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The Unified Soil Classification System Mapping of the Pannonian Basin in Croatia using Multinominal Logistic Regression and Inverse Distance Weighting Interpolation

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Abstract

The Unified Soil Classification System (USCS) is the basis for numerous methods for soil trafficability research. Since USCS data are not always available, various other data and methods are used to correlate and predict the USCS soil group. This paper describes two methods used for the purpose of mapping the Croatian part of the Pannonian Basin (PB) according to the USCS to a depth of 50 cm. In the first method, the possibility of the transfer of 308 profile samples according to the International Soil Science Society (ISSS) classification system into the USCS was examined. The results show that it is impossible to directly transform ISSS data into the USCS. In the second method 414 USCS profiles were used to analyse the weights of factors in the spatial analysis with inverse distance weighting (IDW). The analysis included layers of dominant and associated soil units of the Basic Soil Map of Croatia (BSM), Geological Map of Croatia (GM), drainage and catchment areas. The obtained weights were as follows: BSM 47.12%, catchment area 27.12%, GM 17.67% and drainage 8%. The results showed that PB in Croatia is covered with fine-grained soils, with clay covering almost the entire area and silt dominating in the western and north-western parts of the country.

Keywords:

USCS; ISSS; Soils of Croatia; Trafficability

1. Introduction

In many parts of the world, soil is the predominant and limiting factor for cross-country mobility and trafficability outside the road infrastructure. Research of soil trafficability and vehicle mobility is the subject of interest to various professionals, but is primarily associated with the military, agriculture and the forestry sector.

Numerous methods and models about the relationship between soil and vehicles (wheels and/or tracks) have been developed to determine the possibility of vehicle movement, where the soil type information (along with relief, water, vegetation and other human infrastructure) according to the USCS is one of the main factors used (**Heštera and Pahernik, 2018; Mason and Baylot, 2016**). The USCS is commonly used in the civil engineering practice and was first developed for use in airfield construction during World War II. A few years later, the system was adopted for other civil engineering constructions, such as dams, foundations, etc. The USCS differentiates coarse-grained soils (gravels and sands) classified by their grain size distributions, and fine-grained soils (silts and clays) classified by their plasticity. Besides that, there are two other groups of soils: organic soils and peat (**Holtz and Kovacs, 1981**). The application of the USCS method is limited by the lack of sources for soil types, due to its more complex type distribution (**Hind, 2017; Wright et al., 1981**). Owing to the lack of data on the USCS soil properties, researchers explore the possibilities of prediction and modelling using other available data, such as: organic matter, drainage class, moist bulk density, saturated hydraulic conductivity, available water storage, etc. (**Gambill et al., 2016**).

Early soil taxonomy was mainly developed for agricultural purposes, with soil groups defined by relative proportions of their particles, i.e. grains of different sizes. The U.S. Department of Agriculture (USDA) granulometric classification is the most widely used classification because it has a large database at its disposal. Unfortunately, this system could not be adopted for geotechnical purposes, as it was evident that the plasticity of fine-grained soils rather than grain size determines their engineering behaviour. This was the reason for develop-

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ing the new soil classification (USCS) system to be used for engineering purposes. A comprehensive work summarising the available data on soil properties according to the USDA soil classification system, based on which the physical properties of soil required for soil trafficability according to the USCS could be assumed and determined, was compiled by **Frankenstein and Koenig (2004)**. **García-Gaines and Frankenstein (2015)** made a consensual USDA-to-USCS conversion, while **Gambill et al. (2016)** made a USCS prediction using the random forest method, where the basic parameter was also the USDA soil classification. Depending on the size of the studied area and the number of available samples, statistically significant results can be achieved by prediction models. "However, despite the highly significant empirical relationship between the Atterberg limits and clay content, a reliable prediction of one from the other is often not possible, unless similar soil types are considered." (**Kirchhof, 2017**). The conclusion of all the researchers is that field and laboratory testing should be carried out, which **García-Gaines and Frankenstein (2015)** point out as the most accurate method of conversion from one classification system to another.

The basic idea and aim of every researcher is essentially to obtain data on the physical soil properties for a contiguous area using the available soil data. Depending on the soil properties and available data, different interpolation methods (with their variations) are applied for mapping, such as: Ordinary Kriging, Regression Kriging, Spline, Inverse Distance Weighting, Radial Basis Function, Local Polynomial Interpolation, etc. The most commonly used methods of spatial interpolation of unknown areas of interest for different physical and chemical soil properties and their advantages and disadvantages are described in **El-Sayed (2012); Hengl and Reuter (2009); Ivšinović and Malvić (2020); Robinson and Metternicht (2006); Schloeder et al. (2001)**. Field and laboratory studies are the only accurate methods, but also the most expensive, as they require the highest investment of time and money, which is why researchers resort to building a predictive soil mapping model (**McBratney et al., 2003; Zhu et al., 2015**). The number of samples must be representative to accurately describe the condition and relations of the studied area (**Webster and Oliver, 1990; A. X. Zhu et al., 2015; A. Xing Zhu et al., 2008**). Existing laboratory-prepared data on soil properties are used as a basis for calibrating existing data and mapping new areas (**McBratney et al., 2003**). Pedometric mapping is the most common method for soil mapping, focusing on problems that can be quantitatively formulated and solved with mathematical and statistical techniques (**Lal, 2017; McBratney et al., 2003**). The term "digital soil mapping" is widely used and incorporates procedures including digitalised data and spatial analysis. This method is popular because it provides information of various accuracy levels at a low cost. Using the existing natural base as the foundation and GIS for building soil property models has been used by **Böhner and Selige (2006); Corner et al. (2002); Farewell and Farewell (2010); Li and W. McCarty (2019); McKenzie and Ryan (1999); Zhu et al. (2001)**. Soil trafficability mapping is most widely used for military vehicles, where all available and relevant data from various sources are combined, with maps for agricultural purposes being the most important (**FM 5-33, 1990; Hohmann et al., 2013; Hubacek et al., 2014; Wawer et al., 2003**).

Scientific research and its development depend on earlier achievements. In that sense, pedological maps are one of the most important sources of data for soil characterization. The infrastructure of soil data for the territory of Croatia is that the BSM is currently the most detailed (scale 1:50,000) and relevant cartographic source for soil characteristics, although mapping of the entire territory has not yet been completed - only hand-interpolated maps and some unfinished sheets are available (**Bogunović and Rapaić, 1993**). The reasons for the current impracticability of the data for carrying out spatial analyses were the transfer of analogue data into digital form; moreover it was impossible to link the adjacent map sheets, and also several mapping methods for agricultural purposes during the 1964 to 1985 period were used.

