cooling capacity without the impact of impervious soil coverage is built upon the concept outlined in Deiwick et al. (2020) for estimating and quantifying this capacity in Berlin. The input data is derived from the ABIMO water balance model, which provides actual evapotranspiration figures for pervious block portions, while also considering irrigation. The model is based on long-term precipitation distribution between 1991 and 2020, as documented in the Berlin Environmental Atlas (Maps 04.08.1 and 04.08.2). The cooling potential of pervious block portions is then converted using a formula that accounts for evaporation energy derived from the actual evapotranspiration. This energy requirement varies with temperature, with calculations assuming an average of 20°C.

evaporation energy (20°C) = 682 Wh/l

cooling energy [Wh/year/m²] = actual evapotranspiration without impervious coverage [mm/year] * evaporation energy [Wh/l]

cooling capacity [W/m²] = cooling energy [Wh/year/m²] / (365 * 24 [h])

In both scenarios, whether considering the impact of impervious soil coverage or not, the soil cooling capacity is evaluated using seven categories. The conversion of the linear levels into ratings is based on the minimum and maximum potential soil cooling capacities in Berlin outlined by Deiwick et al. (2020). Typically, the cooling capacity is constrained by the water available for evaporation, which is often determined by precipitation levels. Only in areas with very low depths to the water table can more water evaporate due to groundwater connection than is available through precipitation alone. Berlin experienced an average precipitation of 579 mm during the reference period from 1991 to 2020.

Actual evapo-transpiration [mm/a]	Cooling energy [kWh/a/m²]	Cooling capacity [W/m²]	Cooling capacity level	Cooling capacity rating
0 – < 100	0 – < 68	0 – < 7,8	1	extremely low
100 – < 200	68 – < 136	7.8 – < 15.6	2	very low
200 – < 300	136 – < 205	15.6 – < 23.4	3	low
300 – < 400	205 – < 273	23.4 – < 31.1	4	moderate
400 – < 500	273 – < 341	31.1 – < 38.9	5	high
500 – < 600	341 – < 409	38.9 – < 46.7	6	very high
600 – < 700	409 – < 477	46.7 – < 54.5	7	extremely high

Tab. 1: Evaluation of the soil cooling capacity with and without the impact of impervious soil coverage, calculated from the actual evapotranspiration of pervious areas

Therefore, soil cooling capacities with actual evapotranspiration rates exceeding 600 mm (level 7) were rated as ‘extremely high’. Values falling within the range of average precipitation (level 6) were assessed as ‘very high’. Nearly all land use types received ratings ranging from ‘moderate’ to ‘extremely high’ in the evaluation without the impact of impervious soil coverage. Moreover, the more developed the soil, the lower its potential cooling capacity when impervious soil coverage is not taken into account.

