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Ph.D. Thesis

Conceptual model of the land-use influence on representation of water-stable aggregates in topsoil

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I hereby confirm that this thesis "Conceptual model of the land-use influence on representation of water-stable aggregates in topsoil" was elaborated independently and that I have cited all the information sources used in this thesis.

March 12th 2024, Prague

Author signature

Poděkování

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Abstrakt

Voda v krajině je otázkou optimalizace srážko-odtokových vztahů a posílení retence vody v půdním prostředí. Vodo-stabilní půdní agregáty (WSA) jsou důležitým indikátorem kvality půdy a můžeme pomocí nich půdu a její strukturu blíže popsat, neboť významně ovlivňují infiltraci, retenci, kapacitu a pohyb vody v půdě. Cílem této práce bylo popsat roli WSA na celkovou strukturu půdy a její změny způsobené rozdílným využitím půdy (land-use) a na základě získaných výsledků a výstupů navrhnout koncepční model těchto procesů. Pro porovnání parametrů WSA byly použity vzorky z lokalit v ČR i v zahraničí (Portugalsko, Rusko, Litva, Kazachstán), které se nacházejí přibližně kolem 50. rovnoběžky severní šířky, ovšem představují kontrastní klimatické oblasti. WSA byly zjišťovány pomocí metody mokrého prosévání s využitím laboratorního přístroje. Po provedeném testu bylo určeno zastoupení jednotlivých frakcí a vypočítány další parametry struktury půdy. Vybrané vzorky půdy byly testovány na přítomnost a množství mikroplastů (MPs) v orné a lesní půdě, kdy nejprve došlo k filtraci a následně k obarvení MPs nilskou červení. Pomocí softwaru HYDRUS 1D byla modelována vzorová situace dvou vrstev půdního profilu. V rámci této práce bylo zjištěno, že rozdílné využití půdy má na tvorbu WSA významný vliv. Na všech zkoumaných lokalitách měla lesní půda vyšší zastoupení větších frakcí (>2 mm; 2-1 mm), což má vliv na lepší infiltraci a následné zadržení vody v půdním profilu. Naopak v orné půdě tvořily většinu vzorku frakce menší než 1 mm a na několika lokalitách zcela chyběly frakce >2 mm a 2-1 mm. Lze předpokládat, že při dešti se dopadající voda bude vsakovat velmi pomalu, dojde k vytvoření málo propustné horní vrstvy a následnému povrchovému odtoku (erozi). Z naměřených dat bylo zjištěno, že u lesa vysazeného na bývalé orné půdě dochází k postupné tvorbě WSA, přičemž nejlepší hodnoty z hlediska zastoupení WSA vykazoval les mezi 10 až 24 rokem. Z hlediska výskytu mikroplastů (MPs) bylo v lesní půdě zaznamenáno 62 částic/5g. V orné půdě bylo zastoupení menší s počtem 40 částic/5g. Zjištěný počet MPs je nejspíše ovlivněn vyšší půdní erozí na orné půdě, jejímž prostřednictvím se MPs uzavřené v WSA dále pohybují v životním prostředí (pole-vodní tok). V programu HYDRUS 1D bylo ověřeno, že určení odlišných vrstev půdy a jejich struktury vede k upřesnění infiltrační a retenčních modelů, a zisku přesnějších výsledků. Hlavním výsledkem celé práce je koncepční model, který uceleněně dokládá význam WSA pro životní prostředí a vlivy, které mají na tvorbu WSA podstatný vliv. Vytvořený koncepční model rovněž ukazuje směr budoucího výzkumu v této oblasti.

Klíčová slova: půda, vodostabilní agregáty, WSA, zrnitost, mikroplasty, koncepční model

Abstract

Water in the landscape is a matter of optimizing rainfall-runoff relations and strengthening water retention in the soil environment. Water-stable soil aggregates (WSA) are an important indicator of soil quality and can be used to describe the soil more closely, as they significantly influence the infiltration, retention and movement of water in the soil. The aim of this thesis was to describe the role of WSA on the overall structure of the soil and its changes caused by different land-use and to propose a conceptual model of these processes based on the obtained results and outputs. For the comparison of WSA parameters, samples from localities in the Czech Republic and abroad were used, which are all located around the 50°N, but represent contrasting climatic regions. WSA were estabilished using the wet sieving method. The representation of individual fractions was determined and other parameters of the soil structure were calculated. The selected soil samples were tested for the presence and amount of microplastics (MPs) in arable and forest soil. An example situation of two layers of the soil profile was modeled using the HYDRUS 1D software. It was found, that different land use has a significant influence on the formation of WSA. At all investigated locations, the forest soil had a higher proportion of larger fractions (>2 mm; 2-1 mm), which has an effect on better infiltration and subsequent retention of water in the soil profile. On the contrary, in the arable soil, fractions smaller than 1 mm made up the majority of the sample, and fractions >2 mm and 2-1 mm were completely absent in several locations. Rain water in arable land will soak very slowly, a poorly permeable upper layer will form and surface runoff (erosion) will occur. From the measured data, it was found that a forest planted on former arable land had a gradual formation of WSA with best values between 10 and 24 years. In terms of the occurrence of microplastics (MPs), 62 particles/5g were recorded in the forest soil. In arable soil, the representation was smaller with the number of 40 particles/5g. The detected number of MPs is most likely influenced by higher soil erosion on arable land, through which MPs enclosed in WSA move further in the environment (field-watercourse). In the HYDRUS 1D, it has been verified that the determination of different soil layers and their structure leads to the refinement of infiltration and retention models, and to obtaining more accurate results. The main result of the entire work is a conceptual model that comprehensively demonstrates the importance of WSA for the environment and the influences that have a significant impact on the creation of WSA. The created conceptual model also shows the direction of future research in this area.

Key words: soil, water-stable aggregates, WSA, texture, microplastics, conceptual model

Content

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Chapter II - Methodology

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Introduction

Nowadays, phenomena such as extreme drought and lack of precipitation or, conversely, torrential rains that the soil cannot quickly absorb are becoming more frequent. This often leads to loss of fertile soil, siltation of rivers and possible floods. For agriculture, forestry and other sectors that use water in the landscape, management practices in conditions of precipitation extremes are important. Water in the landscape is a matter of optimizing rainfall-runoff relations and strengthening water retention in the landscape. This task requires a comprehensive approach with a focus on soil protection as a decisive medium of the entire process. Soil structure is significantly influenced by the quantity and quality of soil organic matter. Fixation of organic matter in the soil is mainly caused by complex interactions, such as the sorption of substances or binding of organic matter in soil aggregates. Water-stable soil aggregates (WSA) are an important indicator of soil quality and can be used to describe the soil and its structure in more detail. WSA significantly affect the infiltration, retention, capacity and movement of water in the soil in cooperation with soil aeration, which has been confirmed by many authors, who focus on the influence of land use (Pagliai et al., 2004; Saha et al., 2011a; Kalhoro & Raza, 2017; Polláková et al., 2018) different age of forest stand (Ritter et al., 2003; Wall & Hytönen, 2005a; Podrázský et al., 2015; Holátko et al., 2022), soil organic matter content (Gajic et al., 2006; Šimanský & Jonczak, 2016), carbon representation (Sekaran et al., 2021; Kunmala et al., 2023a), different intensity of rain (Zeng et al., 2018), binding of microplastics (Liang et al., 2021) or on the impact of different earthworm ecotypes (Hallam & Hodson, 2020).

The author of this work has been dealing with the study of WSA for a long time, and his research focused on determining the representation of WSA in soils with different uses (forest/arable) using the wet sieving method. For the comparison of WSA parameters, samples from localities in the Czech Republic and abroad (Portugal, Russia, Lithuania, Kazakhstan) were used. Almost all the investigated localities are located near 50° north latitude, but represent different climatic regions. At the beginning, the basic procedure for determining WSA fractions was established. Subsequently, the influence of different land use was examined. In the next part of the research, the influence of the age of the forest stand planted on former agricultural land was investigated and compared the representation of WSA fractions. At the one selected locality in Czech republic (Praha-Lysolaje), the amount of microplastics (MPs) bound inside the WSA was determined.

Due to the importance of WSA in the environment, the author decided to collect information and parameters that can be obtained by studying them. The aim of this work was to describe the role of WSA on the overall structure of the soil and its changes caused by different land-use and create conceptual model. This model describes which processes influence the formation of WSA and, conversely, what the representation of WSA in the soil environment contributes to. The conceptual model also includes a demonstration of several practical applications.

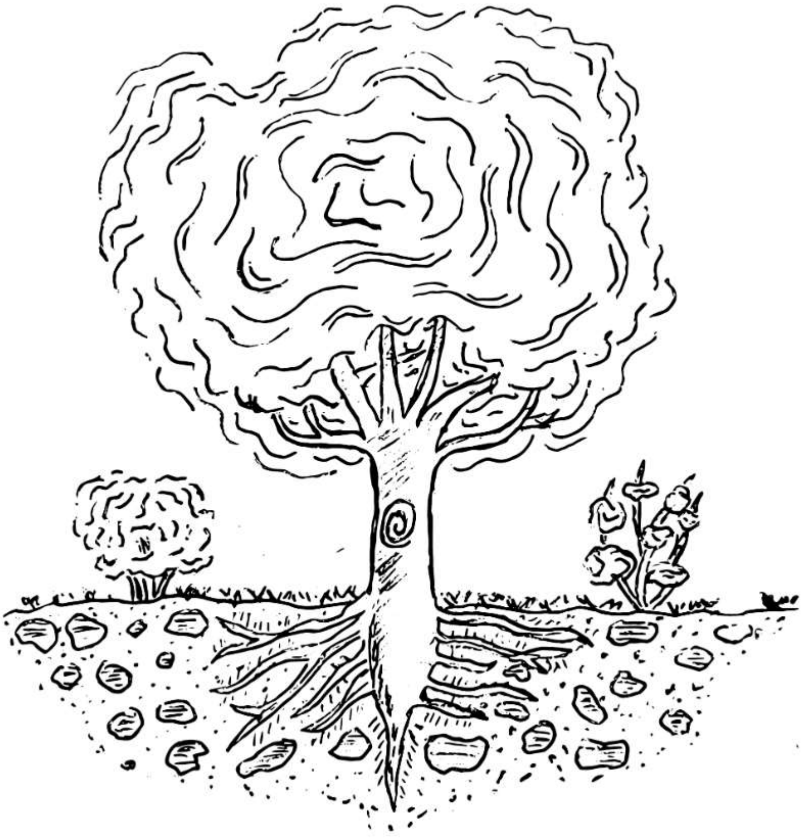
The thesis was divided into three main chapters. In the first of them, a literature review related to the research topic is given. The work process and chosen methods are the content of the second chapter. In the third and last chapter, all obtained results, a conceptual model and practical applications are presented.

Aim of the thesis

The aim of this thesis was to describe the role of WSA on the overall structure of the soil and its changes caused by different land-use and, based on the outputs, to propose a conceptual model of these processes. For the comparison of WSA parameters, samples from localities in the Czech Republic and abroad (Portugal, Russia, Lithuania, Kazakhstan) were used. The sites represent contrasting climatic regions at approximately 50°N, except Portugal which is located near 40°N. The research can be divided into 4 main objectives:

1) Create grain size curves, determine the representation of individual WSA fractions and other parameters at each examined location.
2) Determine the effect of the age of the forest stand planted on former agricultural land in connection with the formation of WSA.
3) Test selected soil samples (arable, forest) from a locality in the Czech Republic for the presence and quantity of microplastics in arable and forest soil.
4) To design a conceptual model that comprehensively illustrate the relevance of WSA to processes in the soil environment and also brings information that can be derived from WSA samples, including practical examples.

Chapter I – Literature review



Soil plays a significant role in the cycle within the entire ecosystem substances and energy flow. Its properties are depending on the parent rock, length and intensity of physical activity and chemical factors. Soil fractions and structure also depend on the methods of management and land-use. It is also an environment for various organisms that, together with solid particles, form a complex assembly of interacting components (Solomon et al., 2000).

1.1 Climate changes

Currently, mankind increasingly encountering the negative effects of global changes in the landscape. We can thus observe manifestations of extreme events such as abiotic situations (drought, floods, spring frosts) and biotic factors (spread of invasive species of plants and animals, calamitous overpopulation of pests) in the nature (Marek, 2022). Despite the occurrence of years with sufficient rainfall, the most significant impact of the changing climate is and will continue to be the loss of water in the landscape and its lack, especially for the needs of agriculture and forestry (Slaboch et al., 2022). Specific examples can be found in the area of the Czech Republic which is located in the temperate zone, area of the transitional climate of Central Europe. The territory of the Czech Republic is influenced by wind circulation and geographical conditions. The climate depends mainly on cyclonic activity and according to its activity the individual years are very variable (Brázdil et al., 2008). Due to specific hydrological conditions associated with the absence of significant transboundary influx, the only source of surface water in the Czech Republic is precipitation (Balvín et al., 2021). The distribution of annual precipitation totals in the Czech Republic is also conditioned by altitude. Extreme events of weather will be more common in the future and can affect different aspects of human life (Kundzewicz, 2016).

Previously recorded weather fluctuations must be taken into account, when several episodes of drought have come and caused considerable damage. Brázdil et al. (2015) rank the years 1904, 1911, 1917, 1921, 1947, 1953 and 1954, 1959, 1992 among the most extreme and detailed dry episodes in the 20th century. However, current analyses see trends in last years to be more extreme (Zahradníček et al., 2014). In the new millennium, drought affected Czech agriculture in 2000, 2003, 2007, 2012, 2015 (Stepanek et al., 2016) and the drought persists also in 2019 (Meitner et al., 2023).

The increased frequency of these dry years, their intensity and area thus have the character of a long-term drought, where the occurrence of colder and rainier periods is no longer sufficient. The last onset of droughts in the Czech lands can be more clearly attributed to significantly increasing temperatures than to any important decrease in precipitation totals (Trnka et al., 2011).

Drought and its negative effects are accumulating, they are beginning to occur in nature, for example, in the decline of shallow groundwater, and the problem of drought is coming to the forefront of society as a whole and can be defined as a prolonged deficiency of precipitation usually for a season or more (Trenberth et al., 2014). According to current knowledge, there is a gradual decrease in soil moisture reserves (Trnka et al., 2011) and the risk of drought is currently the highest in the last 130 years (Brázdil et al., 2009). Extreme events (droughts) are expected to have a negative effect on the formation of soil organic matter, the increase of desertification phenomena, such as drying of the landscape associated with limiting factors such as lack of water in the soil, decrease of filtration, transformation and exchange processes (Gelybó et al., 2018).

In the future, a change in the uniformity of precipitation throughout the year is expected. While winter, spring and autumn precipitation will increase, summer precipitation will decrease. The combination of lower precipitation and higher temperatures will have an adverse impact on crop growing, among other things, due to the increased risk of drought in this season (Stepanek et al., 2016; Skalák et al., 2018) Drought impacts on crops will increasingly be the cause of high yield variability and regional yield declines (Kolář et al., 2014). Mitigating the effects of drought clearly includes caring for the soil, increasing the content of organic matter in the soil and generally maintaining its good structure and fertility (Marek, 2022).

1.2 Soil composition

The soil is made up of solid particles, both mineral and organic, and pore spaces that are filled with water and air (Fig. 1). Soil organic matter (SOM) is attached to the mineral grains and may bind them together in assemblages called aggregates (Webster, 2005). Mineral soil is formed from rock, a slow proces that may take a thousand years to form. Organic matter, which comes from plants and animals, forms at a much faster rate and is widely regarded as beneficial to soil function and fertility in agricultural production (Swaminathan et al., 2021). SOM comes either from plant and crop residues, such as stems, leaves, or indirectly from sewage or manure, animal tissue and excretory products. Important is that while the volume of the solid phase is stable in the soil, the water and air content change in mutual relationship. Soil texture, soil parent material, soil organic matter and disturbance all influence soil stability (Bird et al., 2007).

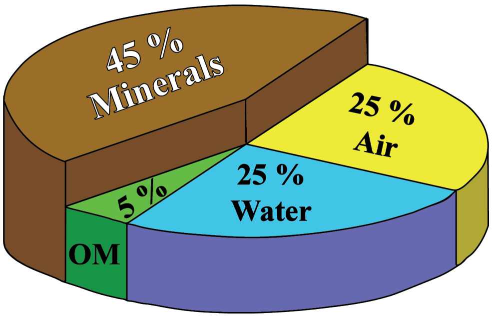


Figure 1: Soil composition. Illustrated by author.

Soil structure

Soil structure is one of the physical parameters of soils, which expresses spatial arrangement of aggregates in soil (Prax et al., 2001). The arrangement includes individual soil particles, sand, silt and clay merged into larger aggregates of varying sizes and shapes (Fig. 2). Shapes include granular, columnar or blocky forms; soils with no apparent structure are termed massive (Brady & Weil, 2002). Soil structure is important for soil productivity and sustainable quality of environment and can be defined in terms of form and stability (Kay et al., 1988). The structure dictates the relationship of water volume to air volume in the soil, the value of both static and dynamic hydro-physical parameters, the rate and degree of water retention, the degree of water availability for plants, soil thermal properties, as well as the soil´s mechanical properties: its consistency, adhesion, friction, soil-soil and soil-metal relationship, all of which determine cultivations conditions (Słowińska-Jurkiewicz et al., 2012).

The variable amount of water contained in volume of soil is important factor affecting the growth of plants. Braekke et al. (1978) reported 64% total biomass of fine roots and 42% of total roots to a depth of 10 cm. Numerous other soil properties depend on water content. Among this are mechanical properties, such as consistency, plasticity, strength, compatibility, permeability, stickiness (Hillel, 2003). Soil structure is also influencing the susceptibility of the soil to the destructive factors of water and wind erosion and strongly affects the nature and pace of the transformation processes of organic matter, the availability of nutrients for plants, or the success of fertilizer application, so it is undoubtedly one of the major determinants of soil fertility (Domzał & Słowińska-Jurkiewicz, 1987).

The most valuable is aggregate structure with the predominance of crumbs created by coagulation of soil colloids and the development of coagulate combinations with larger particles. At the initial stage of soil aggregate formation, exchangeable cations promote the aggregation of soil particles (including inorganic minerals and SOM) to form larger clusters by changing soil particle interactions (Li et al., 2023). Due to formation of durable crumbs resistant to water destruction, the root system of plants and soil microorganisms are provided with suitable conditions for the supply of water, oxygen and nutrients (Domzal et al., 1993).

It is known that soil structure is very significantly influenced by the amount and quality of SOM and the representation of soil aggregates. Water-stable soil aggregates (WSA) have a significant effect on water binding in the soil and availability of plant nutrients (von Lützow et al., 2007). This is generally aimed at improving soil conditions at worse production sites and includes not only drainage, but also irrigation, modification of inappropriate soil reaction or anti-erosion protection (Žalud et al., 2020).

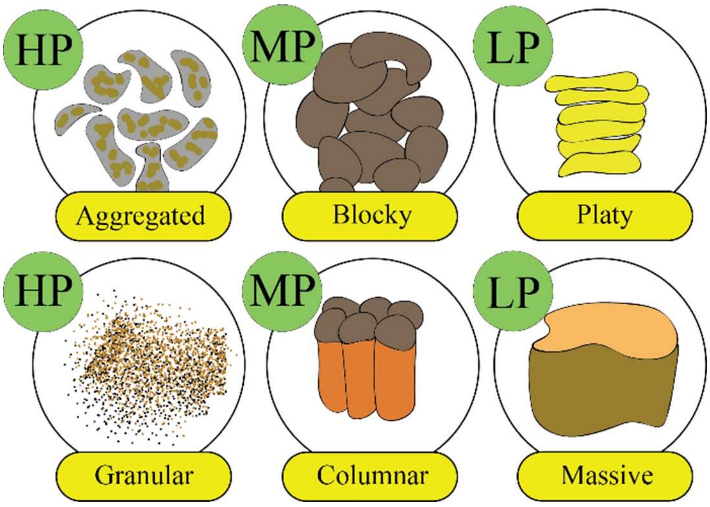


Figure 2: Different shapes of soil structure;
HP, MP, LP stands for High, Medium and Low permeability. Illustrated by author.

Particle size distribution

Soil texture is based on different combination of sand, silt, and clay separates that make up the particle-size distribution (PSD) of a soil sample. The hydrometer method, which is based on Stoke's law is often used. This method governs the velocity at which particles settle in suspension: the larger the particles, the greater are their settling velocities, and vice versa (Suits et al., 2002). In general it includes measuring the mass fractions of three primary particles (sand, silt, and clay) and determining the soil textural class using the texture triangle (Montero, 2005; Mandhaniya et al., 2023). Triangle (Fig.3) shows the USDA-defined limits for the basic soil textural classes (USDA, 1975). PSD of soil is the most basic geotechnical property of soil which affects its overall behavior. Getting to know what a soil sample consists of give a general estimate of its strength (Mandhaniya et al., 2023).

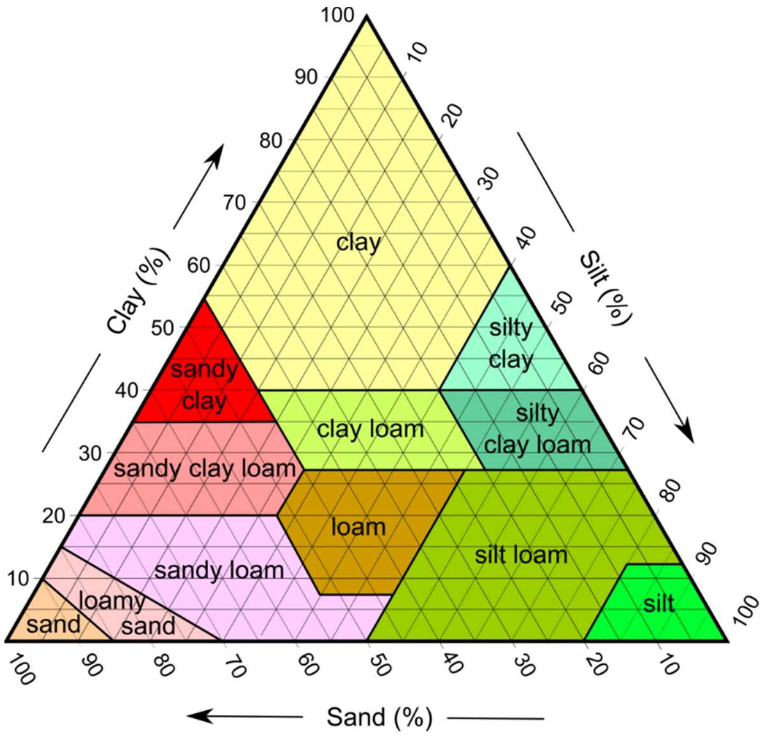


Figure 3: USDA Soil Texture Triangle. Adapted from USDA (1975)

Particle-size analysis data can be presented and used in several ways, the most common being a cumulative particle-size distribution curve (Fig. 4). The percentage of soil particles less than a given particle size is plotter against the logarithm of the effective particle diameter. PSD curves, when differentiated graphically, produce frequency distribution curves for various particle sizes (Dane & Hopmans, 2002).

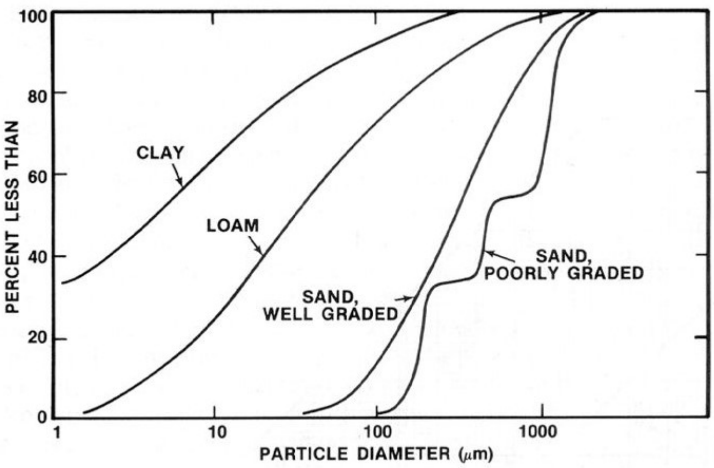
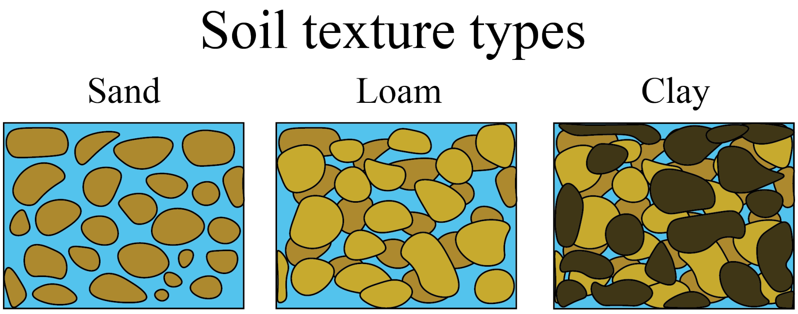


Figure 4: Particle-size distribution curves for several soil materials. Adapted from Hillel (1982)

PSD curves usually exhibit a peak or peaks representing the most prevalent particle sizes. PSD relates to soil's porosity, permeability, consolidation, shear and volume change behavior. Therefore, PSD curve is essential information in engineering and environmental geosciences, sedimentalogy and pedology (Suits et al., 2002), and is used extensively by geologist in geomorphological studies to evaluate sedimentation and alluvial processes, and by civil engineers to evaluate materials used for foundation, road fills, and other construction purposes (Dane & Hopmans, 2002). Hydrologist often use particle size analysis as means of predicting hydraulic properties, particularly for sands (Bloemen, 1980). Arya & Paris (1981) intended to predict water retention and unsaturated hydraulic conductivity of soils for materials rating from sands to clays, which have different retention, infiltration and availability of water (Fig. 5).



Infiltration rate		
very fast	moderately fast	very slow
Water retention		
weak	strong	very strong
Availability of water		
bad	good	medium good

Figure 5: Properites of different soil textural types. Illustrated by author.

1.3 MWD and contact angle

Mean weight diameter

The parameters that can be determined for soil (WSA) include mean weight diameter (MWD), which is the most widely used indicator for estimating aggregate stability (Choudhury et al., 2014). MWD is widely used index to integrate aggregate size distributions obtained by mechanical sieving. In most studies, MWD measurements showed an important variation under different cropping and tillage practices (Mohanty et al., 2012). The greater MWD of soil aggregates under different vegetation covers was due to lower degree of disturbance and higher soil organic carbon (SOC) content. Chellappa et al. (2021) found positive correlation of SOC and MWD depicts that increase in SOC in the soil will increase the MWD of aggregates significantly. Prior research has shown that MWD is closely related to soil texture (i.e., sand, silt, and clay %), organic carbon (OC) content and soil bulk density (Cañasveras et al., 2010). MWD is calculated as the sum of the proportion of aggregates in each size class, proportionally weighted by the mean diameter of aggregates in that size class used (Liu et al., 2019).

Contact angle

Contact angle characterises the wettability of solid surfaces (Rudawska, 2013; Marmur et al., 2017). The contact angle is the angle at which a liquid/vapour interface meets a solid surface (Zhang et al., 2020). The contact angle (CA) is specific for any given system and is determined by the interactions across the three interfaces. Most often the concept is illustrated with a small liquid droplet resting on a flat horizontal solid surface (Fig. 6).

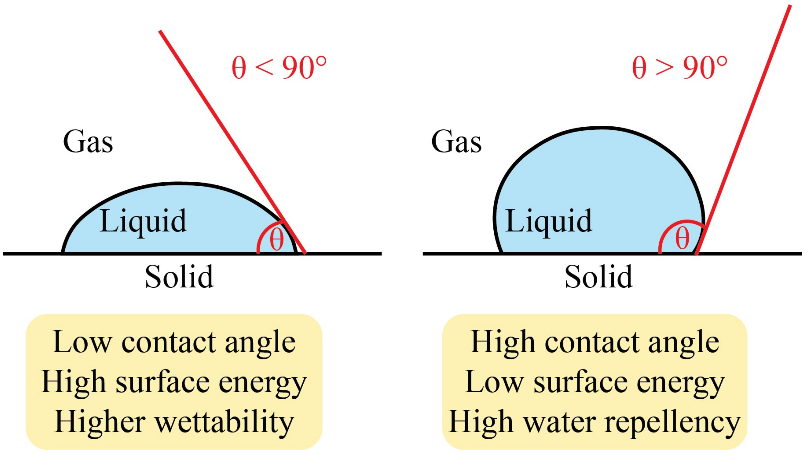


Figure 6: Contact angle by the interactions across the three interfaces. Illustrated by author.

A water drop that is placed on a wettable surface spreads and form CA. The CA for wettable soils is often assumed to be 0 degrees, but for water repellent soils the angle may be large, even larger than 90 degrees (Kutílek & Nielsen, 1994). Higher wettability occurs at low CA <90° and water repellency at high CA > 90° (Szafraniec & Barnat-Hunek, 2020). If the CA between liquid and solid surface is less than 90°, the surface is called hydrophilic, otherwise the surface is called hydrophobic. If the CA surface is in a range of 0-30° this surface is called superhydrophilic. In case of superhydrophobic surfaces the CA exceeds 150° that means that these surfaces are extremely difficult to wet (Zemfira & Milanovskiy, 2015). CA is critical to water infiltration, redistribution, groundwater recharge, solute transport in unsaturated zones, compaction and aeration in variably saturated soils, and temperature-induced water redistribution (Bachmann & Ploeg, 2002).

1.4 Infiltration and retention

Infiltration is the term applied to the process of water entry into the soil, generally by downward flow through all or part of the soil surface. The rate of this process, relative to the rate of water supply, determine how much water will enter the root zone and how much, if any, will run off (Hillel, 2003). Infiltration is in relationship with soil permeability which is the ability of the soil to pass water under saturated conditions (Suharyatun et al., 2023). It is affected by the texture, structure and porosity of the soil. The permeability of a soil during infiltration is mainly controlled by big pores, in which the water is not held under the influence of capillarity forces. There is no doubt that water will move through large voids under saturated conditions and that they have a very important influence on the saturated hydraulic conductivity of soils, even though they may contribute only a very small amount to the total porosity of a soil (Beven & Germann, 2013). Permeability can affect the level of soil fertility because it includes how water, organic matter, mineral matter, air, and other particles are carried with the water into the soil (Rohmat, 2009).

For the water infiltration into soil, macropores are important. The role of macropores in soil-water dynamics was described by (Beven & Germann, 2013). They pointed out that flow in the two domains (the macropores between soil blocks and the "micropores" within soil blocks) is governed by different potential gradients. They also showed that sizes and the structure of the macropores determine the pattern of water flow.

Some of the water may also appear as runoff, causing flash floods typical of the desert although natural runoff seldom exceeds about 10% of annual precipitation (Hillel, 1982). From previous description is clear, that infiltration is an important hydrological process which must be carefully considered in models or procedures for describing the soil hydrology. The primary physical factor influencing the size of surface retention is the micro-relief of the area and any factors which have a bearing on that micro relief (Haan et al., 1982). The soil water distribution during infiltration from ponded surface into uniform, relatively dry soil was first presented by Bodman & Colman (1944). They showed that profile could be divided into the four zones. The saturated zone extends from surface to a maximum depth of approximately 1.5 cm. The transition zone, a region of rapid decrease of soil water content, extended from the zone of saturation to the transmission zone, a zone of nearly constant water content which lengthens as infiltration proceeds (Haan et al., 1982).

One of the important factors influencing infiltration of water into the soil profile is the initial water content. Philip (2006) showed that for all times during infiltration, the wetting front advances more rapidly for higher initial water contents. Lack of infiltration is a problem on grazed, compacted and cultivated soils but not usually on forest soils. Primarily because the forest floor absorbs the energy of falling rain to permits clean water to penetrate to the mineral soil layers. The infiltration capacity of forest soils is nearly always greater than prevailing rainfall intensities (Hewlett & Doss, 1984). These conditions are able to maintain the water supply well. Water supply is the amount of liquid water that reaches the soil surface in a given period; it consists of rain and melt water (Nathan & McMahon, 1990).

Soil aggregate composition is an important characteristic of soil structure and as such has been expected to affect soil water retention (Guber et al., 2004). Terms potential and actual evapotranspiration are also connected with retention of water. Potential evapotranspiration is related to the amount of energy in the environment, it is the evaporative loss from a site covered by a crop supplied with unlimited water (Rosenberg et al., 1983). Actual evapotranspiration can be viewed as a measure of the simultaneous availability of biologically usable energy and biologically usable water in the environment (Major, 1963; Rosenzweig, 1968). Rawls et al. (2003) concluded that organic carbon and bulk density improve estimates of soil water retention derived from soil texture. Concentration on agricultural drainage problems and the downward entry of irrigation water has tended to deflect attention to saturating rainfall.

The term “hydraulic lift” was assigned to describe process since water is moving in liquid phase and the direction of movement is usually upward towards the drier and shallower soil layers. This process that occurs in the soil, is the passive movement of water from roots into soil layers with lower water potential, while other parts of the root system in moister soil layers, usually at depth, are absorbing water (Richards & Caldwell, 1987). For example, roots of wheat seedlings in air-dried soil or soil of moisture content below the “wilting percentage” could be moistened if part of the roots had access either to free water or moist soil. In most plant communities, root length density decreases exponentially with depth of soil (Jackson et al., 1996).

1.5 Erosion of soil

The extricating of the soil from its place and its transportation starting with one spot then onto the next is known as soil erosion (Adhikary, 2020). Climate variability can significantly affect changes in the morphology and properties of the entire soil profile due to erosion, whether windy or in extreme water events (Edwards et al., 2019). Water and wind erosion are both natural processes, which apart from in mountain or arid areas, tend to occur at low rates (Montgomery, 2007), whereas tillage and harvest erosion are the only associated with agricultural activity (Quinton et al., 2022). Soil erosion by water is a serious problem in many parts of the world. It is categorized as the most serious environmental problem because it threatens agriculture and the natural environment (Hagos, 1998). In the case of torrential rains, surface runoff is increased and followed by soil erosion (Žalud et al., 2020).

Erosion removes the top fertile layers of the soil, resulting in loss of organic matter, nutrients, and water holding capacity that can lead to an overall decrease in crop productivity from the soil (Flanagan et al., 2013; Quinton et al., 2022). Soil erosion is a three-stage process which consist of (1) detachment of particles from the soil body that is their original domain; (2) transport of the detached soil particles by flowing water or by wind; (3) deposition of the transported particles, a stage known as sedimentation (Pepper et al., 1996). Sediment travels from upland sources through the streams and may eventually reach the ocean (Holeman, 1968). For example, when a rainstorm strikes a bare soil surface, big quantities of soil material are splashed away. A heavy rainstorm may splash as much as 200 tons of soil (Schwab et al., 1993). Sediments can degrade the water quality and may carry soil absorbed polluting chemicals (Haan et al., 1982).

The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture (Balasubramanian, 2017). Textural changes can in turn affect the water-holding capacity of the soil, making it more susceptible to extreme conditions such as drought. Another factor is raindrop detachement which damages the soil surface reducing the rate at which water can infiltrate into the soil and creates turbulent flow conditions in shallow surface runoff keeping transported sediments in suspension (Kinnell, 2005). The potential erosion risks are higher under intensive arable land use than underforestry or pasture land uses (Xanthakis & Pavlopoulos, 2009). On arable land even deep soil behaves as a shallow soil with limited retention due to the poorly permeable top layer of profile. The result is not only a loss of quality but also humus content with all the negative phenomena associated with it - degradation and compaction of soil structure (Pan et al., 2024).

The equation (Wischmeier et al., 1978) that expresses the effect of the main factors of water erosion and determines the amount of soil lost is:

$$G = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

Where:

G - long-term average annual soil loss (measured in tonnes per hectare per year)

R - rainfall and runoff factor by geographical location, factor of erosive efficiency of rain, expressed as a function of kinetic energy and intensity of erosively dangerous rains

K - soil erodibility factor, expressed depending on the texture and structure of the topsoil, the content of organic matter and the permeability of the soil profile

L - the slope length factor, expressing the influence of the uninterrupted length of the slope on the amount of soil loss through erosion

S - slope factor, expressing the influence of the slope on the amount of soil loss

C - crop and management factor expressed as a function of the development of vegetation and the agricultural technology used

P - support practice factor, effectiveness factor of anti-erosion measures

If the value of long-term average soil erosion (G) does not exceed the value of permissible soil loss (Gp), there is no accelerated erosion at the given location, the location is not threatened by water erosion and the functions of the soil and its fertility are preserved (Novotný et al., 2017).

A degradation of physical properties of soil involves a decline in soil structure resulting to an increase in bulk density, decrease in total macroporosity, reduction in infiltration, and increase in surface runoff and, finally, in aggravation of soil erosion by water (Lal, 2017). Agriculture – including animal grazing – encouraged removal of native forests, prairies and scrublands to prepare seedbeds and reduce weed competition. Ploughing and other tillage also resulted in soil degradation and oftentimes increased soil erosion (Cerdà et al., 2007). What is difficult to assess reliably and precisely are the dimensions – the extent, magnitude and rate of soil erosion and its economic and environmental consequences. Research on erosion has been carried out mainly by civil and agricultural engineers. Their efforts have been directed toward identifying the factors affecting erosion, quantifying soil loss rates, and designing system to reduce those rates (Schwab et al., 1993).

To prevent soil erosion we can use some strategies such as terracing on steep slopes, and use of cover crops, mulching and different tillage – conventional, contour, conservation and no-tillage. However, even after the green revolution and the technological improvements during the twentieth century, agriculture is still the source of most sediments in surface runoff waters (Cerdà et al., 2007). Generally, silty and sandy soils with low content in clay and organic matter are known to be more prone to erosion (Wischmeier & Mannering, 1969). At the field, three general agronomic principles are used: minimal soil disturbance; permanent soil cover; and crop rotations or crop diversity (Andersson & D‘Souza, 2014). One way of achieving and maintaining a fertile soil is to apply organic matter. This improves the cohesiveness of the soil, increases its water retention capacity and promotes a stable aggregate structure (Morgan, 2005).