However, considering BSM's nature and the high value of the data, it is the primary source for all pedosphere research in Croatia (**Heštera, 2020**). The aim of this research was to investigate how the present soil data can be used in the creation of USCS maps for cross country vehicle mobility.

2. Research Area, Data and Methods

2.1. Research area

The investigation of soil trafficability of Croatia and PB in Croatia (29187 km^2) (see **Figure 1**) was conducted in the research area characterized by a soil cover up to 50 cm depth. Only in some parts of the mountain top regions of Slavonia, Žumberak, Zagorje and Medvednica the soil is shallower, with the bedrock close to the surface, but these are very small areas. In geomorphological terms, this small area can be described as mostly hilly on the western side with a few mountains of more than 900 m, while on the eastern side there are plains. This area has a moderate warm climate with hot summers (Cfa – Koppen classification), surface water runoff and agricultural land in plains. The karst region was not included in this investigation because of completely different geomorphological processes in the karst environment. Significant differences in the characteristics of the relief, parent substrate and climate have led to great differences in the pedological characteristics of Croatia. Thus, the lithological base in the form of carbonates (limestones and dolomites), predominant in the coastal

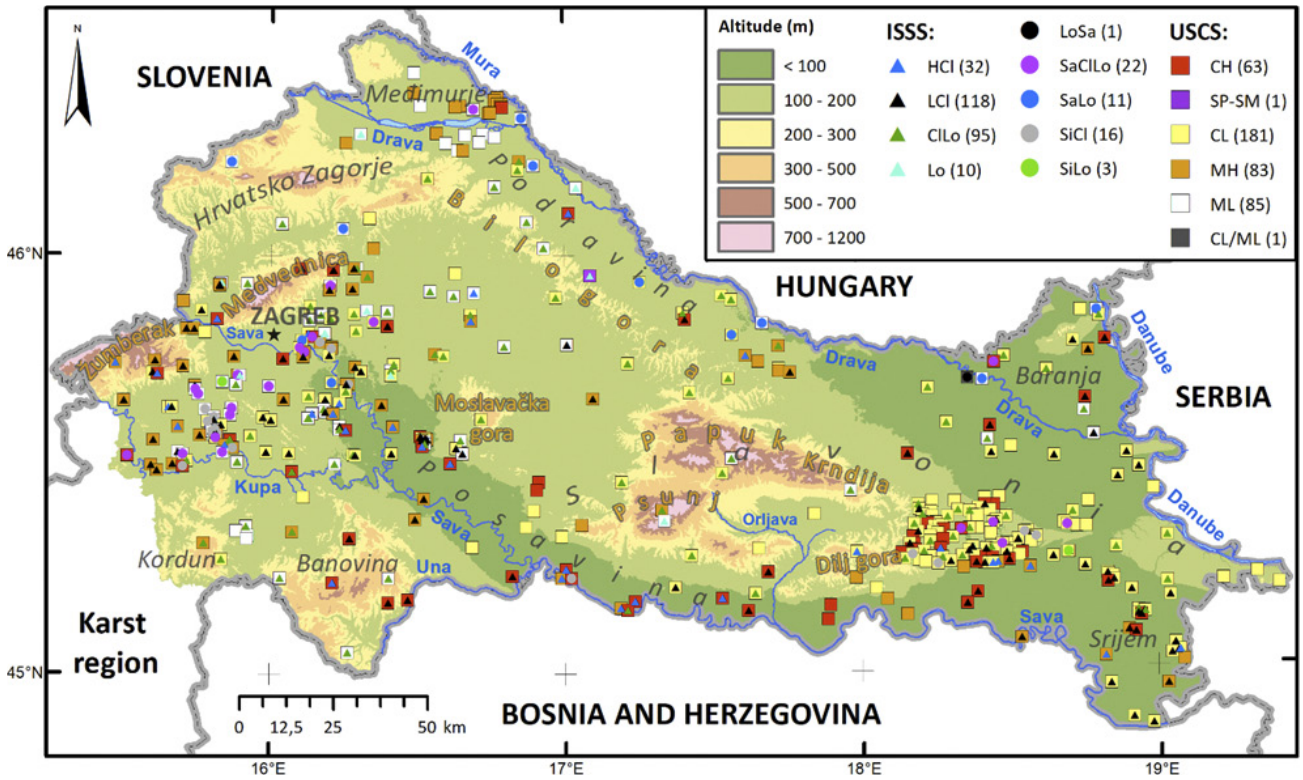

Figure 1: Physical geographic map of PB in Croatia with soil sampling locations for the USCS and ISSS classification

and mountainous regions of Croatia, determines the genetic relief type of karst and fluviokarst. In addition, pedogenesis in this area is greatly influenced by the strong vertical dissection of the relief and the large slopes of the Dinaric Mountains. Thus, most of the soils in this area are formed by residues of carbonate dissolution (Terra rossa), often mixed with other components of erosional, fluvial and glacial material (Cambisols). Large areas are also characterised by naked karst with fragments of terra rossa and cambisols within karst depressions (valleys, coves and fields). PB in Croatia is characterized by floodplains (alluvial soils) and terraces of watercourses (gley soils), especially of the Sava and Drava rivers. The distribution of loess and loess-like sediments is also significant, forming loess plains, where the suffusion type of relief (Luvisols) prevails. The higher relief of the PB in Croatia is associated with the rock mountains (inselbergs) with heights from 500 to 1200 meters. Here the relief type of valleys with fluvial denudation processes is dominant. The lithological structure of the mentioned inselbergs consists mainly of shale, sandstone and metamorphites (rankers). The described morphological differences between the continental and the mountainous and coastal regions of Croatia clearly point to the obvious differences in the morphology of the prevailing soils, and thus to the necessity of a separate analysis.

The boundary of the studied area in the southwest is generally determined by the Črnomelj – Karlovac – Glina Fault, bordering the Pannonian Basin and the Supradinarik regional structural unit (**Prelogović et al. 2001**). In more detail, the border is defined by the geomorphological regional division of the Republic of Croatia between two geomorphological megamorphological units - the Dinaric mountain system and the Pannonian Basin (**Bognar, 1999**). Most of the border regions consist of the Cetinsko and Vojnićko hills, which researchers classify as part of the Pannonian region. For the purposes of this work, around the mentioned hills, the border was moved to the north, that is, to the northern edge of the carbonate complex of deposits of the Mesozoic era. Although according to this principle, the area of Žumberak could be omitted, it is included in the research area due to the principle of spatial connections.

