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SOIL DISTRIBUTION IN PČINJA RIVER BASIN, NORTH MACEDONIA AND ITS IMPORTANCE FOR AGRICULTURAL PRODUCTION

SUMMARY

This paper is a result of many years of field and laboratory research of the soils in Pčinja river basin, North Macedonia, spread out on 237.640,71 ha ranging from 191 to 1664 m above the sea level in order to gain a better understanding of the productive capacities of the soils and measures for their improvement. The catchment area of Pčinja River is a spatial area that extends in two states in the of the Republic of North Macedonia and the part of the Republic of Serbia, whose boundaries are naturally clearly defined. Soil samples were taken by spade and one composite sample was prepared for each sampling site, each containing about 3 kg of soil. Before sieving the samples were air dried. In laboratory, the following analyses have been carried out on the soil samples: hygroscopic moisture, mechanical composition, pH of the soil solution, humus content and total nitrogen, content of carbonates. The mechanical composition and chemical properties of the soils have been determined by standard methods. This area is very heterogeneous, with numerous relief forms, with different expositions and inclinations, and with great differences of altitude. Additionally, there are several geological formations of a very heterogeneous petrographic-mineralogical composition and climate-vegetation zones. Long-term effects of human involvement should also be noted. The vast diversity of the factors required for

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soil formation in this area is the reason for the formation of many different soil types as well as the lower taxonomic units. These types of soils are characterized by different properties (chemical, physical, and physical-mechanical, productive). Therefore, they have varied effects on agricultural production. There are 9 different soil types and 18 complexes of more than two land types distributed in the Pčinja River basin together with a considerable amount of subtypes, varieties and forms. The most represented with the largest area are: Vertisol, Fluvisol, Fluvisol (Colluvial Soils) and Cambisol.

Keywords: soil types, Pčinja River, agricultural production

INTRODUCTION

Soils in Pčinja river basin, North Macedonia, spread out on 237.640,71 ha ranging from 191 to 1664 m above the sea level in order to gain a better understanding of the productive capacities of the soils and measures for their improvement. The catchment area of Pčinja River is a spatial area that extends in two states in the of the Republic of North Macedonia and the part of the Republic of Serbia, whose boundaries are naturally clearly defined.

River sediments is a mixture of inorganic and organic matters suspended by the river. Sediment yield is the total amount of sediment transported to the shore by the river in a given period of time. Erosion is the process by which soil, rocks, or other type of material are broken down into smaller fractions by natural causes (Davis & Reynolds, 2009). Every river carries fine sedimentary material with its flow. When the river's capacity to hold sediment is exceeded, the river accumulates sediment depo-sits. Such deposits occur on the riverbed and on both sites of the river (Bogen *et al.*, 2003).

The most common sediment deposits are river channel depo-sits, alluvial deposits, delta deposits, and river bank deposits. This area (Pčinja River basin) is very heterogeneous, with numerous relief forms, with different expositions and inclinations, and with great differences of altitude. Additionally, there are several geological formations of a very heterogeneous petrographic-mineralogical composition and climate-vegetation zones. Long-term effects from human involvement should also be noted. The vast diversity of the factors required for soil formation in this area is the reason for the formation of many different soil types as well as the lower taxonomic units.

The soils in the area also appear in the complexes that are presented on the soil (pedological) map. These types of soils are characterized by different properties (chemical, physical, and physical-mechanical, productive). Therefore, they have varied effects on agricultural production.In this paper are presented the main aspects of the soil geography. The agrotechnical and meliorative measures are determined based on the properties and processes of the various soil types found in this area with the goal of improving their productive capacity to further increase agricultural production (Markoski *et al*.,2018).

MATERIAL AND METHODS

Study area

The studied area is the water catchment area of the Pčinja river including the artificial lakes Glažnja and Lipkovsko Lake (Figure 1). This area is located in the northern part of North Macedonia including the city of Kumanovo. Figure 2 shows the satellite images of this area in the infrared (Figure a) and visible spectral range (Figure b), showing the mountainous part and valleys.