1.6 Soil aggregates (WSA)

Soil aggregate is a particle of basic soil arrangement, which is formed by aggregates of elementary grains. These aggregates are observable on a macromorphological level, directly in the soil´s profile, in the field, but they can be analysed in a much more exhaustive way in the microscope (Słowińska-Jurkiewicz et al., 2012). The visible aggregates, which are generally of the order of several millimeters to several centimeters in diameter and with bigger diameter than 250 µm are called macroaggregates (Amézketa, 1999). Microaggregates are soil particles with diameter less than 250 µm. We can also divide them into water-stable (WSA) and unstable aggregates (Edwards & Bremner, 1964;).

The process of WSA formation in soil consists of many chemical, biological and physical processes that usually take place simultaneously (Franzluebbers, 2002; Six et al., 2004). Their creation is influenced by many factors, especially soil moisture and activity of plant roots (Kong et al., 2005), content of organic matter (Šimanský et al., 2018), occurrence of soil organisms (Hesami et al., 2014), clay content (Attou et al., 1998; Chenu et al., 2000), amount of Fe and Al carbonates and oxides (Amézketa, 1999).

Recent studies revealed that organic matter in aggregates is better protected against mineralization and leaching than organic matter without aggregates (Urbanek & Horn, 2006). Some authors state that formation of aggregates is the result of the physical forces, while soil stabilization is created by several factors, especially organic and inorganic stabilizing agents (Lynch & Bragg, 1985; Carter & Stewart, 1995). The main physical forces that appear in the formation of WSA include water logging, freezing, compression and drying. An important role is played by the extensive networks of roots that permeate the soil and tend to enmesh soil aggregates. Water uptake by roots causes differential dehydratation, shrinkage and the opening of small cracks (Hillel, 2003). Aggregate stability is used as an indicator of soil structure (Six et al., 2000). A higher proportion of macroaggregaes to microaggregates can increase soil quality as a result of increased biological activity and nutrient cycling (Arshad et al., 2015). Therefore, they are often used for evaluation of soil quality (Scott, 2000; Abiven et al., 2009), or its degradation (Imeson & Vis, 1984; Grandy & Robertson, 2006).

Land use changes such as deforestation and conversion to agriculture have well-documented effects on soil structural properties (Panayiotopoulos & Kostopoulou, 1989; Caravaca et al., 2004b; Kalhoro & Raza, 2017). Land use change causes land aggregation when there is a reduction in the representation of macroaggregates (Haghighi et al., 2010). Aggregation take place especially in the upper layer of soil (Letey, 1991). For WSA creation are important processes associated with the water regime (Regelink et al., 2015; Sekaran et al., 2021) plant growth and by land management (Kay, 1990). Example conversion from forest to pasture in Amazonia resulted in changes in pore-size distribution that reduced water availability to plants (Young, 1990). In southwestern France, deforestation followed by intensive cultivation affected soil structure at the macroaggregate stability, possibly because of a reduction on the earthworm population, which can play an important role in soil aggregation (Besnard et al., 1996). The analysis of soil aggregation is important in a variety of applications.

Aggregate stability and size information may be used to evaluate or predict the effects of various agricultural techniques, such as tillage and organic matter additions, and erosion by wind and water (Nimmo, 2013).

Analysis of dry aggregates may be used to estimate possible wind-erosion effects, while wet analysis may be more appropriate to evaluate or predict erosion due to rainfall impact and runoff. Dry aggregate size distribution strongly affects soil fertility and its resistance to erosion and degradation (Ćirić et al., 2012). During the rainfall, some macroaggregates break down into microaggregates and primary soil particles. This is an unfavorable phenomenon, because smaller particles are more easily moved in the process of soil erosion and possibly create a less permeable layer on the surface, which leads to a decrease in the infiltration rate (Loch, 1994; Le Bissonnais & Arrouays, 1997). The soil is mostly washed away due to heavy rainfall in places where arable soil cannot absorb all the water at once. Then it moves along surface and removes fine soil particles, which is causing soil erosion. The pores between the aggregates should be large enough to allow rapid infiltration and drainage (Tisdall & Oades, 1982).

Aggregate analysis may help us understand most aspects of soil water, including runoff, infiltration, and redistribution, as well as soil aeration and root growth. Moreover aggregate properties are being used in models that predict soil hydraulic properties, including water retention and unsaturated hydraulic conductivity (Nimmo, 1997; Kosugi & Hopmans, 1998).

1.7 General WSA sample preparation

Most frequently is the concept of aggregate stability applied in relation to the destructive action of water. First step is collection of field samples, that are transformed to laboratory and dried. Second step is the performance of dry sieving, followed by wet sieving. In the final stage, samples are dried and weighted. Sampling should be done with appropriate field-sampling equipment. A flat, square-cornered spade is recommended (Kemper & Rosenau, 1986). Samples should be taken at consistent depths if comparisons are to be made and afterwards transported in rigid containers as gently as possible to avoid compression and/or breakdown of aggregates (Carter & Gregorich, 2007). Drying of aggregates before analysis should be done at room temperature. For procedures involving wet aggregates, a wetting method should be chosen based on the purpose of the analysis. Water content before sieving is a major factor in resulting stability.

Fast wetting with no vacuum (Yoder, 1936) involves placing air-drid aggregates onto the sieve and immersing them in water for a period of time before beginning the mechanical sieving process. This type of wetting of dry aggregates produces disintegration and slaking (Panabokke & Quirk, 1957; Kemper et al., 1985) due to compression and expansion of entrapped air, which may be undesirable. High-vacuum fast wetting (Kemper & Koch, 1966) involves de-airing aggregates in a vacuum chamber under high vacuum, then instantaneously wetting the aggregates in the chamber. This method generally produces minimal disruption. Slow aerosol wetting with no vacuum (Kemper & Rosenau, 1986) in which samples on screens are wetted by vapor from below, produces little disintegration. Wetting by slow wicking with or without vacuum (Dickson et al., 1991) allows aggregates to draw moisture from moist filter paper.

Several studies have compared two or more of these wetting techniques in terms of their effect on size distribution or stability (Elliott, 1986; Haynes, 1993). Elliot found a significant difference in size distribution vs. initial water content, confirming that fast wetting caused many of the larger aggregates to break apart. Organic solvents may reduce aggregate disintegration by slaking and may better preserve aggregate structure in drying (Greene-Kelly, 1973; Le Bissonnais, 2016). Soil aggregates determination can be done by physical methods. During the process are usually used dry and wet methods (Devine et al., 2014). It is necessary to state that the result of dry sieving are fractions of soil aggregates. The values of the WSA fractions can only be obtained through subsequent wet sieving.

Methods for dry sieving

These methods which are based on the principle of separating individual grain fractions, measuring the proportion of individual sieves from the coarser to the finest. are used in the first stage of sieving. Chepil (1962) invented a rotary sieve, which was later improved by Lyles (Kemper & Rosenau, 1986). The soil was inserted on first (upper) sieve and then automatically sieving started. Soil was divided into individual fractions, which were weighted after the process (Chepil, 1962). Usually standard dry sieving method is (Savinov, 1936). Over the years different methods of sieving have been developed and have proven extremely effective in determining the particle size distribution of soils. The mechanical sieve shakers utilize different types and natures of agitating forces to sieve the soil (Ekwue, 2008). Another example can be the rotary device (oscillatory sieving analyzer JH-200) for the analysis of dry soil aggregates with different sieves (Kalhoro & Raza, 2017).

Dry sieving is less suitable than wet sieving. In samples with small particle size, these particles tend to clump together and dry sieving is therefore more difficult. To determine the relative resistence of soil disintegration by mechanical forces, it is better to perform more tests and to determine the stability of soil fractions from the results. Dry sieving involves shaking usually air-dried soil, on top of a nest of sieves. Thus, the energy applied to the soil differs greatly between dry and wet-sieving which affects directly the amount of stable soil aggregates that are obtained (Blaud et al., 2016).

Methods for wet sieving

Methods serves to determine the stability of WSA. Most often it is done by immersing individual aggregates in a container with water, usually distilled. If aggregates are not completely stable in the sample, they break down into smaller parts or the formation of mud. Several methods were developed for determining the stability of water-stable soil aggregates. Kopecký (1914) connected a row of tubes, put the sample in the smallest of them and let the water flew through. He found that the slowest water velocity was in the widest tubes. When the water flew through the tubes, the particles gradually began to settle in the corresponding tubes. Rhoades (1932) used the leaching method to determine the overall size distribution. Other way is to use the wet sieving method which was described by Kemper & Koch (1966) and Murer et al. (1993). The process of wet sieving by Kemper & Koch (1966) is described below:

1. Weigh 25 g of air-dried sample
2. Prewet the sample as desired
3. Spread the sample evenly on top of the nest of sieves with openings of 4.76, 2.00, 1.00 and 0.21 mm.
4. Lower the sieves into water so that the sample in the top sieve is just covered with water on the upstroke of the apparatus.
5. Raise and lower the sieves 38.1 mm through the water approximately 30 times per min for 10 min.
6. Remove the sieves from the water, oven-dry, and weigh.
7. Determine the amount of material in each fraction that is sand by rinsing and stirring the sample with a dispersing agent (such as 2g L-1 sodium hexametaphosphate for soils with pH >7, or 2 g L-1 of NaOh for soils with pH <7

Main purpose is to minimize mechanical disruption of the soil particles. It can be briefly explained as the sieving of soil aggregates by mechanical movement of the set of sieves, which are submerged under water during this process. The proportion of soil aggregates with size < 2 mm mainly increase with wet sieving whiles soil aggregates > 2 mm decrease due to the breakdown of the macroaggregates into smaller aggregates (Sainju, 2006; Bach & Hofmockel, 2014).

Tiulin and Yoder were the first to actively use this method (Hillel, 1980). When soil aggregates are wetted slowly at atmospheric pressure or rapidly under reduced pressure, the bonds are still strong enough to hold most of the primary particles (Kemper & Rosenau, 1986). Yoder (1936) pointed out the disadvantages of the leaching method and created a device for the wet sieving process. Set of sieves was placed and immersed in tank (container) with water. This laboratory apparatus then performed a vertical sieve movement at 30 cycles per minute for 30 minutes. The amount of soil on each sieve was dried and then weighed. Wet-sieving affects the aqueous colloidal forces at particle surfaces that can enhance or diminish the cohesive forces between aggregated particles (Blaud et al., 2016). In 1966, Kemper and Koch developed or rather upgraded a device (Fig. 7) similar to that developed by Yoder, but modified it so that only one screen was used and the frequency could change.

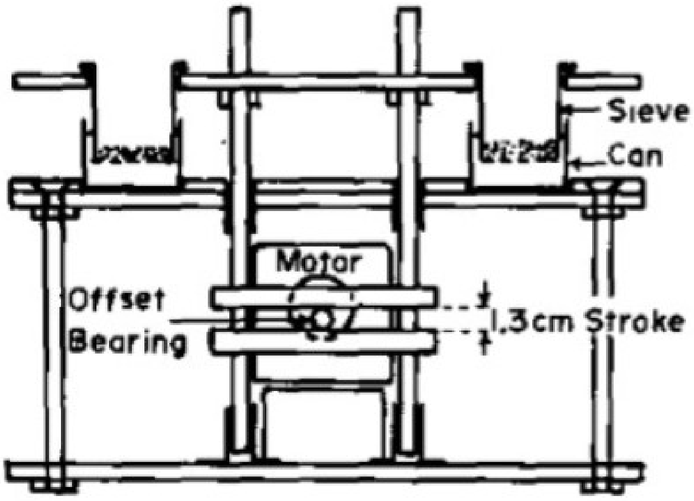


Figure 7: Original device developed by Kemper and Koch (1966)

In past, many researches have developed modifications of sieving techniques or devices, for example Bourget & Kemp (1957), Caron et al. (1992), Angers et al. (1993), Chantigny et al. (1997) and Ekwue (2008). A typical example is that of Elliott (1986) who hand sieved with nine sieve sizes in a 3-cm motion repeated 50 times in 2 min using fast and slow-wetted samples that had been submerged for 5 min before sieving.

The sedimentation method is also used in practice. The dependence of settling speed on the size of soil particles can be used to separate aggregates of different sizes. The main limitation is particles with a diameter greater than 1 mm, where rapid settling occurs and thus cannot be accurately measured. Davison & Evans (1960) extended the sedimentation technique by using glycerol and water in a ratio of 9:1. The resulting solution was 140 times more viscous than water, and due to the resulting friction, measurements were possible in a wider range of fractions. The rate of settling was measured photometrically.

The classical and still most prevalent procedure for testing the water stability of soil aggregates is the wet sieving method. A representative sample of air-dry aggregates is placed on the uppermost of a set of graduated sieves and immersed in water to simulate flooding (Hillel, 2003). Šimanský (2013) during his research proceeded as follows. Soil samples were first air-dried in the laboratory at air temperature. Soil samples were dry-sieved to the following seven size fractions: > 7, 7–5, 5–3, 3–2, 2–1, 1–0.5, 0.5–0.25 mm. Percentages of water-stable aggregates (WSA) were determined by the Baksheev method (Vadjunina & Korchagina, 1986). The size fractions of WSA were as follows: > 5, 5–3, 3–2, 2–1, 1–0.5, 0.5–0.25 mm. The remaining material except for water-stable microaggregates was quantified in each sieve. The microaggregate fraction was calculated as the difference between the total weight of the soil sample and the sums of macroaggregates. On the basis of dry and wet sieving samples, values were calculated of mean weight diameters for dry sieving (MWD).

Newer devices include the Retsch AS 200 basic, but the method is considerably modified. The sieving does not take place with the help of a swinging movement, but with the movement of the sieves with the samples in the water. It works on the principle of an electromagnetic drive. The movement is performed not only in the horizontal, but also in the vertical axis (vibrational movement with a 3D effect), which contributes to a better distribution of the analyzed sample over the surface of the sieve.

Another example is the Eijkelkamp apparatus (Fig. 8) which works on the principle that sieves are placed in a can filled with water, which will move up and downward for a fixed time. Unstable aggregates will fall apart and pass through the sieve and are collected in the water-filled can underneath the sieve. After this fixed time, the cans are removed and replaced by new water filled cans. All aggregates are then destroyed. Sand grains and plant roots will remain on the sieve and only aggregates are considered. After drying the cans with the aggregates, the weight of both stable and unstable aggregates can be determined. Dividing the weight of stable aggregates over total aggregate weight gives an index for the aggregate stability (Royal Eijkelkamp, 2024).

Figure 8: Eijkelkamp apparatus. Adapted from Royal Eijkelkamp (2024)

Modern variant include the ultrasound method. Ultrasound is one of the most common methods to disrupt the structure of matter. The method is suitable for aggregates <20 µm in size, which are very stable and only ultrasonic vibrations will disturb them. However, once their size drops below 2 µm, their structure cannot be disturbed even by ultrasound (von Lützow et al., 2007). The principle is the production of ultrasonic vibrations, the energy of which causes the formation of cavities in the sample suspension. Subsequently, the created cavities will collapse and the resulting shock wave will disrupt the bonds between the individual parts of the aggregate (Whitbread, 1995). The disadvantage of the ultrasound method is the impossibility of determining in advance exactly how long and how much ultrasound energy apply to a specific sample.

1.8 Microplastic locked in soil

Plastics were exponentially growing in production and consumption over the previous few decades worldwide (Jambeck et al., 2015). It should be a warning to humanity, that more than 300 million tons of plastics are manufactured every year wherein 50 % of which are primarily single use (Chen et al., 2020). Microplastics (MPs) are plastic residues with a size <5 mm (Tirkey & Upadhyay, 2021). They are significantly movable in the global environment, and their occurrence is documented even in very remote areas far from sources (González-Pleiter et al., 2020). MPs were found and mainly described in the ocean environment (Horton & Barnes, 2020). Currently, MPs are studied in terrestrial environment, because the main origin of MPs is in agglomerations, which represent settlement and industry, transported by water or air (Lebreton et al., 2017; Hurley & Nizzetto, 2018; Mbachu et al., 2020). For example recently, detection of plastic has been confirmed in distant places like the Polar Regions and the Tibetan Plateau where anthropogenic interference is severely less (Jiang et al., 2019; Peeken et al., 2018). MPs have long been the subject of scientifc articles dealing with environmental pollution.

Primary MPs come from cosmetics and paints and are also released when washing textiles or grinding tyres (Belzagui et al., 2019). Households create MPs that leave together with wastewater (Fig. 9). If the wastewater is treated, the capture of MPs per wastewater treatment plant is relatively high (Carr et al., 2016). However, when sewage sludge is used as a fertilizer, MPs enter the soil (van den Berg et al., 2020). As a result, agricultural soils serve as sinks for microplastic particles, which may have harmful impacts on the organisms and soil structure (Zhu et al., 2018). Secondary, MPs are created by the disintegration of larger plastics (Syberg et al., 2015), for example, when mulching foils, foil sheet material enters the soil (Zhou et al., 2020). Other sources include irrigation using water polluted with plastic, cluttering on roadsides, unlawful discarding of waste and road spillages (Huerta et al., 2016). Even if the pollution described above is not used (sludge fertilization), MPs are still transmitted through the air and subsequently occur in the soil. This makes the soil a significant medium in the overall movement of MPs (Weber et al., 2021).

The relationship between MPs and soil has been the subject of several recent review articles, such as Ng et al. (2018); Galafassi et al. (2019); (Li et al. (2020); Wang et al. (2019) and Jacques & Prosser (2021). At the same time, the methodology for detecting and determining MPs in soil is being defined, for example: Claessens et al. (2013), Song et al. (2015), Zhang et al. (2018), Bläsing & Amelung (2018), He et al. (2018), Zhou et al. (2020).

The results of soil-MPs relationship published so far are not evenly distributed both geographically and in terms of land use, where research on agricultural (arable) land predominates (Yang et al., 2021). For comparison Cincinelli et al. (2017) found during research in Antarctica along the nearshore region of Ross Sea, concentration of 0.17-0.34 particles/kg. Another study on Yunan, China, showed MPs concentration ranged from 7100 to 42 960 particles/kg with an average concentration of 18 760 particles/kg in cropped soils.

Hurley & Nizzetto (2018) were probably the first one to point out the relationship between soil aggregates and MPs in terms of the dynamics of their movement in the soil (mobility). Incorporation of MPs into soil aggregates may promote long-term storage. Plastic detrition in topsoil essentially relies upon plastic’s physicochemical characteristics, type of soil, presence of a functioning microbial community, and ecological conditions (Mashaghi et al., 2013). For instance, weathering forces and exposure to UV radiation speed up plastic composition that is greater in clayey soil as compared to sandy soil (Maddela et al., 2023). On genetically identical soil, the structure may be diferent, especially in the top soil layer compared for diferent land use (Hussain et al., 1999; Celik, 2005). When the macroaggregates are not disrupted (for example, by tillage), particle of soil organic matter (SOM) that forms the centre of a new macroaggregate decomposes and fragments inside the macroaggregate into finer organic matter, which gradually becomes encrusted with clay particles and microbial products, forming microaggregates within macroaggregates (Bossuyt et al., 2002). The contamination of soil plastics could apply a direct and indirect influence developed plants as an outcome of their root uptake or impacts on soil substances physical-chemical and organic characteristics individually (Lwanga et al., 2017).

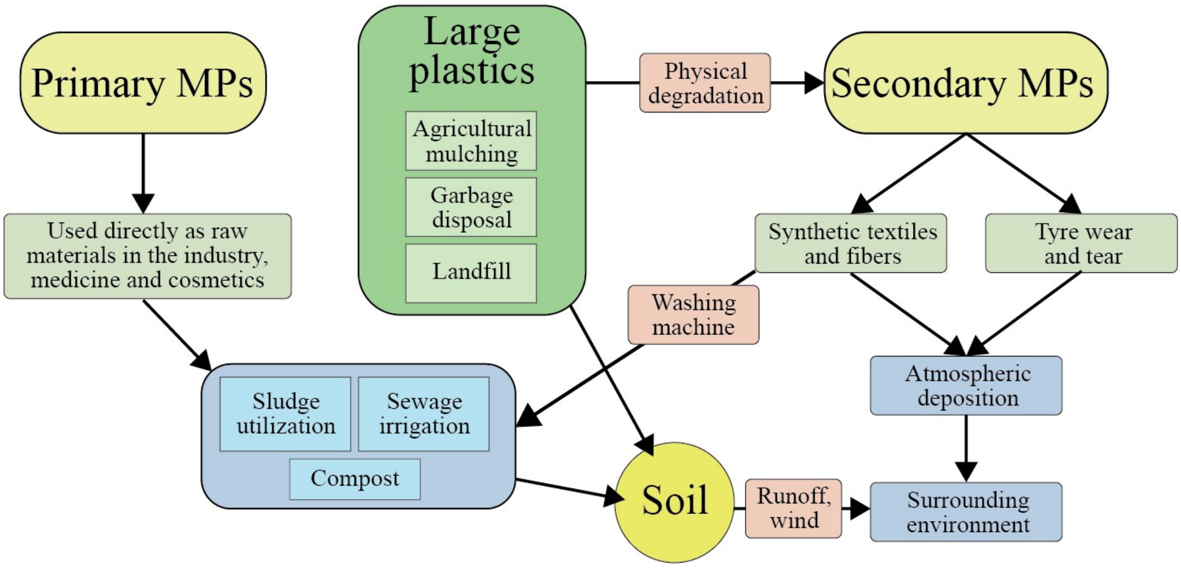


Figure 9: Schematic diagram of the sources of microplastic in soil ecosystem. Simplified by author. Adapted from Yu et al., (2022)

1.9 Environmental models

Hydrological modeling

Nowadays, various hydrological models have been developed around the world to determine the impact of climate and soil properties on hydrology and water resources. Models are mainly used for predicting system behaviour and understanding various hydrological processes and constructed to serve as proof of an idealized logical structure and they are an important element of methodical theories (Adem & Batelaan, 2006). According to Moradkhani & Sorooshian (2008), a model is a simplified representation of real world system. Models capturing the structure and dynamics of scientific endeavor are expected to provide insights into inner workings of science (Borner et al., 2012). The best model is the one which give results close to reality with the use of least parameters and model complexity. A model consists of various parameters that define the characteristics of the model (Devia et al., 2015). For instance it can be precipitation volume, soil properties and vegetation cover.

While choosing a model for specific application, it is important to consider its applicability to simulate the impact of land use and climate change and also prediction performance (Schreider et al., 2002). We generally use models to better understand or explain natural phenomena, and under certain conditions we can predict them in a deterministic or probabilistic sense. Modeling can be defined as a purposeful activity that is developed in order to obtain information about one fact through another fact. While the model itself can be the main one output from a modeling project, substantial value also comes from the process of model development, modification and evaluation.

Modeling can play a variety of roles. It can serve as an information processing methodology, whereby data, knowledge and assumptions are systematically organized for a specific purpose (Jakeman et al., 2006). It also serves as a learning process where working hypotheses are considered and the model subsequently tested (Beven, 2006). Therefore, modeling is not only a technical procedure, but also a learning and social process (Hamilton et al., 2015; Iwanaga et al., 2021).

The importance of modeling lies in the fact that it allows to obtain information about reality (the real world) more efficiently, quickly and safely. Since it is very difficult to capture the real world in all its complexity, only partial objects are the subject of investigation (Dostál, 2011).

Several different criteria have been used to develop a classification system for models, and in many cases these criteria reflect the special interests or needs of a particular discipline. Dawdy & Lichty (1969) suggest four criteria that can be used to choose between alternative models: 1. Accuracy of prediction; 2. Simplicity of the model; 3. Consistency of parameter estimates; 4. Sensitivity of results to changes in parameter values. At one extreme, simulation can be as simple as plugging values into an equation or comparing a pattern. At the other extreme, simulation can closely follow the detailed processes that operate in the real world (Kirkby et al., 1987).

The procedure of steps during modeling is similar in all models. This process can be divided into 6 phases (Fig. 10). The process starts by defining the model purpose and then follows the arrows round the cycle through design, implementation, verification, simulation to summary of results (Topping et al., 2010).

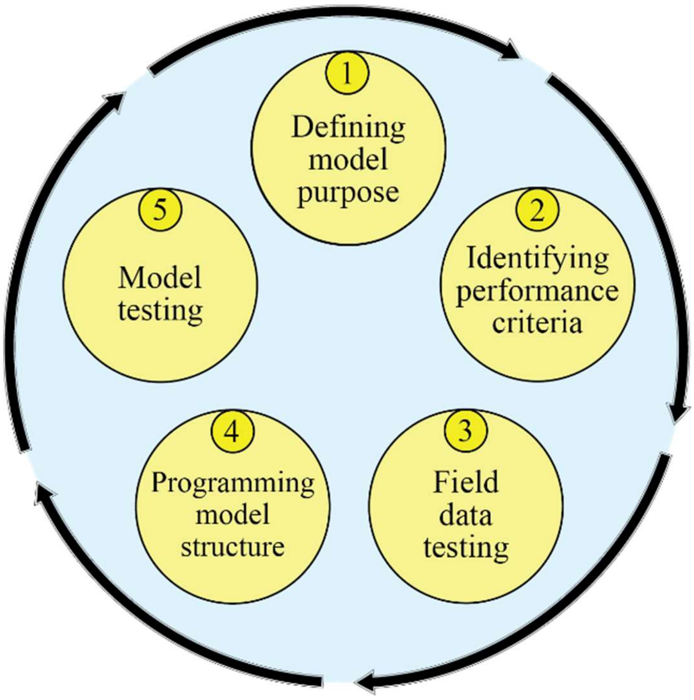


Figure 10: Procedure steps of modeling. Diagrammatic representation of the model development cycle based on Topping et al. 2010. Adjusted by Author.

In practice, movement is not smoothly from point 1 to point 6, but if necessary, it returns to the previous points and repeat them - modeling is an iterative process. Although this procedure is idealized, we should know it and not forget any of these points (Pelánek, 2011). During the process is important which elements we will model and what will be taken into account in the model (Dalkvist, 2011). A correctly constructed model should therefore have only those features and details of the system that are necessary during its creation (Plevný & Zizka, 2010).

The suggested procedure (Vanrolleghem et al. 2005) to go from the real system to a conceptual model can be summarized as follows: I. Determine the system under study, its boundaries and the problem to be solved. II. Collect data on the system to calibrate a complex mechanistic model. III. Calibrate and validate the complex mechanistic model. IV. Generate data with the complex model to calibrate the surrogate model. V. Calibrate and validate the surrogate model. A scheme of the procedure (Fig. 11) is presented. In general, conceptual model can be build build based on parameters of process-based models, knowledge and data (Meert et al., 2014).

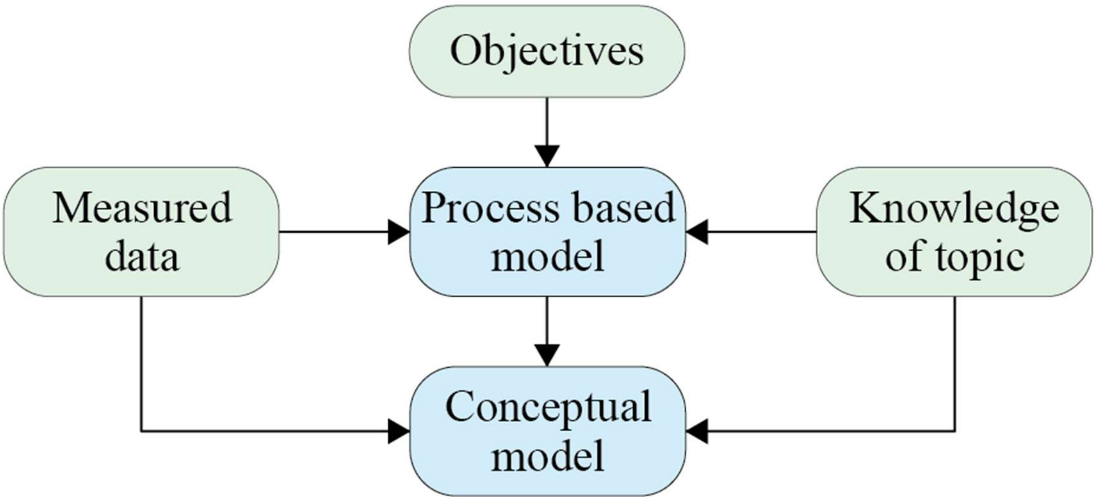


Figure 11: Scheme used for building a conceptual model based on the results of a process-based model. Adapted from (Meert et al., 2014). Illustrated by author.

Types of models

Hydrological modelling is carried out for understanding the Earth's environmental system and it improves decision-making in water resource planning, flood prediction, irrigation practices, groundwater development (Pandi et al., 2021). Hydrologic models can be classified into the stochastic and deterministic based on the presence of random variables, their distribution in space, and temporal variation (Te Chow et al., 2010). It is possible to say a deterministic model makes a forecast while a stochastic model creates a prediction. Chow et al. (2010) stated that hydrological models can be classified into two major categories, namely physical models and abstract (mathematical) models. The mathematical model expresses the laws of phenomena and processes, both in the field of scientific knowledge and in the field of practical human activity (Briš and Litschmannová, 2020).

In another way models are classified based on model input and parameters and the extent of physical principles applied in the model. In general, they are most often divided into empirical models, conceptual models and physically based models (Fig. 12). Empirical, conceptual, physical-based and hybrid model were already represented by Pechlivanidis et al. (2011). The hydrological modelling is a complex, dynamic and nonlinear process but it can be most applicable for flood control and management, groundwater recharge sites, drought analysis, irrigation management, land and soil conservation, its management, and design of hydraulic structures in the watershed (Pandi et al., 2021).

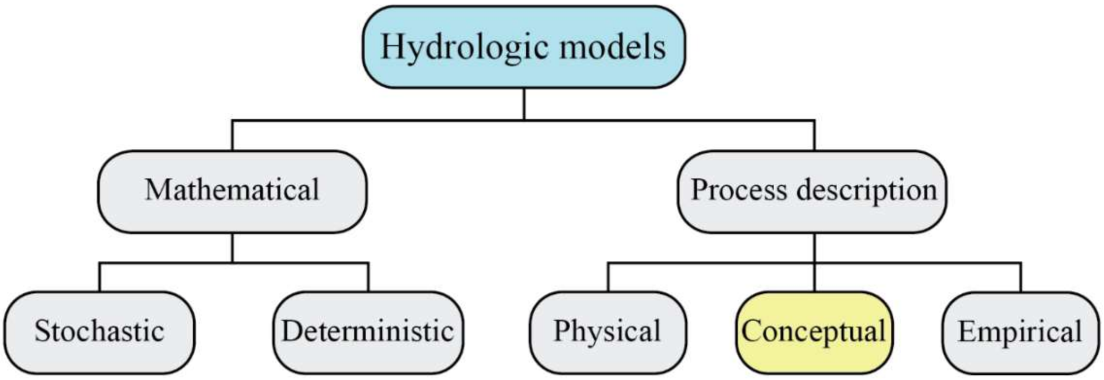


Figure 12: Types of hydrologic models. Illustrated by author.

Empirical model

Empirical models contain no physical transformation function to relate input to output. Such models usually build a relationship between input and output based on hydro-meteorological data (Sarkar & Kumar, 2012). These models take information from existing data without taking consideration of processes of hydrological system (Sejkar et al., 2021).

The major limitation of empirical models is due to the absence of explicit consideration of physical processes such as subsurface flow, surface runoff, and infiltration in the catchment. Also, these numerical models are not capable of modeling the influence of change in vegetation on various hydrological components (Dwarakish & Ganasri, 2015). Empirical modelling was to be capable for various problems related to river basin management: modelling, short-term forecasting, classification of hydrology-related data, and even automated generation of flood inundation maps based on aerial photos, etc. (Solomatine & Ostfeld, 2008).

Physical model

As a simple definition, a physical model is defined as a scaled-down form of a real system (Salarpour et al., 2011). It si based on the physical or geometric similarity between the modeled system and the model (Dostál, 2011). The physically based distributed models are able to explicitly represent the spatial variability of the important land surface characteristics such as evapotranspiration, infiltration, percolation, baseflow and runoff, topographic elevation, slope, aspect, vegetation, soil as well as climatic parameters including precipitation and temperature (Akbari & Singh, 2012). It does not need extensive meteorological data for calibration, but evaluation of large number of parameters for physical characteristic of catchment is required (Abbott et al., 1986). In theory, physics-based models are defined by wholly measureable parameters and can provide continuous simulation of the runoff response without calibration (Beven, 2001).

Conceptual model

Conceptual models (sometimes called grey-box) are simplifications of the complex processes and are intermediate between theoretical and empirical models. Schema (Fig. 13) describes how conceptual modeling fits within the wider context of the modeling process for simulation by showing the key artifacts of conceptual modeling. The arrows show how information flows between these four artifacts. The activities that drive the flows of information are described as knowledge acquisition, model abstraction, design and coding.

Assumptions relate to knowledge acquisition, that is, they fill in the gaps in the knowledge that can be acquired about the real world. Meanwhile, simplifications relate to model abstraction, since they are deliberate choices to model the world more simply (Robinson et al., 2015).

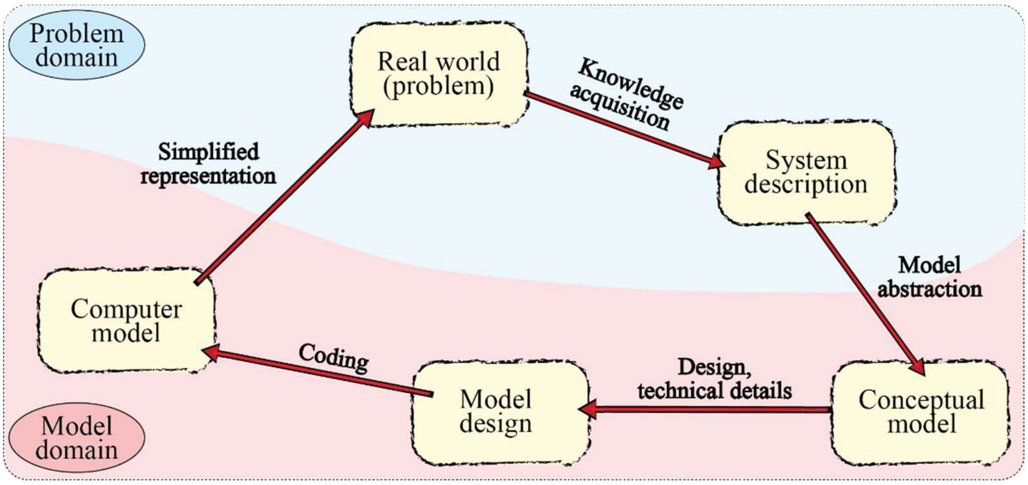


Figure 13: Artefacts of Conceptual Modeling.
Adapted from Robinson (2011). Illustrated by author.

According to Wheater et al. (1993), conceptual models (CM) are based on two criteria: firstly, the structure of the model is specified prior to any modelling being undertaken, and secondly not all of the model parameters have a direct physical interpretation (they are not independently measurable). The main characteristic of CM are: parametric or grey box model; parameters are derived from field data and calibration; simple and easily implemented (Devia et al., 2015). CM generally represent all of the component hydrological processes perceived to be of importance in catchment scale input-output relationships (Wheater, 2002). CM can explains component of hydrological process (Jajarmizadeh et al., 2012). This type of model varies considerably in complexity and the model structure tends to be based on extensive use of schematic storages, which are combined to represent a conceptual view of the important hydrological features. The particular components of these models often have to be described by empirical functions based on the observation of certain processes (Devia et al., 2015). The model is formulated with a number of conceptual elements which are simple portrayal of a reference system. CM advantage is its non linearity which reflect hydrological system’s threshold. Further its classification is into event and continuous models ranging from an hour or less to several years (Salarpour et al., 2011).

The CM itself consists of four main components: objectives, inputs (experimental factors), outputs (responses) and model content (Robinson, 2008).

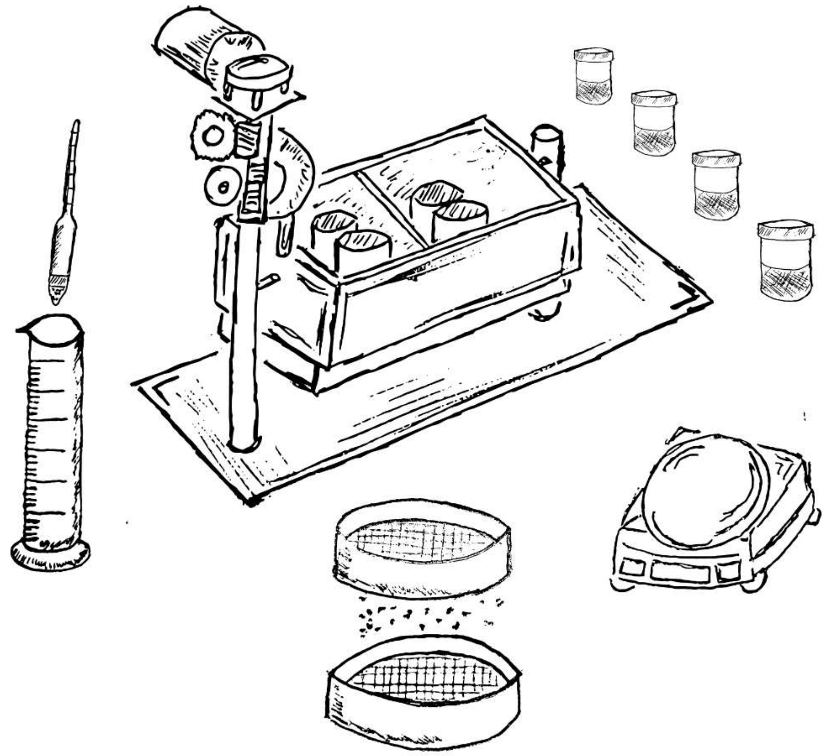
First there are the modelling objectives, which describe the purpose of the model and modelling project. Second there are the inputs (or experimental factors) of the model that can be altered to effect an improvement in, or better understanding of, the problem situation. They are determined by the objectives. Meanwhile, the outputs (or responses) report the results from the simulation model. Finally, the model content consists of the components that are represented in the model and their interconnections. The content can be split the scope of the model and the level of detail (Robinson, 1994).