2.2. Data

The original idea for conducting soil mapping was based on determining correlation parameters between granulometric systems of soil particle sizes (see **Figure 2**), as described in **García-Gaines and Frankenstein (2015)**. During the soil mapping of Croatia in the period from 1964 to 1985 and the preparation of 1:50,000 scale maps, several reference systems for soil classification and mapping were used (**Kovačević et al., 1972; Škorić et al., 1973; Soil Survey Staff, 1951**). Therefore, it was impossible to classify the data on the granulometric composition of the studied profiles (308) to the depth of 50 cm according to the USDA classification, but instead all data were classified according to the ISSS classification system (see **Figure 3**).

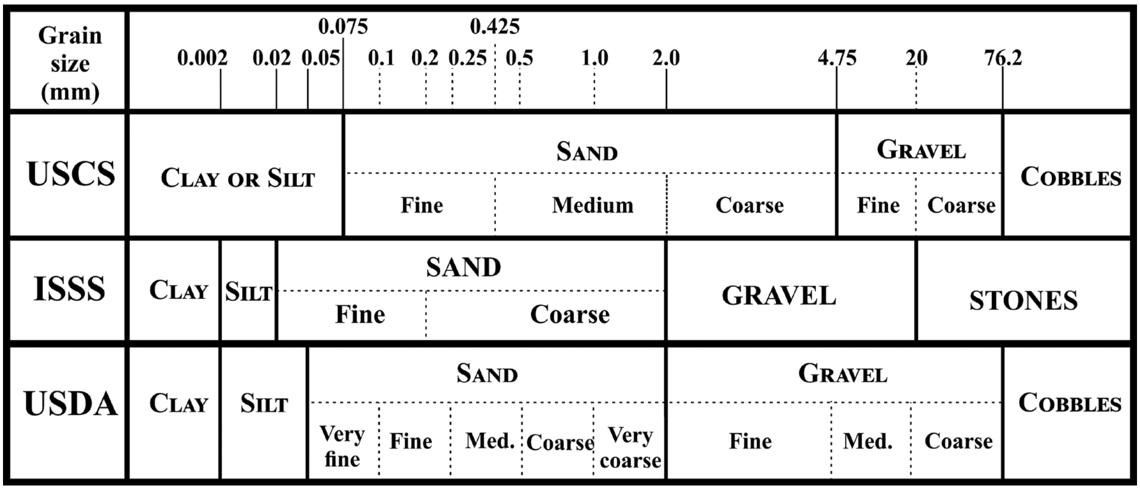

Figure 2: Comparison of particle size limits of the USCS, ISSS and USDA classification systems

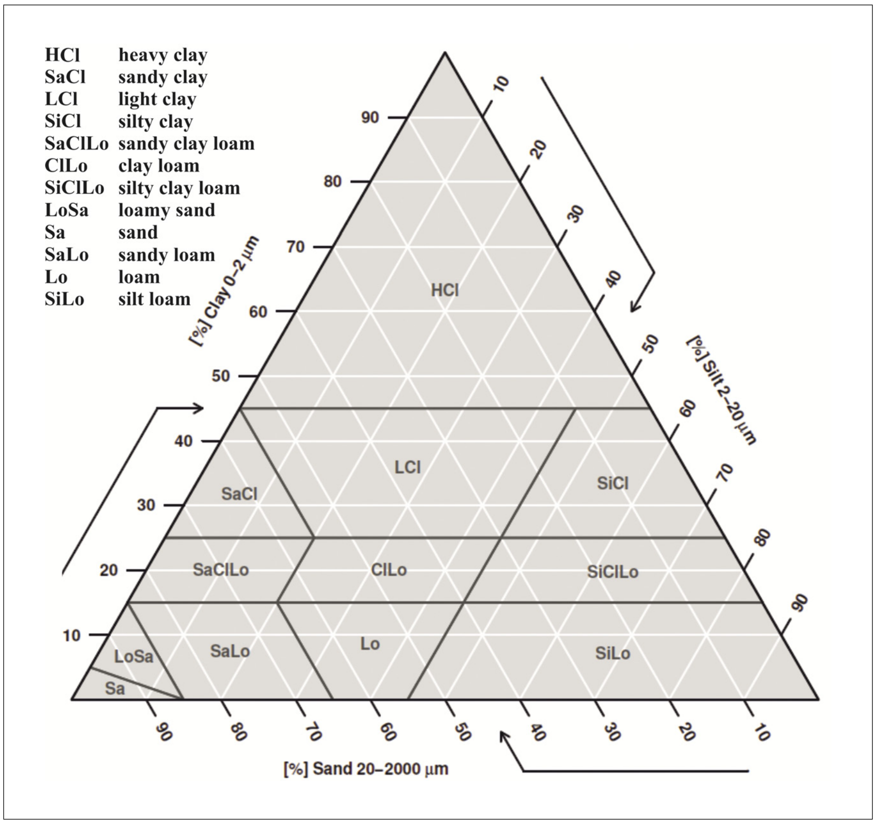

Figure 3: ISSS soil texture triangle (source: **Moeys, 2018**)

After structuring the data according to the ISSS, field, laboratory, and cabinet studies were conducted. Soil samples were collected and classified according to USCS to perform a spatial analysis and to establish correlations with ISSS profiles at the same sites in preparation of the Basic Pedological Map (BPM). The method for processing the profile data and their classification is described in **Heštera (2020)**. Additional profiles were analysed according to USCS (414), 254 profiles were analysed by field work and laboratory analyses in the period between September 2017 and October 2020, while 160 additional profiles were added to the existing ones by subsequent review of the literature (see **Figure 1**). During the laboratory analysis, it was found that the sample profiles were homogenous according to the USCS group up to a depth of 50 cm, thus making the separation of layers by depth unnecessary.