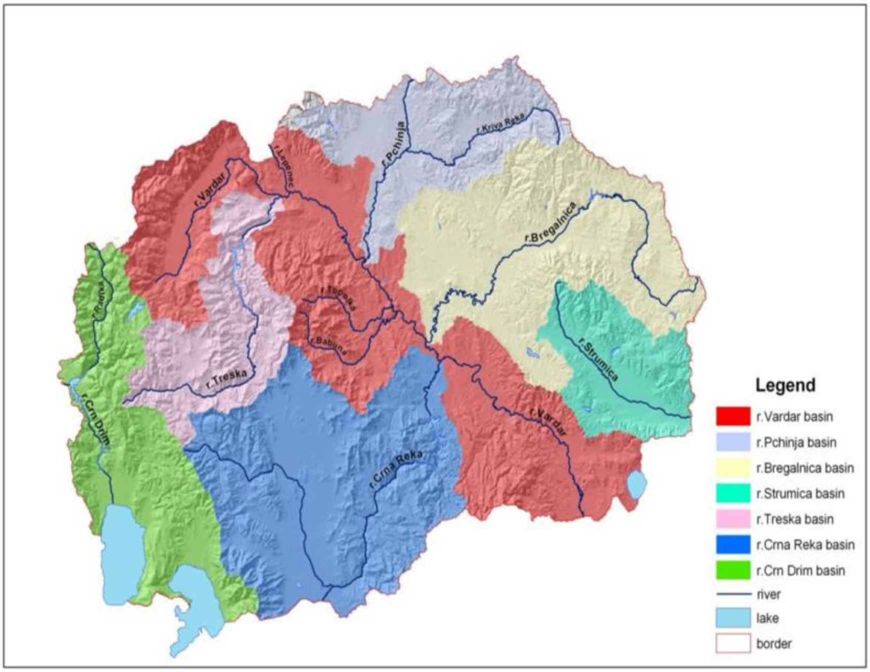

Figure 1. Location of the studied area on the map of North Macedonia

a) Legenda - Aspect (SRTM) b) Legenda – Landforms

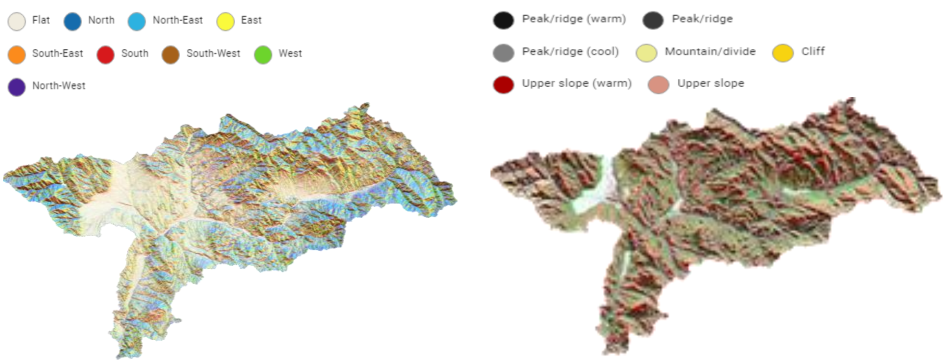

Figure. 2. Satellite image of the Pčinja river basin in the a) Aspect (SRTM) and b) Landforms of the Pčinja River (http://www.e-zemjodelstvo.mk/)

The vegetation of the region can be divided into shrubs and grass vegetation, natural pastures, heterogeneous agricultural lands, hilly meadows and forests (Figure 3). The mountain of Skopska Crna Gora consists mainly of cambisol soils with small areas containing lithosol and regosol. The most common soil in the studied region is vertisol, which is predominant in the central and eastern part of the region. In the southern part along the Pčinja river before its inflow into the Vardar river, the most common soil is the cambisol, as well as fluvial soil. Fluvial soil is observed along all rivers in the studied area (Filipovski *et al.*, 2015). Colluvial and lithosol soils are the least represented in this area.