Modeling software

There are many modeling softwares in hydrology. WEPP model is derived by Flanagan et al., (1995), which provided the soil erosion and sediment yield using the soil, meteorology, land cover, and topographic slope observed by Ramsankaran et al. (2009). TOPMODEL is a physics-based continuously distributed simulation basin model which predicts relative to soil and water saturation and drainage of the basin according to the time series information of topography, evapotranspiration and precipitation (Fares & El-Kadi, 2008). The Soil and Water Assessment Tool (SWAT) model is a field-based, distributed, conceptual, and continuous-scale simulation model employed as a soil and water assessment tool and field-scale model (Suryavanshi et al., 2017). Remote sensing modeling and geographic information system (GIS) are used to create a flood hazard map (Suriya & Mudgal, 2012). LISFLOOD was first attempted by Roo et al., (2000) on European flood alert system; used the soils, land cover, topography and meteorology for flood forecasting, climate scenario, and simulate runoff (Van Der Knijff et al., 2010).

Other types of modeling software focus on parameter calculation within the soil profile. An example is the HYDRUS 1D, which was used in this work to compare two different soil layers. This program allows the insertion of initial conditions, division of the soil profile, etc. The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media. The flow region may be composed of nonuniform soils. Flow and transport can occur in the vertical, horizontal, or a generally inclined direction. The water flow part of the model can deal with prescribed head and flux boundaries, boundaries controlled by atmospheric conditions, as well as free drainage boundary conditions (Simunek et al., 2013).

Chapter II – Methodology



2.1 Selection of method and laboratory devices

For the purpose of water-stable aggregates determination was chosen method based on Baksheev method (Vadjunina & Korchagina, 1986), which have been used by Šimanský (2012) during his research. In a simplified description, dry sieving takes place first, followed by wet sieving. At the beginning of studies, the old laboratory device was examined, tested and its parameters recorded (Fig. 14).

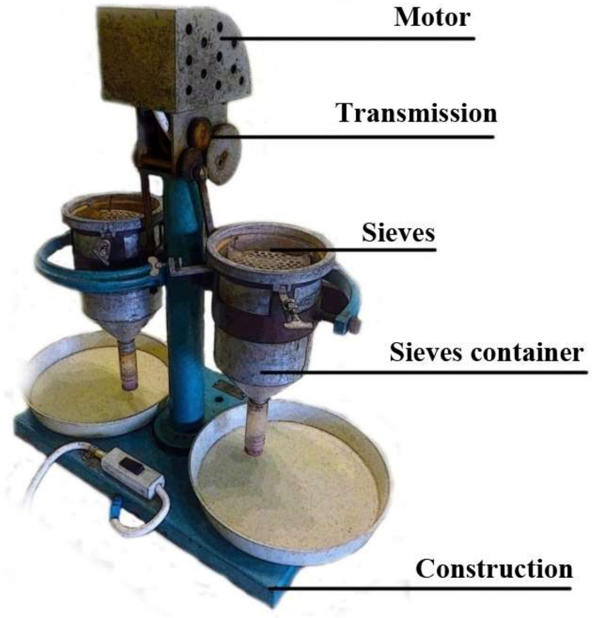


Figure 14: Old laboratory device based on Baksheev method. Visualised by author.

After that, Klíč (2017) designed and created new (inovated) laboratory device for wet sieving, which was tested several times for different soil samples. The device works on the principle of swinging movement of 12 cycles in 14 minutes. One cycle means a swinging movement on both sides, during which the container reaches a tilt angle of 90° (45° on each side). The construction of the device consists of 5 main parts - electric DC motor, transmission part, supporting structure, aluminium containers for sieves and the sieves themselves as can be seen in the device design (Fig. 15).

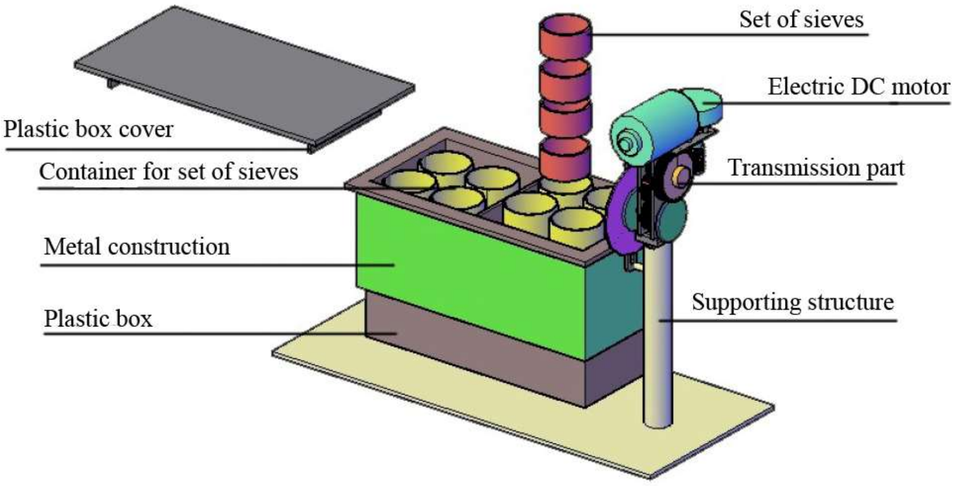


Figure 15: Inovated laboratory device by Klíč (2017)

In the later stages of the research, a new manual tilting device that does not require a connection to electricity was designed and created for the possibility of working in the field. It uses the principle of swinging movement performed by the operator. As with the inovated device, it tilts at an angle of 90°. The sieves with the sample are placed in the inner part of this manual device and the WSA are determined after the process. The manual tilting device can be disassembled into several parts, which allows for better transport in the field and also to distant locations abroad (Fig. 16).

Figure 16: Manual tilting device for possibility to work in the field. Visualised by author.

The advantages and disadvantages of the mentioned device together with other devices working on the principle of wet sieving are briefly described in Chapter 3.

2.2 Research locality selection

The essential subject of the entire dissertation thesis are water-stable soil aggregates (WSA), which were collected as part of the research at three locations in the Czech Republic and also abroad (Portugal, Kazakhstan, Lithuania, Russia). The effort was to cover a larger area and determine how much influence land use has on the formation of WSA. The sites for every country were intentionally chosen on the agricultural (arable) land and forest for contrasting land use. There was an effort to find locations where was border of forest and arable land. Each locality was first selected using satellite images (Mapy.cz; 2022; Google Maps, 2022), to meet the requirements of the researched area (arable, forest). Using the soil map (ČGS, 2022) knowledge from local country sources, it was verified whether the same soil type occurs in the selected area, which was subsequently confirmed by graphs of the particle size distribution curves. The research areas (Fig. 17) are located in the temperate climate zone (Czech Republic, Lithuania, Russia, Kazakhstan) and the subtropical zone (Portugal). All investigated localities are similarly located around the 50° of north latitude except for Portugal. According to the division by Köppen (Beck et al., 2018) the localities represent a mediterranean climate (Portugal) and a humid continental climate (Czech Republic, Lithuania, Russia).

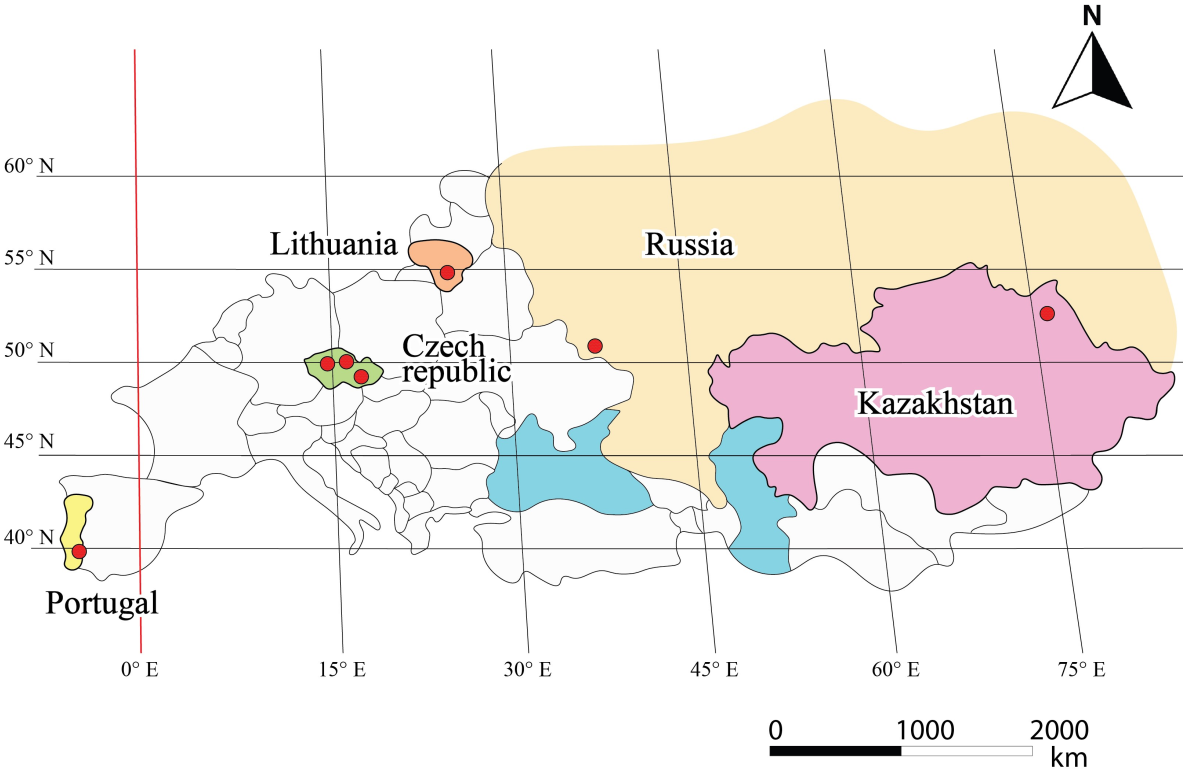


Figure 17: Location of research areas. Illustrated by author.

An identifier (ID) has been assigned to each location (Tab. 1) together with the exact coordinates. Further details are provided below for each location.

Table 1: Research sites with exact locations

Country	Study plots	ID	Land use	Location
Czech republic	Lysolaje	1	Forest	50.1241344N, 14.3560786E
		2	Arable	50.1240394N, 14.3557825E
	Bošovice	3	Forest	49.0493275N, 16.8139539E
		4	Arable	49.0497439N, 16.8137608E
	Chlístov	5	Forest	50.3265261N, 16.1840028E
		6	Arable	50.3267364N, 16.1836261E
	Zákraví	7	Forest	50.3353611N, 16.1926944E
		8	Arable	50.3350606N, 16.1922233E
	Val	9	Forest	50.3210000N, 16.1920556E
		10	Arable	50.3205675N, 16.1910244E
Portugal	Zebreira	11	Forest	39.7901781N, 7.1135103W
		12	Arable	39.8327808N, 7.1576208W
Lithuania	Kaunas	13	Forest	54.7924156N, 24.0865681E
		14	Arable	54.7905786N, 24.0876581E
Kazakhstan	Terenkol	15	Forest	53.1367597N, 76.1689472E
		16	Arable	53.1367083N, 76.1678400E
	Fedorovka	17	Forest	53.3968031N, 76.2877642E
		18	Arable	53.3969669N, 76.2868972E
Russia	Kursk	19	Forest	51.3401361N, 36.0502311E
		20	Arable	51.3407286N, 36.0502225E

Czech Republic

a) Lysolaje

The research area was located on the border of the city of Prague (the locality Housle), Czech Republic. The average annual temperature reaches 8–9 °C, with an average annual precipitation of 500-550 mm (ČHMÚ, 2021). The area, which is part of the flat hills of the Říp bio-region (Culek, 1995), has the altitude of 315 m above sea level. The studied soil classified as the Haplic Luvisol was formed on loess parent material according to the World Reference Base (WRB) for Soil Resources (IUSS WRB, 2014). It is a long-inhabited area from about the tenth century with completely altered vegetation and use of the landscape, where the original communities of lime oak forest (*Tilio-Betuletum*) were converted due to fertility mainly to arable land (Moravec & Neuhäusel, 1991).

Thus, there was complete deforestation, including the slopes of the canyon. The following afforestation was carried out in the first decade of the twentieth century and further afforestation took place in the 1970s of the twentieth century. The current state of the forest therefore lasts for approximately 90 years continuously (Dostálek, 2021). The winter wheat with an intermediate crop is grown on the agricultural (arable) land, and the soil is ploughed at least twice a year. The forest is mixed with 80 % of Scots pine (*Pinus sylvestris*), 15 % of small-leaved lime (*Tilia cordata*) and 5 % pedunculate oak (*Quercus robur*) (ÚHÚL, 2021).

b) Bošovice

Second locality in Czech republic was located near village Bošovice (South Moravia). The nearest climatological station in Slavkov near Brno (212 m.a.s.l.) reports an average annual air temperature of 8.8 °C and an average annual precipitation of 544 mm (Květoň, 2001). The soil cover consists of medium-heavy soils - chernozem and brown earth. The soil at a specific location was classified as chernozem, carbonate anthropic, loess from eolian sediment according to TKSP (Němeček et al., 2011). According to IUSS WRB (2014) it is Haplic Chernozem. The entire area falls into the Central Moravian Carpathians - Ždánický les - Dambořická vrchovina. The landscape is quite regularly undulating, firstly into rounded ridges that connect to the ridges of the main ridge, and secondly into parallel valleys of watercourses heading north or south (Demek et al., 2006; Culek et al., 2013).

c) Chlístov, Zákraví, Val

Specified research sites (Fig. 18) were located within 3 km southeast of Nové Město nad Metují at an altitude of around 400 m. The soil type is cambisol (BPEJ, 2022). The area belongs to the Orlickohorský bioregion (1.69) (Culek, 1995). The potential natural vegetation is oak beech trees, the average annual temperature here is around 7-8 °C and the annual rainfall is 600-750 mm (ČHMÚ, 2021). At these three locations, the influence of the age of the forest stand planted on former agricultural land in connection with the creation of WSA was determined. For the selection of these specific locations with afforested arable land, a comparison of historical and current orthophoto images available on map servers was used (Geoportal, 2022). Graded ages were deliberately chosen, namely 10, 24 and 67 years.

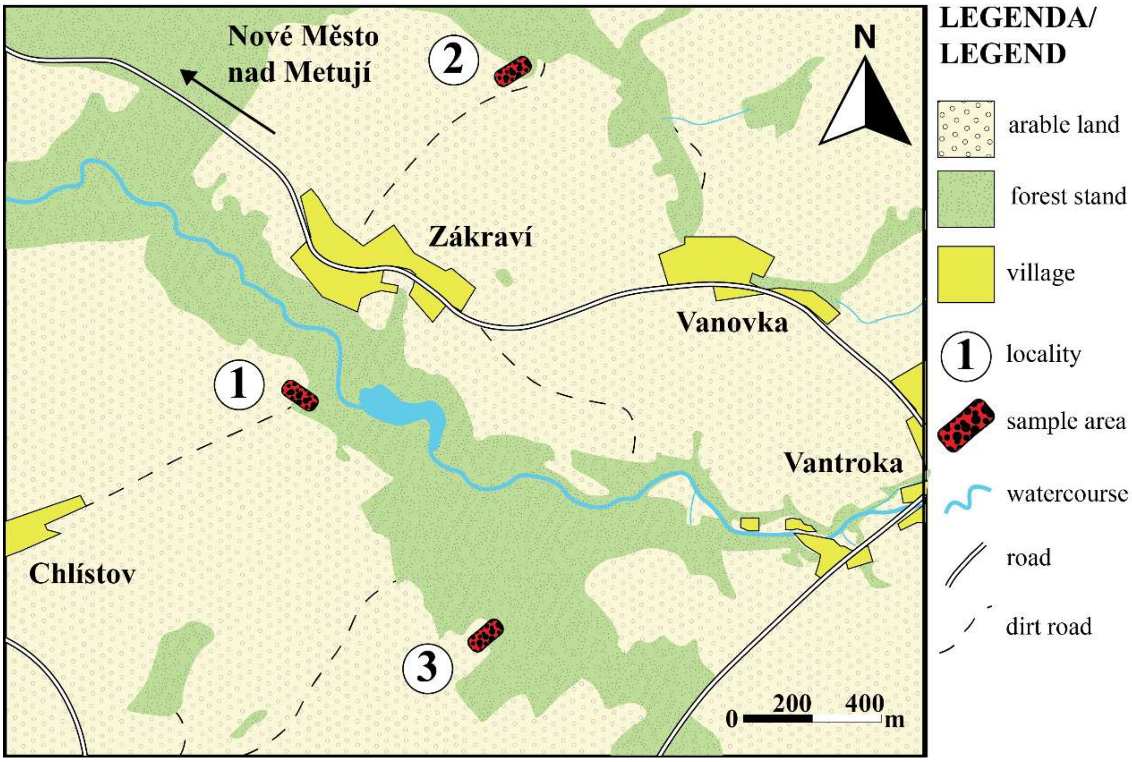


Figure 18: Location of research areas near Nové Město nad Metují.
Adapted from (Klíč et al., 2023)

Portugal

The sampling sites in Portugal are located in Zebreira, within Idanha-a-Nova municipality, in the centre-eastern area of the mainland territory. It is a rural area, with a population of 873 inhabitants and a population density of 8.4 inhabitants per km^2 (INE, 2022). The climate is Mediterranean, with an annual average rainfall of 780 mm and an average daily temperature ranging from 8ºC in the winter to 25ºC in the summer (Duarte, 2022). The terrain is relatively smooth, with alimetry ranging between 200 m and 350 m. The soil derives from distinct parental materials, mostly fluvisols and luvisols, and some acrisols and regosols (Infosolo, 2022). The area is dominated by agricultural land, mostly rainfed but also irrigated arable crops, olive grove, pasture and fallow. There are also some forest land, including *Quercus* and *Eucalyptus* plantations.

Kazakhstan (Terenkol, Fedorovka)

Samples collection were made north-east of the city of Pavlodar in eastern Kazakhstan. The climate is distinctly continental with dry hot summers and cold winters (Rau et al., 2023). Summer temperatures normally reach 40°C, winter -30°C. The annual precipitation is 300 mm and most of the precipitation is in the form of snow, much smaller part in the form of rain (Alimbaev et al., 2023). The natural vegetation is steppe, in some places in the region also salted (not in research area). The soils are classified as Kastanozem (IUSS WRB, 2014), possibly reaching marginally poor chernozems, which are found further north. Soils, when plowed, show extreme susceptibility to erosion (mainly wind). During the period of extensive exploitation of natural steppes in an attempt to convert them into arable land, erosion increased. Most soils were significantly damaged by wind erosion, and after a few years plowing had to be significantly reduced (Koza et al., 2024). A crop rotation/management system was introduced and protective forest (shrubs, low trees) stripes perpendicular to the prevailing winds were planted.

Lithuania

Lithuania lies on the Eastern European Plain, with characteristic lowlands and hills with the highest point only 293 m above sea level. The terrain features numerous lakes and wetlands, and a mixed forest zone covers over 33 % of the country. Lithuanian climate conditions and natural soil productivity are generally favourable for crop production. Consequently, more than 50 % of its land area is use for agricultural purpose (Jukneliené et al., 2021). Country climate can be characterized as a transitional between mild Western European and continental Eastern European climate. The average mean annual air temperature in Lithuania is 6.9°C and 7.9°C in Kaunas (Galvonaitė et al., 2013). The largest effect on the air temperature and its distribution in Lithuania is made by the Atlantic Ocean and distance from the sea. Due to a heating effect of sea, winters on the coast of Lithuania are significantly warmer and springs are cooler. The effect of the Atlantic Ocean could be felt all over Lithuania where the climate is significantly warmer than that in the continental regions of the same geographic latitudes (Laurinavicius & Jukneviciute-Zilinskiene, 2011). Annual precipitation varies from 560 to 910 mm, and is higher on windward slopes of the hillsand lower on their lee side and on the plains (Galvonaitė et al., 2013). The annual amount of precipitation in Kaunas is 600 mm. According to their mechanical composition they are light loam and averagely heavy sand loam with fine sand and pebble (Jukneviciute & Laurinavicius, 2008).

Russia

The territory of Kursk Region is located on the South-Western slopes of the Central Russian Upland and is characterized by a moderate continental climate (Deriglazova, 2021). The temperature regime of the territory is slightly lower than in the neighboring regions of the Central Chernozem Area, and the humidification regime of the region is favorable. When growing most crops (wheat, sugar beet, barely) this climate is suitable for obtaining high yields (Cherkasov et al., 2017). Irigation farming is use on significant part of the area (Khitrov et al., 2019). The typical chernozems (heavy clay soils) have been maintained without changes since 1964. Chernozems (Luvic Chernozems), belongs to the richest soils of the world (Smagin, 2013). The climate is temperate with an average annual temperature of 5.3 °C and average annual precipitation 550 mm (Danchenko et al., 2022). This area has diversity of landscapes, including broadleaved forests (predominantly oak forests), steppes and transitional zones. In the East European Plain, forest-steppes and steppes extendin the zonal direction as continuous zones; further to the east, they occur in isolated intermontane depressions (Khitrov et al., 2019).

2.3 WSA determination procedure

At the beginning of the WSA determination procedure (which is described in detail below), the samples collected at all sites were dried and subsequently size distribution curves were created to verify the same soil texture type. Dry and wet sieving followed (Fig. 19). The samples from the wet sieving were subsequently dried in a laboratory oven and their representation in the entire sample was determined from the obtained values. After finding out these data, forest and arable land were compared, graphs were created and the results were commented. The entire procedure was summarized (Fig. 20, page 51).

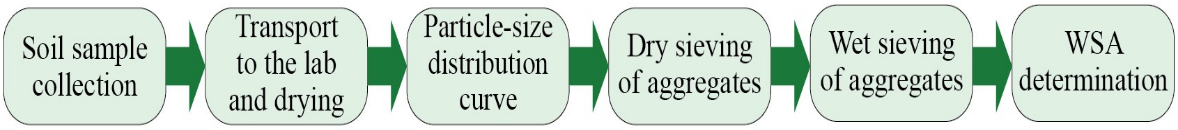


Figure 19: WSA determination procedure. Illustrated by author.

Field samples collection

Forest and arable areas had to be located next to each other (if possible) and had the same soil texture type, which was first determined using soil maps and then verified by particle size analysis in the next step of the procedure. Another condition was that the area, if possible, was in flat terrain, thus eliminating the influence of different soil properties on the upper and lower part of the slope. On examined soil in field (forest and arable), three squares of 1×1 m were always marked out. The top layer of plant litter (especially in case of forest soil) was removed, and then samples were collected with stainless steel shovel from the top of the soil to a maximum depth of 10 cm (horizon O–A). Subsequently, 6 samples with a fresh weight of approximately 2 kg were taken from each 1×1 m ($1m^2$) area. Already at this stage, was an effort to remove as much of the stones from the soil as possible, which was unwanted to the laboratory processes for next steps of the research. A total of 18 samples from forest and 18 from arable land on each locality were taken. The samples were placed in a marked bag to avoid any mistakes and transported to laboratory (Sáňka & Zímová, 2016). The forest and arable soil samples were separately and evenly distributed in a layer approximately 4 cm high, and subsequently small stones and also the remains of organic materials (roots, leaves) were manually removed. Natural drying was going on at laboratory temperature (20°C) for 14 days. It was important to dry aggregates naturaly, because oven-drying increases stability in otherwise unstable aggregates (Gee & Or, 2002), which was unsatisfactory.

Particle size distibution analysis (Hydrometer)

For each investigated locality, a particle size distribution curve was determined separately for forest and arable land by the hydrometer method according to standard ČSN EN ISO 17892–4 (2017). First part of the Hydrometer method was preparation of dispersant (Disp), when 200 ml of distilled water and 8.74 g of dispersant (sodium hexametaphosphate) were poured in laboratory beaker number 1 (LB1) and stirred up thoroughly. In next step, prepared (dried) 150 g soil sample was sieved through sieve with a mesh size of 2 mm. A sample of fine soil (soil with fractions smaller than 2 mm) was obtained and 35 grams of it poured in laboratory beaker 2 (LB2) together with 35 ml of solution from LB1 (distilled water + dispersant). The dilution ratio was 1:1. Distilled water was then poured into the LB2 up to a value of 200 ml and left until the next day (24 hours). The next day, the LB2 was placed on the stove and boiled for 15 minutes at a temperature of 100 C°.

The mixture was stirred regularly during the process. The LB2 was set aside and when it had cooled, its contents were poured onto the top sieve in a set of sieves (1 mm, 0.5 mm, 0.25 mm) and the sample was washed through the sieves. The process of particle size analysis throught listed sieves was adapted from (Drbal, 1965) and slightly modified. The sieves were then placed in a laboratory oven and dried at a temperature of 55°C. A portion of the sample with a fraction smaller than 1 mm (S1) was carefully poured into a volumetric cylinder (VC). Subsequently, the VC was topped up with distilled water up to a value of 1000 ml. The temperature was measured and written down. Using a stirrer, the solution was mixed for 1 minute. The moment the stirrer was pulled out of the solution, the stopwatch was started and the measurement began. The hydrometer was immersed in the VC and the first value on his scale was recorded at 30 seconds. Following measurements were recorded at 1, 2, 3, 4, 5, 15, 45, 120, 150, 300 and 1470 minutes. The temperature was measured and recorded at each time as well. Finally, a particle size distribution curve was created from the obtained values. Crucial for the determination were the values in the graph for clay (0.002 mm), silt (0.05 mm) and the remaining part up to 100 % was sand. From the graphs of the resulting particle size curves, it was possible to determine the soil texture type and, on the basis of this fact, confirm that it was the same soil, which was, however, affected by a different way of land use. After this verification and confirmation, the WSA determination procedure continued.

Sieving process

After the natural drying of the soil sample layer, a mixed sample (Mxs) was then formed. The mixed sample is generally formed as a combination of two or more samples mixed in appropriate proportions to provide the desired average result (Horálek et al., 2010). Standard sample preparation was followed (Gee & Or, 2002). The whole sample (Ws) was first mixed several times. Then the obtained sample was divided into 4 separate samples (4s). The obtained samples (4s) were checked once more. Stones and also unwanted particles such as undecomposed wood residues were removed. Ceramic dish was placed on the laboratory balance KERN EW and zero the balance. After that, it was gradually taken from the individual parts of the 4s sample and placed on a dish so that the resulting sample had a weight of 400g (S_{400}). At this stage, a maximum deviation of ±1 % was considered. A dry sieving was then performed for the resulting 400 g sample (S_{400}).

Dry sieving

A nest of sieves was placed on the OASS203 analytic sieve shaker. This was a modification of the method used by Šimanský (2012) in his research. In case of this thesis, the sieves were placed in descending order of mesh size as follows: 2 mm; 1 mm; 0.5 mm; 0.25 mm; 0.1 mm and in the lower part was plate for collecting particles smaller than 0.1 mm. Sample S_{400} was placed on the on the top sieve (2 mm). Set of mentioned sieves was properly fastened and a shaking program with a intensity of 100% for a duration of 10 minutes was set on a laboratory shaker. The individual fractions that remained on the corresponding sieves (for example: f_1-weight of fraction of 1 mm) were then transferred to marked dishes and weighed on a laboratory scale. For each fraction, including particles smaller than 0.1 mm, its weight was recorded and placed in appropriately marked paper bags.

The next step was to create a 10 g sample (Sw_{10}) according to the representation of the individual fractions of dry sieving (Vadjunina & Korchagina, 1986). The procedure was as follows:

The % representation ($Rep_{\%}$) of a part of the individual fractions (for example f_2; f_1; $f_{0.5}$) of the dry soil sample was determined by calculating:

$$Rep_{\%} = \frac{individual\ fraction\ weight * 100}{S_{400}}$$

For the next procedure, particles smaller than 0.1 mm ($f_{0,1}$) were not included and therefore subtracted in the following formula:

$$Rep_{10} = \frac{Rep_{10} * 100}{100 - f_{0.1}}$$

To determine the weight of each fraction to form a 10 g sample, was according to the formula:

$$S_{10} = Rep_{10} * 0.01 * 10$$

The weights of the individual fractions (2; 1; 0.5; 0.25; and 0.1 mm) were accurately weighted on a laboratory balance. According to the calculation, an exact amount was taken from each fraction (2-0.1 mm) and a 10 g sample wass assembled for wet sieving (Sw_{10}).

Wet sieving

An innovated laboratory device was used for wet sieving. The formed 10 g sample (Sw_{10}) from dry sieving was submerged for 2 hours in a plastic container. This step simulates the wetting of the soil, for example during a light rain. Meanwhile, a nest of sieves with the same diameters as for dry sieving were placed in descending order into the aluminum cylinder (2; 1; 0.5; 0.25; 0.1 mm and lower part for fractions smaller than 0.1 mm). A prepared Sw_{10} sample was placed on the top sieve with a mesh size of 2 mm. It was necessary to carefully rinse the plastic container with the sample several times in order to obtain the entire sample. Then the whole aluminum cylinder was poured with water about 2 cm below the upper edge and closed with a lid to prevent water spillage and soil leaching. The inovated device was started and run for 12 cycles (12 tilts at an angle of 45° to each side). Then the device was switched off and the aluminum cylinders were pulled out of the device. Fractions of water stable aggregates (WSA) were removed from the sieves using a laboratory syringe (or a very weak stream of water) and placed on marked laboratory dishes.

Marked dishes with individual fractions were then placed in a laboratory oven. Drying to constant weight was achieved by exposing the soil sample to 55°C for at least eight hours. The final step after drying was to weigh and record the weights of the individual fractions of WSA aggregates on a laboratory scale. To obtain more accurate results, water sieving was performed several times and their arithmetic mean was calculated. Thereafter it was possible to determine the representation of water-stable soil aggregates in arable and forest soil. Finally, WSA values (g) for each fraction were recalculated into a percentage using formula:

$$WSA\ (\%) = WSA\ (g) * 100/\sum WSA_{if}$$

Where:

WSA (g) – Weight of individual fraction

WSAif – Total weight of WSA for all individual fractions (g)

After each wet sieving, samples of individual fractions of WSA were always clearly stored in marked plastic containers. Additional parameters (CA, MPs, MWD) could then be determined from the samples stored in this way.

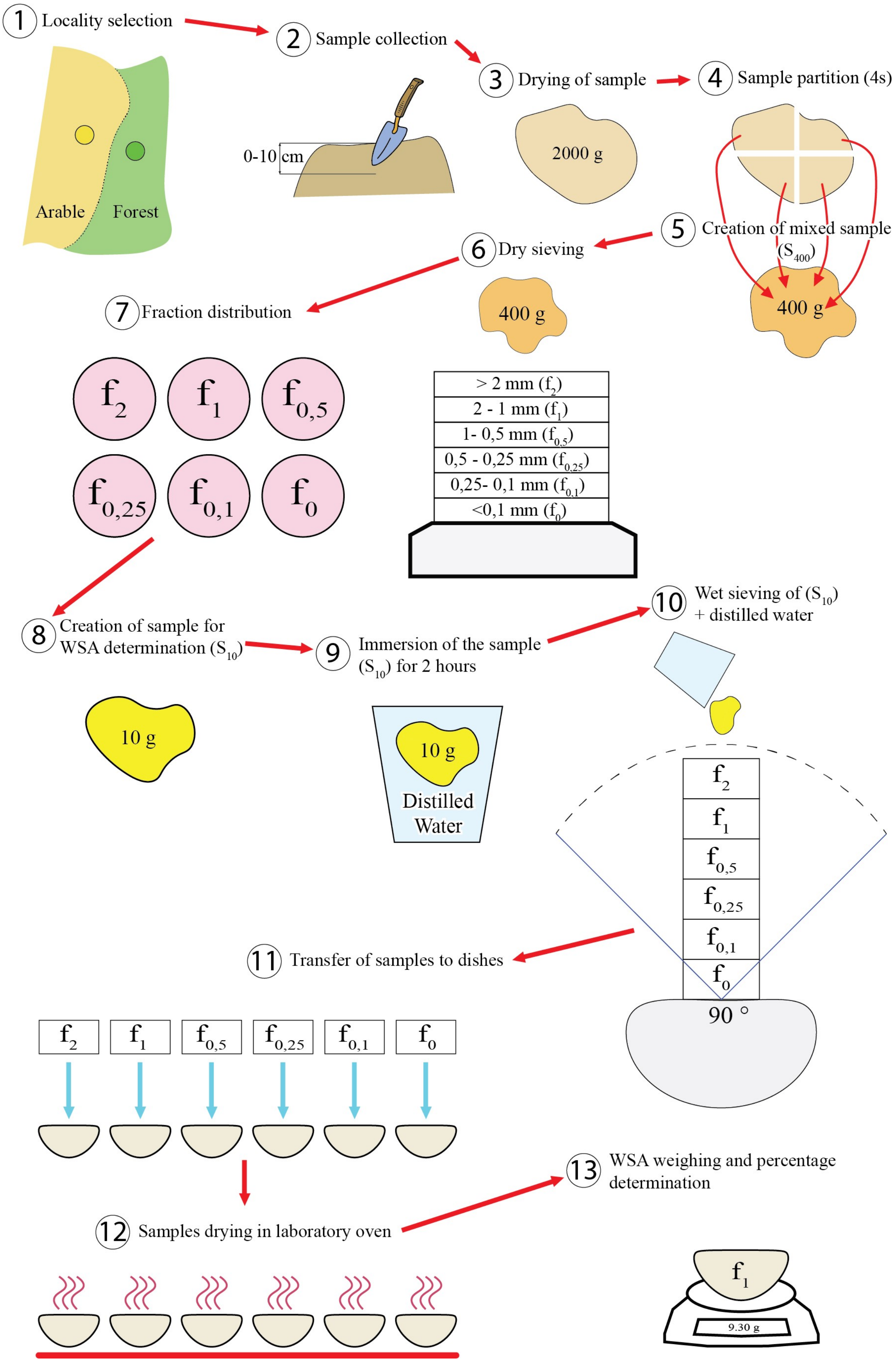


Figure 20: Process of WSA determination. Illustrated by author.

2.4 Parameters calculation

Mean weight diameter (MWD)

Scientific authors often express the amount of WSA differently (weight, percentage). For the possibility of a clear comparison of all obtained data with one parameter, MWD (mm) was selected, which was calculated from the obtained values of soil fractions after wet sieving using formula (van Bavel, 1950):

$$\mathrm{MWD} = \sum_{i=1}^{n} \bar{x}_i \cdot w_i$$

Where:

$\bar{x}_i$ - Mean diameter (mm) of size fraction i

w_i - Proportion of the total sample (by weight) of that size fraction i; and n is the total number of size fractions

Susceptibility of soil to wetting (Sw)

It was also possible to calculate the following parameters from the obtained values:

$$S_W = \frac{MWD_{dry} - MWD_{wet}}{MWD_{dry}} \cdot 100$$

$$S_{WD} = \frac{MWD_{dry} - MWD_{disp}}{MWD_{dry}} \cdot 100$$

$$\Delta S = S_{WD} - S_W$$

Where:

MWD_{dry} - Mean weight diameter of dry sieving (mm)

MWD_{wet} - Mean weight diameter of wet sieving (mm)

MWD_{disp} - Mean weight diameter of wet sieving with dispersion (mm)

S_W- Susceptibility of soil to wetting (%)

S_{WD} - Susceptibility of soil to wetting and dispersion (%)

ΔS - Indication of the susceptibility of the soil to dispersion alone (%)

Percentage of aggregate destruction (PAD)

Aggregate stability was expressed using PAD according to (Zhang & Horn, 2001).

$$PAD = \frac{p_{dry} - p_{wet}}{p_{dry}} * 100$$

Where:

p_{dry} - Proportion of aggregates > 0.25 mm after dry sieving (%)

p_{wet} - Proportion of aggregates > 0.25 mm after wet sieving (%)

2.5 Measurement of the contact angle

The contact angle (CA) was determined by the sessile drop method (Ryley & Khoshaim, 1977; Burghardt, 1985) on a digital goniometer (OCA 15EC DataPhysics, Germany) equipped with a video camera and SCA 20 software. The contact angle is the angle formed by the liquid at the contact line of the liquid, the solid, and the air, the liquid exhibits a certain slope. This slope is termed the contact angle (Butt et al., 2022). The experiment was performed according to the following scheme: a 1 µl drop of distilled water was squeezed from a vertically positioned needle (ø 0.51 mm); the slide with the soil sample was raised until it contacts the water drop so that the drop sits on the sample, then the slide was lowered. The entire process was video recorded. After dispensing, the drop shape was monitored with a digital camera for 50 s, and contact angle, drop diameter, and volume were recorded. Since soil quickly absorbs water, the contact angle was determined from the first clear shot of the droplet landing on the sample. The drop shape was approximated by the manual method.

To determine the contact angle, the drop contour was mathematically described by the Young–Laplace equation using SCA 20, and the contact angle was determined as the slope of the contour line at the three-phase contact point. A flat surface of the sample for measuring the CA was obtained on a membrane filter by depositing a soil suspension on it and placing the filter with the sediment on a slide covered with double-sided adhesive tape. A sample (0.05 g) of milled air-dry soil (< 0.25 mm) was placed in glass beakers (50 ml), 25 ml of distilled water was added, and dispersed by ultrasound (Branson Digital Sonifier 250, U.S.A.) at 450 J/ml. The dispersed suspension was passed through a 0.1 mm sieve to remove single coarse particles of sand fraction from the sample (Bachmann et al., 2000).

A vacuum filtration unit with a porous glass base (ø 40 mm) for a membrane filter (ø 47 mm, pore size 0.45 µm), in a strictly horizontal position, provided uniform precipitation soil sample on the filter surface. The sample suspension passed through a 0.1 mm sieve was shaken, 10 ml of the suspension was transferred to the prepared filter (the filter was previously placed in a beaker with distilled water for uniform wetting, the sample suspension was applied to the filter covered with a layer of water) and the maximum vacuum was created immediately. The filtration time was a few seconds, which minimizes particle size differentiation during settling. The filtration area through this setup was 12.5 cm^2. The concentration of the soil sample on the membrane filter was 1.6 mg/cm^2. On one membrane filter were performed from 5 to 13 repetitions of measurement of the contact angle. The number of repetitions was determined by the properties of the sample and the surface area wetted by one drop of water.