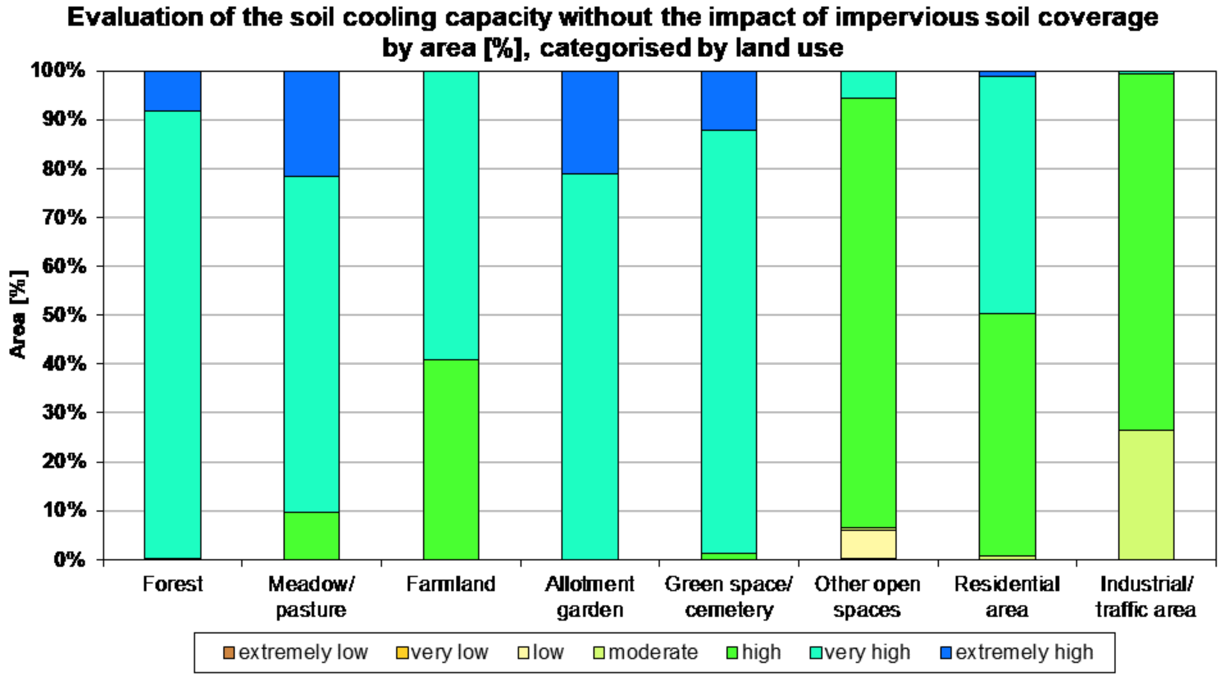

Fig. 1: Evaluation of the soil cooling capacity without the impact of impervious soil coverage by area [%], categorised by land use (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

Map Description

In Berlin, areas characterised by shallow depths to the water table, often situated near water bodies, exhibit an extremely high potential for soil cooling. These regions include the surroundings of the Panke River, the Tegeler Fließ, segments of the Bogenseekette landscape conservation area and Lietzengrabenniederung in Buch, the Neuenhagener Mühlenfließ (Erpe), the Müggelspreewiese as well as the landscape conservation areas Gosener Wiesen and Seddinsee in Treptow-Köpenick. Comprehensive areas of the Berlin forests as well as the predominantly less densely built-up areas on the outskirts, along with larger park facilities located more centrally, exhibit a very high potential for soil cooling. High soil cooling capacities are prevalent throughout the city. Relatively few areas scattered across Berlin display moderate to low potential for soil cooling, typically distinguished by their parent materials such as sand, gravel, or construction and war debris. These areas tend to have high percolation rates and consequently low evaporation rates.

01.12.7.3 Soil Cooling Capacity With the Impact of Impervious Soil Coverage

Description

The soil cooling capacity refers to the soil’s ability to convert solar energy into latent heat through the evaporation of stored water within it. This transformation of solar energy into latent heat means it no longer contributes to heating the air (Damm 2013, LANUV 2015). The more water stored in the soil and evaporated directly by plants and through the soil, the less the air temperature rises due to solar radiation. Thus, soil and climate protection, as well as climate adaptation, are closely intertwined. The soil cooling capacity holds particular significance in urban areas, due to their high degree of impervious coverage, playing a vital role as an ecosystem service.

The cooling capacity depends not only on climatic conditions and soil properties but also on the degree of impervious soil coverage. Since water cannot usually evaporate from soil under an impervious cover, such areas cannot contribute to the cooling of the air. Therefore, as impervious soil coverage increases, the soil's cooling capacity decreases. In order to accurately portray Berlin's conditions, the soil cooling capacity was assessed while accounting for impervious soil coverage (Map 01.12.7.2).