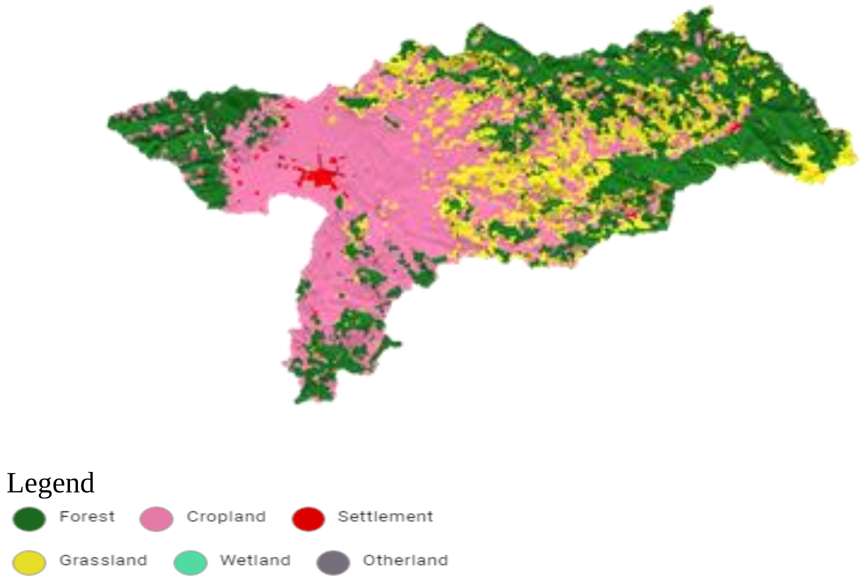

Figure. 3. Land-use map IPCC Land Use Classification - CCI/ESA of the Pčinja River (http://www.e-zemjodelstvo.mk/)

Climate characteristics

The area of the Kumanovo valley is open to the north, which allows unimpeded penetration of air masses from higher latitudes, which causes a decrease in air temperature during the winter months (Zikov, 1995), (Filipovski et al., 1996). For these reasons, the average annual temperature is 11.8°C. The warmest month is July with an average temperature of 22.3°C, and the coldest is January, with an average temperature of 0.4°C.

The average annual minimum temperature is 8.0°C, and the average monthly temperatures are below 0°C only in January and February. In summer, the warm continental air in this area provides quite high air temperatures.

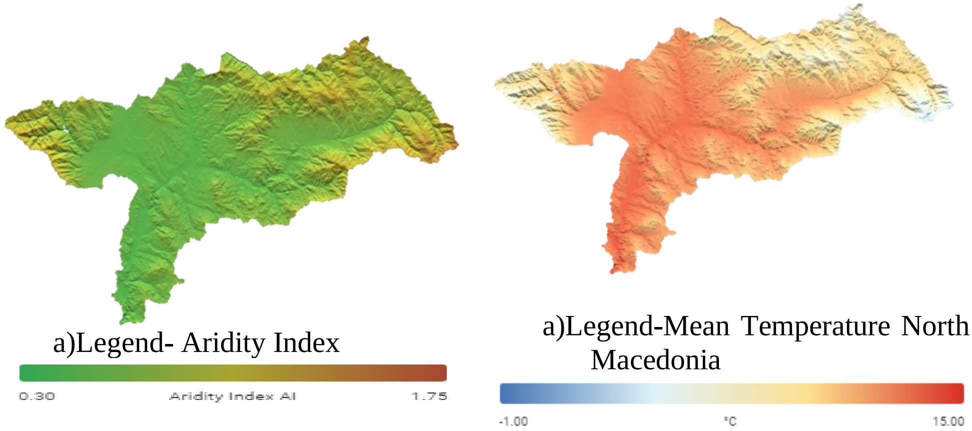

Figure. 4. a) Aridity Index and b) Mean Temperature of the Pčinja River (http://www.e-zemjodelstvo.mk/)

Basic hydrological characteristics

The most important hydrographic object in this area is the river of Pčinja and Kriva Rivers. Pčinja river it rises on the territory of Serbia, below the Bela Voda peak on the mountain of Dukat, at an altitude of 1664 metres. The river valley has a composite character. From the entrance to the Republic of Macedonia it passes through three gorges, between which there are shallow sections. It flows into Vardar in Taor gorge at an altitude of 191 m. The total length of the river is 135 km, with an average slope of 10.9%.