2.6 Microplastics determination

During research, a modification of method for determining microplastics (MPs) in sludge was used (Campo et al., 2019). MPs were determined from samples (forest and arable) at the locality Czech Republic-Lysolaje. After treatment at laboratory, the examined samples were filtered and finally stained with Nile red. The entire procedure was as follows: At the beginning (step 1), the aggregates were dissolved in a solution of the saturated chloride of the compound (30 g NaCl per 100 ml ultrapure water) in a ratio of 1:10 (1 g of aggregate per 10 ml of NaCl solution), followed by a centrifugation the mixture at 2500 rpm for 10 min. Then, treatment of liquid and solid parts was done separately. Liquid parts were filtrated through an 80-µm sieve. The liquid part was left for 24 h in a refrigerator at 4 °C (filtrate 1). The used sieve was washed with the saturated NaCl solution and make up to volume with NaCl solution as in step 1 (50–80 ml). The solution was allowed to settle for 24 h at the room temperature 21 °C. Then, it was subsequently centrifuged at 2500 rpm for 10 min, and again the liquid fraction was poured without filtration through an 80-µm sieve (filtrate 2). Both filtrates (1 and 2) were oxidized separately by adding 10 ml of 30% hydrogen peroxide per 100 ml of filtrate for 30 min. Subsequently, repeated oxidation was performed by adding 10 ml of 30 % hydrogen peroxide, and the samples were left to react for 12 h. After oxidation, both filtrates (1 and 2 from one sample) were combined into one, and it was filtered by a vacuum filtration through a Whatman GF/B glass filter.

All filtrates were transferred to the filtration apparatus quantitatively by rinsing the vessel with running ultrapure water 3 times (the filtrate from the forest soil was filtered longer due to the slower throughput). Solid parts, both from the sieve and the centrifuge tube, were wrapped in aluminium foil and placed in a freezer for 48 h to remove moisture. For the remainder of the solid in the centrifuge tube, it was necessary to use 1–2 ml of saturated NaCl solution to convert to aluminium foil. Frozen solids were oxidized by adding 10 ml of 30% hydrogen peroxide to a given amount of solid (approx. 5–7 g) for 30 min (temperature reaction observed with max. temperature increase to 26 °C and relatively signifcant foaming of samples, larger for a fixed proportion of forest land). Subsequently, repeated oxidation was performed by addition of 10 ml of 30% hydrogen peroxide and the samples left in the reaction for 48 h. To stabilize the reaction, the samples were diluted with 200 ml of ultrapure water and repeatedly oxidized by the addition of 20 ml of 30% hydrogen peroxide and allowed to react again for 48 h. Subsequently, the solution was centrifuged at 2500 rpm for 10 min. The supernatant (liquid fraction) was poured without the use of the 80-μm sieve, and the solid fraction was then discarded. All supernatants were filtered by the same procedure as liquid parts (the extract from the arable soil samples was brown-yellow and from the forest soils bright yellow). All glass filters were then pre-dried in closed petri dishes in an oven at 45°C for 3 h and subsequently dyed with 2 ml of fuorescent dye Nile red (at the concentration of 0.01 mg per 1 ml). Then, the coloured filters were completely dried in closed petri dishes in an oven at 45°C for 24 h (Klíč et al., 2022).

Nile red staining was used for visual identification of microplastics (Shim et al., 2016; Erni-Cassola et al., 2017; Maes et al., 2017a; Maes et al., 2017b; Tamminga et al., 2017; Prata et al., 2019) diluted in reagent grade ethanol, endowed with fluorescence microplastic polymers, making the visual identification easier from mineral and organic particles in a sample. Furthermore, the fluorescent microplastics were photographed in the dark room under 254-nm wavelength of UV light and then it was possible to automatically quantifed MPs by a counting software like ImageJ. Prata et al. (2019) developed a plugin for ImageJ called the MP-VAT that simplifies the counting of microplastics after Nile red staining. The plugin works on principle of converting an image of Nile red–stained microplastics under UV light and turning it in a binary (black and white) output that will count the dark areas, measuring them and generating a CSV file of the counted particles with enough precision. This procedure increases sample throughput and removes the subjective variation inherent to diferent operators (Prata et al., 2019).

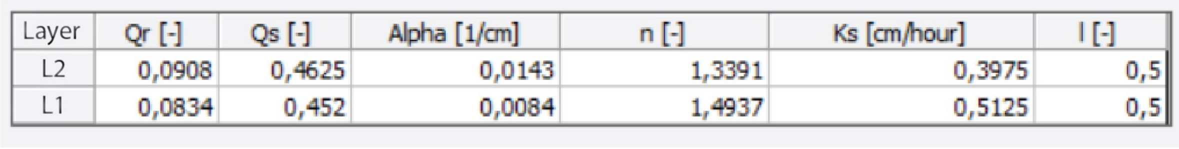
The diameter of the filter was 42.5 mm. In case the counting software showed a noticeable error, MPs were counted manually on the printed magnified image. Soil organic matter (SOM) content was determined by the modifed Walkley–Black method, particularly wet combustion according to (Nelson & Sommers, 1983). Active pH was measured in the filtrate (ratio 1:5). High content of organic matter was removed by 15% solution of H_2O_2.

Statistical evaluation

The statistical evaluation of WSA samples was performed in Microsoft Excel 2016. Data from repeated measurements were always evaluated and the median, standard deviation and confidence interval values for individual fractions were determined. Statistical comparison of the average length of microplastic particles locked in WSA was also made.

2.7 Example of model adaptation using Hydrus 1D

The obtained data from the grain size curves were used to create graphs in the software Hydrus 1D. Two forest soil samples were taken from the Czech Republic – Lysolaje (ID 1). The first sample (L1) was taken from the 0-10 cm layer, the layer containing the aggregates. The second sample (L2) was collected at a depth of 10-30 cm. From both samples, particle size curves were determined (according to the methodology mentioned above) and the representation of clay, silt and sand fractions was determined. The obtained texture was inserted into the HYDRUS 1D and the software calculated soil hydraulic parameters (Fig. 21). After setting other input parameters (Tab 2.), graphs showing infiltration and flow through the soil profile were obtained.



Layer	Qr [-]	Qs [-]	Alpha [1/cm]	n [-]	Ks [cm/hour]	l [-]
L2	0,0908	0,4625	0,0143	1,3391	0,3975	0,5
L1	0,0834	0,452	0,0084	1,4937	0,5125	0,5

Figure 21: Calculated soil hydraulic parameters

Where:

Qr	Residual soil water content, q_r
Qs	Saturated soil water content, qs
Alpha	Parameter a in the soil water retention function [L-1]
n	Parameter n in the soil water retention function
Ks	Saturated hydraulic conductivity, Ks [LT-1]
l	Tortuosity parameter in the conductivity function [-]

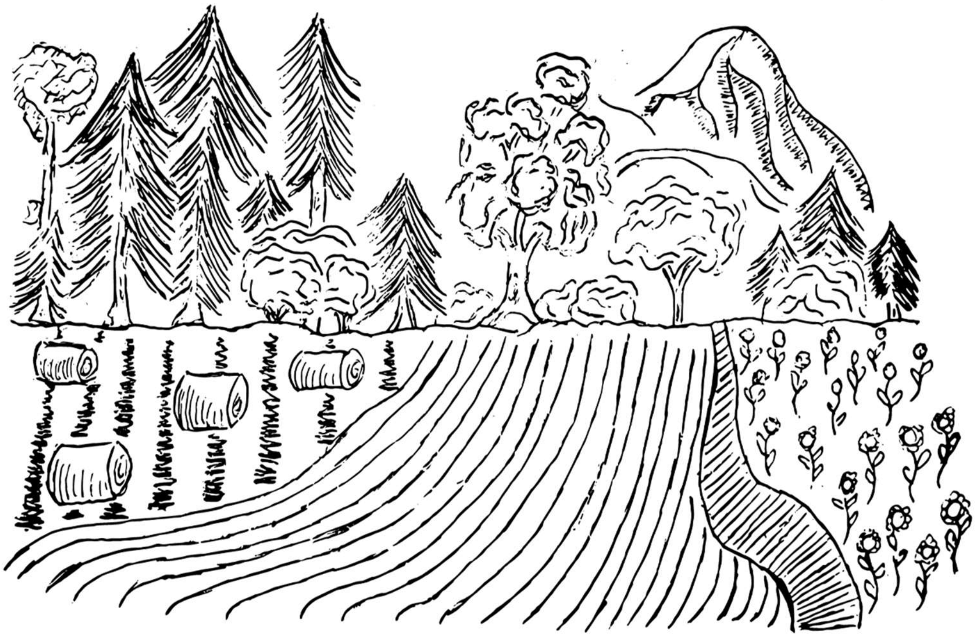
Table 2: Input parameters for HYDRUS 1D

Input parametr	Information/Value
Process	Water flow
Decline from Vertical Axes	1 (vertical)
Depth of soil profile	50 cm
Initial time	0 (hour)
Final time	1 (hour)
Maximum time step	0,5 (hour)
Hydraulic model	Single porosity model (Van Genuchten – Mualem)
Upper boundary condition	Atmospheric BC with Surface Run Off
Lower boundary condition	Free Drainage
Duration of precipitation	1 (hour)
Precipitation rate	20 mm/hour

2.8 Creation of conceptual model

The first step in creating a conceptual model was a problem formulation, which in the case of this work was the absence of a clear description of the various parameters related to water-stable aggregates (WSA). The task was to create a model in which the information and values that the study of WSA can bring us will be collected, refined and indicated their practical use. The design of the model was created in the software Adobe Illustrator CC 2019. The implementation of the model began, in the first phase of which the question was asked: What affects the formation of WSA? The basis was the information found by the WSA research, which was supplemented by the data found by the study of the relevant scientific literature. Individual processes were written down. The second question followed: What do the WSA in the soil affect? The obtained data were then displayed graphically and in the next procedure everything was logically arranged. In this logical arrangement, individual processes and parameters were subsequently specified. As part of the analysis of the determined parameters and values, there was always a comparison (verification) with the literature. The effort for numerical parameters was to find their connections and briefly explain their meaning. In the created conceptual model, the parameters that have already been determined as part of the research were marked. Other parameters can be an inspiring focus of future research. At the very end of the conceptual model, the gained knowledge was summarized and the possibilities of practical use in practice were presented.

Chapter III – Results



During the work, it was possible to compare several devices for determining WSA, including an innovative laboratory device. Their advantages and disadvantages are briefly described (Tab. 3). Innovated laboratory device and Manual tilting device by Klíč were used for the determination of WSA.

3.1 Comparison of devices for WSA determination

Table 3: Comparison of devices for WSA determination

Nest of sieves (manual sieving)	Advantages	o Simplicity o Can be used in the field o Possibility to use sieves with different mesh size o Cheap
	Disadvantages	o Duration of sieving o Manual work o Necessity of operator during the entire sieving o Only 1 sample can be sieved at one repetition
Baksheev laboratory device	Advantages	o Simple operation o Switches itself off automatically o Possibility to sieve 2 samples in one repetition
	Disadvantages	o Cannot be used in the field o Occasional minor errors may occur (old device) o Only a set of original sieves (6-0,1 mm) can be used
Inovated laboratory device by Klíč	Advantages	o Operator turn device off after 12 cycles o Possibility to make up to 4 samples in one repetition (speeding up the process) o Robust construction o Possibility to use different sieves
	Disadvantages	o Cannot be used in the field o High weight, difficult transport o There is a risk of clogging the sieve (clay sample)
Manual tilting device by Klíč	Advantages	o Low purchase price o Fully collapsible construction o Easy transport o Simple operation o Possibility to make 2 to 4 samples in one repetition o Short sieving time (12 minutes)
	Disadvantages	o Necessity of operator during the entire sieving o Manual work o The results may be affected by the operator
Ultrasound	Advantages	o High accuracy o Short analysis time
	Disadvantages	o High price for purchasing the device o High cost of the sieving test

3.2 WSA comparison for different land use

In this section, the results of the comparison of different land use for each examined locations are presented. For each location there are ID numbers for both land uses according to Tab. 1. After dry sieving, the arable soil often has a greater proportion of particles larger than 1 mm. However, after subsequent wet sieving, they break down into smaller particles. In the case of forest soil, in general, the larger fractions remain more water-stable and are still represented in the soil. The results from the localities (ID 5, 6, 7, 8, 9, 10) where the influence of different ages of the forest cover was compared are presented separately in the next subsection of work. An example of a comparison of dry and wet sieving is also given for these locations. For the sake of logical organization, a particle size distribution curve is first shown, which confirms the occurrence of the same soil texture type. The following graphs clearly show a comparison of the representation of individual factions together with commentary. In general, it can be said that the greater the representation of WSA fractions larger than 2 mm in the soil, the better the soil is in terms of infiltration. This fact can be verified by a simple experiment where an open container is placed on the surface of the soil, filled with water and then the rate of infiltration is measured. The experiment shows that the rate of infiltration is several times faster in forest soil. At the end of this subsection, the obtained data are statistically evaluated for all localities. The values from which the WSA graphs were created can be found in the appendices (Tab. 14) of the thesis as well as the results after dry sieving (Tab. 13).

Czech Republic – Lysolaje (ID 1,2)

It was determined from the graphs that forest soil had the following parameters: 31 % clay, 47 % silt and 22 % of sand. Arable land was similar with values: 32 % clay, 40 % silt and 28 % of sand. In this locality, it could be confirmed from the particle size distribution (PSD) curves that both forest and arable land are of the same soil textural type, which is clay loam (Fig. 22).

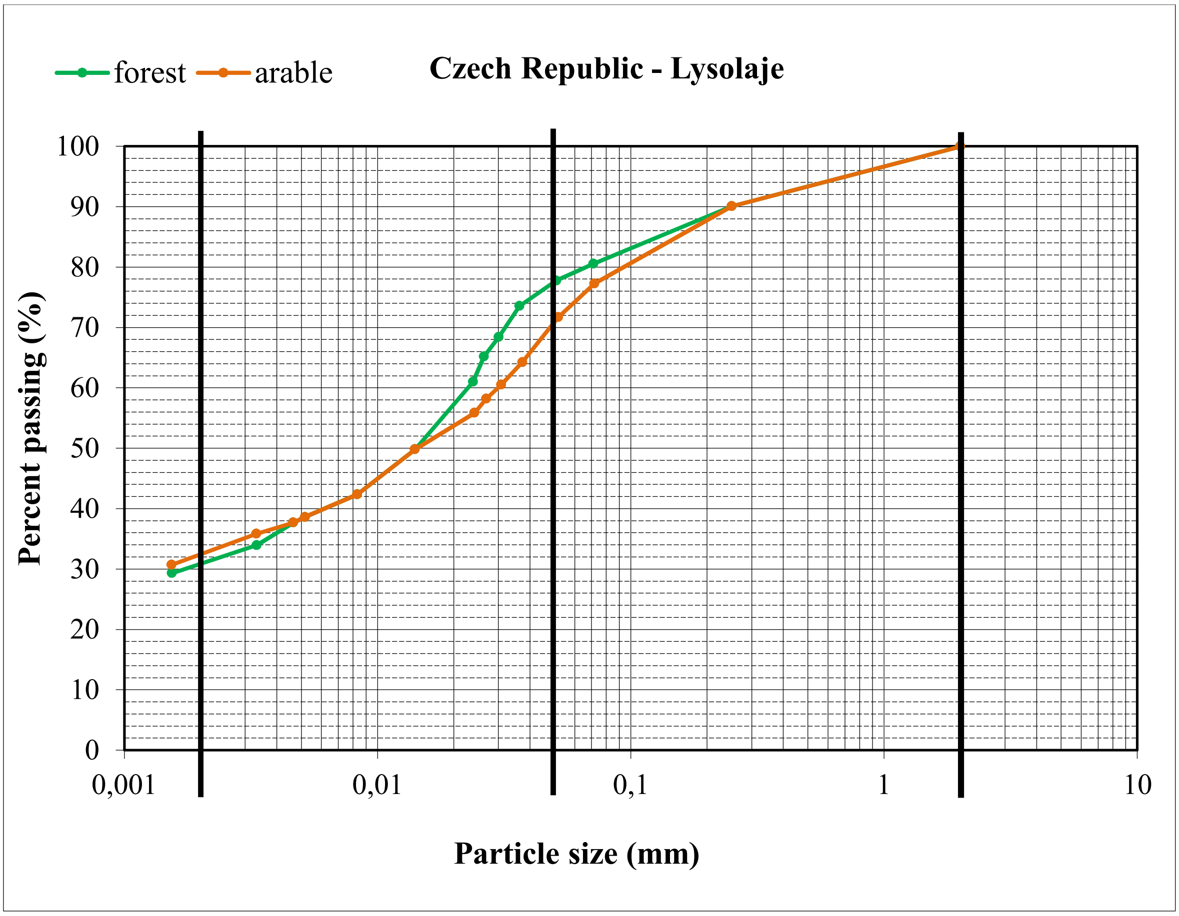


Figure 22: Czech Republic-Lysolaje particle size distribution curve

The forest soil contained the largest proportion of the fraction larger than 2 mm (31.36 %). The 2-1 mm fraction was also highly represented (25.33 %). For the data obtained for the forest soil, a downward trend can be seen from the largest fractions to the lowest, which shows a good soil structure. According to the LHO (ÚHÚL, 2021), the forest was 43 years old, but in fact the forest has been growing here for more than 90 years. Deciduous trees, mainly linden, oak and maple, were dominant here.

On the contrary, in the case of arable soil, a large part of the fraction larger than 2 mm was broken down by wet sieving (Fig. 23). The fraction 0.5–0.25 mm with a total of 31.7 % was the most represented in arable land. In the arable soil, 16.78 % of the fraction in the range of 2-1 mm was preserved, from which it can be concluded that this soil has, despite agricultural management, at least partially preserved infiltration capacity.

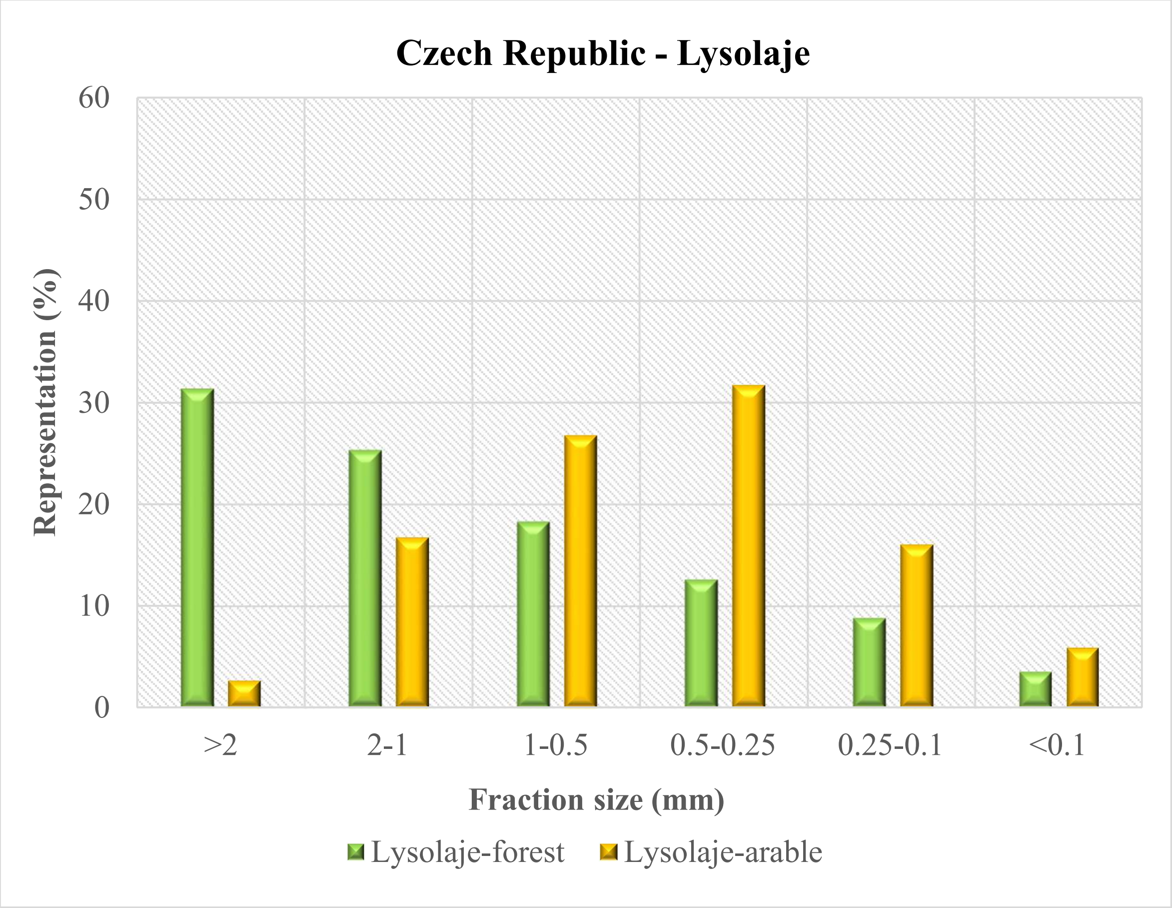


Figure 23: Czech Republic-Lysolaje WSA determination

Czech republic – Bošovice (ID 3,4)

At this locality, the forest soil contained 19 % of clay, 48 % of silt and 33 % of sand. According to the graph (Fig. 24), arable land had a slightly higher proportion of clay (22 %) and silt (49 %). Conversely, the sand content (29 %) was lower. Both examined samples belong to the same soil textural type, which is loam.

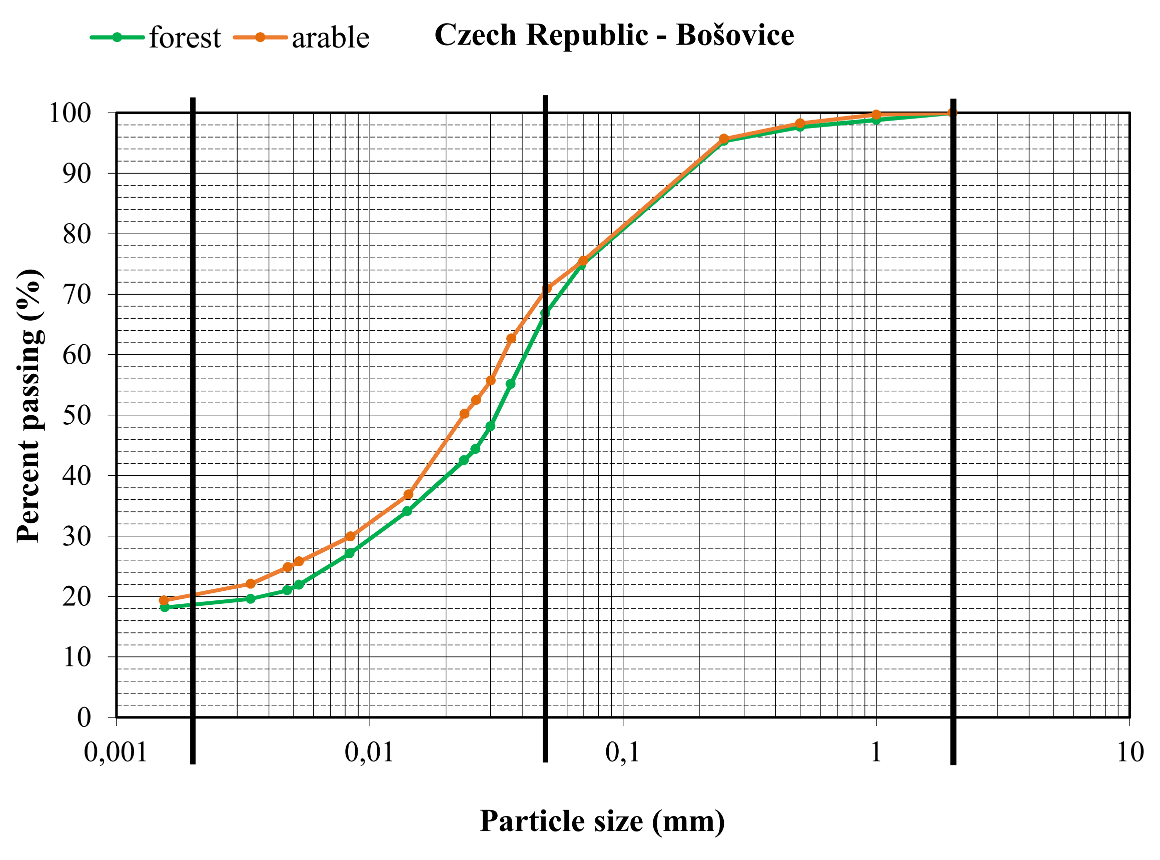


Figure 24: Czech Republic-Bošovice particle size distribution curve

It is noticeable that in this locality the forest again had a higher representation of fractions larger than 2 mm and also fractions in the range of 2-1 mm (Fig. 25). The value of the fraction greater than 2 mm had a value of almost 39 %. Therefore, a good level of infiltration can be assumed in this forest stand, which mainly consists of acacia with an age of 65 years. Arable soil had the largest fraction of 1 – 0,5 mm with a value of 33.21 %, which was comparable to forest soil (28.96 %) for this fraction. In the arable soil there was also a representation of fractions larger than 1 mm (21.84 %), which contributes to a better infiltration, which, however, will be smaller compared to the forest soil.

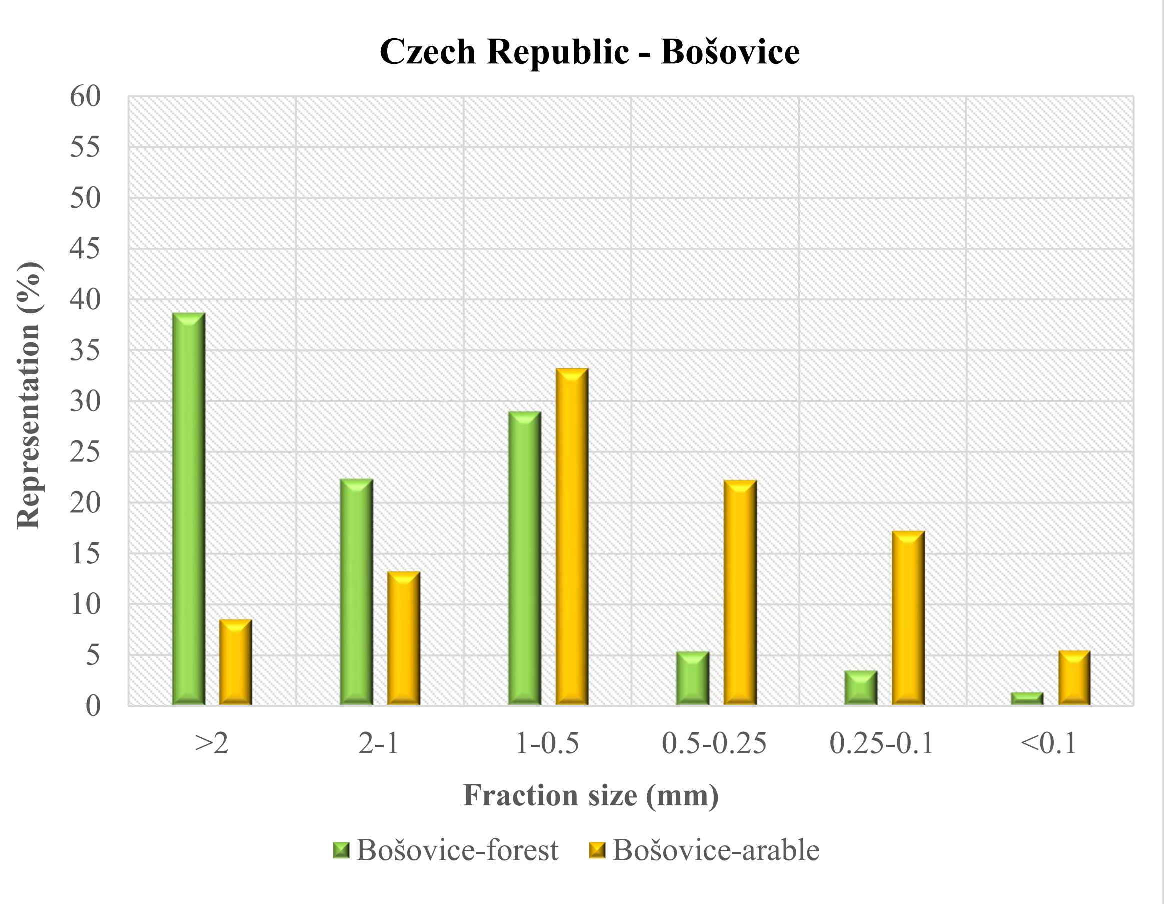


Figure 25: Czech Republic-Bošovice WSA determination

Portugal – Zebreira (ID 11,12)

The shape of the size distribution curve of Portugal soils (Fig. 26) differs greatly from that in the Czech Republic. It has a greater slope and a lower representation of clay particles. On the contrary, it contains a much larger amount of sand. The arable soil contained 12 % clay, 16 % silt and the remaining 72 % was sand. Forest soil had very comparable results as it contained 7 % clay, 19 % silt and 74 % sand. Due to the mentioned values, both soils were classified as sandy loam texture.

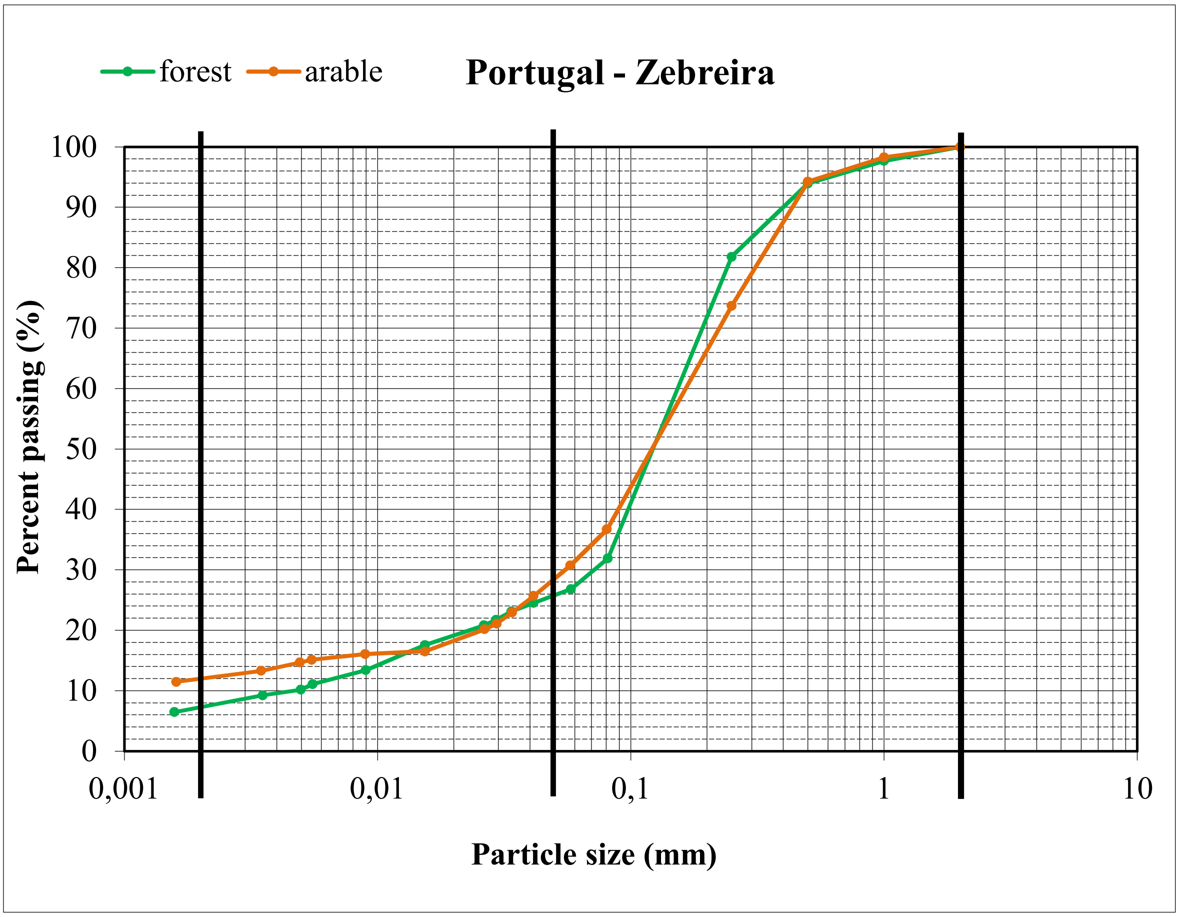


Figure 26: Portugal-Zebreira particle size distribution curve

In the case of the Portuguese forest, where mainly oak grew, it was found that the larger grain size fractions (> 2; 2-1 mm) constituted approximately 30 % of the sample (Fig. 27). Due to the presence of a larger amount of aggregate, there will be sufficient infiltration, but probably due to the high proportion of sand (determined from the soil curve) the water retention will be very low. Compared to the Czech locations, there was more than twice the share of the 0.5-0.25 mm fraction (33.48 %). Arable soil had a large proportion of fractions (89.66 %) ranging from 1 mm to the smallest particles. The remaining amount, which belonged to the larger fractions, will have a slightly positive effect on infiltration. However, in arable soil, particles larger than 2 mm weren´t almost represented (< 1.2 %). Larger fractions slightly predominate in the forest soil.

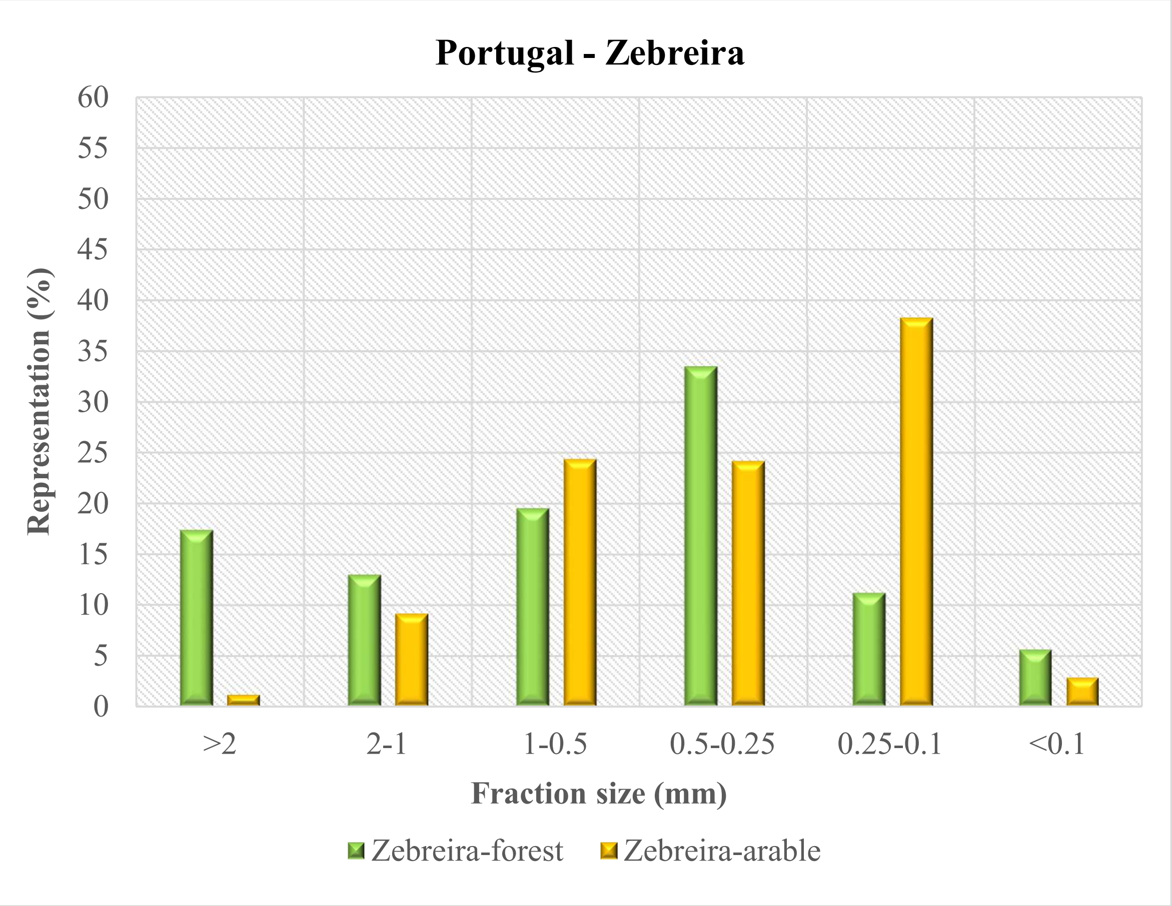


Figure 27: Portugal-Zebreira WSA determination

Lithuania – Kaunas (ID 13,14)

Soil samples collected in Lithuania had a high proportion of sand particles and a very low proportion of clay soil particles (Fig. 28), especially for the forest soil, which contained 12 % clay, 15 % silt and 73 % sand. Arable land had a slightly higher proportion of clay (18 %). Most of the sample consisted of sand (68 %) and a smaller part of silt (14 %). The shape of the size distribution curve is comparable to Portugal and Kazakhstan – Terenkol and is also classified as sandy loam.

