Underground systems. A framework for urban soil assessment.

Theme 1: New interdisciplinary and intercultural approaches for facing global changes and their local impact.

Keywords: soil; land; subsoil; urban waters; urban transformation

Authors

Alexandre Bossard
Scientific collaborator. Catholic University of Louvain (UCLouvain), Louvain Institute for Landscape, Architecture and Built Environment, -SST-LAB-Super-Positions
alexandre.bossard@uclouvain.be

Chiara Cavalieri
Professor of Urbanism. Catholic University of Louvain (UCLouvain), Louvain Institute for Landscape, Architecture and Built Environment, -SST-LAB-Super-Positions
chiara.cavalieri@uclouvain.be

Olivier Ska
ABV Environment – Partner
o.ska@abv-development.com

Abstract

Over the last years, in the framework of ecological transition, the question of soil has been critically revised in the fields of urbanism and urban planning. This paper focusses on how to integrate soil and subsoil sciences in urban assessment via a systemic reconceptualization of urban soils as a three-dimensional element composed by different strata: (a) the land, the place where urban policies and zoning laws apply, (b) the living soil, an ecosystem service that is often replaced by different urban utilities; the (c) subsoil, the hydrogeological structure that plays a crucial role for major urban functions. Although these strata are domains of different disciplines and regulations (urbanism, pedology, geology…), modifications of land use can cause major dysfunctions through these different layers, such as for example the pollution of both ground and surface water bodies, or the reduction of the natural soil capacity to infiltrate, store, and ultimately recycle water.

Through data gathering (from land cover to urban plans, pedology, hydrogeomorphology and geology…) and integrated analysis (urban and soil sciences) this work describes, analyses and categorizes the transversal connections of this threefold system in the capital region of Brussels.

A region where not only the pressure of densification entails the development of former productive areas for new dwellings, and thus where soil as such becomes crucial, but also where climate change is increasingly revealing major water dysfunctions as a result of an intensive process of urbanisation of waters (covering, piping, pumping, discharging…) that has progressively replaced the space of both soil and subsoil.

The purpose of this paper is to unravel paths towards a deep soils-oriented classification of urban tissues based on the different interaction of the soil strata, as a basis for encouraging a better assessment of the environmental impact of urban developments, as well as to produce soil-oriented approaches for urban transformation. This work is part of the **3Dcit-is** research (ABV Environment ; ELI UCLouvain ; LAB UCLouvain) funded by Innoviris (Join R&D Project, 2019).

Introduction

Over the last decades, the question of soil has been critically revised in the fields of urbanism and urban planning. European and international policies and programs demonstrate an increasing interest in limiting land consumption and favouring a sustainable land use: the "no net land take" initiative, aiming zero land consumption by 2050, as part of the "Roadmap to a Resource Efficient Europe" (EC 2011)[1], the Green Deal, as well as the United Nation acknowledging the importance of the soil by proclaiming 2015 the "international year of soil" (United Nations 2013).

In the '80s, in his seminal text 'Progetto di suolo', Bernardo Secchi (Secchi 1986) started to introduce the question of soil as an active rather than technical support to urban and territorial design. Today, this active support, enriched by its living matter and its ecosystemic functions, is placed by the ecological transition at the centre of the urban debate (Viganò and Guenat 2022, 43).

Soil fulfils many functions which are essential for the city: (a) the function of food or vegetal materials production and of source of raw material – both still often externalized outside the city (Mantziaras and Viganò 2016, 24) - is experiencing a renewed interest (Perrin and Soulard 2017); (b) soil also serves as a physical support for human constructions and (c) plays a role as an archive by preserving clues to trace history (Havlicek 2016, 24–25); furthermore soil is (d) a cultural, recreational and aesthetic element, and (e) fulfils the functions of preserving the living environment and regulating climate change or the water cycle (Viganò and Guenat 2022, 55).

However, a degraded soil is not able to fulfil many -if not all- of these essential functions (Cavalieri 2019). The impacts of soil dysfunction in urban areas can be numerous (Hazelton, Murphy, and CSIRO Publishing Staff 2009, 9): damage to buildings, erosion, flooding, degraded ecosystems. Moreover, soil leads to risks of flooding, drought and heat islands, accentuated by climate change, as well as pollution of groundwater and rivers (Labo XX+I 2021; Mantziaras and Viganò 2016, 30–31). To partially mitigate these risks, soil protection and regeneration should be systematically assessed in urbanism and urban planning.

[1] Translated in Belgium as "Stop Béton" or "bouwshift" in Flanders.

State of the art

Despite the increasing awareness of the necessity of an ‘Urbanism of Soil’ (Viganò and Guenat 2022), and more precisely of understanding the soil as a volume, current policies often overlook the third dimension by only considering the soil as a technical support, rather than a living and complex environment able to provide and regulate ecosystems services while also generating cultural services. In this work we propose to unpack the volume of soil by distinguishing, describing - and ultimately relinking – three different strata: the *land,* a political surface where regulations apply, the *soil* as a living environment (horizon O,A,B,C), and the *subsoil* (horizon R) as a geological construction. In this part of the work, we will specify how we conceptualise and use for this work the notion of soils and subsoil.

Soil is the very thin part, up to a few metres thick (Havlicek 2016, 22), which lies under our feet and is supported by the subsoil, which is a pure mineral structure (Mantziaras and Viganò 2016, 22). What differentiates the soil from the subsoil is its role as a living environment, hosting insects, worms, fungi, bacteria and other micro-organisms as well as other small animals and plants (Protasoni 2022, 23). This relationship between soil and life goes beyond the unique role of a living environment, as soil is itself shaped by life (Darwin 1881). The structure and matter of the soil is produced and transformed by living beings, from the decomposition of plants to the transformation of matter by worms. Thus, the physical and chemical properties of the soil are the result of transformations induced by living beings. This particular relation comes from the position of the soil as the point of contact between the atmosphere, the earth and living organisms, and its structure is at the same time the result of this interaction (Peleman et al. 2022, 9).

The process of soil genesis is long, a soil takes hundreds of years to acquire the structure it has today (Mantziaras and Viganò 2016, 23) and it should therefore be considered dynamically, as an element in constant transformation and evolution (Vialle 2022, 117). This dynamic view of soil leads it to be considered as a system, via which one can 'care' (Viganò and Guenat 2022, 43), in order to enable the emergence of future soils better suited to fulfil their functions.

Subsoil, as a support under the layer of the soil, starts when the organic matters completely disappears (horizon R: bedrock). In urbanised environments, it might hosts infrastructures (energy, water, metro, ...) ; it is used as a source of raw material, or ultimately function as a natural underground water -permeable or impermeable- tank. In this work, we observe the subsoil from a hydrogeological point of view, focusing on its capacity to infiltrate and storage urban waters. In this sense, underground water reserves are not only used to supply the city but are part of an entire water cycle. Hence the renewal of these stocks is of utmost importance to improve the water cycle (De Bondt 2017, 9). In this sense, subsoil can play, through infiltration, a regulating role in water managing, by flattening the impact of seasonal rain variation, allowing the infiltration and retention of water on rainy days, thus creating water stocks for dry periods.

During the 20th century, in urban environments, soil and subsoil were considered as a potential space to build on, where technical networks (water, gas, electric cables ...) or other infrastructure (metro, underground roads, storage spaces ...) can be placed to free up space on the surface (Boivin 1989). This vision has significantly influenced urban soils and subsoils. Underground constructions have a large impact on the groundwater system (Zunino 2011): they act as barriers and may require permanent water pumping or other technical infrastructure to maintain them. The properties of soils have also been considerably modified, through compaction, mixing, and the addition of other natural or manmade materials, resulting in large variations in soil properties even on a small scale (Hazelton, Murphy, and CSIRO Publishing

Staff 2009, 9). Urban soils or 'technological soils' have been heavily modified by process of urbanisation, both in terms of composition and matters. Despite heavy modifications, recent works demonstrate that urban soils can be a source of regenerations (Viganò and Guenat 2022, 53). Variations on urban soil types are therefore products of the cultural, social and technological history of cities (Hazelton, Murphy, and CSIRO Publishing Staff 2009, 12). Somehow the lack of consideration for soil in urban environments due to its invisibilisation and hence its low cultural importance, ends up by influencing its properties (Vialle 2022, 115). Nowadays, a large part of urban soil no longer - or to a much lesser degree - fulfils its role of living environment. Soil sealing, soil displacement, drilling or pollution cause changes in soil functioning, compromising its ability to host life and thus its capacity to regenerate (Havlicek 2016, 23).