For further analyses, it was necessary to create a continuous pedological layer, which did not exist for the territory of Croatia at a scale of 1:50,000. Before conducting the analyses and planning the sampling, the topological relationships and the location of spatial units

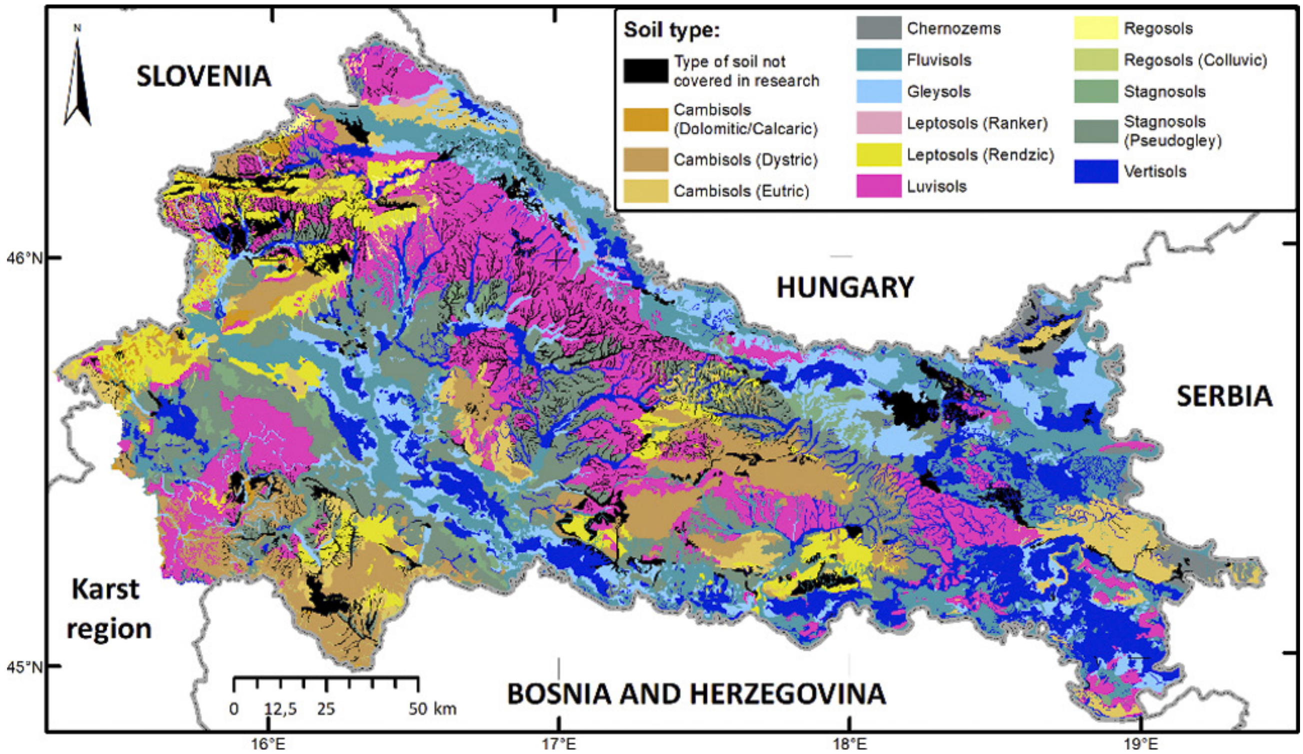

Figure 4: Map of dominant pedological World Reference Base of Soils units

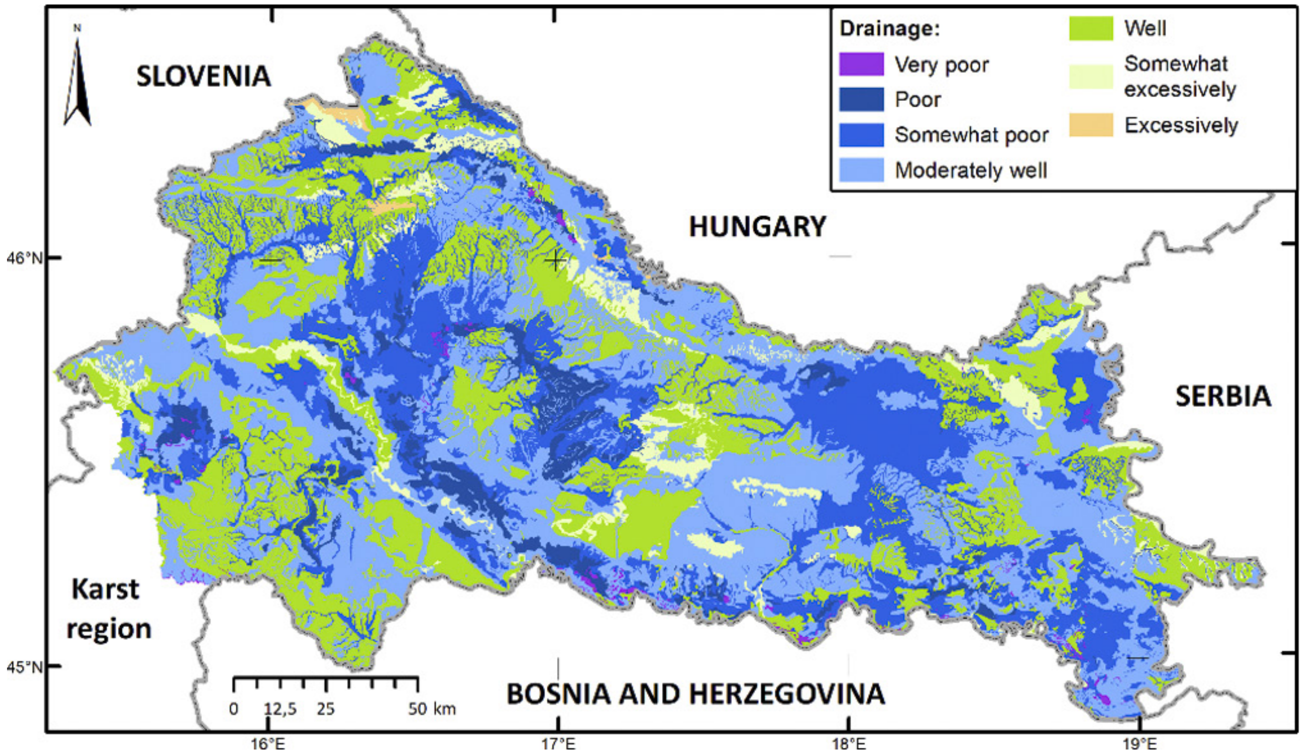

Figure 5: Map of soil drainage properties of PB in Croatia according to BPM

were corrected in the HTRS96/TM coordinate system. The main problem in the creation of a continuous pedological layer was the correction of the location, the establishment of correct topological relationships and the assignment of unique attributes for the database. The topological correction was made on 81 sheets with open-source GIS software *OpenJump* using the tool *Warp*. The database on the sheets (9) of the marginal areas was filled with the content of the Special Pedological Map of Croatia at a scale of 1:300,000 (**Bogunović et al., 1997**).