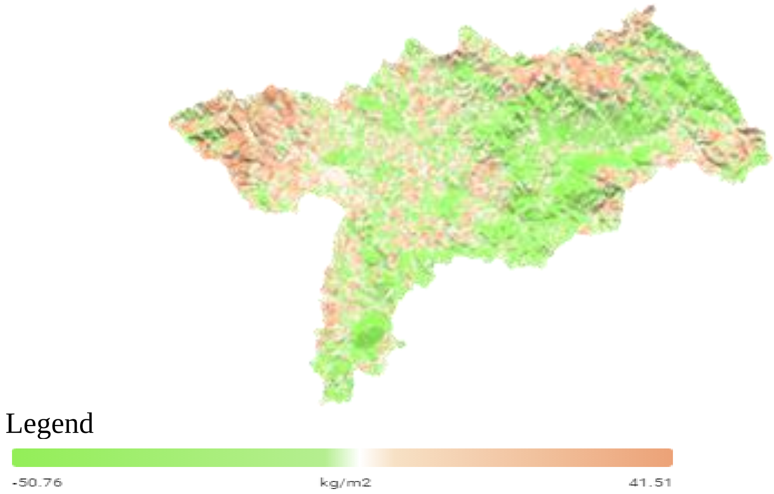

Figure. 5. Water Deficit (anomalies) – MODIS of the Pčinja River (http://www.e-zemjodelstvo.mk/)

Sampling

The filed research of the soils has been done according to methods described by (Markoski *et al*., 2020). In laboratory, the following analyses have been carried out on the soil samples: hygroscopic moisture; mechanical composition; pH of the soil solution; humus content and total nitrogen; content of carbonates; content of CaCO3; Cation exchange capacity (CEC). The mechanical composition and chemical properties of the soils have been determined by standard methods described by (Bogdanović *et al*., 1966), (Mitrikeski & Mitkova, 2013); (Džamić *et al*.,1996).

RESULTS AND DISCUSSION

The formation, the distribution and the soil properties in this area are in close correlation with the environmental conditions, i.e. the soil genesis conditions, such as the geographical position and the relief, the hydrography, the parent material, the climate, the vegetation, the time period and the human factor. The soil (pedologic) map, figure 6; with Table 1 on the distribution of the soil types, differentiates the following properties in the geography of soils.

Figure. 6. Soil map - Soil types and complexes distribution in the catchment area of the of the Pčinja River (http://www.maksoil.ukim.mk/masis/)

Table 1. Soil types and complexes distribution in the catchment area of the of Pčinja River (ha)

SOIL TYPES AND COMPLEXES (WRB Soil Classification)	Symbol	Ha
I. SOILS OF THE PLAINS		
1. Fluvisol	J	9824.06
2. Gleysol	G	153.77
Total		**9977.83**
II. SOILS OF COLLUVIAL FANS		
1. Fluvisol (Colluvial Soils)	K	**4110.22**
III. SOILS OF LAKE TERRACES AND OF UNDULATED HILLY RELIEF		
1. Regosol	R	9885.78
2. Complex of Regosol and Leptosol	R/E	3107.1
3. Vertisol, Chromic Luvisol on saprolite, Regosol	V/Lc/R	7222.17
4. Complex of Humic Calcaric Regosol, Regosol and Vertisol	Rz/R/E	934.36
5. Vertisol, Humic Calcaric Regosol	V/Rz	11888.4
6. Chromic Luvisol on saprolite	Lc	6202.23
7. Complex of Chromic Luvisol on saprolite, Regosol, Humic Calcaric Regosol, Vertisol	Lc/R/ Rz/V	7816.43
8. Regosol, Vertisol	R/V	3521.22
9. Vertisol	V	26615.26
10. Albic Luvisol Chromic Luvisol on saprolite	La/Lc	84.59
11. Regosol, Vertisol, Leptosol	R/V/E	19436.55
12. Chromic Luvisol on saprolite, Vertisol	Lc/V	5022.2
13. Chromic Luvisol on saprolite, Regosol	Lc/R	5374.55
Total		**111221.06**
IV. MOUNTAIN SOILS		
1. Leptosol	E	1838.22
2. Complex of Cambisol and Regosol	B/R	14644.59
3. Cambisol	B	29356.01
4. Humic Eutric and Umbric Regosol	Lm	10757
5. Humic Eutric and Umbric Regosol, Regosol	Lm/R	288.16
6. Cambisol, Leptosol, Regosol	B/E/R	22986.88
7. Cambisol, Humic Eutric and Umbric Regosol	B/Lm	14381.53
8. Cambisol, Humic Eutric and Umbric Regosol, Regosol	B/Lm/R	134.9
9. Cambisol, Leptosol	B/E	7556.35
10. Cambisol, Leptosol Humic Eutric and Umbric Regosol	B/E/Lm	11815.39
11. Rendzic Leptosols, Chromic Leptic Luvisol on hard limestones	Eh/Lvd	611.72
Total		**114370.75**
1.Urbisol	Urb	**2071.07**
Total area of this region		**237640.71**