Between soil and subsoil in the capital region of Brussels

Soil consumption and the degradation of its functions are starting to be handled in Brussels-Capital Region. The Règlement Régional d'Urbanisme (RRU) (Gouvernement de la Région de Bruxelles-Capitale 2006) provides regulations limiting soil sealing in gardens and yards, and, in case of new constructions, requires a rainwater management on the scale of the parcel itself, by implementing water infiltration or water re-use via the use of tanks. Operations as such, that intervene in the early stage of the process (water-cycle), and thus "source-control measures", are proposed by De Bondt against the so-called "end-of-pipes" solutions that have proven to be costly and of limited effectiveness (De Bondt 2017, 13).

In line with the European strategy for 2030, presented in November 2021 (Commission to the European Parliament et al. 2021), which aims to preserve and restore soils as living environments, as living soil, Bruxelles Environnement, the administration in charge of the environment and green spaces in Brussels-Capital Region propose the "Good Soil" strategy ('Good Soil' 2020). The study, launched in 2019, proposes general guidelines to protect the soil and improve its quality; promote projects that strengthen living soils as well as implementing tools for monitoring soil conditions. Within this framework, an atlas ('Atlas des sols bruxellois' 2022), based on surveys, shows models of different heavy metal pollution and of soil moisture. Moreover, as a monitoring tool, a database indicating the soil quality index (Indice de Qualité des Sols Bruxellois, IQSB) was created. It consists of an evaluation of soil quality by citizens or by professionals, not only considering the soil pollution, but also analysing the soil as a living environment (presence of organic matter, insects, roots) and its structure (compaction, permeability, the presence of manmade materials …).

Projects related to soil and water infiltration are not only regulatory or governmental. Brusseau (Crespin 2020), and the ongoing Brusseau bis, are research projects funded by the regional agency (Innoviris, co-create) bringing together researchers and citizens science to address water and flooding issues in a participative process. The idea of 'watershed solidarity' (water-sensitive citizen's actions) is one of the main concepts brought forward by this collective. Indeed, water infiltration, and therefore the presence of soils that can fulfil this function, is one of the main levers for reducing runoff. The problems of the water system, in relation to soils and soil sealing, are also the subjects of the book *Water vs. Urban Scape: exploring integrated water-urban arrangements* (Ranzato et al. 2017) and are approached by the study of the research group LaboXX+I (2021), founded by regional administrations, which focuses on the periphery of the Belgian capital, crossing the Brussels-Capital Region and the Flemish regional border. An issue of the magazine L Latitude Logbook, *CAVES* (Aragone, Cauciello, and Ranzato 2020), also focuses on the questions of basements and their relation with water.

A new gaze at the urban soil and subsoil

Within this framework, the goal of this paper is to unfold the different dimensions of soil, placing the ‘living soil’ in relation to urban surfaces and the subsoil. This question becomes particularly relevant regarding the increasing pressure on urban soil. The European policies of 'no land take' and the current trend of 'inward urbanisation', which strengthen the protection of agricultural and natural soils against urban sprawl and car dependency, suggest the re-centring of development projects inside the cities, thus, while preventing natural soil sealing, increasing the current pressure on urban soils (Vialle 2022, 117). This trend is clearly visible in Brussels-Capital Region, as large projects and planification concentrate construction on industrial wastelands (Josaphat, Heyvaert, Delta, Tour et Taxis, Bistebroek, Gare du Nord, etc.). The soil on these sites is often still permeable and those projects generate impervious surfaces and soil pollution management, leading to large soil displacement to the periphery. It is therefore urgent to imagine a city which is not only 'soil-destructive', but also 'soil-regenerating' (Viganò and Guenat 2022, 53), and accordingly placing the issues of soil and subsoil at the core or urban transformations. This shift also introduces a different vision of the city, which has been based on the externalisation of agricultural and natural materials production (Mantziaras and Viganò 2016, 24–25). In this sense, the clear separation between agricultural and natural areas located outside the cities and in the cities themselves where artificialisation and pressure on the soil are facing significant limits, should be reconsidered. With this in mind, the methodology presented in the following paragraph intends to provide tools for a better assessment of soils in urban areas. This method does not address the soil as an isolated element, but considers it within its context, by considering what lies underneath it, the subsoil, and what stands above it, the urban surface (land) and its regulatory frameworks.

Methodology

This paper focuses on how to integrate soil and subsoil sciences in urban assessment via a systemic reconceptualization of urban soils as a three-dimensional space composed by different strata: (a) the *land*, the place where urban policies and zoning laws apply, (b) *the soil*, an ecosystem service that is often replaced by different urban utilities; (c) the *subsoil*, the hydrogeological structure that plays a crucial role for major urban functions. Although these strata are domains of different disciplines and regulations (urbanism, pedology, geology, hydrogeology…), modifications of land use can cause major dysfunctions through these different layers, such as the pollution of both ground and surface water bodies, or the reduction of the natural soil capacity to infiltrate, store, and ultimately recycle water.

Using this threefold structure, this work first proposes a set of operations for each category, such as to gather, collect, and process the available and pertinent data; to produce and describe some critical cartographies accompanied by quantitative charts. Secondly, it observes the interactions (in terms of dysfunctions, missing links, as well as of opportunities) between these strata, opening up some paths for revising currently in use urban assessment methods.

'Land'

Data

For the first layer, we propose to use the term *land* for describing the soil surface, that is to say the space where the soil and human-beings and their activities intersect, the space where land use, planning tools, protection rules are mostly applied.

Being this stratum closely related to urban policies, most of the data is issued by the regional administrations, such as perspective.brussels or Bruxelles Environnement. These datasets therefore, unlike the others used in this paper, do not necessarily represent reality but rather describe a future and regulatory function for the regional space.