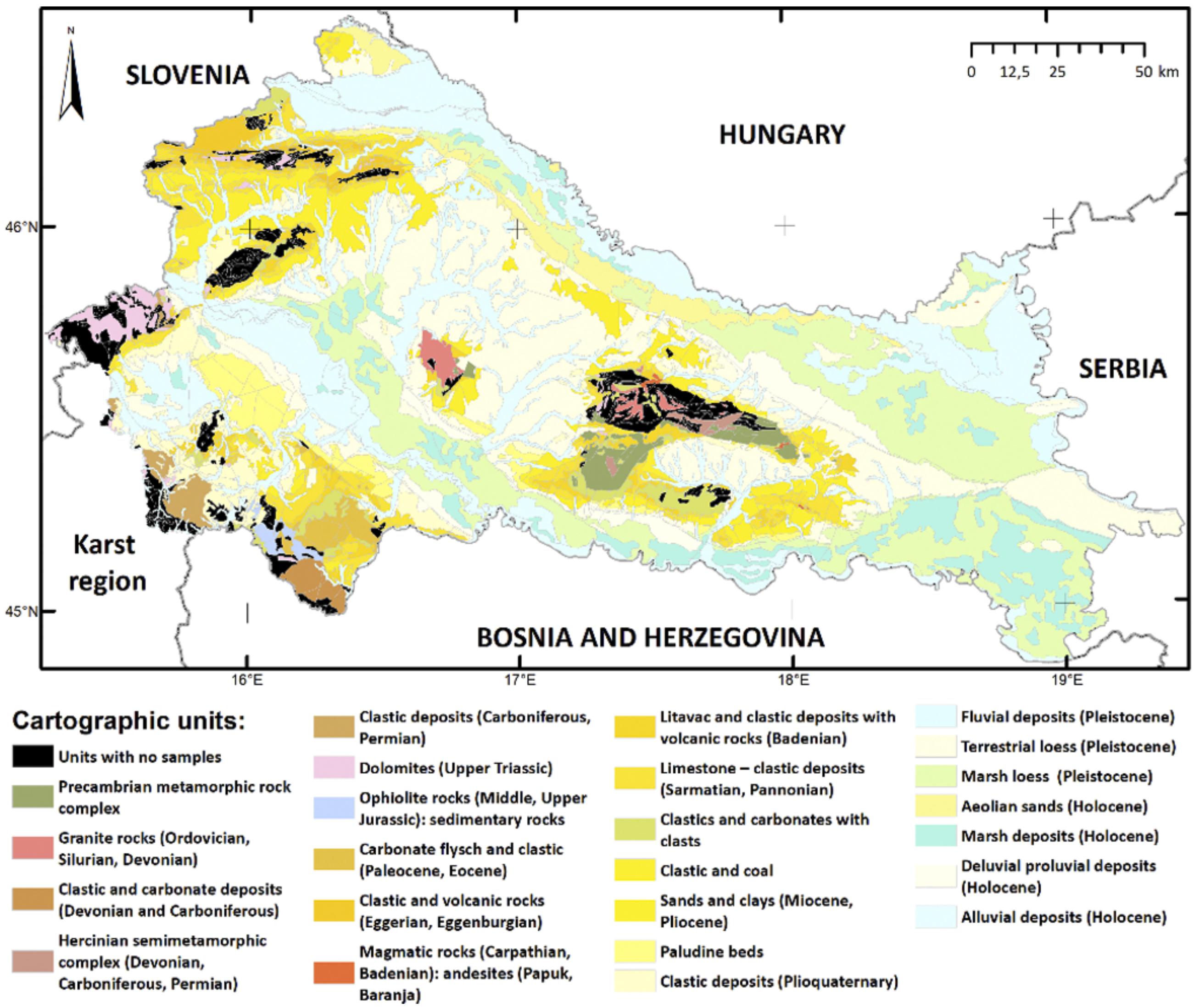

Figure 6: Map of geological units (based on **Velić and Vlahović, 2009**)

A detailed description of the actual implementation of the topology correction and part of the attributes can be found in **Bogunović and Rapaić (1993)** and **Heštera et al. (2019)**. All map units that had been qualified as man-made soils were classified as original type of soil before anthropogenic influence. For the purposes of this investigation, the names of the originally mapped units were standardized according to the proposal of **Husnjak (2014)** in the World Reference Base of Soils (see **Figure 4**). **Figure 4** presents only dominant BSM units (14), because the presentation of dominant and associated soil units (62) of BSM would be unreadable. Data on soil drainage conditions were taken from the BPM data (see **Figure 5**).

The part of BSM related to Posavina's maps (**Kovačević et al., 1972**) includes six drainage categories, in contrast to map sheets that have seven categories, which is why the category with the lowest drainage level was skipped during data structuring. Data on some other soil properties (e.g. organic matter content) could not be retrieved because the data were inconsistent or unavailable. The GM at a scale of 1:300,000, prepared based on the data of the basic geological map at a scale of 1:100,000, served as a reference layer for the geological characteristics of the study area (**Velić and Vlahović, 2009**).

The Digital Elevation Model (DEM) at the spatial resolution of 25 m, derived from the data CRONO GIP project was used to delineate catchment areas (see **Figure 7**). The procedure included ArcGIS Pro 2.9.1 tolls: *Fill*, *Flow Direction* and *Basin*. Automatically derived raw data was hand-corrected based on data from the Topographic map of Croatia at a scale of 1:25,000[1].

2.3. Methods

The research process was conducted in two parts. The first part is related to the possibility of transferring the

[1] Source: https://geoportal.dgu.hr/services/tk/wms

Figure 7: Map of catchment areas of PB in Croatia

results of existing data obtained by previous sampling based on profiles classified by the ISSS method into the USCS, with the aim of transferring the results to the mapped units of BSM. The second part of the research is related to the establishment of correlations between the existing data layers (pedology, geology, hydrology, geomorphology, etc.) and the available information on soil type from the USCS profiles.