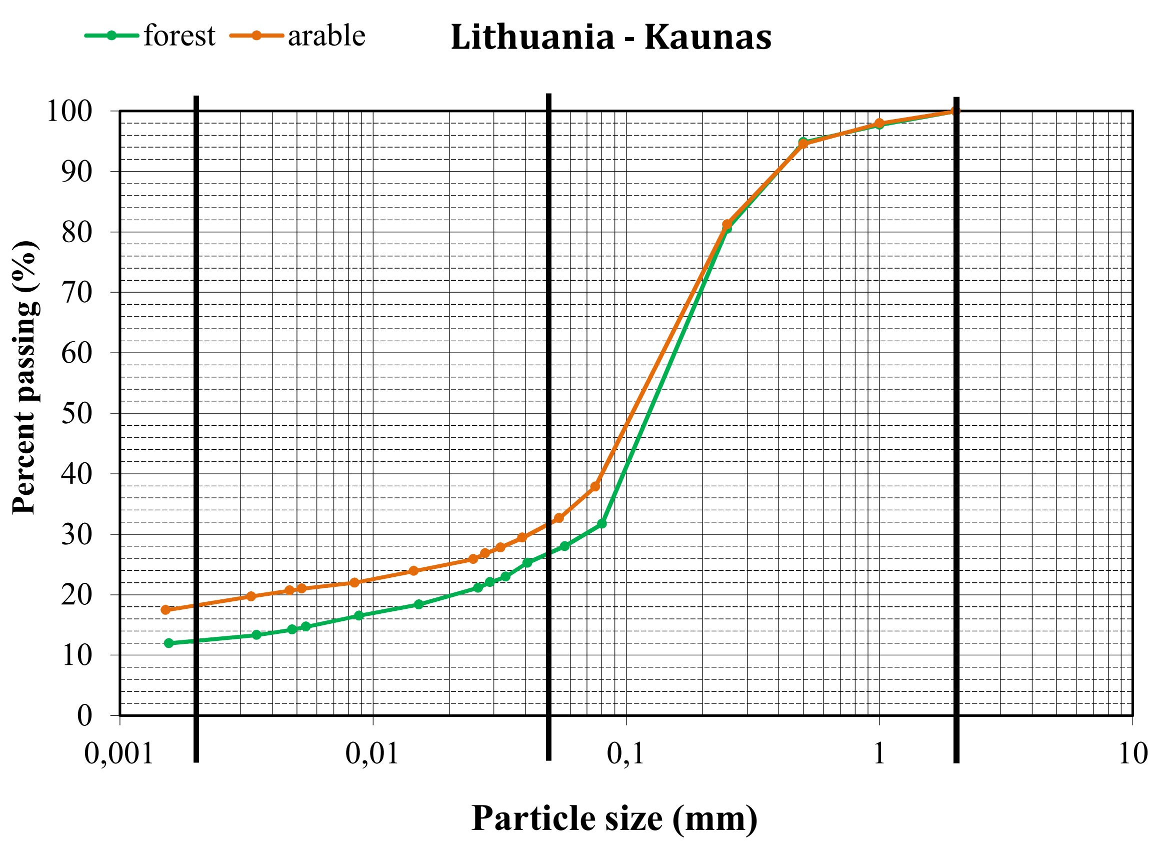


Figure 28: Lithuania-Kaunas particle size distribution curve

In the case of the land-use comparison in Lithuania (Fig. 29), it was found that the WSA fraction greater than 2 mm was completely absent in the arable land sample, and even the 2-1 mm fraction was represented by less than 1.5 %. On the other hand, there was a large representation of smaller particles, specifically the 0.25-0.1 mm fraction contains almost half of the sample with a value of 48.70 %. In the case of this locality, the forest floor had only a slightly better structure. Fractions greater than 2 mm and 2-1 mm constituted approximately only 5 % of the entire sample. The absence of larger fractions (>2 and 2-1 mm) have a fundamental effect on the bad infiltration into the soil, when due to rain, a poorly permeable upper layer of soil will be formed and water runs off on the surface.

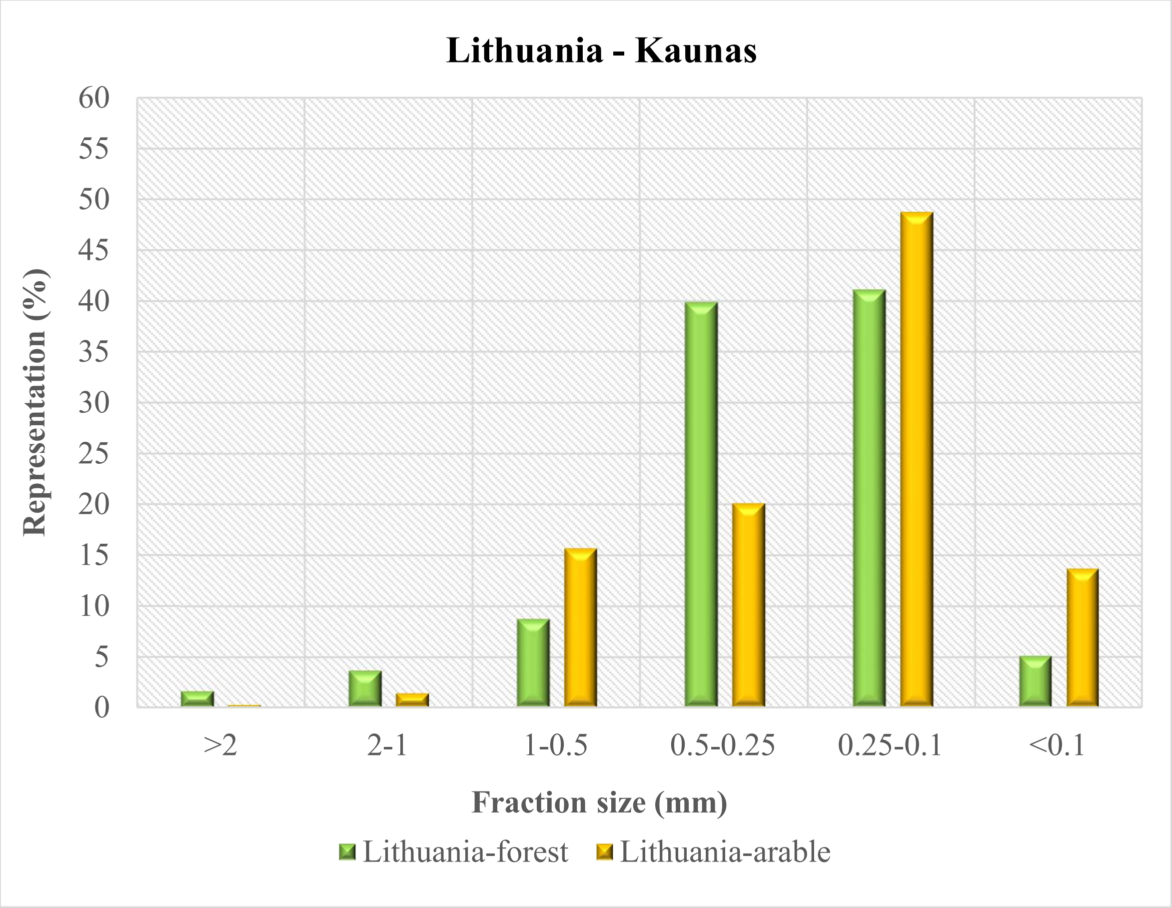


Figure 29: Lithuania-Kaunas WSA determination

Kazakhstan – Terenkol (ID 15, 16)

The values obtained at this location are comparable to Lithuania and Portugal, where there is a significant presence of sand in the PSD curve (Fig. 30). The forest soil contained 71 % sand, 22 % silt and 7 % clay. In the case of arable soil, a similar shape of the grain size curve was created, which also corresponds to the composition consisting of 73 % sand, 14 % silt and 13 % clay. According to the values obtained, it was possible to classify the soil texture type as sandy loam.

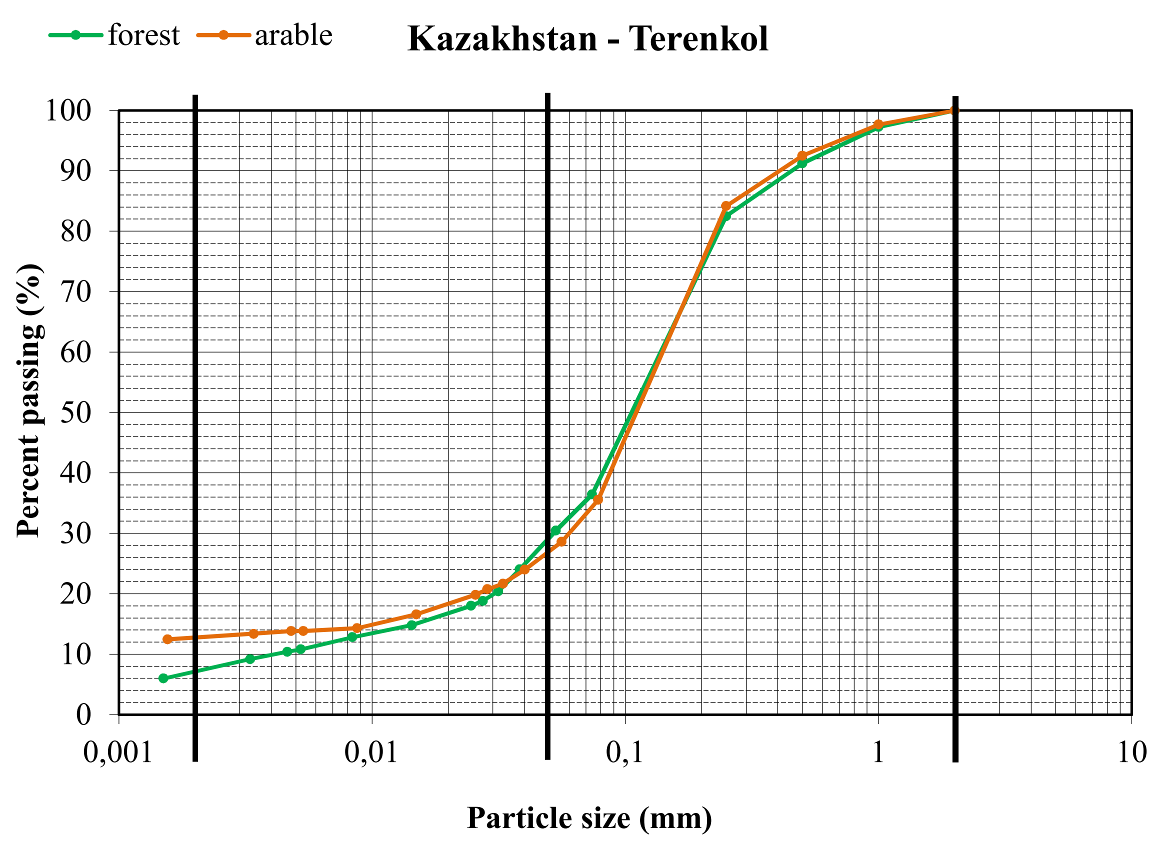


Figure 30: Kazakhstan-Terenkol particle size distribution curve

In the case of arable land, fractions larger than 1 mm were completely broken down, and even fractions in the range of 1-0.5 mm make up only less than 8 % of the total sample (Fig. 31). More than half of the sample (52.78 %) was broken down to the smallest fractions in the range of 0.25-0.1 mm, which were described as microaggregates. Even the forest soil does not have fundamentally better parameters, as the fraction in the range >2 – 0.5 mm made up only less than 13 %. It can be assumed that infiltration for both types of land use will be of similar poor quality.

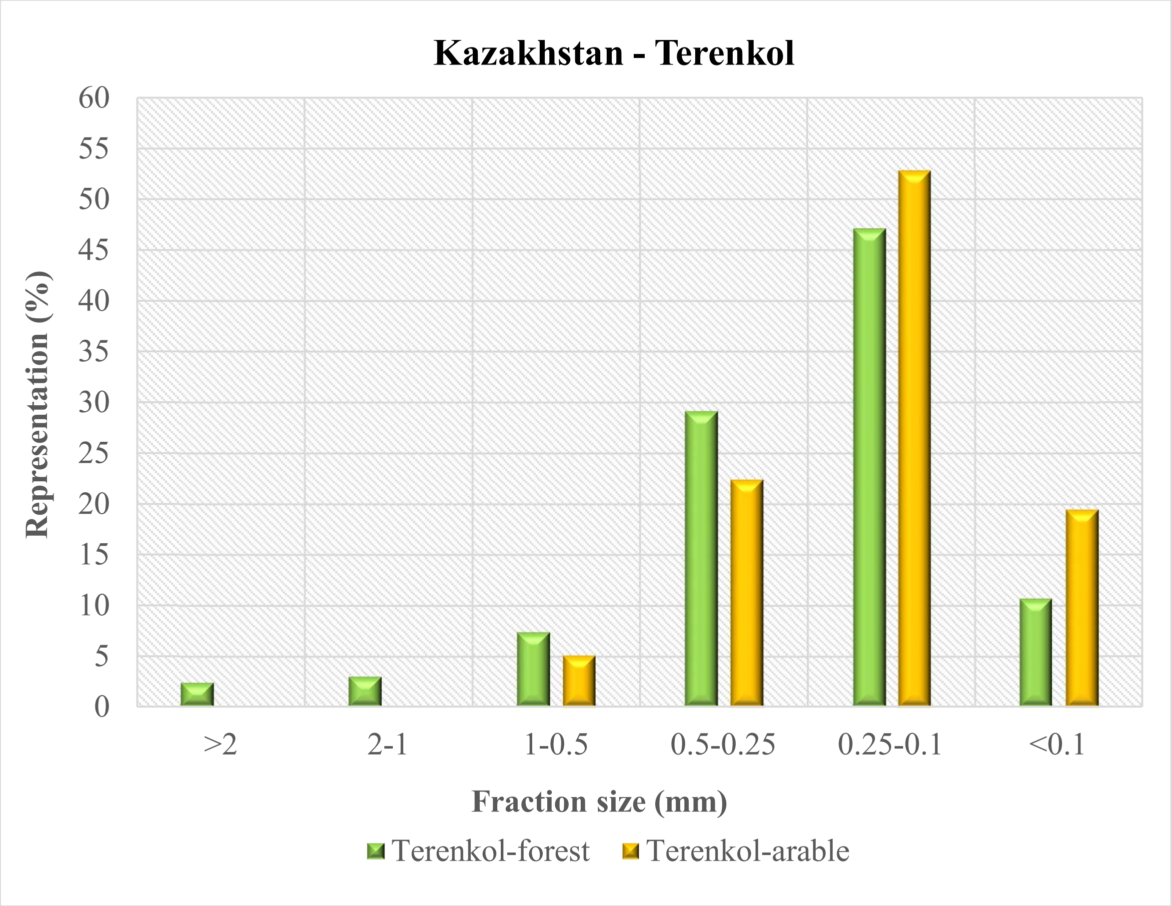


Figure 31: Kazakhstan-Terenkol WSA determination

Kazakhstan – Fedorovka (ID 17, 18)

Compared to the Terenkol site, Fedorovka showed a greater representation of clay particles and a decrease in the representation of sand (Fig. 32). The arable soil contained 16 % clay, 29 % silt and 55 % of sand. Similarly, 17% clay, 30% silt and 53% sand occurred in the forest soil. The soil texture type at this location was sandy loam.

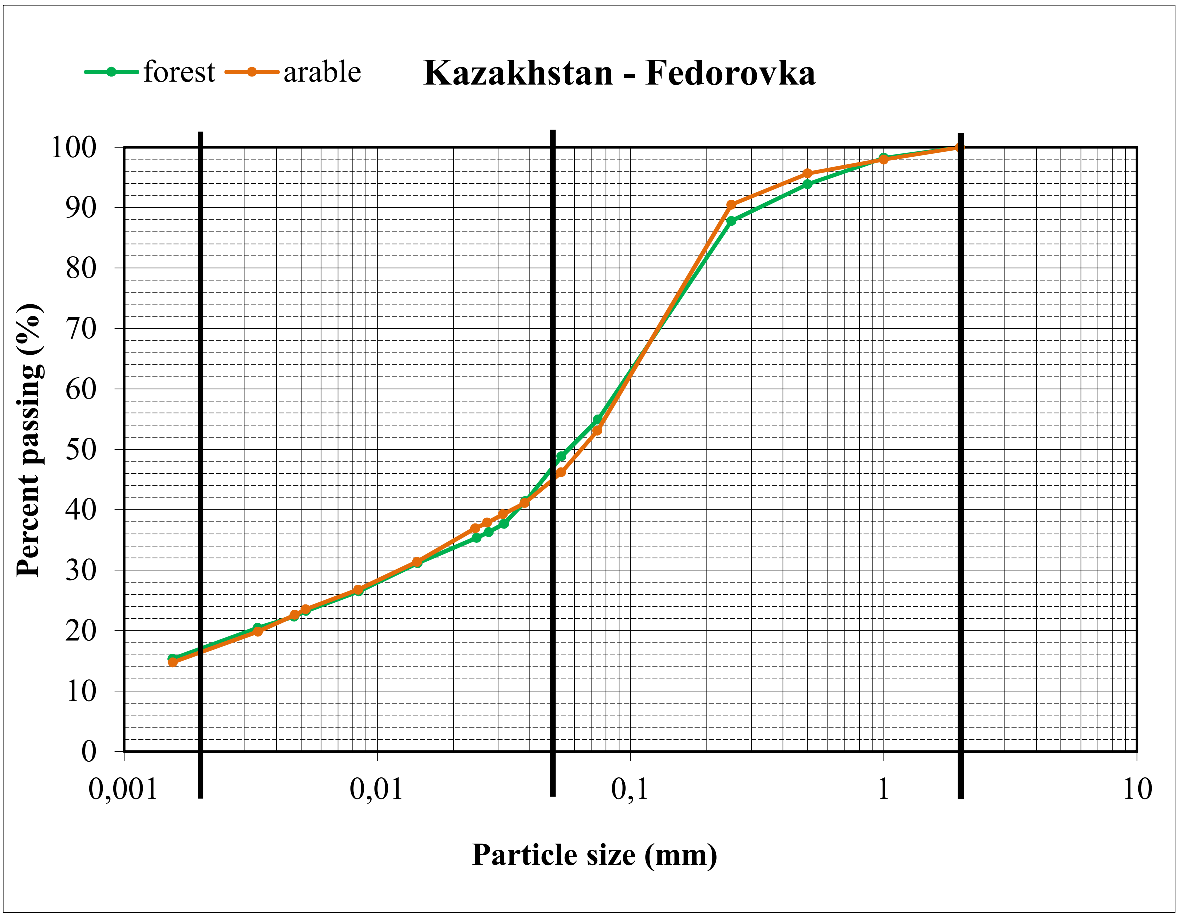


Figure 32: Kazakhstan-Fedorovka particle size distribution curve

The larger fractions in the forest soil have a higher representation (Fig. 33) compared to the Terenkol. The influence has a greater representation of clay, which can aggregate better. The forest soil fraction in the range >2 to 0.5 mm made up 32.27 % of the sample, which certainly had a positive effect on infiltration. In arable soil, these larger fractions were absent with the exception of 1-0.5 mm (6.44 %). Conversely, fractions smaller than 0.5 mm made up 93.57 % of the sample. Infiltration in this arable soil will be very poor due to the poor permeability of the topsoil.

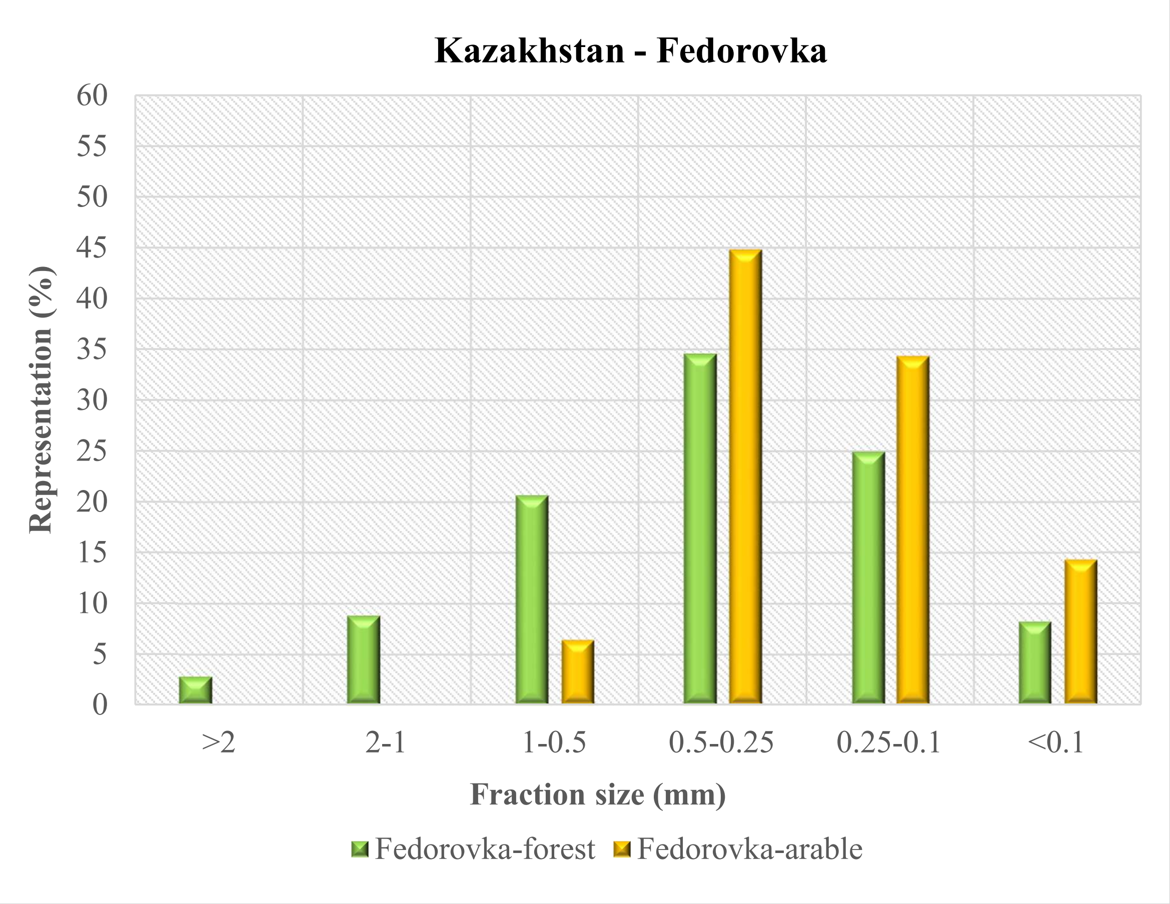


Figure 33: Kazakhstan-Fedorovka WSA determination

Russia – Kursk (ID 19, 20)

Much of the soil consisted of dusty particles (Fig. 34). The representation of sand was the lowest of all examined localities. In the case of the forest soil, it was found that it consisted of 76 % dust, 16 % clay and only 8 % sand. Arable land had almost identical values: 76 % dust, 19 % clay and only 5 % sand. According to the USDA soil texture triangle, the soil was classified as silt loam.

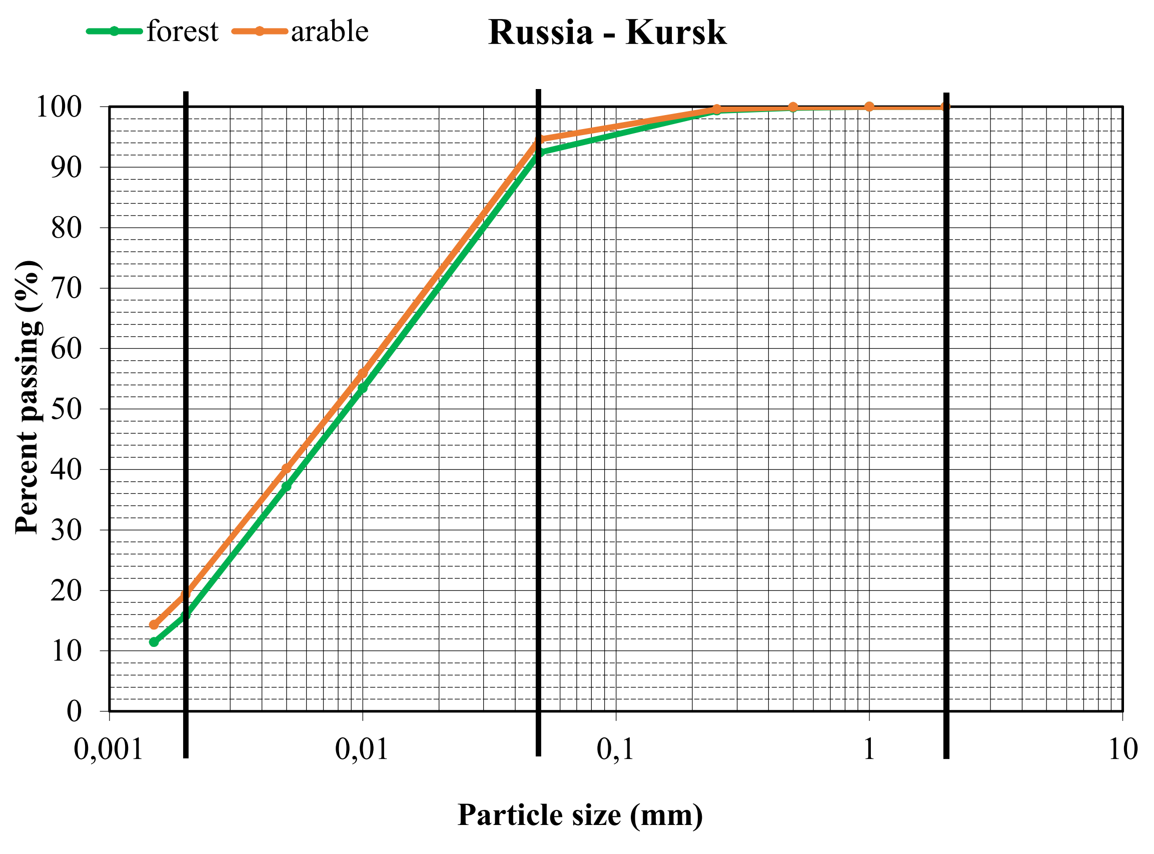


Figure 34: Russia-Kursk particle size distribution curve

Data from a scientific article focused on Water Stability and Labile Humic Substances of Typical Chernozems under Different Land Uses (Kogut et al., 2012) were used to determine the representation of WSA at the Kursk site. Larger fractions in the forest soil by the size of the 3-1 mm fraction, had 80 % representation, which was the most of all investigated sites (Fig. 35). In comparison, Bošovice (60.96 %) and Zákraví (61.90 %) had the closest values for these fractions. There was a very small representation of smaller fractions in the forest sample. Arable soil had the greatest representation for microaggregates, i.e. particles smaller than 0.25 mm. However, it contained 9 % of fractions in the range of 3-1 mm, which have a slightly favorable effect on the infiltration in this soil.

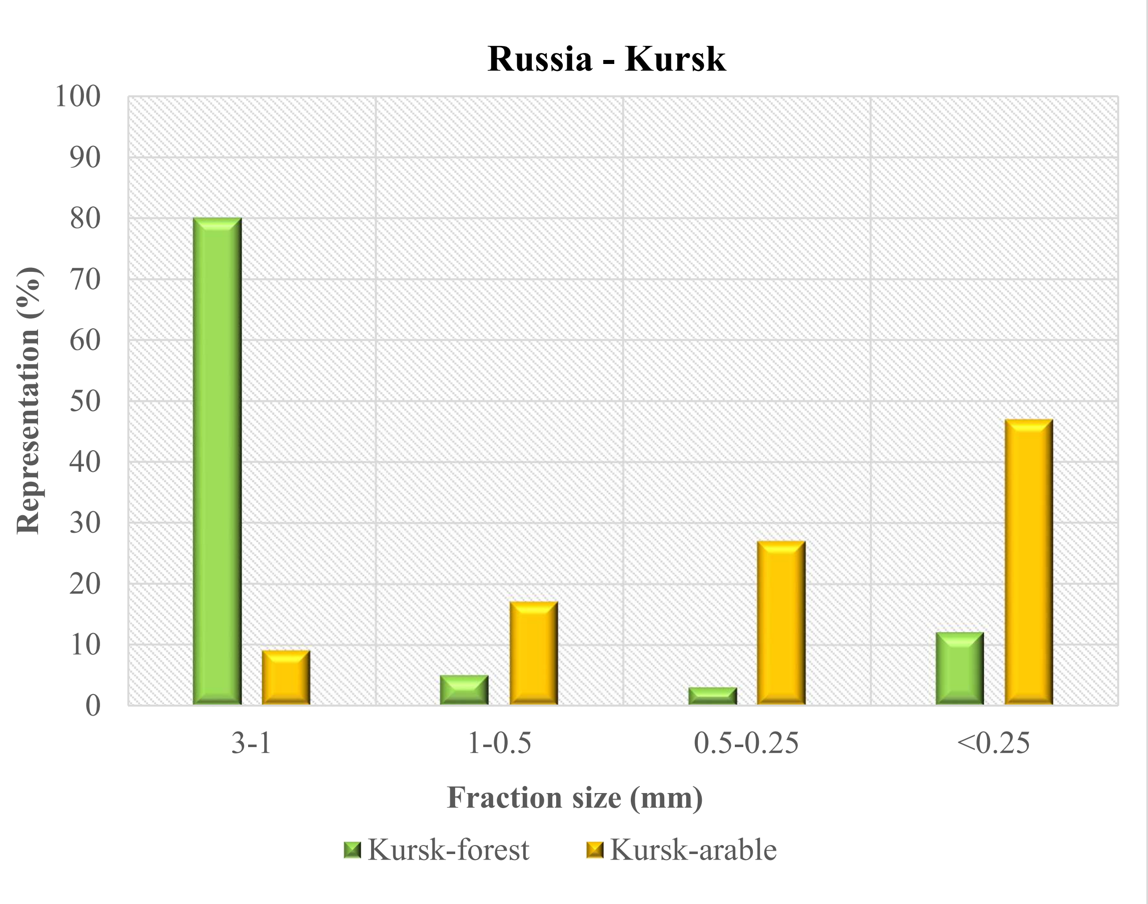


Figure 35: Russia-Kursk WSA determination

In summary, for all localities it is possible to state that the representation of larger fractions (> 1 mm) is always higher in the forest soil, although in the case of some (Kazakhstan, Lithuania, Portugal) the differences are not significant. Forest soil in Russia had the biggest proportion of fractions larger than 1 mm. It is caused due to the large presence of clay, when smaller soil particles are constantly grouped together, which are subsequently aggregated into larger fractions that have a beneficial effect on the soil.

In a global comparison, the examined localities in the Czech Republic performed very well, where the representation of WSA was also high - especially in the case of the forest in Zakraví (Fig. 41) with a value of 62 % for fractions > 1 mm. The lowest values (5.26 %) for > 2-1 mm in the case of forest use, were recorded in Lithuania-Kaunas. In case of arable soil, the Czech Republic-Bošovice location had the best structure (fraction > 1 mm). On the other hand, in Lithuania-Kaunas, larger fractions were completely dissolved into smaller ones and were thus completely absent from the sample. The connection between WSA and soil type was evident from the measured data. In sandy soils, WSA of higher fractions weren´t almost represented and fractions in the lower scale of the macroaggregate predominated. On the contrary, in loamy soils there was a higher formation of WSA and the representation of small parts wasn´t so high. Soil classification was determined for each location (Tab. 4).

Table 4: Research localities with determined soil classification

Country	Study plots	ID	Land use	Soil classification	Location
Czech republic	Lysolaje	1	Forest	Clay loam	50.1241344N, 14.3560786E
		2	Arable	Clay loam	50.1240394N, 14.3557825E
	Bošovice	3	Forest	Loam	49.0493275N, 16.8139539E
		4	Arable	Loam	49.0497439N, 16.8137608E
	Chlístov	5	Forest	Silt loam	50.3265261N, 16.1840028E
		6	Arable	Silt loam	50.3267364N, 16.1836261E
	Zákraví	7	Forest	Silt loam	50.3353611N, 16.1926944E
		8	Arable	Silt loam	50.3350606N, 16.1922233E
	Val	9	Forest	Silt loam	50.3210000N, 16.1920556E
		10	Arable	Silt loam	50.3205675N, 16.1910244E
Portugal	Zebreira	11	Forest	Sandy loam	39.7901781N, 7.1135103W
		12	Arable	Sandy loam	39.8327808N, 7.1576208W
Lithuania	Kaunas	13	Forest	Sandy loam	54.7924156N, 24.0865681E
		14	Arable	Sandy loam	54.7905786N, 24.0876581E
Kazakhstan	Terenkol	15	Forest	Sandy loam	53.1367597N, 76.1689472E
		16	Arable	Sandy loam	53.1367083N, 76.1678400E
	Fedorovka	17	Forest	Sandy loam	53.3968031N, 76.2877642E
		18	Arable	Sandy loam	53.3969669N, 76.2868972E
Russia	Kursk	19	Forest	Silt loam	51.3401361N, 36.0502311E
		20	Arable	Silt loam	51.3407286N, 36.0502225E

Larger fractions (> 2 mm, 2-1 mm) have a great influence on infiltration. Due to the fact that they were often commented on for individual locations, their statistical evaluation is preferentially presented here. The statistical evaluation of the other fractions is given in the appendices of the work (Fig. 61, Fig. 62, Fig. 63, Fig. 64).

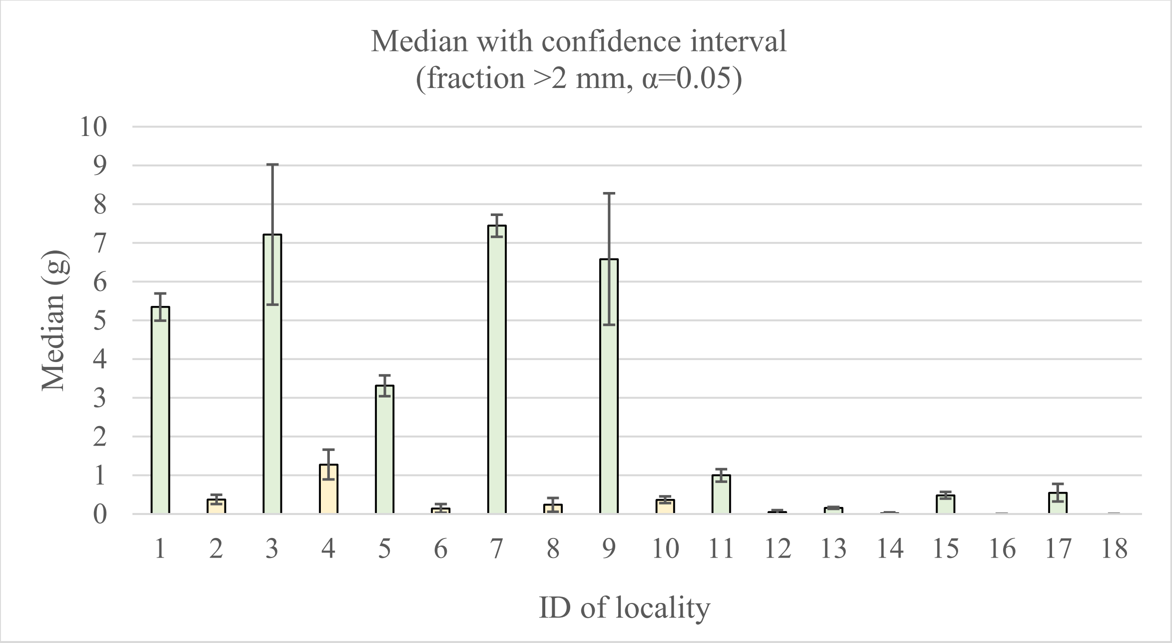


Figure 36: Median of WSA fractions >2 mm

The size of the larger fraction can be affected by sample preparation and insufficient removal of small gravel (Fig. 36). For this reason, the confidence interval can be larger. During the research, the effort was to minimize these errors as much as possible.

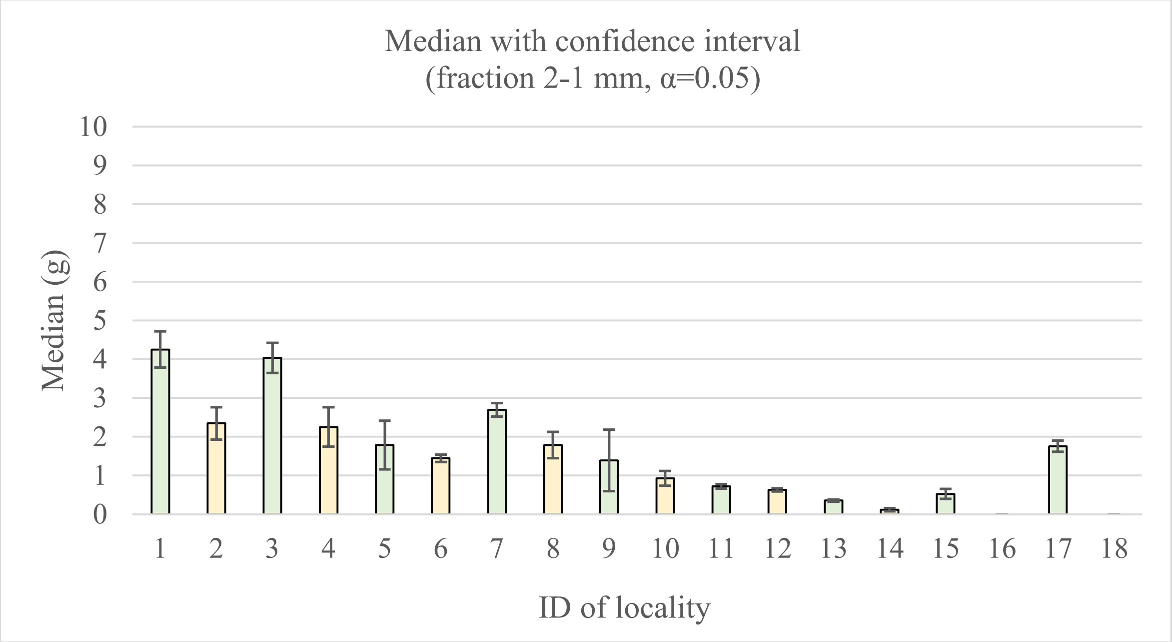


Figure 37: Median of WSA fractions 2-1 mm

In the case of the 2-1 mm fraction, there were smaller sizes of confidence interval (Fig. 37). As part of the sample evaluation, the small gravel content was no longer represented enough to result in variable WSA values.

3.3 The influence of forest age on the formation of WSA

The influence of different forest ages on the formation of WSA was investigated at the locations Chlístov (ID 5, 6), Zákraví (ID 7, 8) and Val (ID 8, 9). The characteristics of the sites (Tab. 5) were determined by a field research and supplemented with information from the literature and electronical sources (Geoportal, 2022).

Table 5: Characteristics of the research locations around Nové Město nad Metují

Locality	Chlístov	Zákraví	Val
The age of the forest stand in 2022 (years)	10	24	67
The composition of species (%)	beech 100	spruce 80, larch 10 cherry 5, pine 3, fir 2	spruce 99, larch 1
Soil type	cambisol		
Cultivated crop (2022)	corn	barley	barley
Composition of forest soil (%)	clay – 11 silt – 56 sand - 23	clay – 9 silt – 52 sand - 39	clay – 14 silt – 62 sand - 24
Composition of arable soil (%)	clay – 13 silt – 62 sand - 25	clay – 14 silt – 51 sand - 35	clay – 17 silt – 61 sand - 22
Soil texture	silt loam		

An example of afforestation near Chlístov is shown below (Fig. 38). The situation with other two locations can be found in the appendices of the work (Fig. 59, 60).