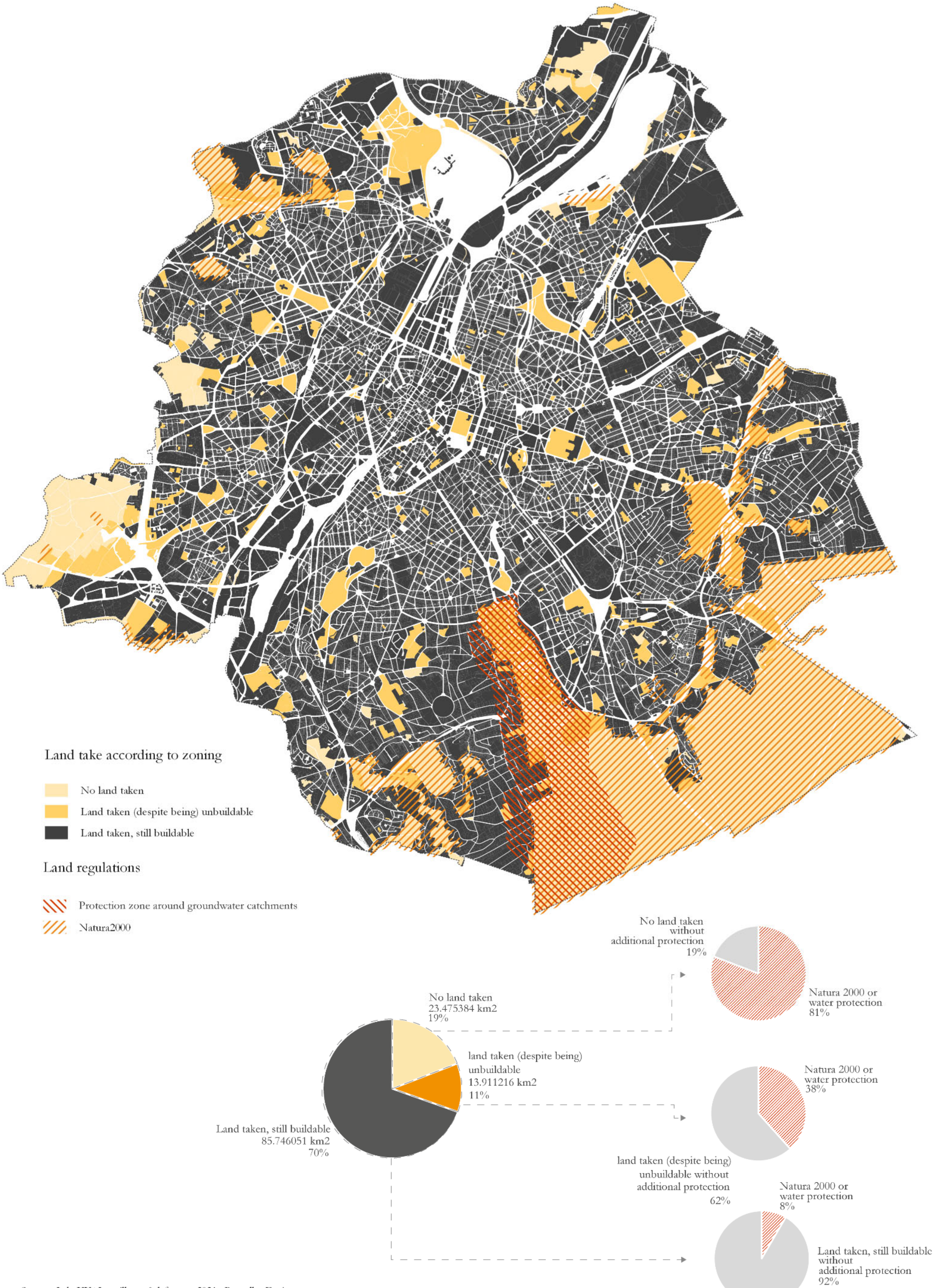
The first dataset analysed is the Plan Régional d'Affectation du Sol (PRAS), the regional zoning plan, from which the approval of building permits depends directly. A first step in the study of this plan in relation to the question of soil consists of a reclassification of the 21 'affectations' proposed. We have therefore grouped the affectations into three categories, based on the study of LaboXX+I (2021): (1) land taken, still buildable (2) land taken (despite being) unbuildable and (3) no land taken. The distinction between land take and no land take is based on the European definition of this concept ('Land Take in Europe' 2019), which for example defines urban parks as land take in the same way as built-up areas, since they are both produced by urbanisation.

Other land regulations (or protections) also overlap with the PRAS. Firstly, the Natura2000 areas, which derive from European directives (*Directive 92/43/CEE* 1992; *Directive 2009/147/CE* 2009), aim to protect natural habitats, and therefore the soil of these habitats. Secondly, the region of Brussels-Capital defined protection zones around groundwater catchments supplying the city with potable water. This protection limits the possibility of construction and activities that could lead to a degradation of the soil and therefore of the quality of the water pumped.

Moreover, overlapping this geography with other environmental risks (such as flooring risk, heat islands, air and soil pollution), the to-be-urbanised pattern becomes critical (Labo XX+I 2021).

Cartography

The map in *figure 1* highlights the broadness of urbanisation foreseen by the zoning, reaching 70% of the Brussels-Capital Region. Land not dedicated to construction and not seen as urban parks, thus following the European definition of no-land take, exists only in a few places close to the borders of the Region. In the South-East, the Sonian Woods and the Bois de la Cambre stand out as the most extensive no land take areas. These spaces are recognised as such, as shown by the various protective regulations that are superimposed on these areas. Indeed, 81% of the no land take surface is also protected by an additional regulation (Natura2000 or groundwater catchment protection).



Source : LaboXX+I - spillover & leftover - 2021 ; Bruxelles Environnement - Natura2000 & water protection

Figure 1 - Land take, land regulations and distribution of land in Brussels-Capital Region.

Soil

Data

The second layer proposed is that of the 'soil', referring to the living soil as described before. This chapter observes than the question of land cover (vs land use), and by means of data processing, classify the quality and potentials of existing soils in Brussels Capital Region. This type of observation grounds on the hypothesis that, although living soil takes a very long time to regenerate, damaged soil can be revived by promoting a soil-regenerative city (Viganò and Guenat 2022, 53), that should both act towards the protection of undamaged soils and the regeneration of damaged ones.

To produce such geography, we used several indicators. The first is a land cover dataset, at one metre resolution, generated from satellite imagery, and produced during a study on Belgian ecotopes (Radoux et al. 2018). This dataset helps build a detailed overview of the rate of soil sealing, hence considering soils that therefore no longer fulfil their biological functions. However, especially in urban areas, even permeable soil is not free from human intervention, that can compromise its role as a living environment.

Pollution is one of these factors limiting soil life. The available data on pollution, provided by Bruxelles Envrionnement ('Inventaire de l'état du sol' 2020), covers the parcels currently studied and therefore does not give an exhaustive view of the real soil pollution in Brussels-Capital Region. Moreover, this dataset is simplified and does not distinguish the types of identified pollution (hydrocarbons, heavy metals, etc.). New soil assessment databases are being built (see state of the art), including indicators about compaction and share of organic matter, but are still not exhaustive at the scale of the Brussels-Capital Region.

It is therefore difficult to assess precisely the impact of pollution on living soils but we can nevertheless assume that it has an impact on the soil's inhabitants, if not on their quantity (some plants, for example, tolerate pollution quite well (Ashraf, Ozturk, and Ahmad 2010, 35–36)), at least in terms of their diversity.

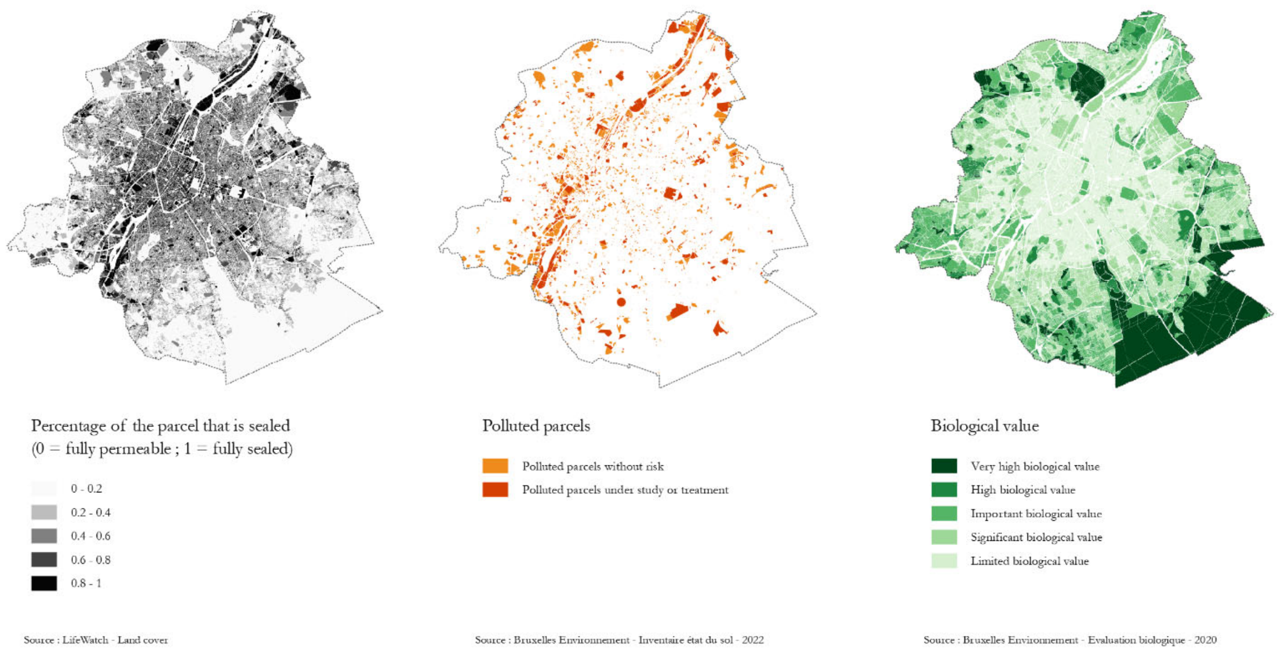


Figure 2 - Cartography of the three indicators

The third indicator explored is the biological value, provided by parcel, for Brussels-Capital Region by Bruxelles Environnement (Dubois and Rengle 2020). This indicator does not specifically concern the soil, but given the strong link between the state of the soil and the biodiversity that it allows, it remains valuable for evaluating the existence of living soil.