The methods used in the classification of available data on soil profiles for the classification according to the ISSS method were described by **Heštera (2020)**, where the grain size boundaries were defined as shown in **Figure 2** and the classification was done on the basis of the ISSS triangle (see **Figure 3**) according to **Moeys (2018)** in R software. The sampling method, laboratory methods and the number of samples - profiles, i.e. the sampling density q was determined according to the results by **Heštera (2020)**. The average coverage of USCS samples was 1 sample per 70 km^2. The sampling locations were determined based on the following criteria and constraints:

- The proportion of the area covered by the BSM cartographic unit was determined proportionally by the number of samples. Cartographic units covering less than ≈ 0.2% of the total area were not included in the analysis due to the limited number of available samples.
- The sampling locations according to USCS within each mapped BSM unit were defined by previous sampling locations during the BSM creation. The GPS device was used to locate previous sampling locations.
- Areas located near military training areas were preferred for the purpose of future surveys.

USCS samples covered 99.9% of the area of the BSM dominant soil type map unit (14), or 94.4% of the area when map units were divided into dominant and associated types (62). The coverage of the samples on geologic map units (24) was 95.6% of the total area. Both the drainage (7 units) and catchment area (19 units) layers cover 100% of the studied area.

While conducting the spatial analyses, regularities and anomalies in the distribution and occurrence of USCS soil groups in certain areas were identified. For example, a particular soil type according to the BSM that spanned the entire study area had different soil groups according to the USCS, but after including the watershed, the results would become unambiguous. Since categorical variables were involved, it was necessary to numerically describe the mutual relationships between the analysed layers. The following layers were used to build the model: cartographic units of predominant BSM soil types (see **Figure 4**), followed by a more detailed subdivision into several BSM categories comprising the predominant soil type and associated soils, then the soil drainage properties (see **Figure 5**) catchment areas (see **Figure 7**) and map units of GM (see **Figure 6**). The analysis also included the relative importance analysis through multinomial logistic regression to determine how well the used layers describe the USCS variable. The calculation was performed with the R software packages *nnet* (**Venables and Ripley, 2002**) and *domir* (**Luchman, 2022**).

The obtained results of the model pseudo-R^2 were standardized for each parameter (**Luchman, 2014; McFadden, 1977**) and used for mapping. Pseudo- R^2 is used in logistic or multinomial regression models, like R^2 in linear regression. The difference lies in its interpretation – the values of pseudo- R^2 tend to be considerably lower than those of the R^2 index and should not be judged by the standards for a "good fit" in ordinary regression analysis. For example, values of 0.2 to 0.4 for pseudo- R^2 represent an excellent fit (**McFadden, 1977**). The mapping was performed with ArcGIS Pro 2.9.1, automating the processes with the ModelBuilder visual programming language. The creation of the map included the following steps:

The analysis was performed separately for two basic parameters on 414 profiles: Liquid Limit (LL) and Plasticity Index (PI), which define the USCS fine-grained soils classification group. This part of the analysis is based on the results of **Dumbleton and West (1966)** and **Skempton (1953)**, who confirmed that there is a correlation between the plasticity index, liquid limit and clay mineral content in natural soils as well as artificial mixtures. The IDW analysis was performed for each of the four layers (pedology - dominant and associated unit, geology, drainage, and catchment area) at 50 m pixel size, within their unique categories with the corresponding number of profiles (minimum of 2). Polygons of a unique category within the layer also represented a mask during the raster analysis. A maximum of 12 nearest neighbouring points were used with the maximum distance of 70,000 m. The IDW power of 1 was applied because of large distances between the points, as suggested in **Robinson and Metternicht (2006)**. As for our case, it can be said that we were limited (in a good part of the cases) with a small number of points located in a relatively large space, and the mentioned relationship is inversely proportional to the weighting exponent (smaller space and more points - higher weighting exponent).

In this step, data from LL and PI were combined separately and a factor correction was applied according to the obtained standardized pseudo-R^2 values (see **Table 2**). Areas without data (BSM and/or geology) were assigned standardized values of the other present layers.

The final step included aggregation and classification of the results according to the USCS group applying the raster analysis on the LL and PI layers.

The IDW method (**Equations 1 and 2**) involves estimating unknown values based on the weighted average of nearby known values, with the weights inversely proportional to the distance from the unknown location to the known locations (**Isaaks and Srivastava, 1989; Li and Heap, 2011; Shepard, 1968**). The equation can be expressed as:

$$Z(u) = \frac{\sum_{i=1}^{n} wi(u) \cdot Zi}{\sum_{i=1}^{n} wi(u)} \tag{1}$$

Where:

Z(u) represents the estimated value at the unknown location *u*;

Zi represents the known value at location;

wi(u) represents the weight assigned to the known value *Zi* based on its distance to the unknown location *u*.

The weight *wi(u)* is calculated using the inverse of the distance between the unknown location and each known location. The weight function is expressed as:

$$wi(u) = \frac{1}{d(u,i)^p} \tag{2}$$

Where:

d(u,i) represents the Euclidean distance between the unknown location *u* and the known location *i*;

p is a parameter that determines the influence of distance on the weight.

The Deterministic IDW Interpolation Method was chosen primarily because of the small number of samples in the relatively large study area, and also because the spatial structure of the studied layers is predetermined by the layers used in the analysis. Due to the relatively small number of samples (**Radočaj et al., 2020**) and the absence of a spatially correlated distance between the samples, the kriging method was not selected, since research has shown both reliable and unreliable results in **Qin et al. (2021)**. The IDW method was used because when applied, the values do not exceed the maximum and minimum input values, i.e. the resulting values are within the corresponding input values.

3. Results

Laboratory analysis showed that all the individual samples are homogeneous according to the USCS group up to a depth of 50 cm. The results of the comparison of the analyzed samples at identical sites (308), in which possible correlations between ISSS and USCS were investigated, are presented in **Table 1**. The obtained results show that it is impossible to use the ISSS classification to predict USCS, i.e. a separate soil group (ISSS or USCS) cannot be uniquely assigned to a corresponding group in another soil classification. Therefore, the obtained results can be considered as preliminary, to be followed by further analysis on a larger number of samples, which is why the above approach was rejected as the basis for a possible mapping method.

The initial multinomial logistic regression analysis included the predominant map units of BPM, drainage, geologic units, and catchment areas. A USCS variable variability value of 0.537 pseudo-R^2 was obtained with this model for the USCS variable. Further analysis, i.e. including the present BPM soil type in the association, resulted in an increase in the coefficient of 0.12 meaning that more detailed information on soil types resulted in a value of 0.666 (see **Table 2**).