The vast diversity of the factors required for soil formation in this area is the reason for the formation of many different soil types as well as the lower taxonomic units. These types of soils are characterized by different properties (chemical, physical, and physical-mechanical, productive). Therefore, they have varied effects on agricultural production. There are 9 different soil types and 18 complexes of more than two land types distributed in the Pčinja River basin together with a considerable amount of subtypes, varieties and forms. The most represented with the largest area are: Vertisol, Fluvisol, Fluvisol (Colluvial Soils) and Cambisol. The papers of Filipovski (2015); (WRB, 2014) address these conditions in details. Table 1 contains data on the soil types and complexes distribution according to the relief forms in the catchment area of the Pčinja river in ha. It can be seen from the Table that the soils spread on lake terraces and of undulated hilly relief dominate in the catchment area and cover an area of 111221.06 ha, followed by the soils spread on mountainous terrains with 114370.75ha. The soils on plains and sloping terrains (colluvial soil) cover small areas (9977.83 ha, and 4110.22 ha).

The erosion processes, i.e. the human factor are strongly reflected in the geography of the soils in the area. The area of soils that occurred from erosion processes (Leptosols, Regosols, Fluvisols-Colluvial Soils and their complexes) is more than 25% of all areas and unfortunately, the spreading process for these areas is still active, (Markoski *et al.*, 2018).

The individual terrain forms differ from each other by their terrain, geological structure, their climate – vegetation and hydrographic conditions and by the degree of anthropogenization. This is reflected on the geography of soils and their properties, as well as on the degree of their utilization and the measures that need to be undertaken in the agricultural production of the area, (Markoski *et al*., 2020); (Mitkova *et al*., 2017).

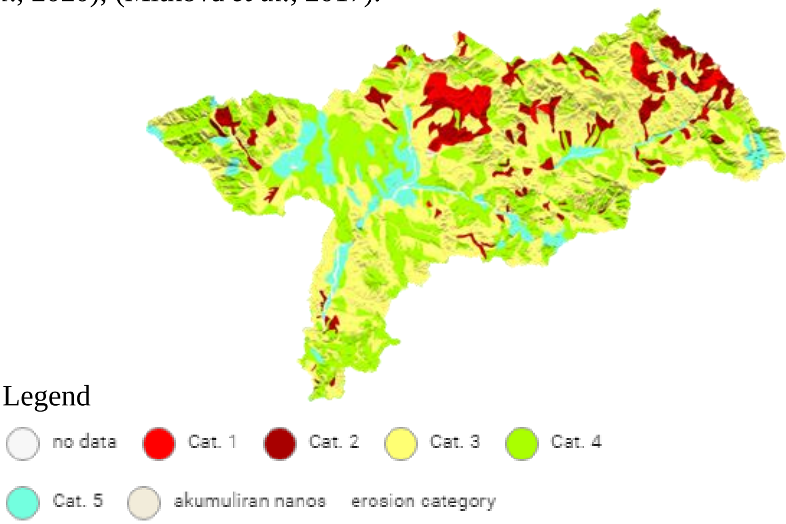

Figure. 7. Soil erosion of the Pčinja River (http://www.e-zemjodelstvo.mk/)

The following graphs model soil properties such as pH, texture, calcium carbonate, organic matter, soil depth and CEC. The data are obtained from all previously obtained data from analyzed soil properties. Similar data for such models can be found in the researches of (Markoski *et al*., 2015), (Markoski *et al.*, 2022).