Cartography

Starting from these three indicators and their related cartographies, we proceeded in overlapping this information, observing the different combinations that result. An area could, therefore, be classified as mainly unsealed, polluted and having a small biological value, also highlighting the correlation between these indicators.

The map (*figure 4*) shows this classification and confirms the link between soil sealing and the biological value of the area. In order to get an idea of the soil condition in Brussels-Capital Region, a statistical analysis (*figure 3*) has been carried out. Although large areas are sealed, the broad surface of permeable parcels with high biological value, such as parks and the Sonian Forest, make this category one of the largest in the region in terms of surface area. This analysis therefore deconstructs the image of a city in which the soil has already lost all its ecological value and is merely a surface waiting to be built. However, it also highlights the scale of the task of improving the quality of the soil in the city, given that impermeable areas with low biological value is still by far one of the most important categories. Policies regulating soil sealing at the level of the parcel, such as the RRU (see *state of the art*), can have a significant impact on that scale, but also on a larger scale as their effect is cumulative.

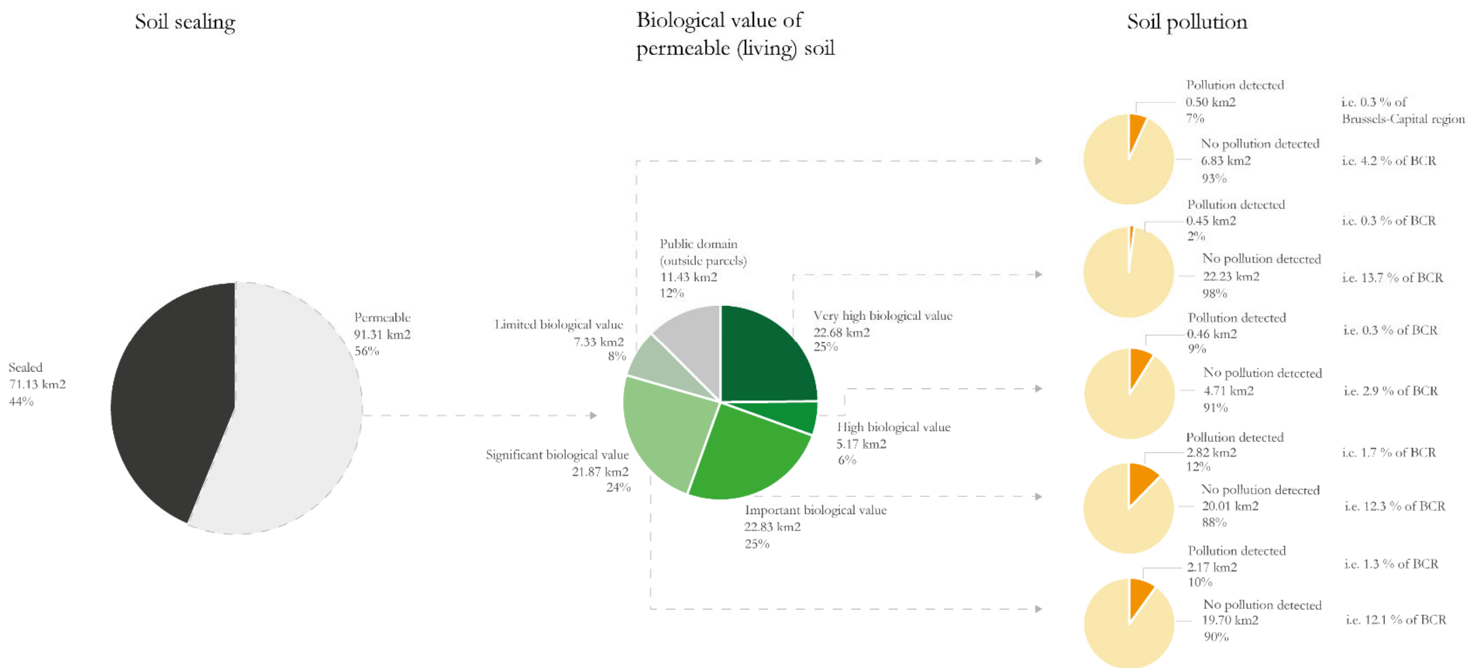


Figure 3 - Distribution of soil according to its condition.

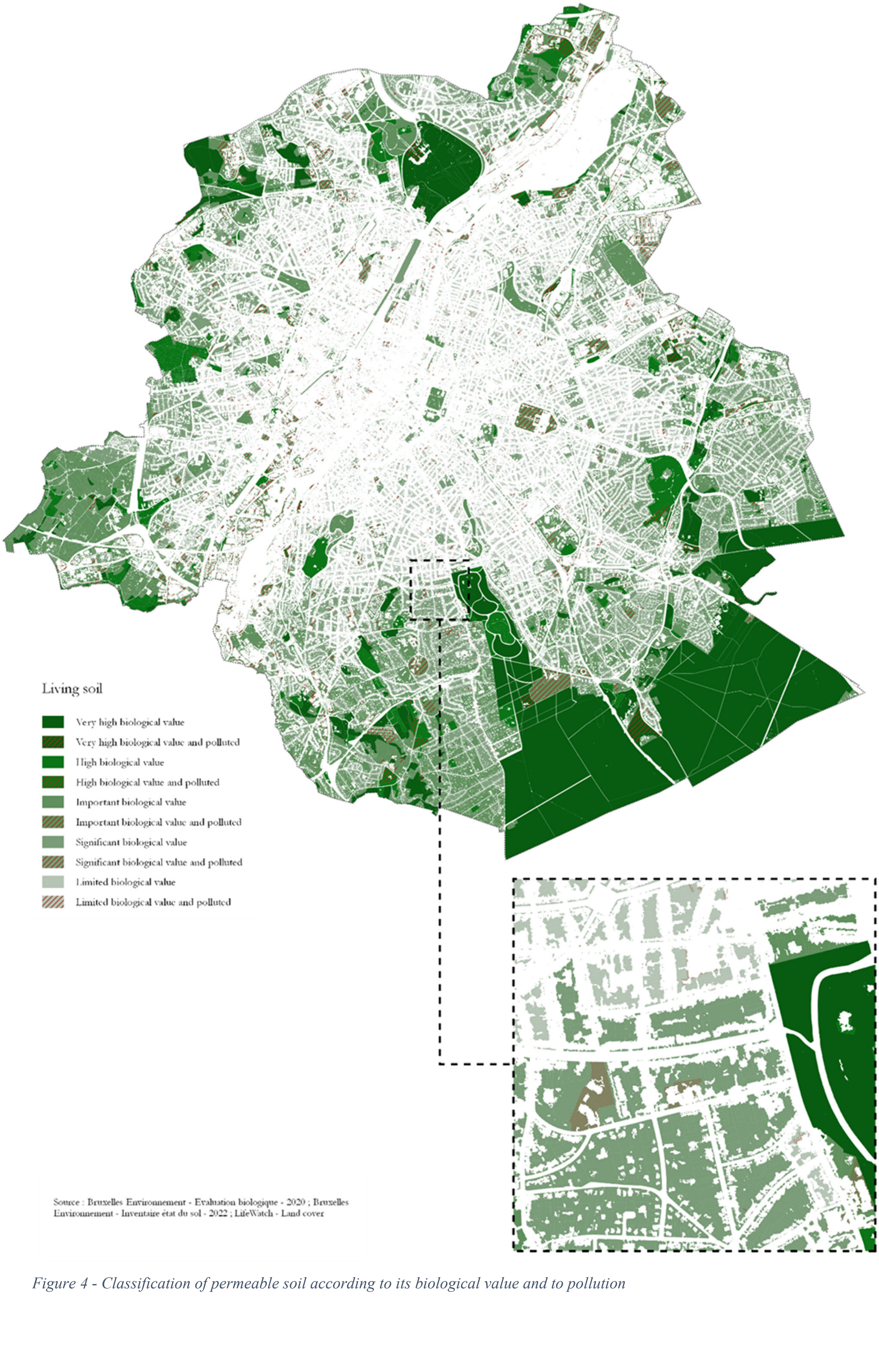


Figure 4 - Classification of permeable soil according to its biological value and to pollution

Subsoil

Data

The third strata of analysis is 'subsoil' (horizon R). As mentioned before in this work, we observe subsoils as interactors or interceptors of urban transformation. In this sense, the most important urban function of this strata is that of infiltrating (or not) and storing (or not) rain, runoff, or leaking water.