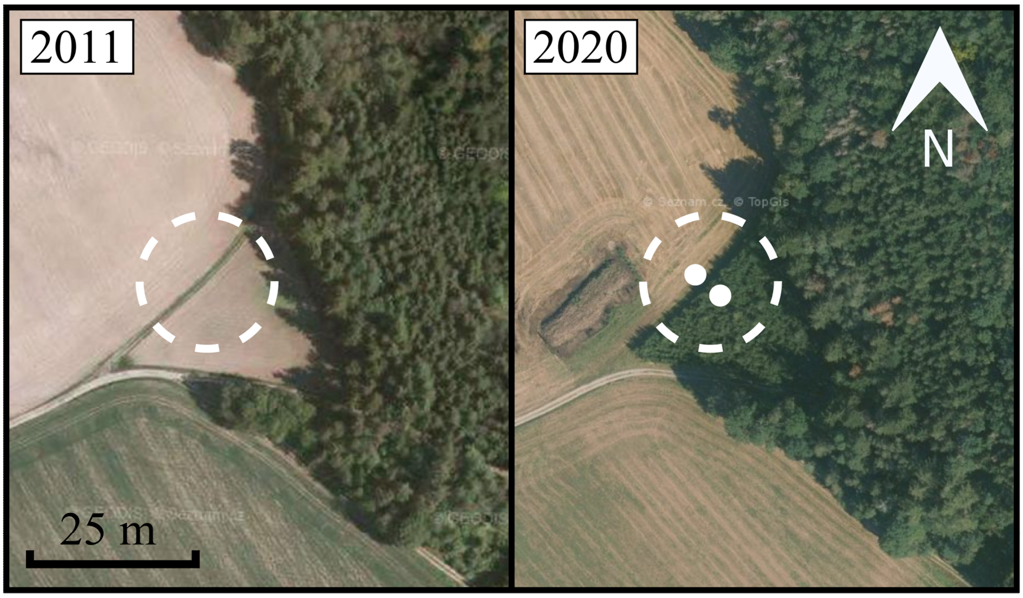


Figure 38: Afforestation near the village of Chlístov with marked collection points. Adapted from Klíč (2023)

Particle size curves (Fig. 39) confirmed the same soil type – silt loam - at the examined locations (Chlístov, Zákraví, Val) and both land uses (Tab. 5).

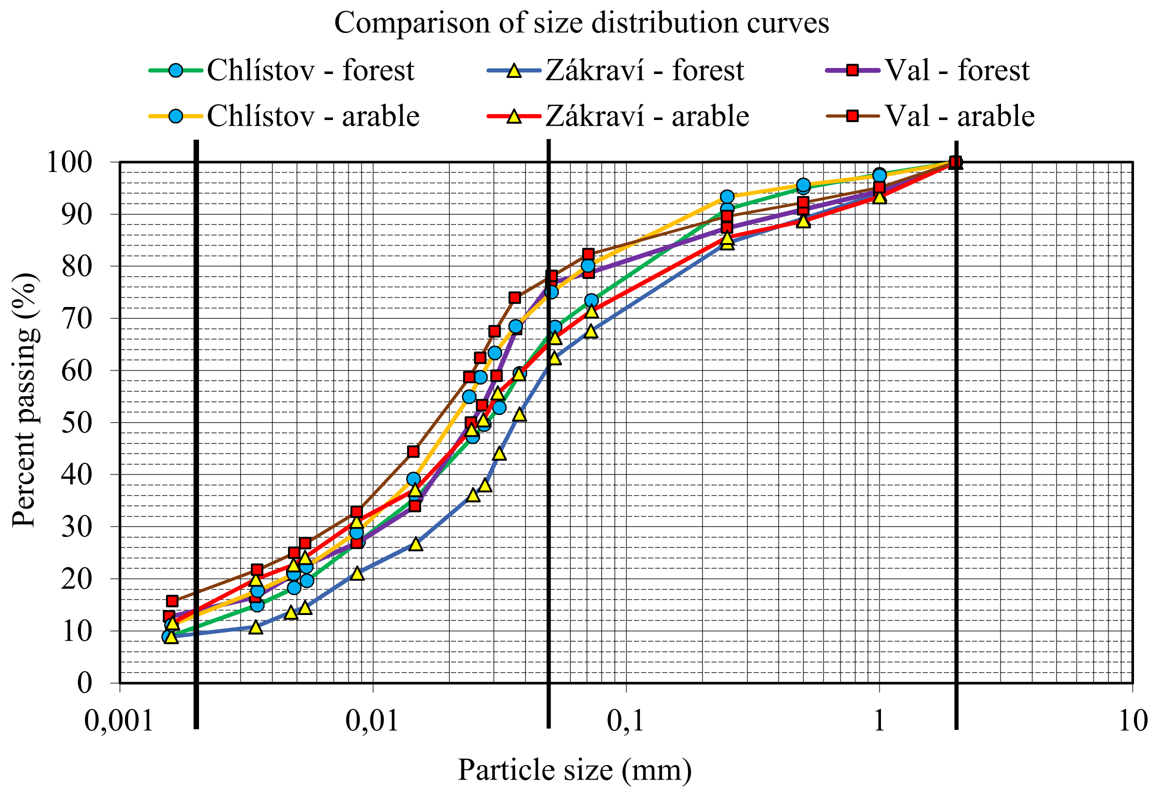


Figure 39: PSD curves for locality Chlístov, Zákraví and Val (Czech Republic)

After dry sieving (Fig. 40, Tab. 6), fractions of aggregates >2 mm were significantly represented in the forest soil (53.39–82.73 %). The remaining fractions in the forest soil had a representation of less than 14 %, and the lowest values reached fractions <0.1 mm and partly in the range of 0.25–0.1 mm. Similarly, the fraction >2 mm (29.10–48.80 %) reached the highest values for arable land. The value of 19.79% for the < 0.1 mm fraction in arable soil was also significant for locality Chlístov.

After wet sieving (Fig. 41), there was no significant breakdown into smaller fractions at the Zákraví and Val locations, and the most represented soil aggregates >2 mm (approximately 45 %) still remained. On the contrary, for arable land, the fraction >2 mm had the smallest representation. There was a significant decrease, and a large part of the >2 mm fraction (approximately 80 %) consisted of small stones after wet sieving, but these were manually removed from the sample and were not counted as WSA values. The highest value obtained (33.15 %) for arable land was at the Chlístov location for the 0.5-0.25 mm fraction. When comparing, it is important to take into account that the values on the y-axis are different for each graph (Fig. 40, 41).

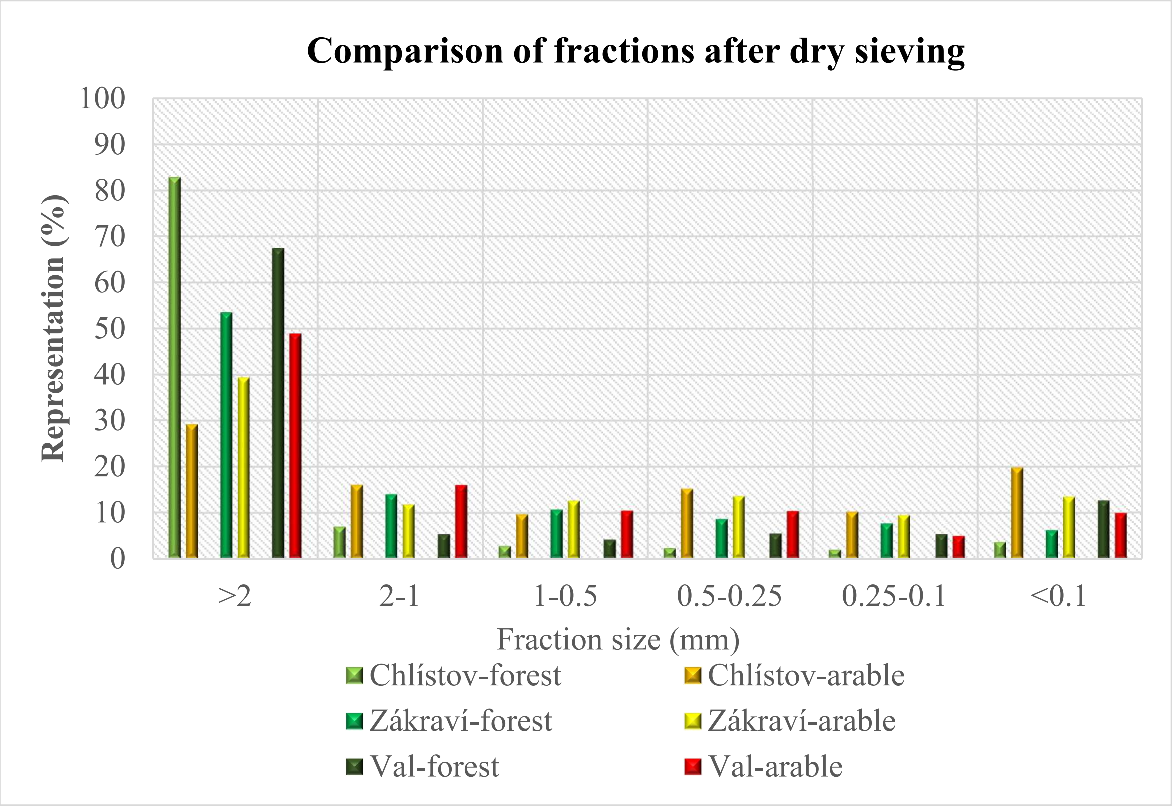


Figure 40: Comparison of fractions after dry sieving for Chlístov, Zákraví and Val

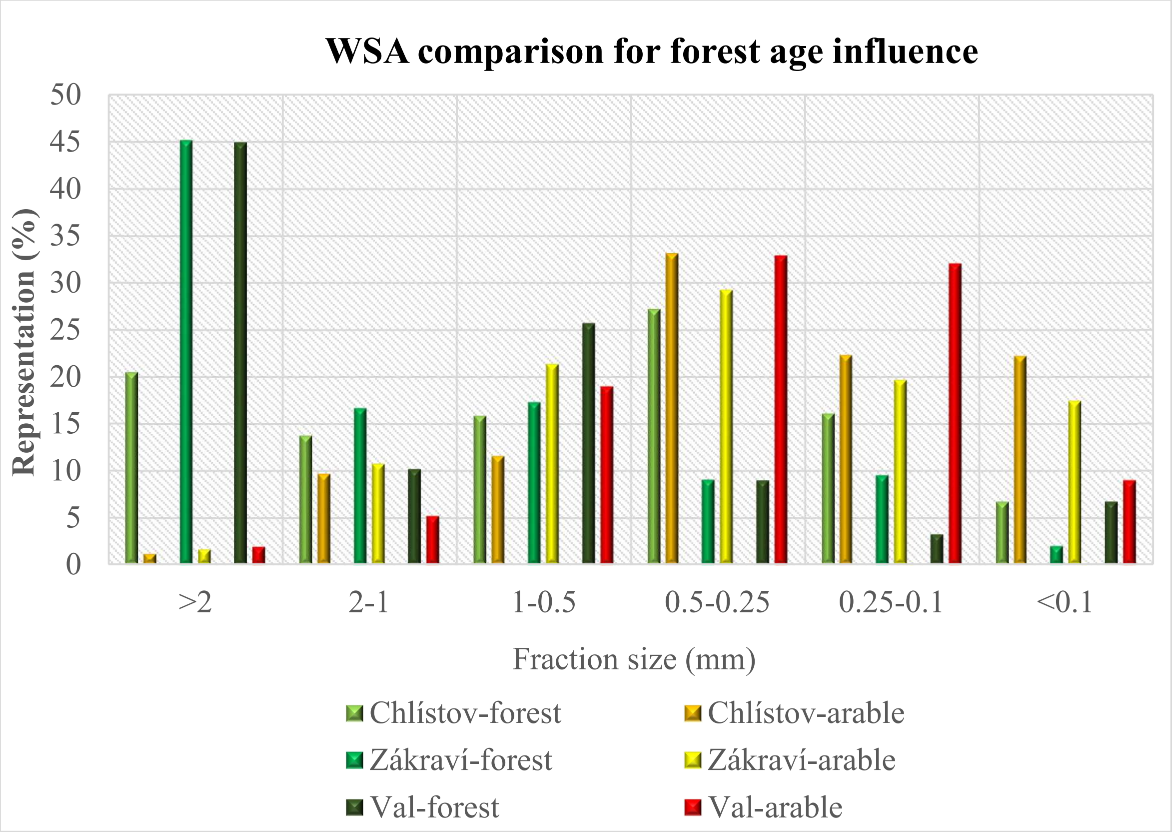


Figure 41: Comparison of fractions after wet sieving for Chlístov, Zákraví and Val

Table 6: Results of Dry and Wet sieving, SV - Sieving method.

				Fraction size (mm)					
Locality	Land use	Age/ Crop	SV (%)	>2	2-1	1-0.5	0.5-0.25	0.25-0.1	<0.1
Chlístov	forest	10	dry	82.73	6.91	2.69	2.20	1.89	3.60
			wet	20.46	13.72	15.82	27.23	16.08	6.69
	arable	corn	dry	29.10	16.01	9.68	15.21	10.21	19.79
			wet	1.15	9.65	11.54	33.15	22.32	22.20
Zákraví	forest	24	dry	53.39	13.91	10.52	8.52	7.58	6.08
			wet	45.19	16.71	17.35	9.13	9.60	2.03
	arable	barley	dry	39.30	11.75	12.59	13.54	9.45	13.37
			wet	1.63	10.70	21.37	29.25	19.64	17.42
Val	forest	67	dry	67.34	5.25	4.08	5.40	5.27	12.67
			wet	44.92	10.23	25.75	9.06	3.26	6.77
	arable	barley	dry	48.80	15.91	10,35	10.27	4.85	9.83
			wet	1.91	5.18	18,96	32.91	32.05	8.99

Forest age infuence

In Chlístov-forest, the representation of fractions >2 mm was lower (20.46 %) and the value (27.23 %) for the fraction 0.5–0.25 mm prevailed. Greater representation of WSA fractions in the range of 0.5 to less than 0,1 was found, which together made up exactly 50 %. The fraction larger than 2 mm had only half the representation compared to the other two locations (20.46 %). Thus, it seems that in such a young stand (10 years) aggregation into higher fractions is taking place, but a higher representation of water-stable soil aggregates has not yet been formed.

The Zákraví location with a stand age of 24 years had significantly better results in terms of the occurrence of larger WSA fractions. The fraction greater than 2 mm had a value of 45.19 %, which indicates favorable soil conditions for infiltration and subsequent retention of water in the soil. A decreasing tendency from higher to lower fractions is visible (Fig. 24). Such favorable soil conditions are probably influenced by the arrangement of the stand. Trees were located in a square with a distance of approximately 1.2 m, which has an effect on higher root activity and thus better formation of WSA.

A higher (44.14 %) representation of the fraction larger than 2 mm was also visible in the results from the Val location with an age of 67 years. In contrast to the two previous forest stands, there was an increased value for the 1-0.5 mm fraction. It represented more than a quarter of the sample (25.75 %), which could be due to the fact that the spruces grow at a greater distance (approximately 2.5 metres) from each other than in the second and first sites. The development of the roots of these trees thus takes place in the deep soil layer and the influence on the formation of WSA is no longer so high. From the overall comparison of all investigated sites, it was found that the greatest increase in the larger fractions of WSA in forest soils occurs between 10 and 24 years. It is evident that the influence of the age of the forest on the formation of WSA was significant and it will be appropriate to study this topic in more detail during future research.

3.4 Value of MWD in global scale

For the comparison of all investigated locations, it is appropriate to use the MWD value, which is quite often also found in scientific articles. Thus, it is possible to compare the obtained results with global data. The MWD parameter indicates the average size of the fraction contained in the entire sample. It follows that the higher the MWD value, the higher the proportion of larger fractions in the soil, which subsequently have a significant effect on infiltration into the soil profile. From the results (Fig. 42), it was possible to state that the highest MWD values were recorded on forest localities in the Czech Republic, namely Bošovice, Zákraví and Val. The Kursk location in Russia also achieved a similar result. Mentioned localities have Loam (Bošovice) and Silt loam (Zákraví, Val, Kursk) texture. On the contrary, the lowest MWD values were achieved by locations with arable land - Kaunas, Fedorovka and Terenkol. In the case of these locations, small fractions of WSA predominated and the designated soil texture type was Sandy loam. It is clearly visible (Fig. 42) that the MWD values after wet sieving were always higher for forest soil, although in some cases (Kaunas, Terinkol) the difference was not very significant. All the determined values (MWDdry, MWDwet, MWDdisp) are listed in the appendices of the thesis (Tab. 12).

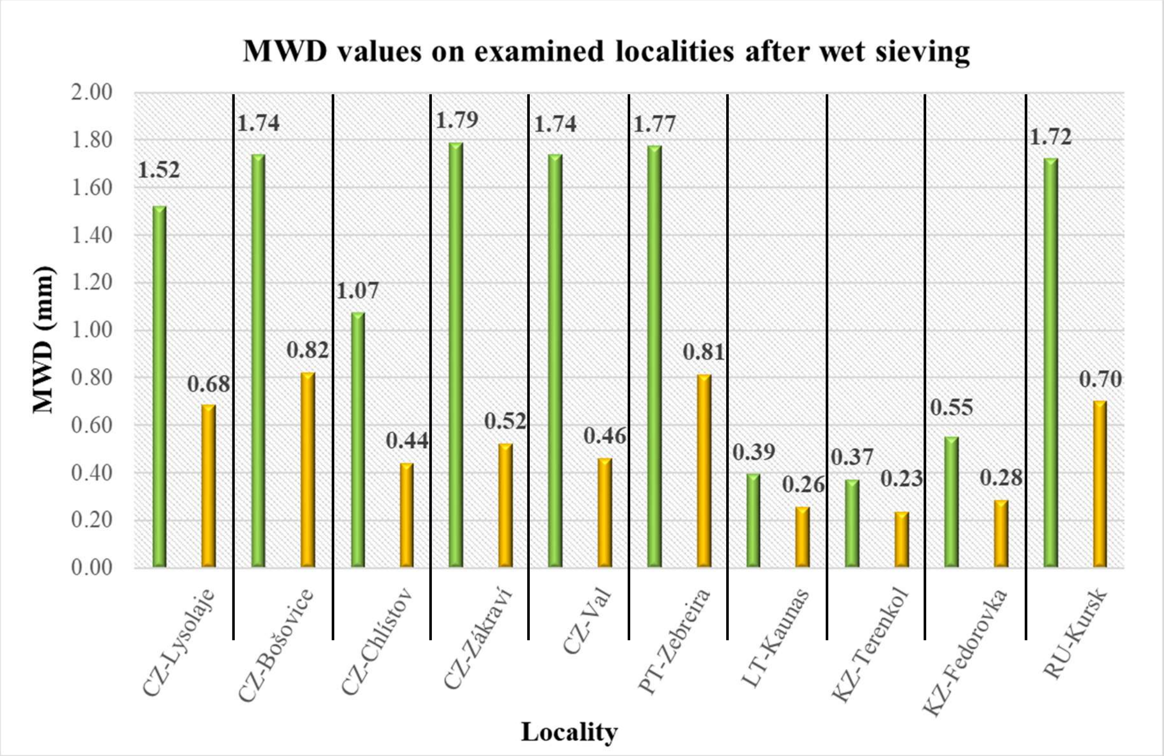


Figure 42: MWD on examined localities after Wet sieving. Green – forest, Orange - arable

From the obtained MWD value, it was also possible to determine stability and crustability (Tab. 7) based on criteria according to Le Bissonnais (2016). No research locality was included among the very stable soils, where the MWD value must be greater than 2 mm. It should be noted that the calculated value of MWD declines if a given size-distribution is dominated by small aggregates. MWD serves as an indicator of the resistance of soils to erosion, which is smaller with increasing MWD value.

Table 7: Stability and crustability based on MWD value. Adapted from Le Bissonnais (2016).

Class	MWD value (mm)	Stability	Crustability	Locality
1	< 0.4	Very unstable	Systematic crust formation	LT-Kaunas-forest LT-Kaunas-arable KZ-Fedorovka-arable KZ-Terinkol-forest KZ-Terinkol-arable
2	0.4 – 0.8	Unstable	Crusting frequent	CZ-Lysolaje-arable PT-Zebreira-arable KZ-Fedorovka-forest CZ-Chlístov-arable CZ-Zákraví-arable CZ-Val-arable RU-Kursk-arable
3	0.8 – 1.3	Medium	Crusting moderate	CZ-Bošovice-arable PT-Zebreira-forest CZ-Chlístov-forest
4	1.3 – 2.0	Stable	Crusting rare	CZ-Lysolaje-forest CZ-Bošovice-forest CZ-Zákraví-forest CZ-Val-forest RU-Kursk-forest
5	> 2	Very stable	No crusting	-

MWD values were futher used to calculate indicators (Sw, Swd, ΔS, PAD). A quantitative indicator of the susceptibility of soils to wetting (Sw) could describe variation in erosion and soil characteristic. It is possible to state dependence in connection with erosion. The higher the value of Sw, the more erosion occurs. On the contrary, the value of MWD decreases with increasing value of Sw. This Sw indicator can be useful to compare various soils and thus specify the strength of erosion on a given location and for different land uses.

When comparing the different land uses, larger values of Sw, and therefore greater risk of erosion, occured on all arable lands (Fig. 43). Again, this confirms the theory that without sufficient representation of WSA and thus a higher MWD value, the soil is more susceptible to soil erosion during rains. However, in the case of KZ-Terenkol, the arable land reached only a slightly higher value of Sw than in forest, which means a greater susceptibility to erosion. From a practical point of view, this means that there is a very similar risk of erosion in both forest and arable land. The greatest risk of water erosion is on the Lithuania-Kaunas topsoil, where Sw had a value of 83.64 %. Conversely, the best results were found in the forest stands of the CZ - Bošovice (14.51 %) and CZ-Zákraví (7.73 %). Due to such low values of Sw, the risk of soil erosion is also low.

Another indicator is Swd, which indicates the susceptibility of soil to wetting with dispersion. Swd is likely to be with bigger value than Sw for any soil. The ΔS, which is difference between Swd and Sw, gives an indication of the susceptibility of the soil to dispersion alone. The calculated values are compared below (Tab. 8).

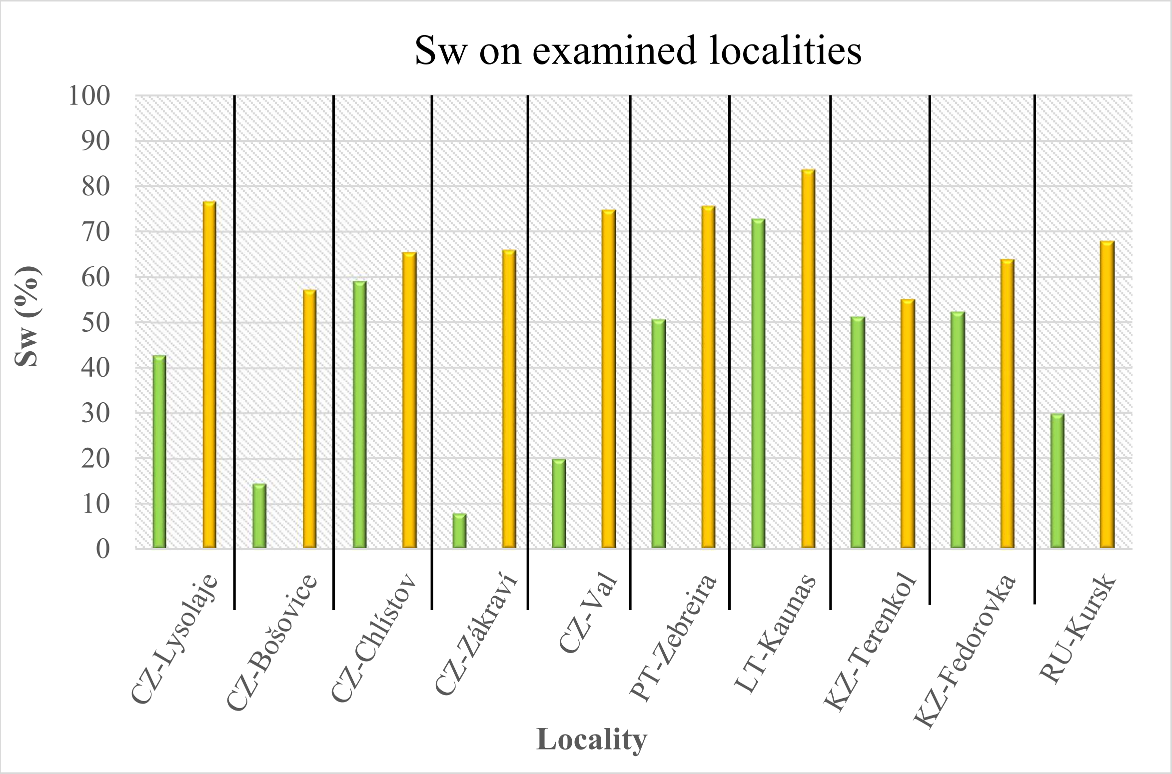


Figure 43: Susceptibility of soils to wetting on research localities. Green – forest, Orange - arable

Percentage of aggregate destruction (PAD)

Aggregate stability was expressed using percentage of aggregate destruction (PAD). The proportions of soil aggregates larger than 0.25 mm after dry and subsequent wet sieving were always compared. The PAD value therefore expresses how many % of dry soil aggregates are removed during the wet sieving process. It is known that the lower the PAD value, the more stable the soil structure. Soil with a low PAD value is therefore more resistant to water erosion and has higher fertility. In the overall comparison (Fig. 44), it can be seen that arable land had a greater PAD value, which logically corresponded to the higher wettability (Sw). It means that there was a greater breakdown of macroaggregates (>0.25 mm) into microaggregates. The largest breakdown occured at the LT-Kaunas location with a value of 57.9 % (arable land). The forest in the CZ-Bošovice, on the other hand, shows a very good PAD value (8.4 %). More than 91 % of the sample after wet sieving still remained in the category of macroaggregates. The comparison of the PT-Zebreira site was interesting, where forest (51.5%) and arable land (53.9%) had approximately the same PAD value and are therefore equally susceptible to breakdown into microaggregates.

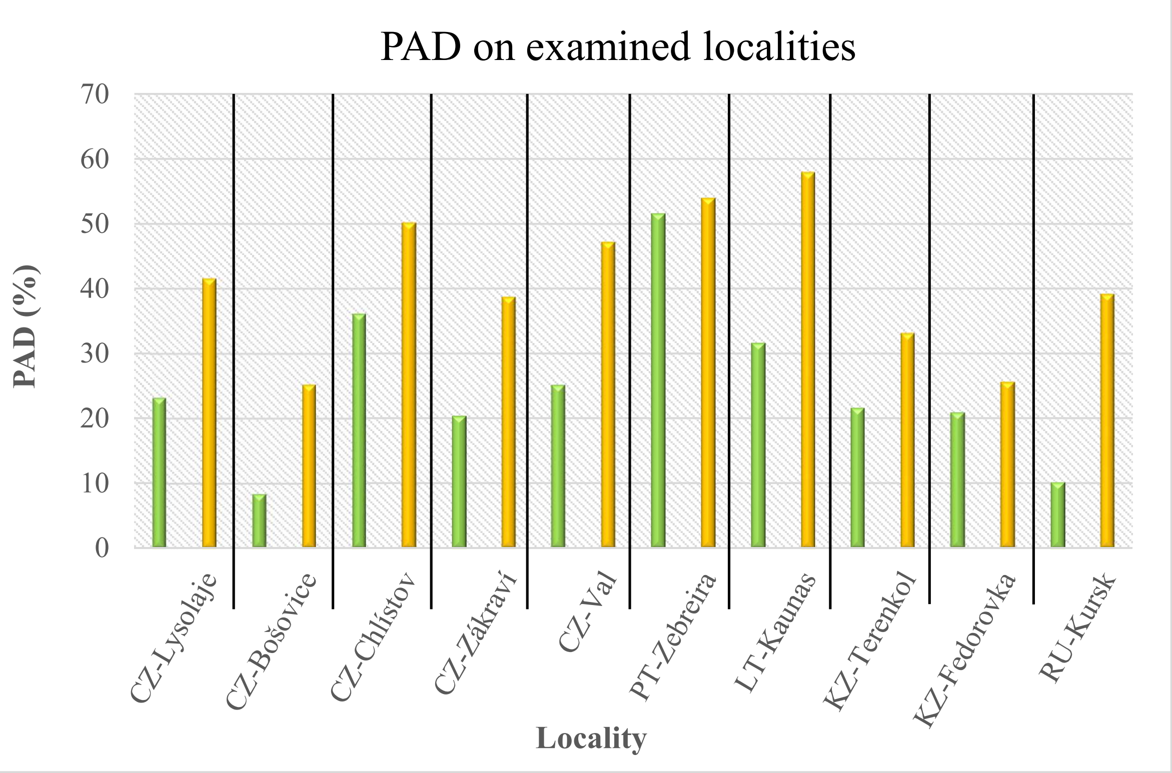


Figure 44: PAD on examined localities

Contact angle (CA)

Low contact angle (CA) values (below 90°) are related to good wetting whereas high contact angle (above 90°) indicate poor wetting. Soil macroaggregate fractions of 6 experimental plots were investigated, with two land uses identified in each plot, forest and arable land (Fig. 45). Two soil fractions were investigated (1-0.5; 0.5-0.25 mm). The obtained values of the CA of the solid phase vary from 23° to 70°. Soil fractions under forest generally showed greater water repellency, which is likely due to the greater accumulation of organic matter under this type of land use.

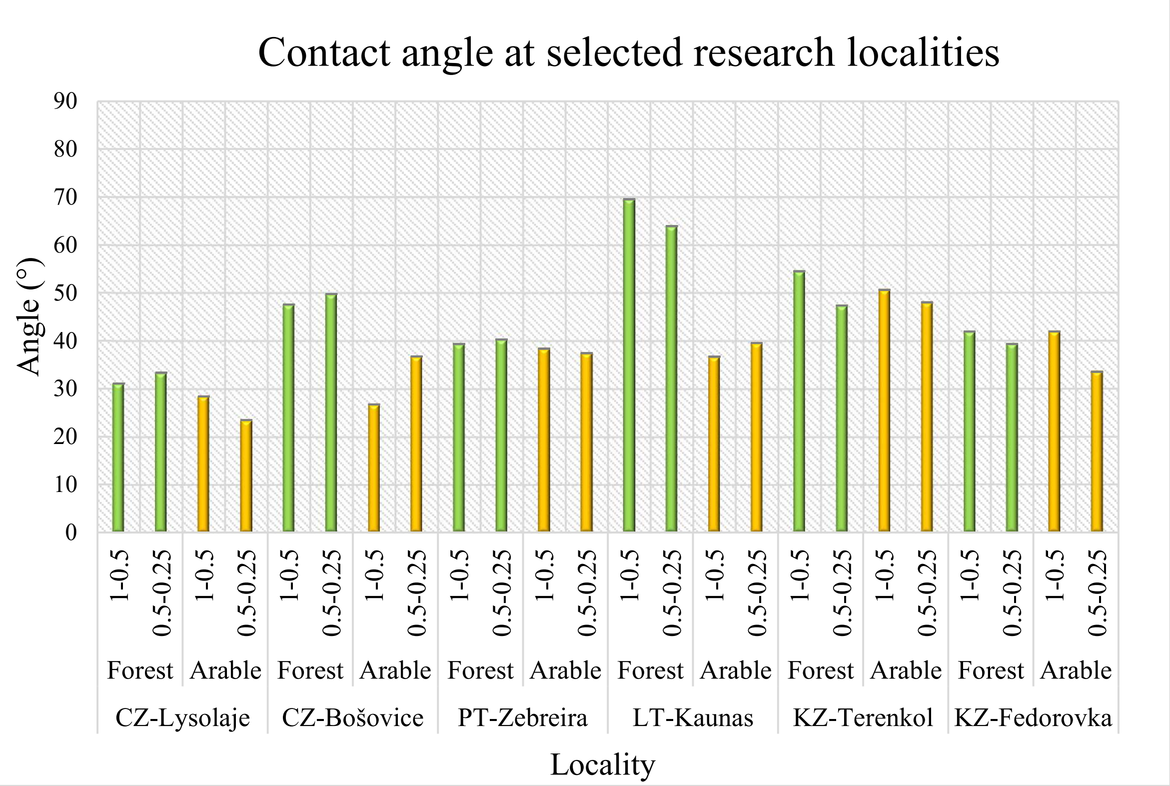


Figure 45: Contact angle at selected research localities

The highest CA values were observed for the 1-0.5 mm fraction in the soil under forest in LT-Kaunas, KZ-Terenkol at 69.5° and 54°, respectively. In the forest soil of Fedorovka, Kazakhstan, the values of CA between fractions 1-0.5 mm do not differ significantly and lie in the range of 41°. It is known that plowing leads both to a decrease in the content of organic matter in the soil and to a change in its qualitative composition, which is reflected in the value of CA (Matveeva et al., 2020). A decrease in the CA value of arable soils in all experimental plots was revealed, the greatest differences between arable and forest were found in the plots LT-Kaunas and CZ-Bošovice. The lowest value (23°) of CA was measured in the arable land on localitiy CZ-Lysolaje, for fraction 0.5-0.25 mm.

The redistribution of CA values between fractions of different sizes indicates both the transformation of the qualitative composition of organic matter and changes in soil structure under different land use. In general from literature (Woche et al., 2005), sandy soils have larger contact angles than silty soils. This statement was not confirmed by measured values during this research.

Correlation

The correlation or mutual relationship between the two indicators was calculated. In theory, the higher the MWD value after wet sieving, the lower the PAD value should be. The calculation revealed that the value of the correlation wass – 0.42, and according to Evans (1996), it can be characterized as a moderate negative correlation. It was confirmed that as the MWD value increases, the PAD decreases. The closer the value is to 1 or -1, the stronger the linear correlation is. The second examined correlation was the relationship between PAD and Sw, which was marked as a strong positive correlation with a value of 0.75. It means that the value of Sw has a strong influence on MWD and if one variable increases, the other variable also increases.

Table 8: Indicators calculated from MWD value for each locality

Country	Study plots	ID	Land use	Sw (%)	Swd (%)	ΔS (%)	PAD (%)
Czech republic	Lysolaje	1	Forest	42.73	95.44	52.71	23.2
		2	Arable	76.63	95.77	19.13	41.5
	Bošovice	3	Forest	14.51	95.40	80.89	8.4
		4	Arable	57.13	95.90	38.78	25.2
	Chlístov	5	Forest	59.03	95.42	36.39	36.1
		6	Arable	65.37	91.34	25.97	50.1
	Zákraví	7	Forest	7.73	89.69	81.96	20.3
		8	Arable	65.87	86.87	21.00	38.7
	Val	9	Forest	19.69	92.61	72.93	25.1
		10	Arable	74.70	91.81	17.11	47.2
Portugal	Zebreira	11	Forest	50.49	90.20	39.71	51.5
		12	Arable	75.60	90.43	14.83	53.9
Lithuania	Kaunas	13	Forest	72.72	86.86	14.13	31.6
		14	Arable	83.64	88.65	5.01	57.9
Kazakhstan	Terinokol	15	Forest	51.17	73.55	22.38	21.5
		16	Arable	54.96	62.79	7.83	33.1
	Fedorovka	17	Forest	52.24	87.00	34.76	20.8
		18	Arable	63.86	81.93	18.07	25.6
Russia	Kursk	19	Forest	29.80	97.92	68.12	10.11
		20	Arable	67.89	97.84	29.95	39.08

3.5 Microplastic occurence in WSA

The research was carried out in the Czech Republic - Lysolaje (ID 1,2) for different land use (forest/arable). The parameters of the examined soil were determined (Tab 9.).

Table 9: Soil properties of locality for MPs determination

Soil properties	**Arable**	**Forest**
clay (<0.002 mm) (%)	32	31
silt (0.002-0.05 mm) (%)	40	47
sand (0.05 - 2 mm) (%)	28	22
Texture class	Clay loam	
OM (%)	3.70	8.84
pH	5.95	6.21
Sw (%)	76.63	42.73
Swd (%)	95.77	95.44
ΔS (%)	19.13	52.71
PAD (%)	41.51	23.23

Sw - Susceptibility of soil to wetting, Swd – Susceptibilty of soil to wetting with dispersion,
ΔS - indication of the susceptibility of the soil to dispersion alone, OM – organic matter,
PAD – Percentage of aggregate destruction

The forest (2-1 mm) and arable (0.5-0.25 mm) fractions had the most detectable amount of microplastics (Fig. 46) and were selected for further investigation.

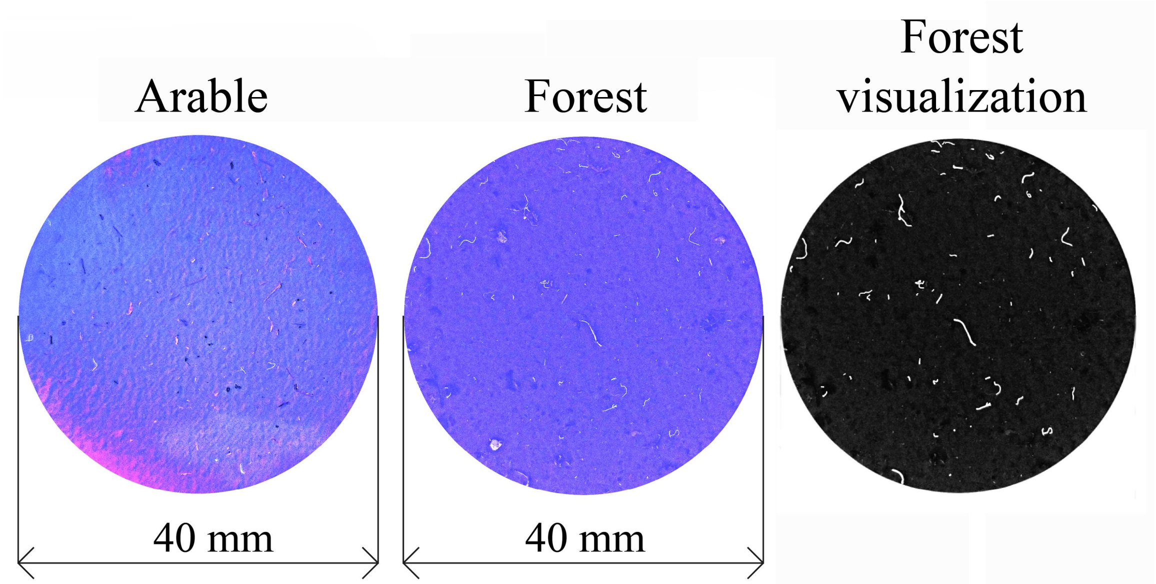


Figure 46: Forest and arable samples for MPs determination with forest visualization.