From **Table 2,** the most important variable are the soil type properties (pedology), followed by catchment area and geology in order of importance, while drainage properties contribute least to the accuracy of the model.

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Table 1: Matrix of investigated samples classified according to the USCS and ISSS soil classification

ISSS classification	**USCS**						**Total**
	High plasticity clay (CH)	**Low plasticity clay (CL)**	**High plasticity silt (MH)**	**Low plasticity silt (ML)**	**Low plasticity clay/silt (CL/ML)**	**Poorly graded sand – Silty sands (SP-SM)**	
Heavy Clay (**HCl**)	11	6	13	2			**32**
Light Clay (**LCl**)	25	49	34	10			**118**
Clay Loam (**ClLo**)	3	53	7	32			**95**
Loam (**Lo**)		2		7		1	**10**
Loamy Sand (**LoSa**)					1		**1**
Sandy Clay Loam (**SaClLo**)	5	6	2	9			**22**
Sandy Loam (**SaLo**)		4		7			**11**
Silty Clay (**SiCl**)	2	5	4	5			**16**
Silty Loam (**SiLo**)		1		2			3
Total	46	126	60	74	1	1	308

Dominance analysis has been established as a tool to identify the relative importance of nonnumerical predictors. Data with a higher pseudo-R^2 coefficient (0.666) were included in the IDW spatial analysis, although this excluded 5.5% of the area compared to possibly performing analysis with only the dominant member (pseudo-R^2 coefficient 0.537). It must be noted that »*pseudo-R^2 index values tend to be considerably lower than those of the R^2 index and should not be judged by the standards for a "good fit" in ordinary regression analysis. For example, values of 0.2 to 0.4 for p^2 represent an excellent fit*.« (**McFadden, 1977, p. 35**).

The final result of this investigation - the soil map according to the USCS (see **Figure 8**) shows that the entire area of PB in Croatia can be described as an area covered by the fine-grained soil group according to the USCS. One SP/SM sample was excluded from the analysis because there were 3 other CL samples on the same map unit. Laboratory analysis and data from the available literature showed that it was not necessary to separate the profile layers according to the USCS up to 50 cm of depth. The reason for this is that the samples were taken almost exclusively on agricultural land, which was mixed by mechanical tillage to a depth of 50 cm over time. Some regularities were observed in the arrangement and distribution in terms of particle size. In the western parts of the study area almost exclusively silts (MH and ML) can be found, while towards the east they were less represented or completely absent. The reason for such an arrangement is primarily due to the general flow direction of the watercourse towards the east, which is why larger soil particles accumulate in the upper parts of the watercourse, while smaller clay particles are further flushed to the lower parts of the watercourse.

Another reason for this distribution is the fact that a large part of the parent substrate from which the soil formed in PB in Croatia is of aeolian origin, where the soil was brought from the Alps after the Ice Age, so that the lighter (smaller) particles were transported eastward by the prevailing north and northwest winds (**Zaninović et al., 2008**). Granulometric zonation from east to west is also related to the different climatic and relief conditions both during the Pleistocene and at present. These conditions are primarily related to the greater relief dynamics and moisture in the western part of PB in Croatia, which causes more intense processes of destruction and, consequently, greater compaction and increased content of clayey fraction within loess-like deposits. The eastern parts are drier and have much less vertical dissection of the relief, and the accumulation and development of the mostly typical loess deposits prevails (**Bognar, 1978**). The next reason for this situation are the higher precipitation amounts in the west, with the influence of continentality leading to a decrease in the amount of precipitation towards the east and thus to a lower leaching of the smallest particles in the eastern parts of the studied area (**Zaninović et al., 2008**). The areas where clay materials (CH) can be found are mainly located along the valleys of the middle and lower course of the Sava River and in the larger basins of the lowlands,

Table 2: Results of relative importance analysis of parameters included in the model

Model parameter	**General Dominance (pseudo-R^2)**	**Standardized value (%)**	**Overall rank of importance**
Pedology - dominant and associated unit	0.314	47.12	1
Catchment area	0.181	27.21	2
Geology	0.118	17.67	3
Drainage	0.053	8.00	4
∑	**0.666**	100.00	

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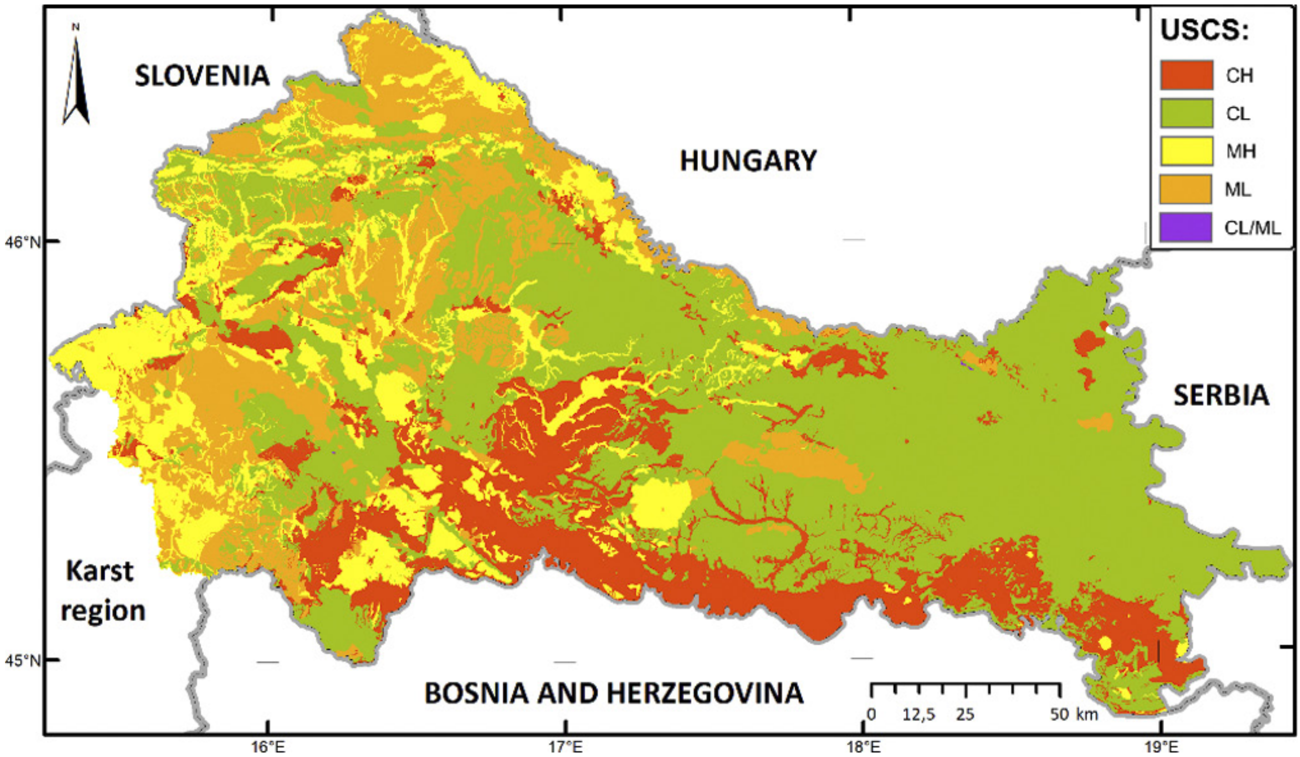