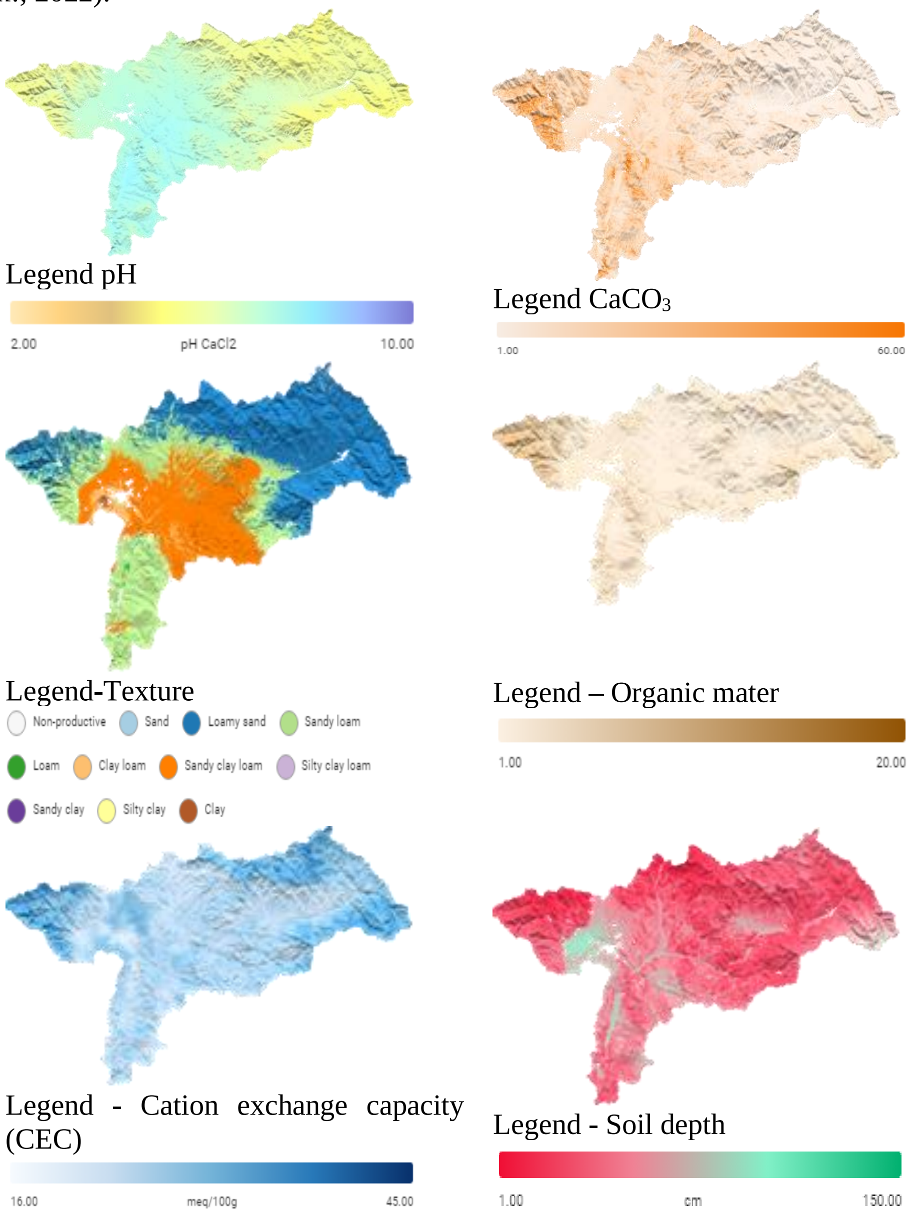

Figure 8. Model soil properties of the Pčinja River (http://www.e-zemjodelstvo.mk/)

Soil significance according to relief forms for agricultural production in the area. The properties (mechanical composition and chemical properties) of individual soils formed in the area are described in detail in the papers of (Markoski, M, *et al*., 2015); (Filipovski 2015). Here, together and according to relief forms, we will explain their significance for agricultural production in the area, the measures for improving their productive ability will be explained in the conclusions. Crop suitability layers were prepared based on this crop information by reclassifying and overlaying for each of the crops Tabel 2. The final layers are masked out by using forest (natural vegetation tree dominated area.

Table 2. Optimal crops norms conditions.