For this operation, the research used two databases. The first, produced by the study Brustrati3D (Devleeschouwer et al. 2018), represents the geological layers of the Brussels-Capital Region. The second classifies subsoil in hydrogeological units (Bruxelles Environnement 2020). To pre-process these datasets, the geological layers are sorted according to their depth and also to the hydrogeological unit to which they can be attached.

Three hydrogeological units are important for our work: aquifer, aquitard and aquicludes.

Aquifers are porous and permeable mineral structures, allowing water circulation, which makes them perfect reservoirs from which water can be pumped easily. These strata contain, or can contain, water because of their porosity. The distinction between porosity, which determines the amount of water that can be stored in a mineral structure, and permeability, which measures the ability of water to move through the structure, is important here because it refers to two distinct capacities of the subsoil: first, the ability to store water and second, the capacity to infiltrate it. Moreover, an important distinction for this study: an aquifer can be *confined* when it is surrounded by impermeable strata, or *unconfined*, water can therefore circulate to other surrounding strata.

An aquitard includes geological layers that slow down the circulation of water and are therefore not very permeable. Aquitards can therefore be saturated with water, but infiltration, as well as pumping, are difficult.

Finally, *aquicludes* are impermeable strata, which prevent water movement. However, this category can be porous and consequently contain water. This categorization therefore depends more on the permeability of the structures than on their porosity. Aquicludes are generally clay strata, which do not allow a good circulation of water, unlike sand structures, which are found in the aquifer group (De Bondt and Claeys 2008).

Cartography

To better understand these relationships, in addition to the maps, we produced several sections of Brussels-Capital Region as well as zooms allowing the hydrogeological superpositions of the different subsoil strata to be seen more precisely (*figure 5*).

The first observation is that of detecting the profile of the first barrier to infiltration for any of the different sections produced and consequently to calculate volumes of permeable/porous subsoil. As shown in the section (*figure 5*), the first barrier to infiltration could be due to: groundwater, an aquitard, an aquiclude, or to a combination of these elements.

Moving from a vertical analysis, using sections, to a horizontal analysis, using cartographies, the volume of permeable/porous soil (before the first barrier) is calculated per parcel (*figure 6*). At first glance, the patterns of this map recall the topography and the valleys. Indeed, along the valleys, the upper part of subsoil is composed of impermeable alluvial clays, thus considered as an aquitard, and the groundwater level is also closer to the surface. On closer inspection, however, there are many differences with the topography, because of less permeable geological structures or a higher groundwater level. This map allows us to determine the water storage potential of the subsoil and thus its potential to regulate flood risks, and this for the entire Brussels-Capital Region.

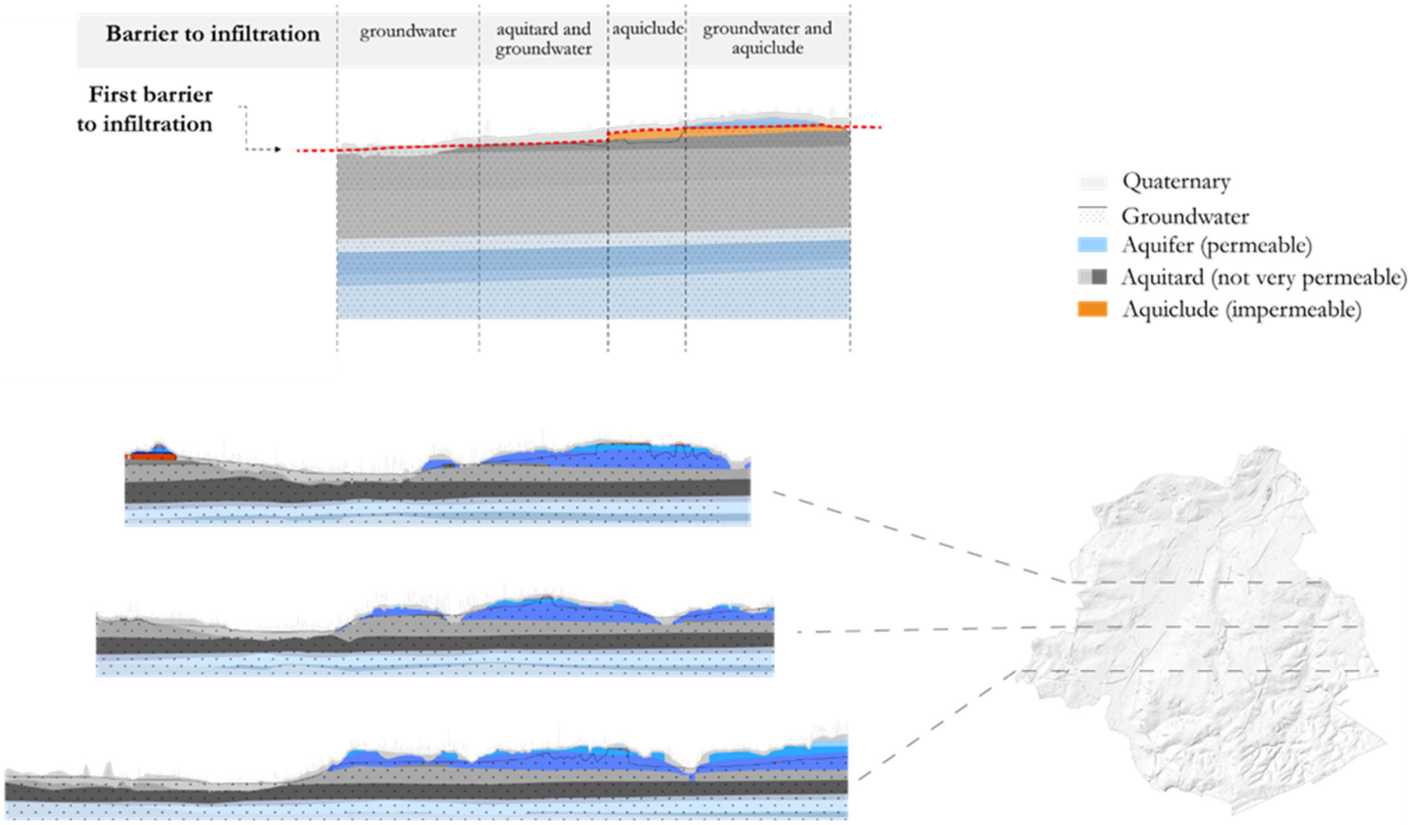


Figure 5 - Sections describing the evaluation of the first barrier to infiltration and three section of the Brussels-Capital Region