Methodology

The calculation of the soil cooling capacity with the impact impervious coverage also builds upon the concept outlined in Deiwick et al. (2020) for estimating and quantifying this capacity in Berlin. The data on actual evapotranspiration from pervious block portions, calculated using the ABIMO water balance model, is scaled up to cover the entire block segment area based on the degree of impervious soil coverage. Evaporation from impervious surfaces is disregarded.

Calculating the cooling capacity of the entire block segment area follows the same process used for calculating the cooling capacity for areas without the impact of impervious coverage. This process involves applying the following formulas:

evaporation [mm/year] = evaporation pervious [mm/year] * (1 – degree of impervious soil coverage [%] / 100)

cooling capacity [W/m²] = evaporation [mm/year/m²] * evaporation energy [Wh/l] / (365 * 24 [h])

The evaluation of the soil cooling capacity follows the same criteria, whether impervious soil coverage is considered or not (cf. Section 01.12.7.2, Tab. 1).

When impervious coverage is taken into account, the soil cooling capacity drops significantly, often placing areas into lower categories of cooling capacity, such as 'very low' (level 2) or 'extremely low' (level 1), even if they would not be categorised as such if impervious coverage were not considered. However, the assessment remains unchanged for completely pervious areas.

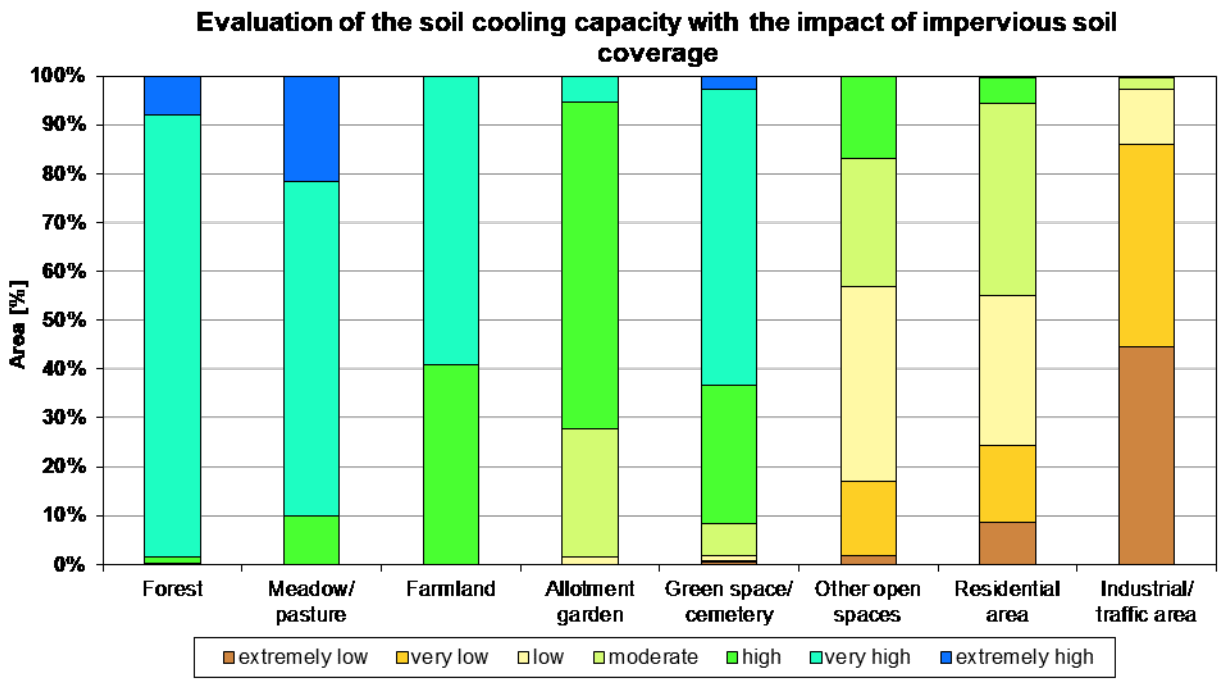

Fig. 1: Evaluation of the soil cooling capacity with the impact of impervious soil coverage by area [%], categorised by land use (incl. impervious areas, excl. streets and bodies of water, not all land uses are shown)

As the degree of impervious soil coverage increases, both the actual evapotranspiration and soil cooling capacity decrease proportionally. The greatest reductions in evapotranspiration due to impervious soil coverage are typically observed for areas used for residential and industrial/ traffic purposes.