Using the filtration method, a sample was created to determine the abundance of MPs for each fraction (Tab. 10). In addition to the quantity, the average length of one microplastic particle was also determined and statistically evaluated (Tab. 10).

Table 10: Number of microplastics particles and statistic of microplastics length

Fraction (mm)		1	0.5	0.25
Number of MPs particles (5g)	Forest	62	22	20
	Arable	10	7	40

Statistic of MPs length	Arable land	Forest Land
n	40	62
SD	0.75	0.68
VAR	0.56	0.46
MODE	0.28	0.55
MED	0.36	0.55

n - total number of MPs in 5 g aggregate of selected sample,

SD - standard deviation, VAR - variance, MODE - mode, MED – median

The results showed that the difference in the number of MPs in the total amount of 5 g is different, but also that MPs occur in both larger and small fractions. Particles were not homogeneously distributed, but it was assumed that in the forest soil, the 5 g of the most detectable fraction from soil sample contained 62 particles, which means 12 400 particles per 1 kg. In the case of agriculture soil, there were 40 particles per 5 g, which done 8 000 particles per 1 kg.

Abundance results (8000 and 12,400 pt/kg) were rather in higher range values compared with published data. At the locality Czech Republic-Lysolaje, although there is no fertilization with sewage sludge, the higher abundance of MPs is probably due to the fact that the locality is in a peri-urban environment with influence from industry and transport. It is important to mention that the results do not directly report the entire soil profile, but only the topsoil (0-10 cm) due to the presence of water-stable aggregates mainly in this layer. Due to the particle size distribution curve, most of the soil was in the form of aggregates and the percentage of soil in the primary structure was minimal. It means that the results can be used for the whole top layer (Ap horizon). However, this only applies to soils with the higher clay content. For sandy soils, was assumed that the percentage of aggregation would be lower and, conversely, the higher percentage would be in the primary structure.

3.6 Use for refining hydrological models

At the Lysolaje - forest (ID 1), two layers of soil (Fig. 47) were compared for the presence of WSA and their particle size distribution curves were created. The soil layer (0-10 cm → L1) and the subsequent layer (10 – 30 cm → L2) were investigated. In the first step (wet sieving), WSA were determined in both layers and it was confirmed that in the lower layer (10-30 cm) fractions larger than 1 mm were less represented. For the fraction > 2 mm, the decrease was significant, as approximately 31 % occured in L1, and only 6 % in the subsequent layer L2. The difference, although in a smaller amount (about 5 %), was also for the 2-1 mm fraction.

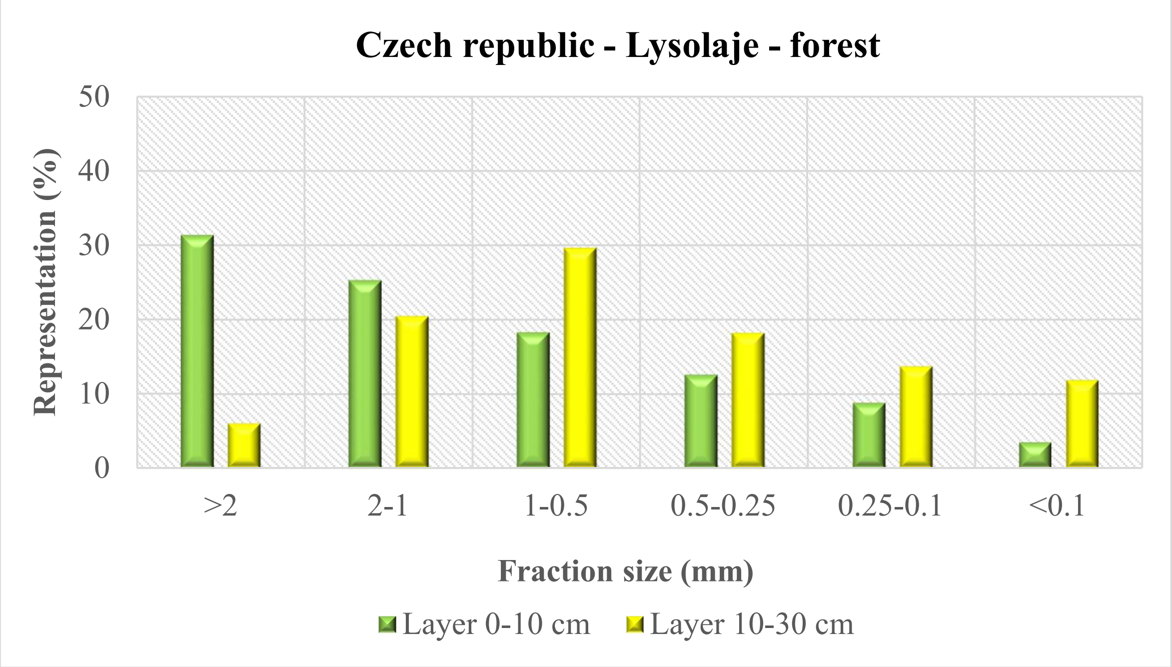


Figure 47: Czech Republic-Lysolaje - comparison of two soil layers of forest

Soil type was Haplic Luvisol (Fig. 48). Dominant characteristic is the formation of the argic sub surface horizon. The argic horizon is a subsurface horizon which has a distinctly higher clay content than the overlying horizon. The textural differentiation may be caused by an illuvial accumulation of clay, by predominant pedogenetic formation of clay in the subsoil or destruction of clay in the surface horizon, by selective surface erosion of clay, by biological activity, or by a combination of two or more of these different processes. Generally, luvisols have favourable physical properties. They have granular or crumb surface soils that are porous and well aerated.

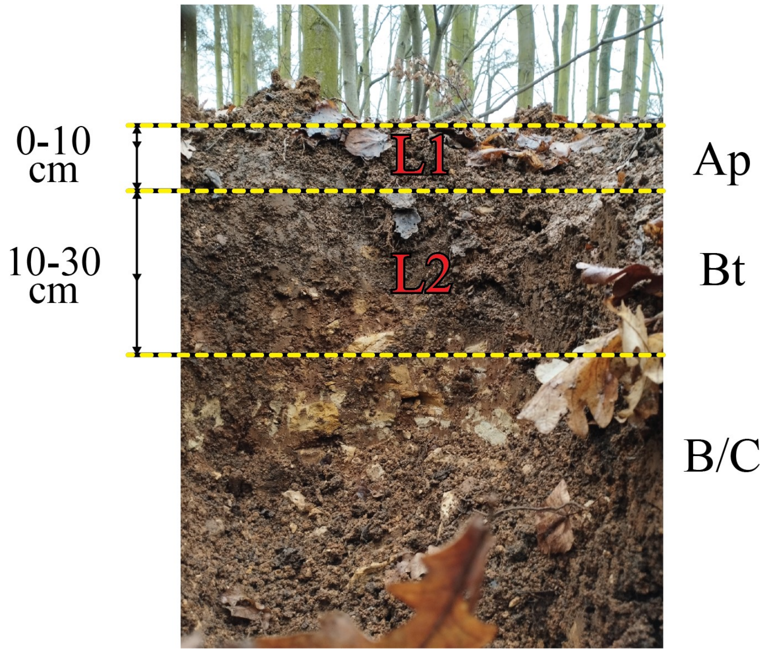


Figure 48: Soil profile of Czech Republic-Lysolaje research locality

The representation of clay, silt and sand was determined from the shape (Fig. 49) of the particle size distribution curves (Tab. 11). Due to the higher proportion of clay, the lower layer had properties that correspond more to clayey soil compared to the upper part of the soil, which was determined to have a clay loam texture.

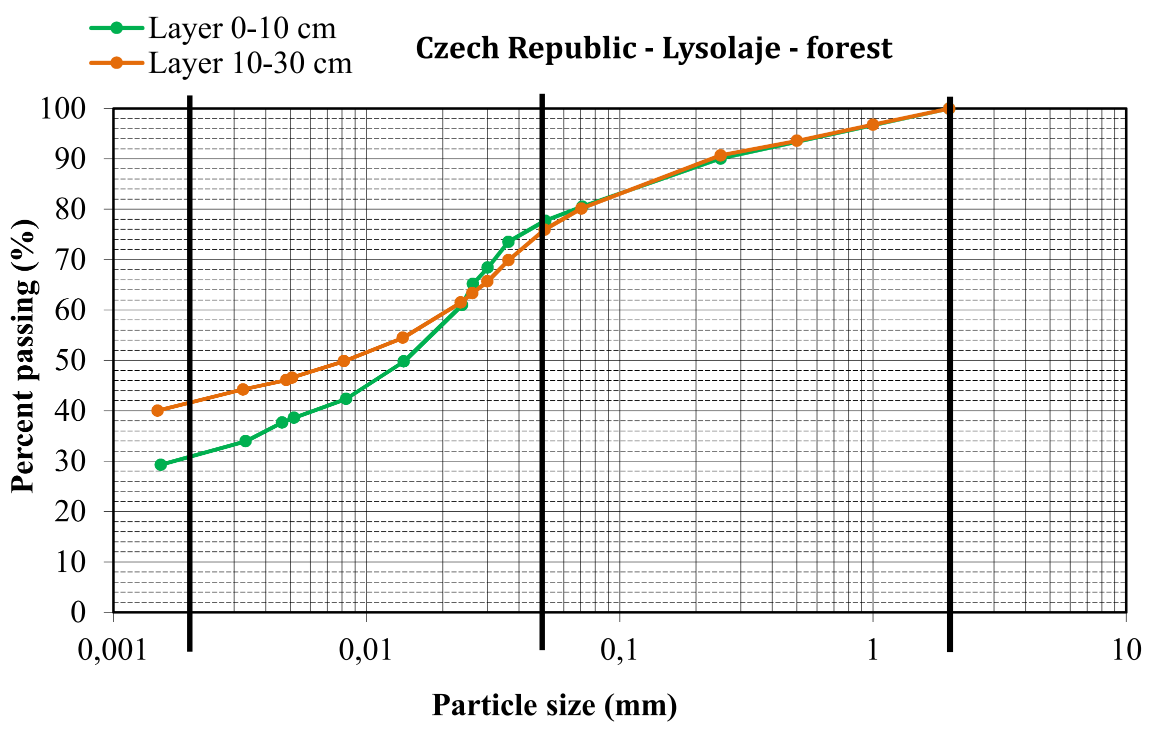


Figure 49: Comparison of PSD curves for different layers of soil profile at locality Czech Republic-Lysolaje with forest land use

Table 11: Soil properties for different soil layers

Soil properties	Layer L1 0-10 cm	 L2 10-30 cm
Clay	31 %	42 %
Silt	47 %	34 %
Sand	22 %	24 %
Texture class	Clay loam	Clay

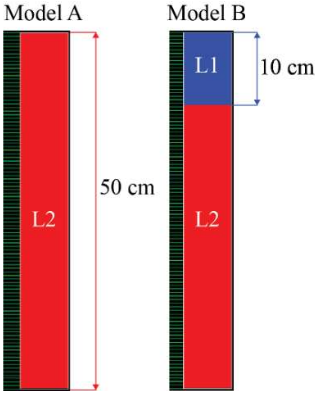


Figure 50: Layers illustration

The values were entered into the hydrological program for environmental modeling HYDRUS-1D and analysis of water flow in porous media was performed. Two model situations were created. In the first (A), the entire soil profile consisted only of a properties of layer 10-30 cm considering as soil without the presence of WSA. In the second (B), the 0-10 cm layer (presence of aggregate) was represented in the first 10 cm, and the rest of the profile consisted of a layer (10-30 cm). The situation was graphically depicted (Fig. 50).

Cummulative infiltration

Infiltration occured faster (12 mm/h) in model B, which consisted of two layers. Due to the higher representation of fractions >2 mm in the 0-10 cm layer, soil aggregates had a favorable effect on the faster course of infiltration in the same time period. In model A, due to the absence of a top layer with good permeability, infiltration was slower and the value in this case was 8 mm/h, which will affect the surface runoff (Fig. 51).

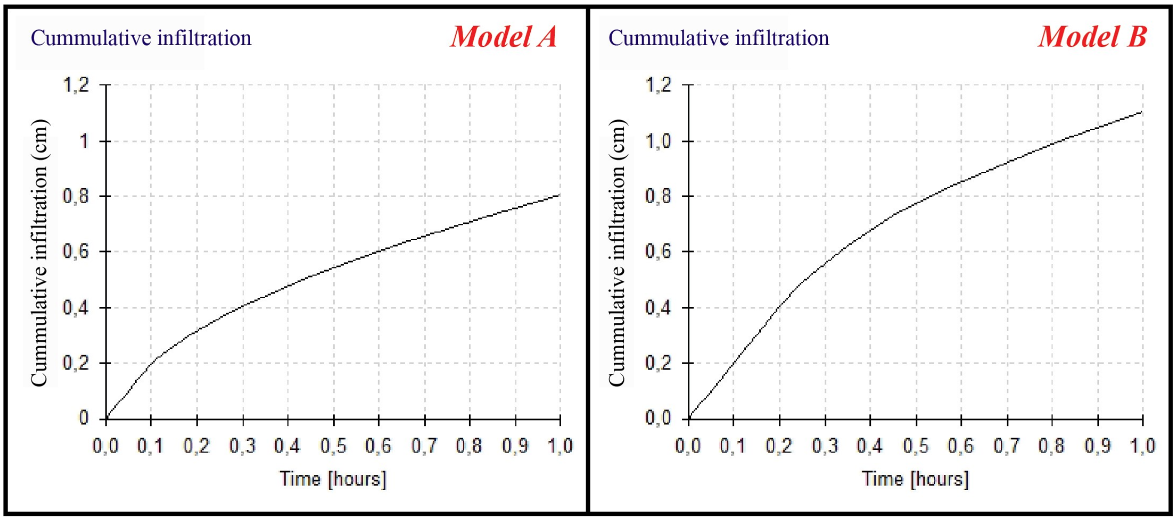


Figure 51: Cummulative infiltration in two different soil layers

Soil Water Storage (SWS)

SWS capacity is defined as the total amount of water that is stored in the soil within the plant's root zone. A soil storage decreases the volume of runoff, contains potential pollutants, and increases the amount of water entering the ground to recharge groundwater systems. Due to the presence of WSA, there was a better flow through the soil profile and more water was retained in the soil in a shorter time. This water bound in the soil can then be used by plants for their proper growth.

In the case of model situation A, approximately 199 mm was retained in the soil in the same time (1 hour). It can also be seen from the graph (Fig. 52) that water storage started at the beginning at a value of 19.12 cm. In contrast, for model B, the water retention in 1 hour was higher with a final value of 202.5 mm. Due to the faster infiltration found in the previous graph (Fig. 51), the initial value of water storage was 19.22 cm.

The obtained results correspond to reality, because SWS and movement of water are controlled by the size and spatial distribution of macropores, through which water can move rapidly but which drain under gravity, and micropores, through which water moves more slowly but can retain water against gravity.

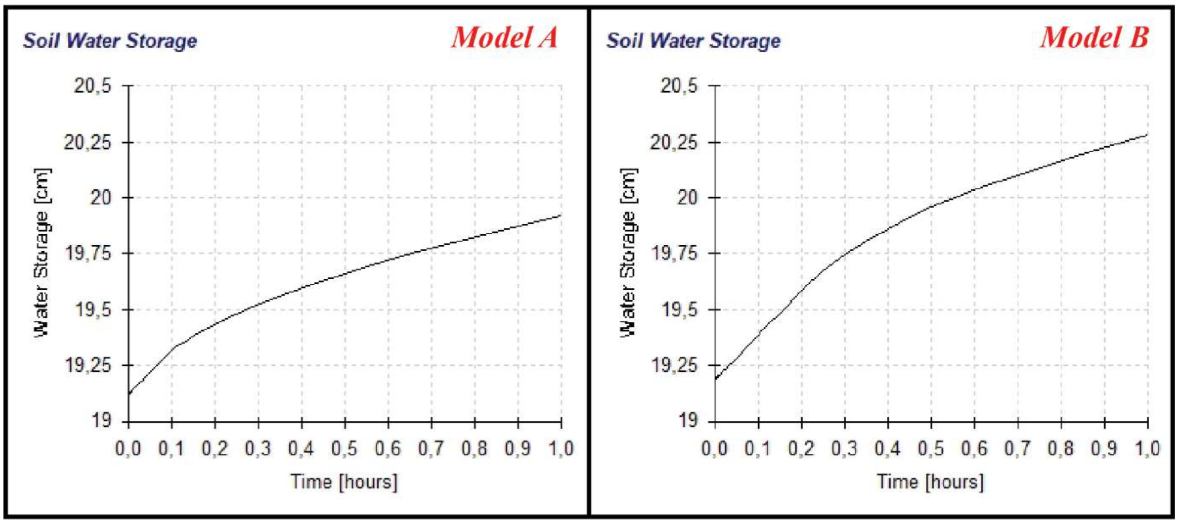


Figure 52: Soil Water Storage in two different soil layers

Water Flux

The graph (Fig. 53) shows two quantities (depth, velocity) with a vector whose negative value indicates the direction of spreading. In this case, it spreads into the soil. In model A, initial infiltration into the soil occured later and the water flow through the profile was slower. In this case, the water reached a depth of approximately 20 cm. On the contrary, in model B, due to the presence of the upper layer, infiltration occured faster and initially the curve had a steeper course. A greater change occured at a depth of 10 cm, where the examined layers met. Here, the flow of water slowed down and the curve had a gradual course. In the case of model B, the water flowed to a depth of approximately 25 cm.

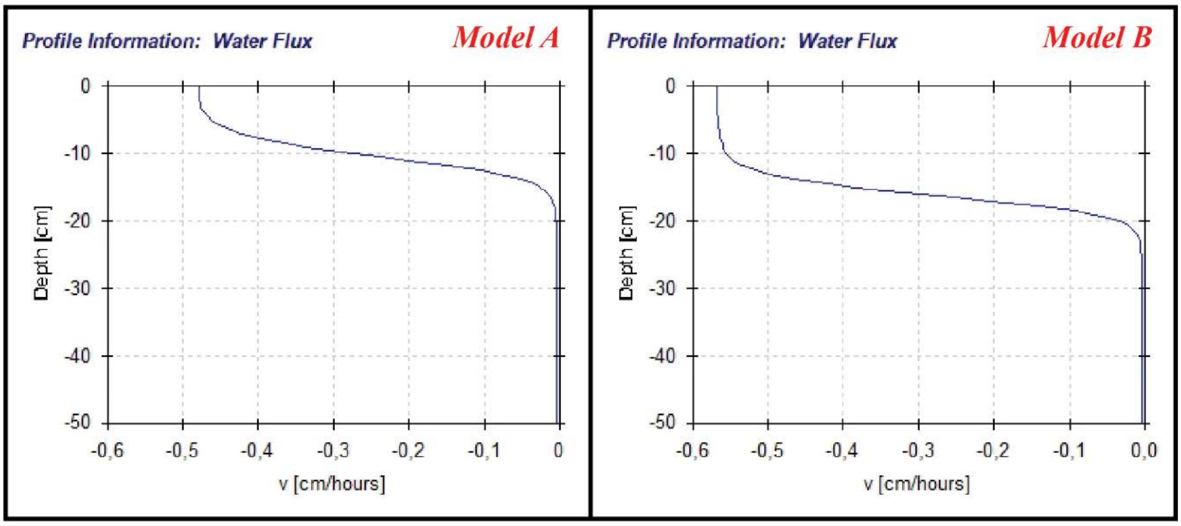


Figure 53: Water flux in two different soil layers

From the obtained results, it can be seen that WSA are important for adjusting the parameters of environmental models. Knowledge of different soil layers and their structure can lead to refinement of infiltration and retention models, and gain more accurate results.

3.7 Conceptual model

The first step in the creation of the conceptual model was asking two basic questions, finding the answers and their graphic representation (Fig. 54, Fig. 55). Thus, initial considerations and information related to WSA were created. These considerations were then logically and clearly organized (Fig. 56) and selected parts of the conceptual model were more closely commented.

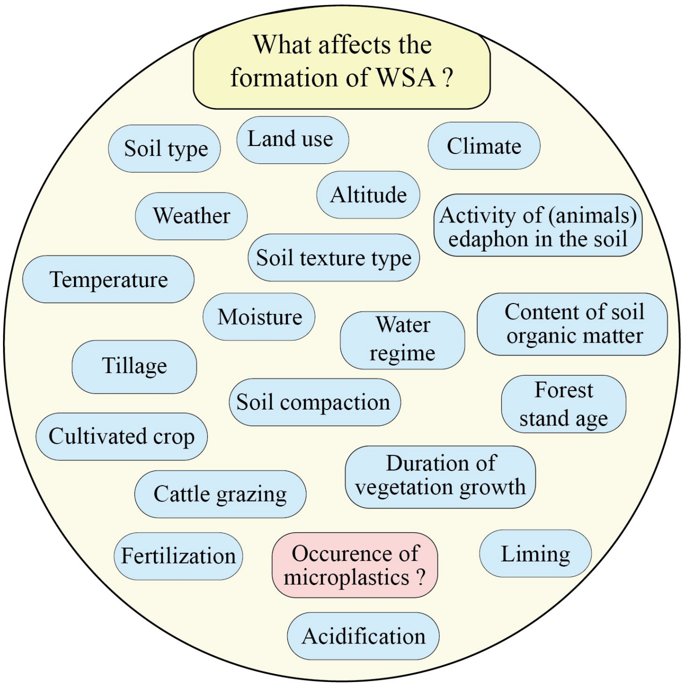


Figure 54: What affects the formation of WSA?

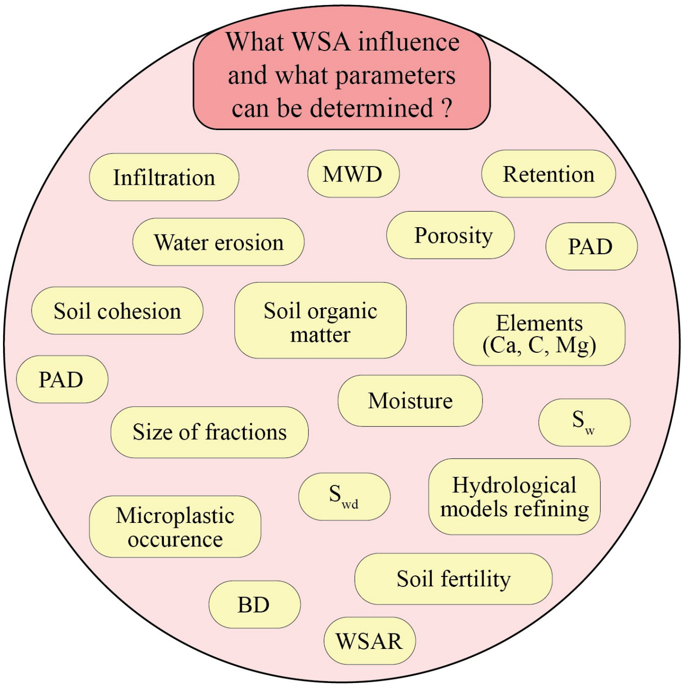


Figure 55: What WSA influence and what parameters can be determined?

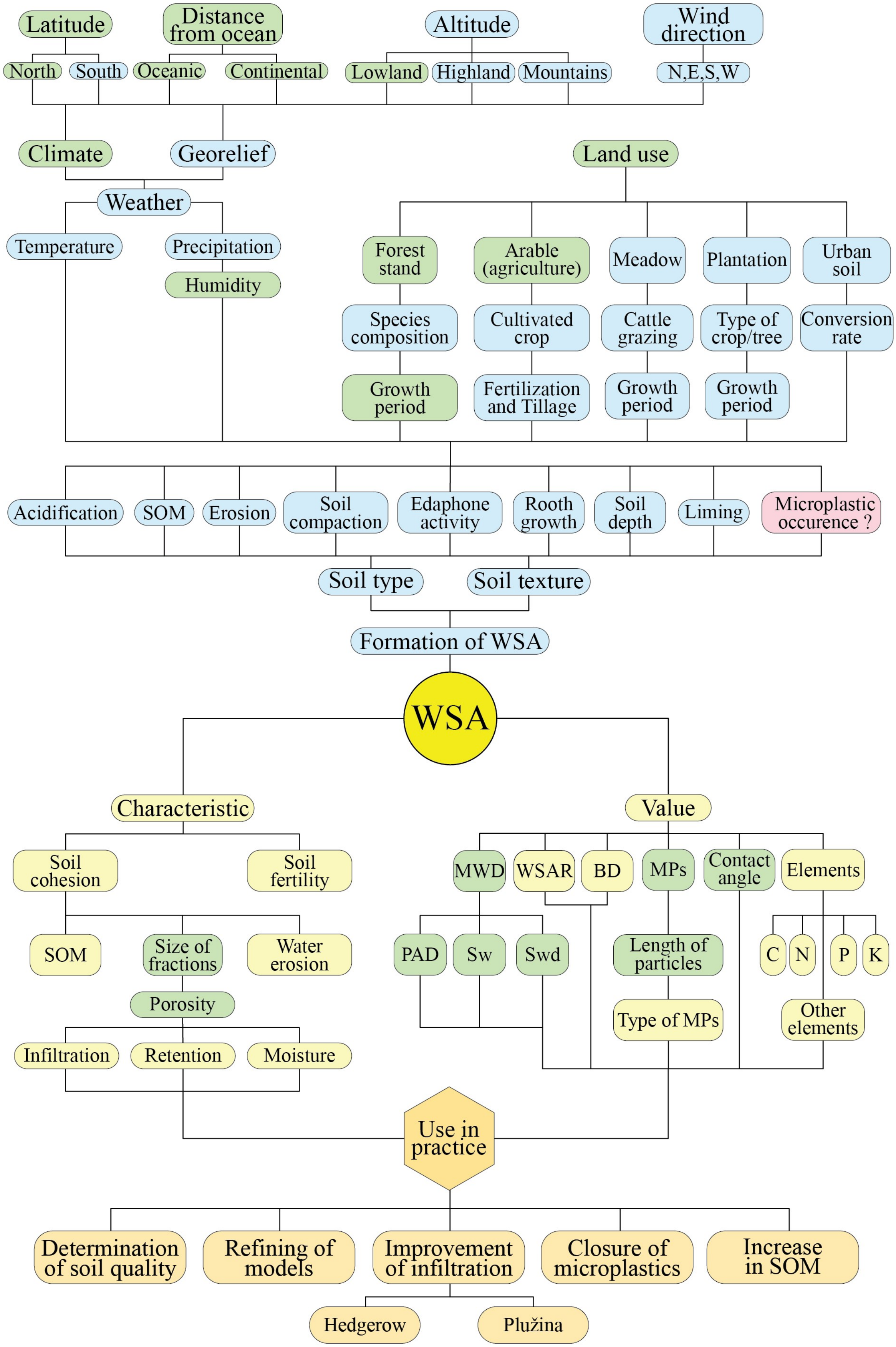


Figure 56: Water-stable aggregates conceptual model. Created by author.

Description of the created WSA conceptual model

In the model (Fig. 56), the parts of the model that have already been examined are marked in green. The entire conceptual model can be divided into 3 main sections. In the first, there are phenomena that influence the formation of WSA - such as Latitude, Distance from ocean, Altitude and Wind direction. For example, Latitude will have a different temperature that is highest around the equator and decreases towards the poles. The temperature also decreases with increasing altitude. The higher the temperature in a given location, the greater will be the activity of soil organisms under favorable conditions, which will have a positive effect on the faster formation of WSA.

In general, the influences on the creation of WSA can be divided into climatic, georelief and land use. In terms of climate (weather), it depends on the different intensity of precipitation and the already mentioned temperature. The effect of moisture (irrigation) on the occurrence of WSA was investigated in a research on a maize field in Portugal. However, no dependence was found from the results. Apparently, on this arable land, aggregates cannot be formed in a short time (1 year).

Georelief and land use play an important role in the impact of rainfall, which influence the rate of infiltration and the movement of rainwater over the surface, which often causes soil erosion in the case of arable land. In forest soil, the presence of larger WSA (> 2 mm) results in better infiltration and also water retention. The other types of land use listed in the conceptual model (Fig. 56) have not yet been investigated for the purposes of this thesis. However, it is possible to assume from the literature that the representation of larger WSA will be in the order: Forest > Plantation > Meadow > Urban soil > Arable. It is precisely because of these contrasting conditions that Forest and Arable were selected for WSA's interim investigation. Precisely because forest and arable form contrasting conditions, they were chosen for the investigation of WSA.

So far, the influence of different forest ages on the formation of WSA has been investigated. It was found that with the longer presence of forest on arable land, better soil structure and WSA formation occur with increasing age. The forest showed the highest values between 10 and 24 years. It is evident from the conceptual model that there are still several categories where research focused on the occurrence and influence of WSA formation could take place.

In the case of forest and plantation, for example, information on the effect of different species composition. In the case of arable land the effect of different crops and fertilization; and in the case of urban soil, the conversion rate.

Climate a georelief together with land use influence a whole range of other processes (for example: SOM content, Soil compaction, Rooth growth and others mentioned in the conceptual model). This section also shows the occurrence of microplastics in the red box. The reason for this is the fact that it has not yet been confirmed how much influence MPs have on aggregation in the soil. The question still remains whether MPs are only aggregated inside soil particles, or whether MPs themselves contribute to the aggregation of smaller and creation of larger soil particles. The processes mentioned above influence the development of soil type as well as soil structure and together form the WSA.

The second section shows the characteristics and value that can be obtained by researching WSA. In the characteristics category, it is possible to find out soil fertility and soil cohesion. Soil fertility is influenced mainly by the presence of WSA, but also by other phenomena such as fertilization, soil compaction and the tillage (method of plowing). Size of fraction and content of SOM can be determined from soil cohesion. In this section, it is also important to mention the influence of water erosion. Between Size of Fraction and Porosity is the mutual relationship. It is fact that the larger the fraction size, the greater the porosity, which increases infiltration into the soil profile.

The value of MWD is an important parameter, because it is possible to derive several other parameters from it (Sw, Swd, PAD, ΔS), which indicate good or bad properties of the examined soil. Value marked with the abbreviation WSAR stands for water-stable aggregation rate. There is a correlation that if the PAD is higher, the value of the stability ratio of water-stable aggregate (WSAR) is lower and vice versa. The bulk density (BD) parameter indicates that if it increases, porosity decreases.

In the case of microplastics (MPs) enclosed inside the WSA, it is possible to determine their quantity, the length of the particles and, theoretically, the exact type of MPs. The contact angle (CA) provides information about the wettability of soil, where it was found that its value is higher for arable soil. It is also possible to determine various elements from the obtained WSA, where C and N are most often determined. Some of the future research should focus on the determination of elements.

In the last, third part of the model, practical uses in the landscape are presented. The characteristics and parameters give us information about the quality of the soil, its current condition and resistance to erosion, which can be used in the case of pricing and subsequent sale of the land. For soils of poor quality, it is possible to develop recommendations and procedures leading to an increase in WSA in the soil by increasing the SOM content. Planting and maintaining hedgerows leads to a reduction in runoff velocity, better infiltration and mitigation of water erosion. By studying different soil layers, hydrological models can be refined for different soil types and species. It can be used, for example, for better estimation of the infiltration rate, soil profile flow and water storage.

The relationship between WSA and the MPs contained in them is still not entirely clear. Here, it would be theoretically possible to use forests and plantations as limiting and restraining means for the movement of MPs in the environment, as they are less mobile in these land uses. On the contrary, in arable land, where aggregation is not so strong, disintegration and transport of MPs occurs through surface runoff (water erosion). This leads to pollution of the environment, rivers, ponds and subsequent consumption of MPs by aquatic animals. If these fish are at the same time human food, health damage may occur. The exact influence of the presence of MPs in the human body and its consequences have not yet been determined, but in any case they will not have a positive impact on human health. Illustration (Fig. 57) represents the sloping terrain of arable land with infiltration trench, hedgerow and plužina. If torrential rain occurs, the soil will be washed away, resulting in poor infiltration of the top soil layer and subsequent surface erosion. Three situations how WSA in nature can contribute to reducing erosion, improving infiltration conditions and also subsequent water retention are numerically marked (Fig. 57).

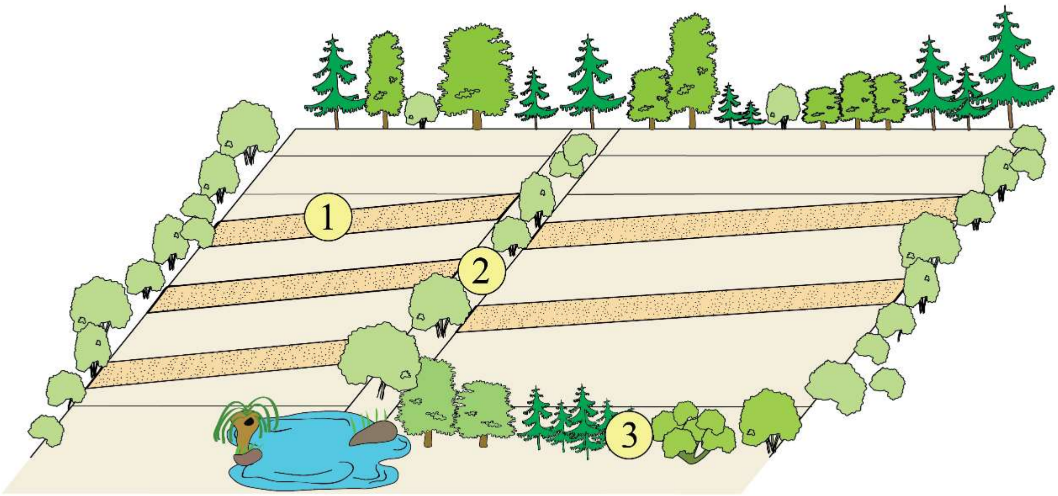


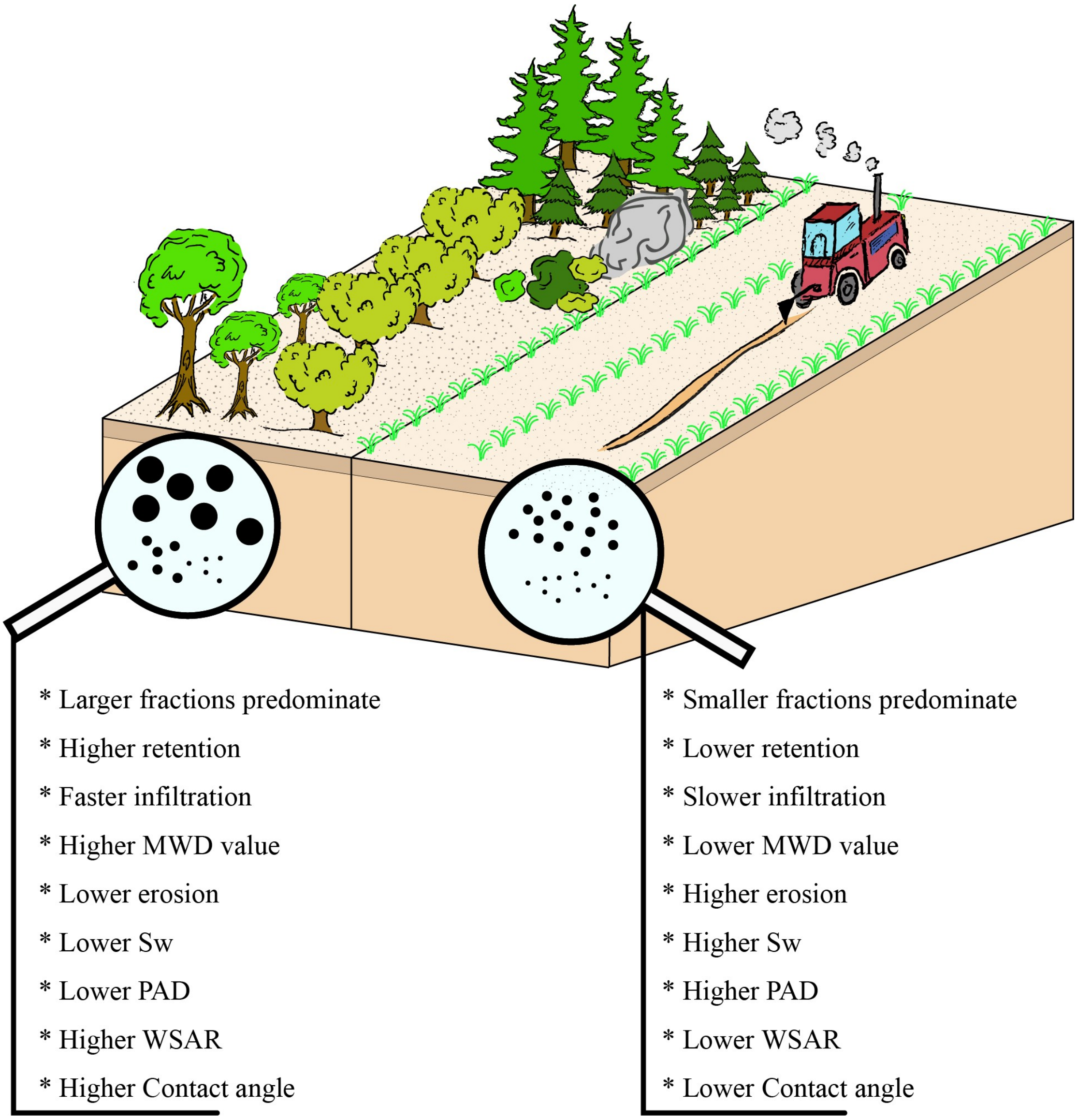
Figure 57: Practical use of WSA in landscape. Illustrated by author.
1- infiltration trench, 2 - plužina, 3 - hedgerow

The first situation represents a infiltration trench, which can be formed by a planted anti-erosion crop (clover, alfalfa). When water runs off the surface from a higher position on the slope, it will slow down on this strip. Due to the presence of an anti-erosion crop, which with its roots contributes to the improvement of soil conditions and slower water flow, part of the precipitation will be absorbed. The remaining rainfall can then be captured by an anti-erosion crop placed in the strip below. In this way, it is possible to stabilize the slope more and prevent high soil erosion. This strip can also be made up of larger stones, which will also slow down the water runoff and improve water absorption into the soil. If the "stone strip" is properly formed, it is possible to cross it with agricultural machinery.