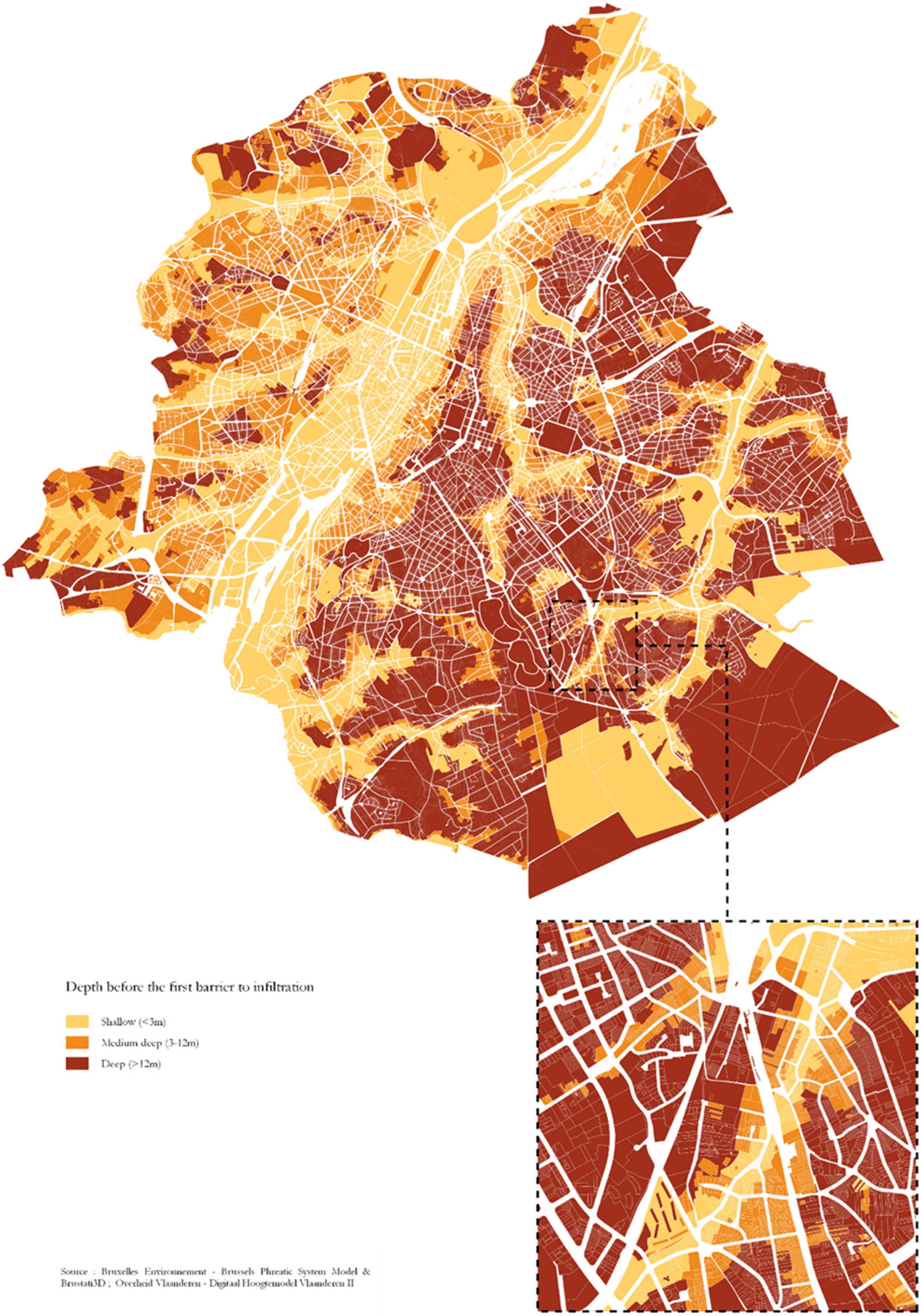


Figure 6 - Map of the depth before the first barrier to infiltration

Results

Interrelations between strata

After a first step of analysis, where strata have been observed as separated items and single units, a second step of the work is that of observing the interaction between the different parts. Interactions that are observed through a common unit of observation, that of the parcel.

As many factors, as well as many regulations applies to the different strata, the crossing possibilities are multiple and still under observation. In this article we propose a first possible reading, while opening paths for continuing this work.

The map in *figure 8* illustrates these relationships between strata by showing only the areas where the soil is permeable and the subsoil has a high infiltration potential. As these two elements are linked, soil and subsoil need both to be permeable to allow water infiltration, the maps show the actual areas where the function of infiltration can be fulfilled. The question of land is also represented on this map, with different colours regarding the affections. The impact of planning on water infiltration is visible: the proportion (*figure 7*) of non-buildable land is higher when only the areas that can infiltrate water are selected (47%), compared with the total non-buildable land of the Region (30%).

However, quite a sizeable portion of the infiltration areas are still in land take zones, highlighting a threat to the soil and subsoil function of infiltration, as the soil of these parcels could be sealed.

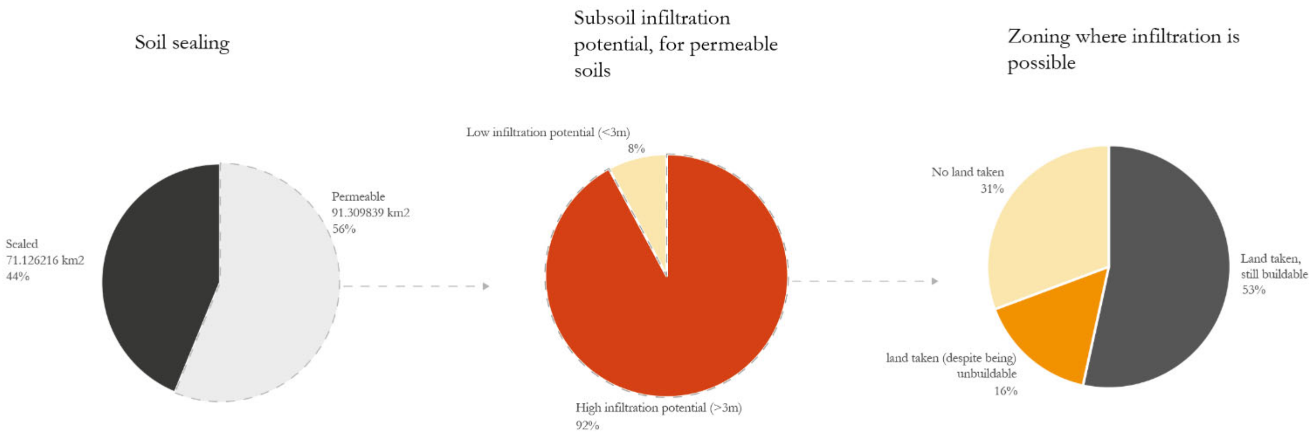


Figure 7 - Distribution of permeable soil, subsoil where water infiltration is possible and its zoning.