CROP	**Temperature max Jume (°C)**	**Soil depth (m)**	**Soil pH**	**Soil texture**	**LGP Spring**	**Aridity index (rainfall and ETo) April-June**
Wheat	23-27	>0.9	6.0-8.2	Sandy loam silty clay loam	>100	>0.5
Corn	24-28	>0.75	5.8-7.8	Sandy loam silty clay loam	>120	>0.5
Barley	18-24	>0.5	6.2-8.0	Sandy loam silty clay loam	>100	>0.5
Sunflower	18-26	>0.8	6.2-8.0	Sandy clay loam to clay	>140	>0.5
Potato	24-28	>0.6	5.0-6.7	Sandy loam to silty clay loam	>120	>0.5
Alfalfa	25-32	>0.7	6.0-8.0	Loamy sand to silty clay loam	>150	>0.5

By matching the optimal crop norm condition given in the table, the most suitable areas for production of the crops were developed as seen in the maps that follow. The delineation of the agro-ecological zones was made by combining agro-edaphic constraints with the five agro-climatic zones delineated in the country. In the process of delineating the agro-ecological zones, all agro-edaphic and biophysical constraints of the country in terms of limiting the agriculture productivity were considered, analyzed and mapped. Each of the constraints and their thresholds based on country dynamics intensity. All considered layers were reclassified and overlaid. Finally, agro-ecological zones, which give the information about the combination of similar limitations and potentials, were found out by overlaying the agro-climatic zones and agro-edaphic constraints layers.

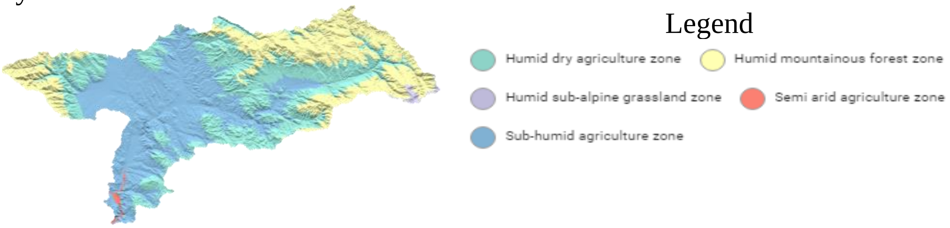

Figure. 9. Agro-Climatic Zones of the Pčinja River (http://www.e-zemjodelstvo.mk/)

Based on the agro-climatic zones, soil conditions (pH, texture, organic matter, carbonates, CEC), irrigation conditions and other data, graphical data are given for the conditions of cultivation of some crops in this catchment area. According to the models, it can be seen on which areas the best yield results from agricultural plants would be achieved.