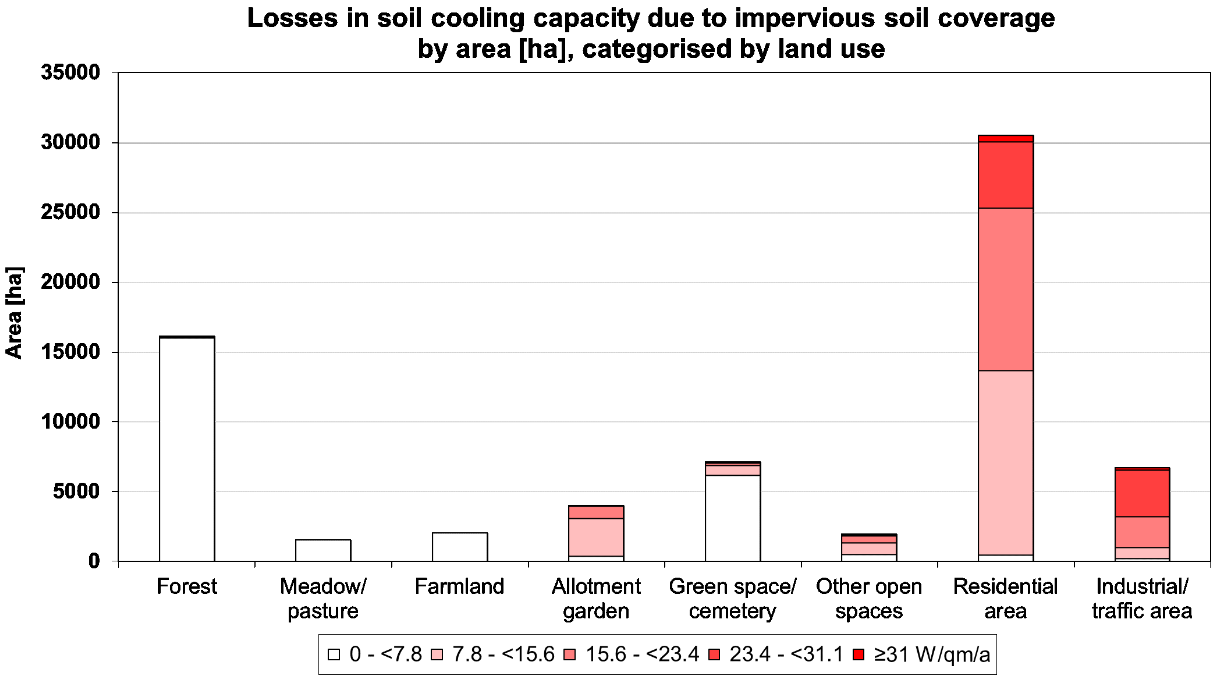

Fig. 2: Losses in soil cooling capacity due to impervious soil coverage by area [ha], categorised by land use (incl. impervious areas, excl. streets and bodies of water; not all land uses are shown)

Map Description

In Berlin, the average evaporation from pervious portions of block areas (excluding roads and bodies of water) is 365 mm/year on average. This translates to an average cooling energy of 249 kWh/m²/year or 28.4 W/m². For the entire city, this amounts to 184.4 TWh/year, resulting in an average permanent cooling capacity of 21 GW. As the degree of impervious soil coverage increases towards the city centre, the soil cooling capacity decreases, often reaching ‘very low’ or ‘extremely low’ levels for areas that are largely impervious.

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