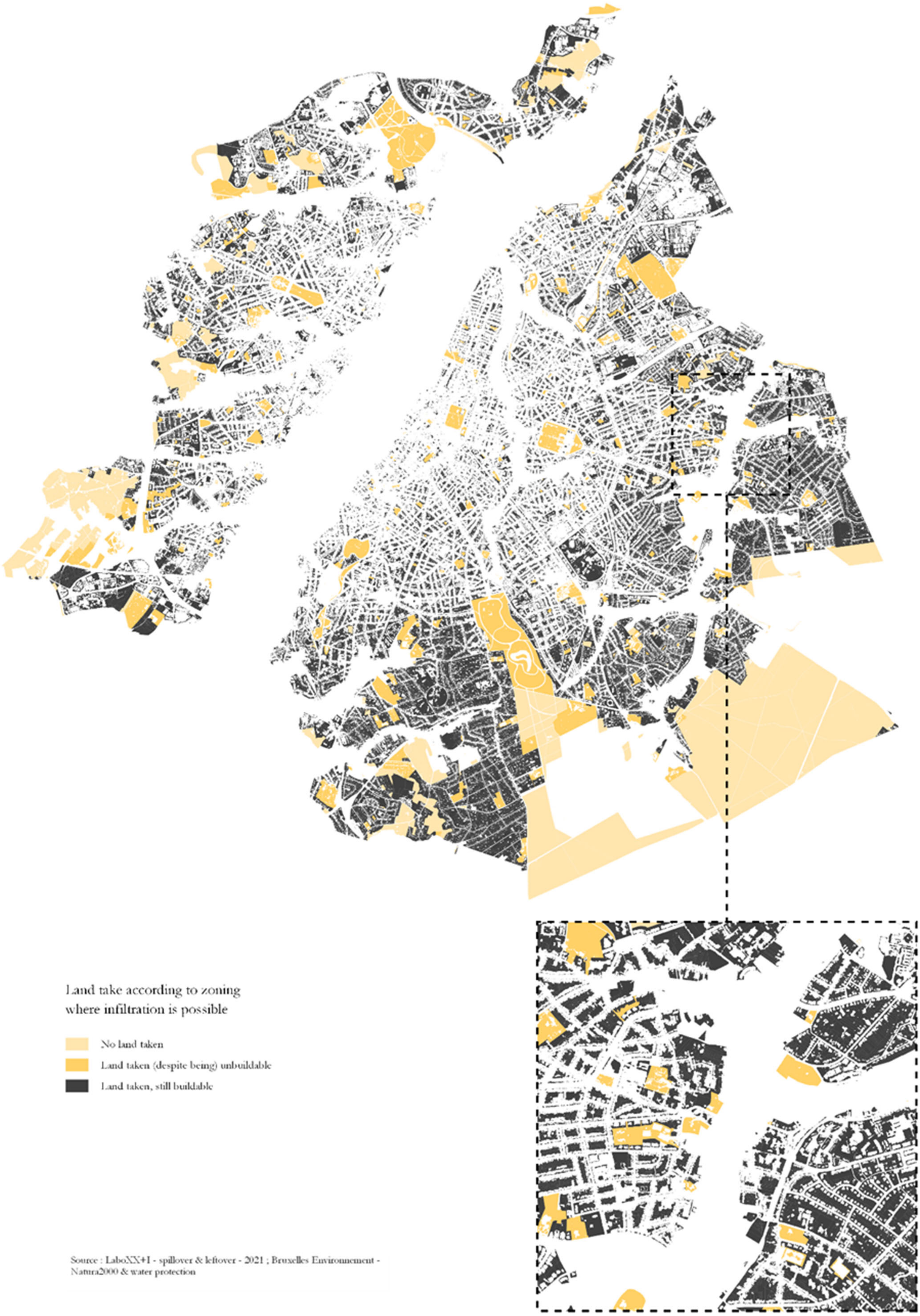


Figure 8 - This map shows land take according to zoning where water infiltration is possible in soil and subsoil

Potential of improvement of soil and subsoil functions

Despite the multiple crossing readings still open to evaluations, this article proposes to recategorize the urban tissue while considering underground dynamics, and in this sense also providing a tool for a better assessment of soil and subsoil for cities to face the ecological transition. The three strata can therefore be crossed with the aim of revealing potentials of improvement of soil and subsoil functions.

For example, the map of *figure 9* shows a combination of: the mostly impermeable parcels, with low biological value, and with a good infiltration potential. This selection highlights a specific geography where a land use cover change could have a significant impact both from the point of view of biodiversity and the one of rainwater infiltration, and thus reducing flooding events.

These parcels represent one third of the total number of parcels of the Brussels-Capital Region, but only 14% of the total surface. They are therefore generally small since they are situated in the most densely built areas of the Brussels-Capital Region.

These parcels are generally located upstream, resulting from the proximity between the subsoil infiltration potential and the topography. From the point of view of 'watershed solidarity' (see *state of the art*), these parcels are therefore all the more important because an increase in infiltration will have positive effects on the downstream flood risks.

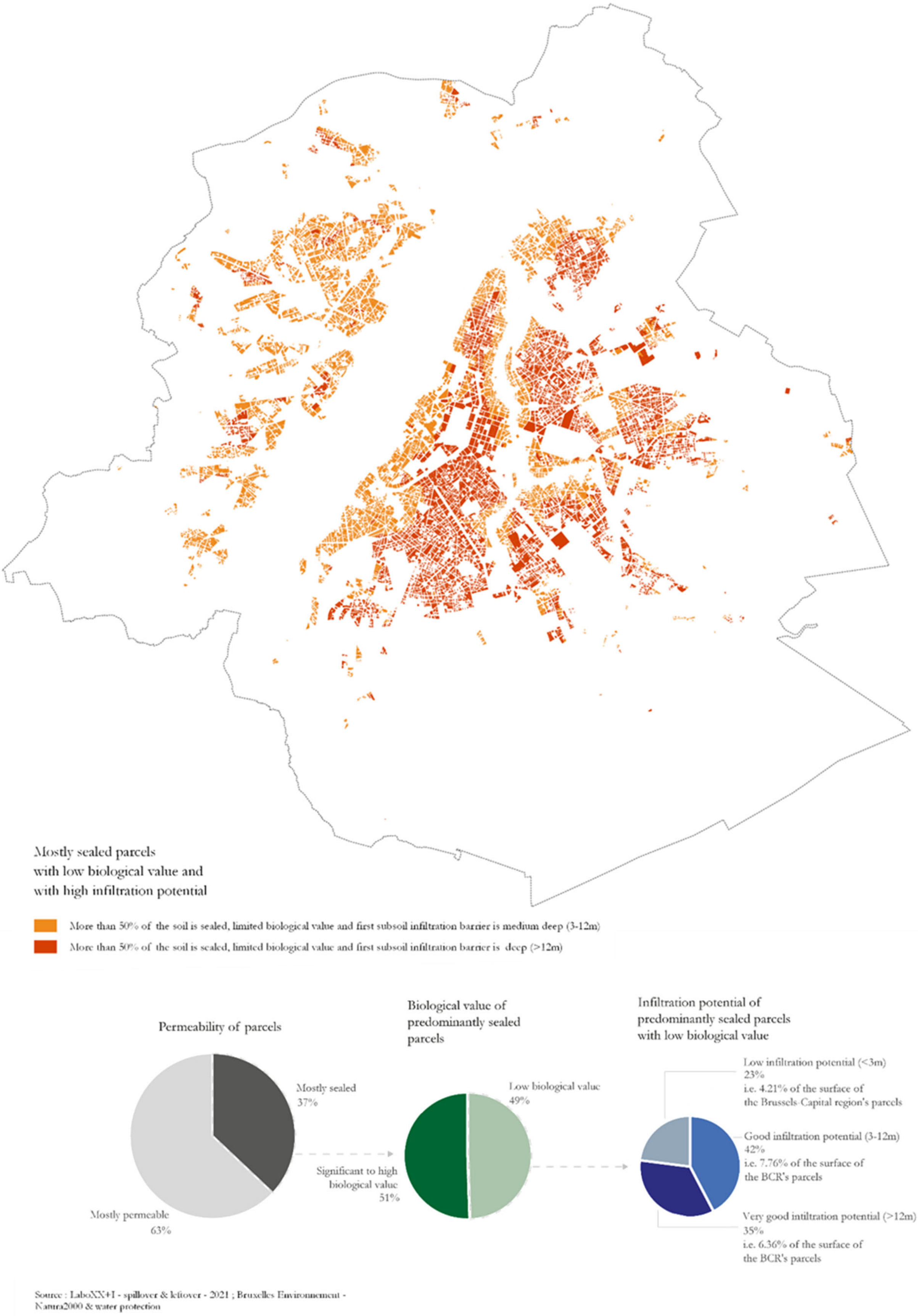


Figure 9 - Parcels where the soil is mostly sealed, biological value is low and the subsoil infiltration potential is high. Distribution of these parcels according to the subsoil infiltration potential.

Conclusions

These examples of combining the different strata give an insight of the possibilities offered by the method presented in this paper. After crossing the different data, resulting in a multitude of new groups, the identification of broad categories is useful, as shown in the last two maps (*figures 8 & 9*).

This clustering can follow a logic specific to the studied issue. For example, when studying rainwater infiltration, impermeable soils laying on permeable subsoils or permeable soils laying on impermeable subsoils lead to the same conclusion: infiltration is limited. It would therefore be possible to group them together in one category. Another approach is to identify potentials and create new clusters according to that (as shown in the previous map, *figure 9*), thus increasing the possibilities of assessment of the soil and subsoil in urban projects.