Figure 8: Map of USCS groups of PB in Croatia

where the conditions for sediment accumulation are more favourable.

4. Conclusions

In the attempt to map PB in Croatia according to the USCS, only one of the two applied methods proved successful. In the first method the analysis showed that it is impossible to use granulometric subdivision according to ISSS for the purposes of modelling data transformation in USCS for the territory of PB in Croatia. The reasons for that were found in the more complex division of soil groups for engineering purposes within the USCS classification system compared to the simplicity of textural classification systems, and consequently in the limited availability of databases using the USCS system in comparison to the large availability of databases using other systems in soil science and agriculture. Further investigation with the same method is needed, but with a larger number of samples to make a final judgement about the applicability of this method.

In the implementation of the first and second method, the main problem was the unstructured pedological database that had to be topologically and attributively corrected and unified. In the second method the results showed that a higher quality and more detailed structuring of the parameters lead to better results (there is an increase of the pseudo-R^2 coefficient from 0.537 to 0.666). The result of the pseudo-R^2 coefficient of 0.666 proves that there is a statistically significant correlation between the used categorical-non-numerical parameters in the model. The mapped soil units (in conjunction with the associated soil type) contribute to the final USCS classification with 47.12% and allow the physical properties of the soil to be mapped with a sufficient level of detail to unambiguously describe the USCS properties of the uniform area. Apart from the BSM, the second most important contribution (27.12%) is the catchment area, where a number of geomorphological, geological and climatic processes form a unique unit that can be used to define the USCS soil group (with the exception of the Sava and Drava rivers due to their length). The contribution of GM with 17.67% and drainage with 8% can be considered as parameters that improve the accuracy of the model, but as separate layers they are not sufficient to define the USCS group. A greater amount of data on some other soil properties would certainly lead to better results, as described in **Gambill et al. (2016)**.

The IDW method potentiates the mapping of the whole area with a low number of samples, even if some parts of the study area are not covered by profiles on the particular geological and pedological units. If the original sampling of soils from the described territory had been carried out according to the USCS classification, different results would have been achieved than by using the IDW method. There are a few areas represented on the map (with large distances between sample points) that are in a circular shape, which is not natural. Such cases show a disadvantage of the IDW method, which can be improved in further investigations with higher sample density.

The resulting map is suitable for further analysis at the regional and national level, while it is unsuitable, or

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can only be used with restraint for local research (scales smaller than 1:50,000), i.e. additional soil sampling would be required for micro locations. With the obtained results, a base layer connected to the USCS was created, which will allow further studies on the trafficability of the soil for vehicles at all reference soil layer depths of 0-15 cm, 15-30 cm and 30-45 cm in PB in Croatia. Determination of soil USCS groups will allow the use of a large amount of previous research (**ITL-93-1, 1993**), which defined the ranges of various numerical factors of soil properties that affect vehicle mobility.

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SAŽETAK

Kartiranje tala panonskog dijela Hrvatske prema *Unified Soil Classification System* upotrebom multinomne logističke regresije i interpolacije inverzijom udaljenosti

Unified Soil Classification System (USCS) osnova je brojnih metoda za istraživanje prohodnosti tla za vozila. Budući da podatci o USCS-u nisu uvijek dostupni, koriste se razni drugi izvori i metode za korelaciju i predviđanje USCS grupe tla. U ovome radu opisane su dvije metode korištene u svrhu kartiranja hrvatskog dijela panonskog bazena prema USCS-u do dubine tla od 50 cm. U prvoj metodi ispitana je mogućnost prijenosa 308 uzoraka tla prema sustavu klasifikacije *International Soil Science Society* (ISSS) u USCS. Rezultati su pokazali da nije moguće izravno transformirati podatke ISSS klasifikacije u USCS. U drugoj metodi korišteno je 414 USCS profila u analizi težišnih faktora u prostornoj analizi s ponderiranjem obrnute udaljenosti. Analizom su obuhvaćeni slojevi dominantnih i asocijativnih jedinica tala Osnovne pedološke karte Hrvatske (BSM), Osnovne geološke karte Hrvatske (GM), dreniranost tla i slivna područja. Dobivene ponderirane težine bile su: BSM 47,12 %, slivno područje 27,12 %, GM 17,67 % i dreniranost tla 8 %. Rezultati su pokazali da je panonski dio Hrvatske prekriven sitnozrnatim tlima, pri čemu je glinom prekriveno gotovo cijelo područje, dok prahovi dominiraju u zapadnim i sjeverozapadnim dijelovima panonskog bazena Hrvatske.

Ključne riječi:
USCS, ISSS, tla Hrvatske, terenska prohodnost vozila

Author's contribution

Hrvoje Heštera (1) (PhD, expert for GIS, cartography and military geography) designed the original idea, methodology and research concept, conduct field work, performed data preparation, structuring, modelling and analysis. **Mladen Pahernik** (2) (Associate professor, expert for GIS and geomorphology) participated in the research concept, research methodology organisation and field work. **Biljana Kovačević Zelić** (3) (Professor, expert for soil mechanics) participated in the research concept and laboratory examinations of soil samples. **Maja Maurić Maljković** (4) (Associate professor, expert for animal genetics and statistics) conducted the Multinomial Logistic Regression analysis. The entire work was written collaboratively by all of the authors.