The second illustrated situation is "the Plužina" which in the past was not used to capture precipitation, but rather to divide the slope into individual plots of land for farmers. These strips, perpendicular to the contour lines, were often formed from stones collected in and around the field. Stones had a beneficial effect on the channeling of water and its infiltration. Just the fact, that in the most cases shrubs and smaller trees grow on Plužina, has an effect on the improvement of soil conditions and the formation of WSA, although to a lesser extent than in forest. From the point of view of a practical solution, two variants are possible. A partial drainage pipe can be placed down the slope within the Plužina, which will bring the water to the pond below the slope. The water in the pond can be further used for irrigation or as a water reservoir. The second option includes as first capturing the precipitation in the anti-erosion strip or infiltration trench (1). This water would be then transferred to the border of the Plužina through pipes and a partial drain and then led down the slope, heading to the pond or water reservoir.

The third situation consists of the planting and restoration of hedgerows, which is a part of the landscape that provides natural shelter for small animals as well as larger animals. Shrubs and small trees often grow in the hedgerow. In the past, small fields were joined in large fields, which resulted in a decrease of hedgerows. However, the hedgerows are of fundamental ecological importance, as they support the mentioned biological diversity, protect the soil from the erosive action of the wind and prevent it from being washed away during rains. They therefore form a kind of barrier against landslides. It also depends on the age of the hedgerow and its management. In general, it can be said that the older the hedgerow, the higher the occurrence of WSA of larger fractions (> 2 mm, 2-1 mm) should be, which has a significant effect on the improvement of infiltration within the hedgerow.

From all the obtained results, values and characteristics, it can be said that even though WSA are only present in a relatively small part of the entire soil profile, they have a non-negligible influence on the subsequent properties of the soil. As already stated and confirmed, the biggest difference in WSA representation is in the case of forest and arable land, which is illustrated (Fig. 58) and supplemented by additional information that applies in the most cases to both investigated land use. Numerical parameters (Sw, PAD, Contact angle) are also summarized in the illustration.



* Larger fractions predominate	* Smaller fractions predominate
* Higher retention	* Lower retention
* Faster infiltration	* Slower infiltration
* Higher MWD value	* Lower MWD value
* Lower erosion	* Higher erosion
* Lower Sw	* Higher Sw
* Lower PAD	* Higher PAD
* Higher WSAR	* Lower WSAR
* Higher Contact angle	* Lower Contact angle

Figure 58: Obtained information and characteristics for both land use (forest, arable). Illustrated by author.

Discussion

Comparison of different land use

It was found that different land use has a significant influence on the formation of WSA. At all investigated locations of this thesis, the forest soil had a higher proportion of larger fractions (>2 mm; 2-1 mm), which will have an effect on better infiltration and subsequent retention of water in the soil profile. Słowińska-Jurkiewicz (1989) similarly confirms the same influence in terms of land use. A number of authors have come to a similar conclusion, i.e. that macro aggregates during wet sieving of cultivated soils are lower than those of uncultivated soils (Pagliai et al., 2004; Greenland, 2006). It was documented that the soil contained the most fractions of WSA in the case of forest or pasture, where the fraction in the range of 4.76 – 0.25 mm - macroaggregates) had a representation between 83 – 90% of the sample and, conversely, in arable soil, particles smaller than 0.5 mm (Mostafa et al., 2008). When measured in perennial crops and crops such as orchards, higher WSA values were measured than in annual crops (Han et al., 2010).

Individual authors quite often express the representation of WSA in different ways (for example, only as a fraction greater than 0.25 mm), and therefore, from the point of view of exact comparison, it is appropriate to use the MWD value if the authors state it in their work. Values found within this doctoral thesis (Fig. 42) correspond to the fact that MWD is higher in forest soil compared to arable land. For comparison Gajic et al. (2006) reported MWD values for forest as 2.32 (0-10 cm depth) and for cropland as 1.21 (0-10 cm depth). Zhu et al. (2021) reported in their research that the stability of soil aggregates for different land uses (0-20 cm depth) was in the order of forest soil > grassland > cropland with exact MWD results: 1.45 (forest), 0.73 (grassland) and 0.32 (arable land). The same trend was confirmed by Podrázský et al. (2015), where the values were higher, apparently because of of better soil quality: 2.29 (forest), 2.00 (pasture), 1.29 (arable). Liu et al. (2014) found that across all depths (0-100 cm), MWD were significantly higher in forestland and grassland compared with farmland. Exactly the following values were measured for the 0-5 cm layer: 0.17 (farmland), 1.54 (natural grassland), 1.13 (shrub forestland). Kurmi et al. (2020) compared native forest and plantation with different age and found quite high values where forest had MWD 5.79 (layer 0-10 cm). The 10-year-old plantation had the worst results (MWD=4.91), while with increasing age there was an increase in the MWD and thus an improvement in the soil structure.

The influence of forest age on the formation of WSA

Research focused on the formation of aggregates in the forest, which was planted on the formal arable land, found that in the first stand (CZ-Chlístov) with an age of 10 years, a significant part of the fractions larger than 2 were disintegrated into smaller fractions and the soil was not of very good quality. Aggregates that are smaller than 1.2 mm are a useful indicator of soil degradation (Whalen & Chang, 2002).

The second investigated 24-year-old forest and its soil conditions had a significant influence on the formation of water-stable soil aggregates, which can be noticed in the fraction > 2 mm. From Table 6, it can be seen that the percentage composition during dry and subsequent wet sieving for the >2 mm fraction almost did not change, which indicates the good infiltration properties of the this soil. The other two fractions in the range of 2-0.5 mm had a representation of more than 25 % of the entire sample. Arable land at the Zákraví locality with cultivated barley shows higher values (22,05 %) for the 1-0.5 mm fraction compared to the first Chlístov locality (11.30 %), where corn was grown. The oldest forest stand with an age of 67 years had the large representation (44.14 %) for fractions >2 mm, indicating the cohesion of the aggregates after wet sieving.

Most of the researches have been focused mainly on the conversion of pasture or forest to arable land. For example Spohn & Giani (2010) compared the dynamics of the representation of macro and micro aggregates during the conversion of pasture to arable land on podzols in northern Germany in a time series of 0 to 45 years in different areas. The share of macro aggregates decreased over time, while the representation of micro aggregates increased. Both processes slow down their dynamics around 20-25 years. The return to the original state after a disturbance depends on its intensity and research by Linsler et al. (2015) has shown that a permanent grassland disturbed by a single plowing returns to its original parameters in 5 years. Conversely, in the case of conversion of degraded arable land to pasture, the change is noticeable after 10 to 15 years (Kösters et al., 2013). Regarding the bulk density (BD), determined in research by Ritter et al. (2003), BD values were higher in newly forested areas. For pasture and old forest, the BD value was lower.

Similar to the research in this dissertation, Wall & Hytönen (2005) studied the effect of afforestation of farmland with spruce in southern Finland in 10 and 60 year old stands and compared them with surrounding farmland and old forest.

They found that under local climate and soil conditions, 60 years is not enough for the soil under afforestation to reach old forest parameters, however, there is a difference compared to arable land in the form of an increase in pH, OM content, total N and a decrease in BD (increase in WSA).

As part of this dissertation, a greater representation of WSA fractions in the range of 0.5 to less than 0.1 was found in the first forest location (CZ-Chlístov), which together made up exactly 50 %. In terms of the occurrence of particles larger than 2 mm, the value is more than half that of compared forested localities, 20.46 % to be exact. Thus, it seems that in such a young stand (10 years) the aggregation into higher fractions is already visible, but it was not enough to create a higher representation of water-stable soil aggregates.

Solomon et al. (2000) states that stabilization of fractions in the 0.02 to 0.06 mm range may take 15 to 20 years after disturbance. The stabilization of the macroaggregate, on the other hand, takes place more quickly (within five years), as soon as the previous arable area is covered with vegetation. The conversion of natural forest cover to tree plantations (pines) was investigated by Nascimento et al., (2021). An approximately 13-year-old plantation established in a 3 × 3 m clip had a lower representation of macro aggregates and a higher micro aggregates, i.e. a similar effect to arable land.

The second investigated forest location, Zákraví, with a stand age of 24 years, had significantly better results in terms of the presence of larger WSA fractions. The fraction greater than 1 mm here had a value of 61.90 %, which indicates favorable soil conditions for infiltration and also the subsequent retention of water in the soil (Six et al., 2004; Nichols & Toro, 2011). Such favorable soil conditions were probably influenced by the arrangement of the trees. The trees there were located approximately in a square clip with a distance of 1.2 m.

A higher (55.15 %) representation of the fraction larger than 1 mm is also visible in the results from the third location with an age of 67 years. Unlike the two previous forest stands, there was an increased value for the 1– 0.5 mm fraction, which made up almost a quarter of the sample (25.75 %). Spruce trees grow there at a greater distance from each other than in the second and first locations, and for a longer period of time there is no intensive root growth, which can have an effect on WSA formation (Grafg & Frei, 2013).

From the results of this work (Tab. 6), it is possible to say that the greatest increase in the larger fractions of WSA in forest soil occurs between 10 and 24 years. A similar conclusion was reached by Podrázský et al. (2015), and therefore that the greatest change occurs between 15-30 years, i.e. the influence of arable land persists.

Research focused on the distribution of WSA in tea plantations of different ages (0-55 years) is comparable. From the values, it is possible to observe the greatest positive change for the formation of WSA is between 0 and 25 years, and then there is a slight decrease in the largest fractions (Zhu et al., 2019). It is therefore evident that the influence of the age of the forest on the formation of WSA is significant and it will be appropriate to study this topic more detaily in future research.

Determination of microplastics in arable and forest land

From the point of view of MPs mobility considerations, it is important that structured soils do not break down into a primary structure, but into smaller aggregates. Measured abundance results (8000 and 12 400 pt/kg) by this thesis work are rather in higher range values that can be compared with published data. Scientifc articles present a relatively wide range from hundreds of MPs particles to more than 40 000 particles per 1 kg of soil, where it also depends on land use and the method of using sewage sludge, mulching foils, etc. (He et al., 2018; Zhang & Liu, 2018; Yang et al., 2021). In areas with less pollution (Chile, Switzerland), the values are lower in the range of 120–600 pt/kg (Scheurer & Bigalke, 2018; Corradini et al., 2021).

At the studied locality Lysolaje, although there is no fertilization with sewage sludge, the higher abundance of MPs is probably due to the fact that the locality is located in a peri-urban environment with infuence from industry and transport. Wind transmission is also a signifcant source of MPs pollution (Rezaei et al., 2019). Evenly distributed rainfall can also have an efect (Mbachu et al., 2020).

Results in this thesis did not directly report the whole soil profle, but only the top soil (0–10 cm) was investigated due to presence of water-stable aggregates mostly in this layer. Due to the particle size distribution curve, most of the soil is in the form of aggregates and the percentage of soil in the primary structure is minimal, so it can be said that the results can be used for the whole top layer (Ap horizon). However, this only applies to soils with higher clay content. For sandy soils, it can be assumed that the percentage of aggregation would be lower and, conversely, the higher percentage would be in the primary structure. From results (Tab. 10) it can be deduced that MPs are bound in soil aggregates and if they move, they move together with them.

This was confirmed by measurements, because MPs were extracted from WSA, that is they were contained in aggregates which do not disintegrated in water after 2 hours and do not disintegrated even after subsequent wet sieving. The efect of land use is that forest WSA have a larger diameter (MWD) than arable land. By being larger, they are also more stable to movement during water erosion, in accordance with published work (Wan & El-Swaify, 1998). Furthermore, it can be assumed that MPs bound in aggregates will be more stable against further degradation.

Therefore, the opinion of He et al. (2018) which states that the top soils provide a potentially degradative environment, mostly due to the efect of UV radiation cannot be fully supported. This assumption is likely to apply only to a limited extent to MPs hidden in aggregates. Similarly limited is the fact that the typical physical process for microplastics in soils is leaching. Soil aggregates are set in motion only in the event of surface runoff and not by leaching; thus, the MPs bound in the water-stable aggregates do not leach.

WSA modeling

The conceptual model created in this work clearly shows the importance of WSA in the environment. Processes have been identified that have a positive or negative effect on the formation of WSA. Within the framework of the conceptual model, the most important data that can be obtain through the study of WSA, further description of properties of soil and practical use were summarized. To obtain an accurate computer model, the next steps would be designing the technical details and then coding. According to available sources, only Milanovskiy & Shein (2015) dealt with the creation of the conceptual model, which, however, focused only on partial parts related to WSA. WSA modeling is not very common and usually it is more about comparing or determining the relationship between other parameters such as SOM (Curaqueo et al., 2010), carbon content (Catania et al., 2018), plowing effect (Bartlova et al., 2015) etc. Aggregate stability increases with organic matter content in the soil and can be improved through a combination of management practices such as reduced tillage. It is important to avoid extensive tillage and reduce physical disturbances to prevent the destruction of soil aggregates. By keeping soil covered with surface residues, erosive impacts can be minimized as well.

Summary and Future research

It is evident from the created conceptual model of WSA, that even though WSA are only present in a relatively small part of the entire soil profile, they have a non-negligible influence on the subsequent properties of the soil. As already stated and confirmed, the biggest difference in WSA representation is in the case of forest and arable land, where the forest soil in all locations had a greater representation of fractions larger than 1 mm. In the case of forest soil, when it rains, due to smaller fractions, a poorly permeable layer is formed and subsequent surface erosion occurs. If the arable land is afforested, a more significant formation of aggregates begins to appear between approximately 10 and 24 years. From the findings of microplastics, more of them were found in the forest soil. The forest therefore has an effect on their preservation and reduces their movement through the environment. During the research, it was found that an important parameter is the mean weight diameter (MWD), which gives information about the stability and crustability of the soil. It is usually used in the scientific articles literature and thus a global comparison is possible through it. Knowing the topsoil in which WSA are located and determining its structure helps to refine hydrological models.

Future research can focus on several topics. The change in land use affects the formation of WSA, which affects the top layer of the soil. On a larger area (a hectare or more), this change is essential for the formation of runoff, especially during torrential rainfall. The aim of the research would be to verify the level and extent of individual parameters and to model the influence of land-use on the basis of historical changes in the landscape (watershed) and to assess the influence on (historical) floods.

Further research can also be focused on micropollutants such as microplastics and probably substances such as pharmaceuticals. These micropollutants can be "stabilized" in WSA, especially macro-WSA (>0.25 mm), which are more stable against water erosion and thus leaching from the soil. It is possible to model this process (physically and mathematically) and to propose appropriate measures that would support this process and could be incorporated into other measures, such as phytoremediation of problematic micropollutants. It is still possible to assess the state (composition) of WSA and use it as a suitable supplement to the assessment of the current state of soils. The information obtained can be used for the proposal of suitable melioration measures, or for the assessment of their effectiveness.

List of abbreviations

ΔS – Indication of the susceptibility of the soil to dispersion alone [%]
4s – Division of whole sample to four samples
Alpha – Parameter a in the soil water retention function [L-1]
BC – Boundary condition
CA – Contact angle
CM – Conceptual model/s
DC motor – Direct current motor
Disp – Dispersant
f_2, f_1, $f_{0.5}$, $f_{0.25,}$ $f_{0.1}$ – Fraction with diameter 2; 1; 0.5; 0.25; and 0.1 mm
GIS – Geographic information system
ID – Identifier
Ks – Saturated hydraulic conductivity, Ks [LT-1]
L – Tortuosity parameter in the conductivity function [-]
L1 – Layer one (0-10 cm)
L2 – Layer two (10-30 cm)
LB1 – Laboratory beaker number 1
LB2 – Laboratory beaker number 2
MPs – Microplastics
MWD - Mean weight diameter
$\mathrm{MWD}_{\mathrm{disp}}$ - Mean weight diameter of wet sieving with dispersion [mm]
$\mathrm{MWD}_{\mathrm{dry}}$ - Mean weight diameter of dry sieving [mm]
$\mathrm{MWD}_{\mathrm{wet}}$ - Mean weight diameter of wet sieving [mm]
Mxs – Mixed sample of soil
n – Parameter n in the soil water retention function
OC – Organic carbon
PAD – Percentage of aggregate destruction [%]
p_{dry} – Proportion of aggregates >0.25 mm after dry sieving [%]
p_{wet} – Proportion of aggregates>0.25 mm after wet sieving [%]
PSD – Particle-size distribution
Qr – Residual soil water content, qr
Qs – Saturated soil water content, qs
$\mathrm{Rep}_{\%}$ – Representation of individual fractions (%) of whole sample
Rep_{10} – Representation of fractions for 10 g sample (prepared for wet sieving)

rpm – Rotation per minute
S1 – Sample with a fraction smaller than 1 mm
S$_{400}$ – Resulting sample of weight 400 g
SOC – Soil organic carbon
SOM – Soil organic matter
SV – Sieving method
Sw$_{10}$ – Sample of weight 10 g prepared for wet sieving
S_W – Susceptibility of soil to wetting [%]
S_{WD} – Susceptibility of soil to wetting and dispersion [%]
SWAT – The Soil and Water Assessment Tool
SWS – Soil water storage
TKSP – Taxonomický klasifikační systém půd ČR
TOPMODEL – Topography based Hydrological Model
UV radiation – Ultraviolet radiaton
VC – Volumetric cylinder
WEPP model – The Water Erosion Prediction Project
w_i – Proportion of the total sample (by weight) of that size fraction i
WRB – World Reference Base (for soil resources)
Ws – Whole sample
WSA – Water-stable aggregates
WSA$_{if}$ – Total weight of water stable aggregates for all individual fractions (g)
WSAR – Water-stable aggregates stability rate (%)
$\overline{x_i}$ – Mean diameter (mm) of size fraction i

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Appendices

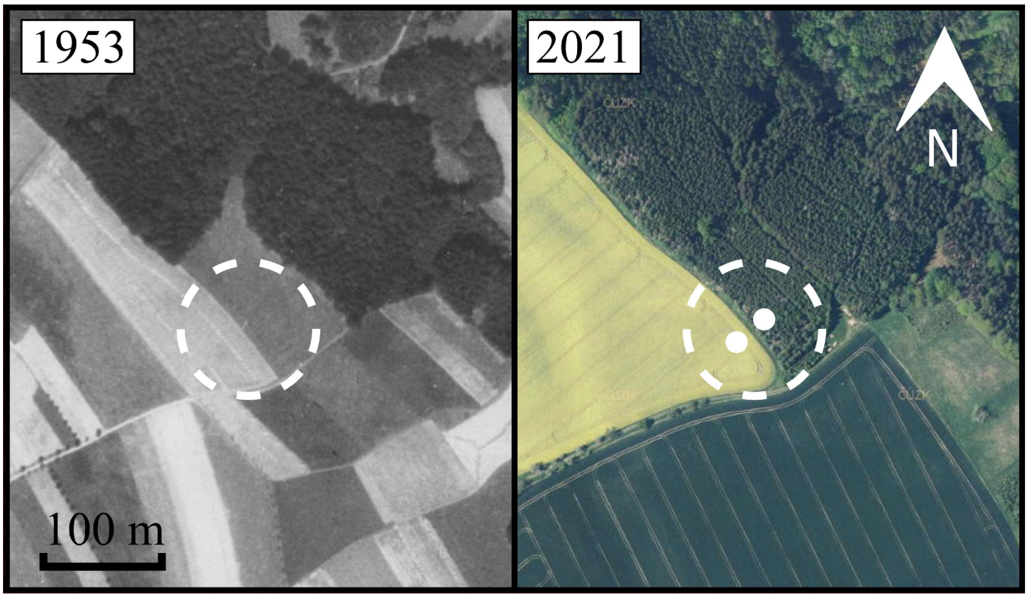

Figure 59: Afforestation near the village of Zákraví with marked collection points. Adapted from Klíč (2023)

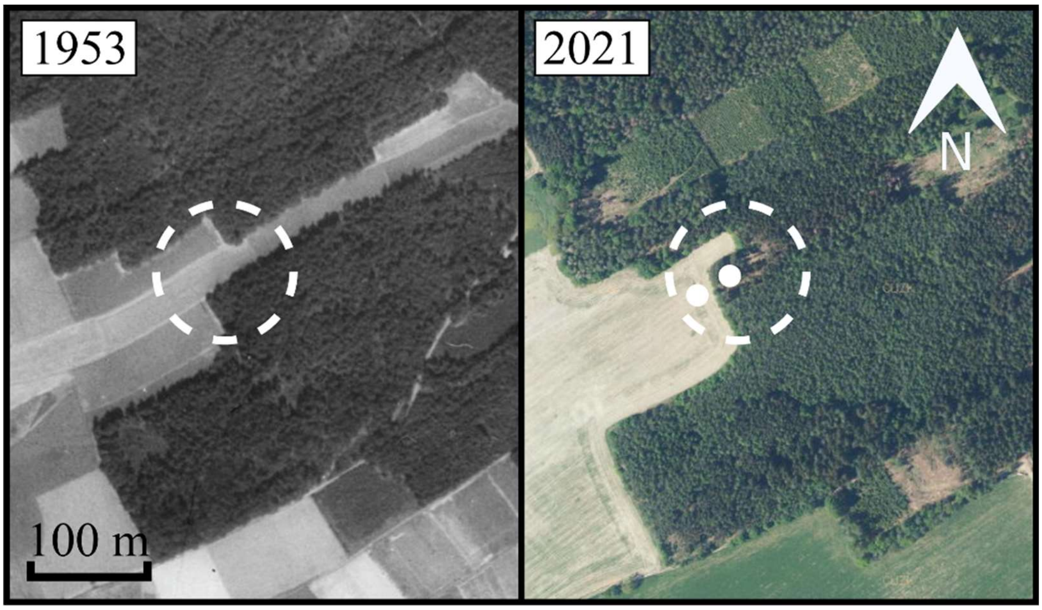

Figure 60: Afforestation near the village of Val with marked collection points. Adapted from Klíč (2023)

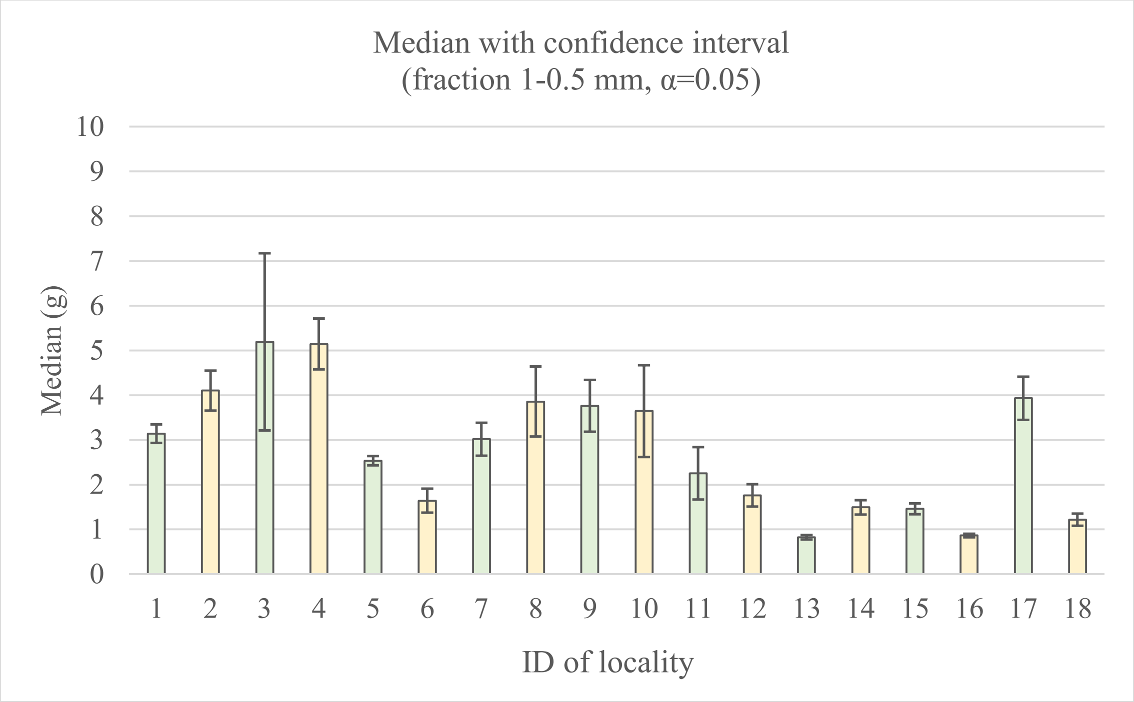

Figure 61: Median of WSA fractions 1-0.5 mm

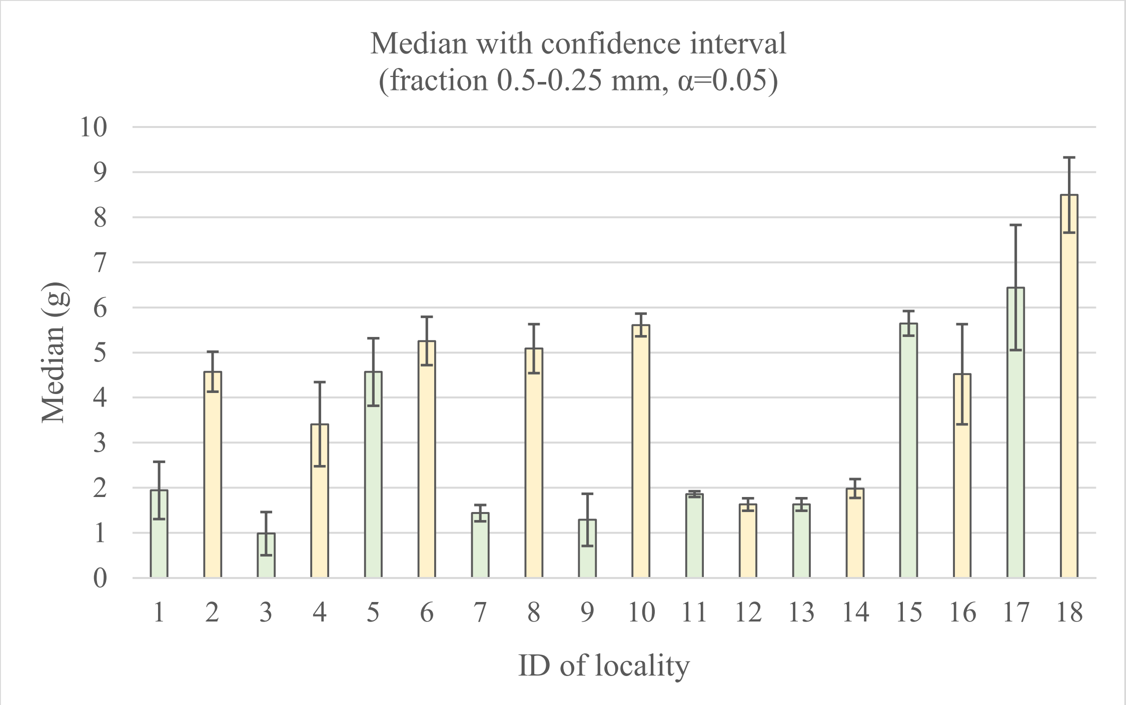

Figure 62: Median of WSA fractions 0.5-0.25 mm

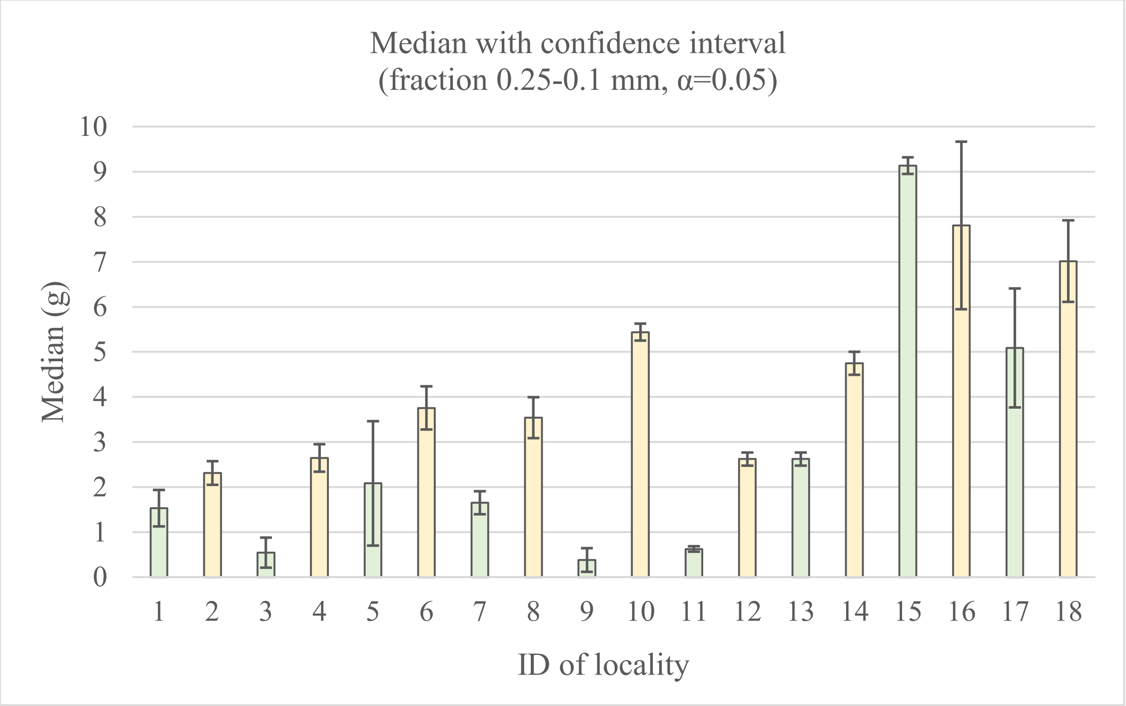

Figure 63: Median of WSA fractions 0.25-0.1 mm

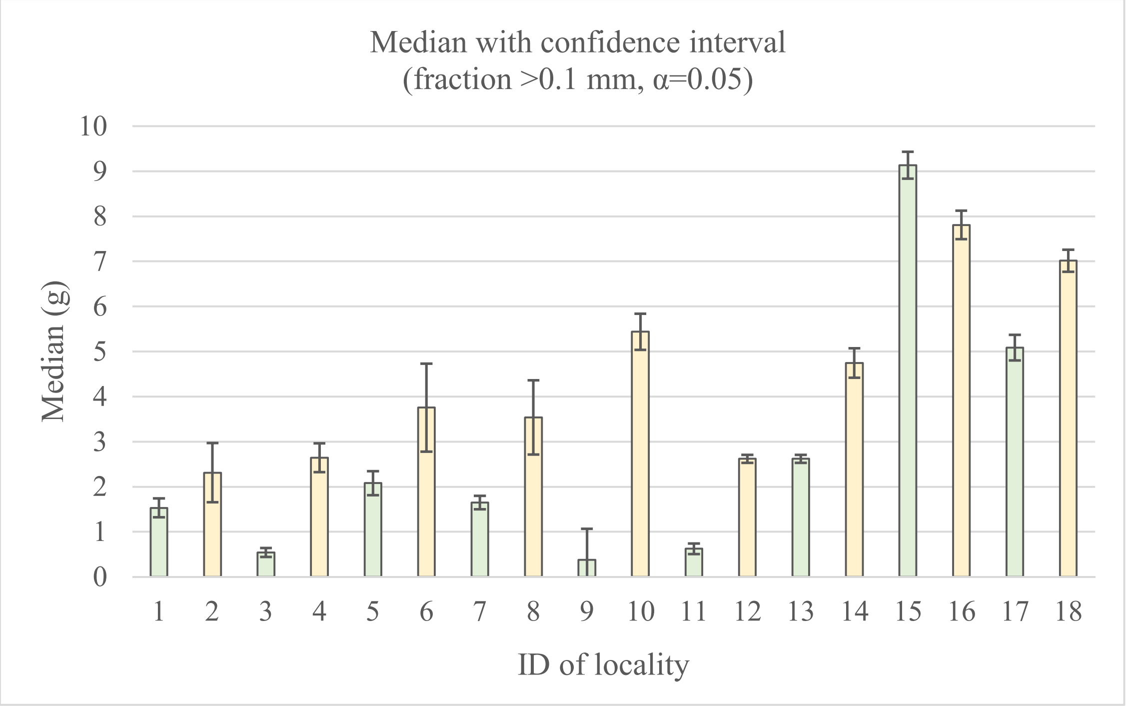

Figure 64: Median of WSA fractions <0.1 mm

Table 12: Results of MDWdry, MDWwet and MWDdisp

Locality	ID	MWD (mm)		
		Dry	Wet	Disp
CZ- Lysolaje - Forest	1	2.66	1.52	0.12
CZ- Lysolaje - Arable	2	2.91	0.68	0.12
CZ - Bošovice - Forest	3	2.03	1.74	0.09
CZ - Bošovice - Arable	4	1.91	0.82	0.08
CZ - Chlístov - Forest	5	2.62	1.07	0.12
CZ - Chlístov - Arable	6	1.27	0.44	0.11
CZ - Zákraví - Forest	7	1.94	1.79	0.20
CZ - Zákraví - Arable	8	1.52	0.52	0.20
CZ - Val- Forest	9	2.17	1.74	0.16
CZ - Val - Arable	10	1.83	0.46	0.15
PT - Zebreira - Forest	11	2.04	1.77	0.20
PT - Zebreira - Arable	12	1.54	0.81	0.20
LT- Kaunas - Forest	13	1.44	0.39	0.19
LT- Kaunas - Arable	14	1.59	0.26	0.18
KZ - Terinkol - Forest	15	0.76	0.37	0.20
KZ - Terinkol - Arable	16	0.51	0.23	0.19
KZ - Fedorovka - Forest	17	1.15	0.55	0.15
KZ - Fedorovka - Arable	18	0.77	0.28	0.14
RU-Kursk-forest	19	2.45	1.72	0.05
RU-Kursk-arable	20	2.18	0.70	0.05

Table 13: Fraction representation (%) after dry sieving for research localities

Dry sieving representation (%)				Fraction (mm)					
Country	Study plots	ID	Land use	>2	2-1	1-0.5	0.5-0.25	0.25-0.1	<0.1
Czech republic	Lysolaje	1	F	82.23	10.68	3.82	1.41	0.68	1.18
		2	A	96.14	1.24	0.74	0.49	0.40	1.00
	Bošovice	3	F	52.08	23.43	12.57	4.45	3.75	3.71
		4	A	44.65	27.80	17.20	5.95	2.12	2.28
	Chlístov	5	F	82.73	6.91	2.69	2.20	1.89	3.60
		6	A	29.10	16.01	9.68	15.21	10.21	19.79
	Zákraví	7	F	53.39	13.91	10.52	8.52	7.58	6.08
		8	A	39.30	11.75	12.59	13.54	9.45	13.37
	Val	9	F	67.34	5.25	4.08	5.40	5.27	12.67
		10	A	48.80	15.91	10.35	10.27	4.85	9.83
Portugal	Zebreira	11	F	54.09	17.35	17.68	5.84	3.84	1.19
		12	A	40.76	10.04	12.46	13.10	11.19	12.45
Lithuania	Kaunas	13	F	37.87	9.93	4.92	21.27	23.21	2.80
		14	A	39.95	13.12	14.24	15.81	13.25	3.63
Kazakhstan	Terenokol	15	F	15.21	6.52	9.07	15.05	41.64	12.50
		16	A	8.62	3.68	6.33	11.89	55.94	13.53
	Fedorovka	17	F	21.65	17.02	20.01	17.38	17.54	6.40
		18	A	13.60	8.42	14.92	19.12	27.70	16.22

F – forest, A – arable

Table 14: Fraction representation (%) after wet sieving for research localities

Wet sieving representation (%)			Fraction (mm)					
Country	Study plots	Land use	>2	2-1	1-0.5	0.5-0.25	0.25-0.1	<0.1
Czech republic	Lysolaje	F	31.36	25.33	18.31	12.62	8.85	3.54
		A	2.70	16.78	26.78	31.70	16.09	5.94
	Bošovice	F	38.66	22.30	28.96	5.33	3.42	1.33
		A	8.55	13.29	33.21	22.23	17.25	5.46
	Chlístov	F	20.46	13.72	15.82	27.23	16.08	6.69
		A	1.15	9.65	11.54	33.15	22.32	22.20
	Zákraví	F	45.19	16.71	17.35	9.13	9.60	2.03
		A	1.63	10.70	21.37	29.25	19.64	17.42
	Val	F	44.92	10.23	25.75	9.06	3.26	6.77
		A	1.91	5.18	18.96	32.91	32.05	8.99
Portugal	Zebreira	F	17.35	12.95	19.51	33.48	11.13	5.58
		A	1.13	9.20	24.38	24.20	38.27	2.82
Lithuania	Kaunas	F	1.62	3.64	8.70	39.86	41.08	5.08
		A	0.25	1.43	15.73	20.14	48.70	13.75
Kazakhstan	Terenokol	F	2.43	3.04	7.45	29.18	47.10	10.79
		A	0.00	0.00	5.18	22.49	52.78	19.55
	Fedorovka	F	2.83	8.80	20.64	34.57	24.95	8.22
		A	0.00	0.00	6.44	44.82	34.36	14.39
			-	>1	1-0.5	0.5-0.25	<0.25	-
Russia	Kursk	F		80	5	3	12	
		A		9	17	27	47	

F – forest, A – arable