This last point is central to this paper. The pressures of climate change and demographic growth in Brussels-Capital region require a better consideration of the impact of urban projects on the soil and subsoil. Indeed, whether it concerns biodiversity issues, water management (and the subsequent problems of flooding and drought), or urban climate, considering the soil and subsoil is a key element in which to intervene in order to limit risks and improve cities resilience.

Some questions posed by this paper are open to further exploration. Underground constructions have a significant impact on the subsoil functions. For example, some sections of the Brussels metro act as a barrier, affecting groundwater levels, requiring constant pumping and causing diversion of clean water to the sewage system. Implementing these elements to the model presented in this paper could be an interesting addition.

The recent evolution of soil studies, which not only considers pollution and soil sealing, but also soil structure and emphasis on the soil as a living entity, is also worth investigating. The effectiveness and relevance of measures promoting soil life and water infiltration also depends on their location and context. This opens the door to the spatial study of the implementation of this type of measure, not only in relation to the soil and subsoil but also in relation to, for example, existing green and blue corridors.

Biography

Aragone, Andrea, Davide Cauciello, and Marco Ranzato. 2020. *CAVES*. L Latitude Logbook. Bruxelles: Latitude. https://issuu.com/latitudeplatform/docs/caves_llogbook.

Ashraf, M., M. Ozturk, and M. S. A. Ahmad, eds. 2010. *Plant Adaptation and Phytoremediation*. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-90-481-9370-7.

'Atlas des sols bruxellois'. 2022. Text. Bruxelles Environnement. 25 March 2022. https://environnement.brussels/thematiques/sols/good-soil/atlas-des-sols-bruxellois.

Boivin, Daniel J. 1989. 'De l'occupation du sous-sol urbain à l'urbanisme souterrain'. *Cahiers de géographie du Québec* 33 (88): 37–49. https://doi.org/10.7202/021998ar.

Bruxelles Environnement. 2020. 'Unités hydrogéologiques de la Région de Bruxelles-Capitale (UH/RBC)'. Text. Bruxelles Environnement. 14 April 2020. https://environnement.brussels/thematiques/geologie-et-hydrogeologie/eaux-souterraines/hydrogeologie/unites-hydrogeologiques-de-la.

Cavalieri, Chiara. 2019. 'Soil: From Conservation to Modification "No Net Land Taken" in Flanders'. In , 105. Jakarta: International Forum on Urbanism (Faculty of Architecture TU Delft).

Commission to the european parliament, Council, European economic and social committee, and Committee of the regions eu. 2021. *Soil Strategy for 2030 : Reaping the Benefits of Healthy Soils for People, Food, Nature and Climate*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699.

Crespin, Dimitri. 2020. 'Case Study from Belgium on BrusSEau - Project on Water Management in Brussels'. OECD TIP Co-creation project. https://stip.oecd.org/assets/TKKT/CaseStudies/37.pdf.

Darwin, Charles. 1881. *The Formation of Vegetable Mould through the Action of Worms, with Observations on Their Habits*. London: John Murray.

De Bondt, Kevin. 2017. 'The Forgotten Connections between Groundwater and Urban-Water Management Policies'. Thèse de doctorat, Bruxelles: Vrije Universiteit Brussel.

De Bondt, Kevin, and Philippe Claeys. 2008. 'Cartographie du potentiel d'infiltration-percolation en région bruxelloise.' Rapport d'étude. Bruxelles: Vrije Universiteit Brussel (VUB), Bruxelles Environnement.

Devleeschouwer, X, C Goffin, J Vandaele, and B Meyvis. 2018. 'Modélisation stratigraphique en 2D et 3D du sous-sol de la Région de Bruxelles-Capitale'. 2016B0512. Institut Royal des Sciences Naturelles de Belgique ; ervice Géologique de Belgique.

Directive 92/43/CEE. 1992. *OJ L*. Vol. 206. http://data.europa.eu/eli/dir/1992/43/oj/fra.

Directive 2009/147/CE. 2009. *OJ L*. Vol. 020. http://data.europa.eu/eli/dir/2009/147/oj/fra.

Dubois, Quentin, and Julien Rengle. 2020. 'Actualisation de la carte d'évaluation biologique de la Région de Bruxelles-Capitale'. Bruxelles: Bruxelles Environnement.

EC. 2011. 'Roadmap to a Resource Efficient Europe (No. COM(2011) 571)'. European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0571.

'Good Soil'. 2020. Text. Bruxelles Environnement. 21 September 2020. https://environnement.brussels/thematiques/sols/good-soil.

Gouvernement de la Région de Bruxelles-Capitale. 2006. *Règlement Régional d'urbanisme. Titre 1*. Vol. 11, 13, 16. http://urbanisme.irisnet.be/pdf/RRU_Titre_1_FR.pdf.

Havlicek, Elena. 2016. 'Le sol urbain : surface inerte ou capital naturel'. In *Le sol des villes: ressource et projet*, by Panos Mantziaras and Paola Viganò, 19–35. VuesDensemble. Genève: MétisPresses.

Hazelton, Pam, Brian Murphy, and CSIRO Publishing Staff. 2009. *Understanding Soils in Urban Environments*. Victoria, AUSTRALIA: CSIRO Publishing. http://ebookcentral.proquest.com/lib/uclouvainbe/detail.action?docID=656450.

'Inventaire de l'état du sol'. 2020. Text. Bruxelles Environnement. 29 March 2020. https://environnement.brussels/lenvironnement-etat-des-lieux/en-detail/sol/inventaire-de-letat-du-sol.

Labo XX+I. 2021. *L'urbanisation du 20e siècle dans et autour de Bruxelles Exploration de la zone sur base de douze questions urbaines.* Departement Omgeving, avec Perspective.brussels, Bouwmeester Maitre Architecte, Team Vlaams Bouwmeester. Bruxelles.

'Land Take in Europe'. 2019. Indicator Specification. European Environment Agency. 11 December 2019. https://www.eea.europa.eu/data-and-maps/indicators/land-take-3.

Mantziaras, Panos, and Paola Viganò. 2016. *Le sol des villes: ressource et projet*. VuesDensemble. Genève: MétisPresses.

Peleman, David, Elsbeth Ronner, Martina Barcelloni Corte, and Paola Viganò. 2022. 'Exploring the Soil: Not a Sentimental Journey'. *Oase*, no. 110: 5–15.

Perrin, Coline, and Christophe-Toussaint Soulard. 2017. 'Introduction. L'agriculture dans le système alimentaire urbain : continuités et innovations'. *Natures Sciences Societes* 25 (1): 3–6.

Protasoni, Sara. 2022. 'Das Edaphon : Raoul Heinrich Francé and the Ecology of Soil'. *Oase*, no. 110: 23–32.

Radoux, Julien, T. Coppée, A. Bourdouxhe, Q. Vandersteen, Marc Dufrêne, and P. Defourny. 2018. 'Ecotopes v2.9 Technical Report'. Université catholique de Louvain, Earth and Life Institue ; Université de Liège, Gembloux AgroBiotech.

Ranzato, Marco, Andrea Bortolotti, Catalina Dobre, Luisa Moretto, Géry Leloutre, and Université libre de Bruxelles Faculté d'architecture La Cambre-Horta. 2017. *Water vs. Urban Scape: Exploring, Integrated Water-Urban, Arrangements*. Berlin: Jovis.

Secchi, Bernardo. 1986. 'Progetto Di Suolo'. *Casabella: Composizione/Progettazione*, 1986.

United Nations. 2013. *World Soil Day and International Year of Soils*. *A/C.2/68/L.21*. UN,. https://digitallibrary.un.org/record/759987.

Vialle, Antoine. 2022. 'Downscaling Urbanism to the Fine Grain of Urban Soils : Another Look at the Urban Footprint'. *Oase*, no. 110: 115–23.

Viganò, Paola, and Claire Guenat. 2022. 'Our Common Soil'. *Oase*, no. 110: 53–66.

Zunino, Gwenaëlle. 2011. 'Imaginer les espaces souterrains de la ville de demain'. *Note rapide*, October 2011, Institut d'aménagement et d'urbanisme edition.