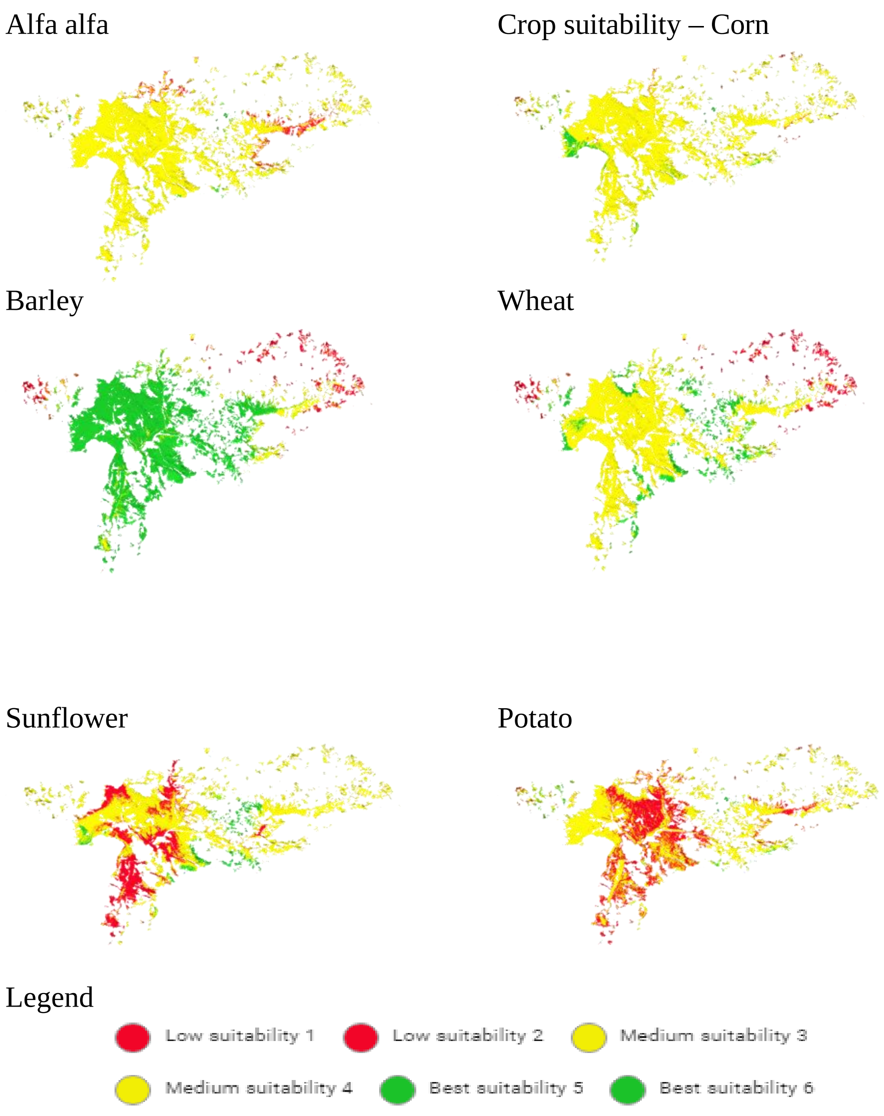

Figure. 9. Crop suitability of the Pčinja River (http://www.e-zemjodelstvo.mk/)

In mountain reliefs, part of the Humic Eutric and Umbric Regosols is under summer pastures, a smaller part under forests, and a small part is cultivated. Fields are mostly abandoned, and some produce potato and seed material for it, then rye and oats, and at lower altitudes some fruit trees are cultivated. As for the use of Cambisols, it can be said that they have the greatest significance for forestry, because they produce and then exploit most of the wood mass in our country. By deforestation some of these soils are converted into pastures or into now abandoned fields. A very small part is cultivated, used as fields, and a smaller part as pastures. Potatoes are most commonly cultivated field crops, some forage field crops can be successfully grown, as well as crops for green fertilization. Some of these soils can be successfully turned into artificial grasslands. Several fruit crops can be successfully grown (chestnut, walnut, plums, apples, pears, raspberries, blackberries, ribes).

Among the soils formed on lake terraces and of undulated hilly relief, Chernozems, Vertisols and Humic Calcaric Regosols are characterized by greater productivity in comparison with Regosols, Chromic Luvisols on saprolite and Albic Luvisols. Depending on the conditions for irrigation these soils have heterogeneous use. Field crops, vegetable crops, forage crops, industrial crops, vineyards, orchards are cultivated on them.

Fluvisols (Colluvial Soils) are significantly less productive than Fluvisols (with which they border. They are less sorted, do not have a flat relief, have higher impact from drought, contain less nutrients, do not supply water from groundwater.

In the plain terrains of the area, Fluvisols are of the greatest significance for agricultural production. This is due to the favorable physical and chemical properties, the deep solum, the provided conditions for irrigation and the presence of available forms of P2O5 and K2O. They provide relatively high yields of all agricultural crops. Mollic Vertic Gleysol and Gleysols are potentially fertile. The former have good chemical properties, but poor physical properties, and the latter have relatively good properties, but have shallow underground waters, occasional floods at some sites, anaerobic conditions and due to this, poor nitrification.

CONCLUSIONS

There are 9 different soil types and 18 complexes distributed in the Pčinja River basin together with a considerable amount of subtypes, varieties and forms. They are formed on four relief forms (plain terrains, sloping terrains, mountain terrains and undulating-hilly terrains and lake terraces) that have different significance for agricultural production. In order to increase their productive ability, the following joint measures should be undertaken according to relief forms:

- Joint measures for soils from mountain terrains: (protection from erosion, fertilization with organic and mineral fertilizers, proper tillage, liming if necessary);

- Joint measures for soils from lake terraces and undulating-hilly terrains: (deep tillage, humization: organic fertilizers and phytomeliorations, intensive use of mineral fertilizers N and P2O5, and for plants that need potassium during the entire year and for obtaining much higher yields and K-fertilizers, anti-erosion measures, proper irrigation method);

- Joint measures for soils from sloping terrains: (anti-erosion protection measures, irrigation, humization, intensive use of mineral fertilizers);

- Joint measures for soils from plain terrains: (regulation of the water regimen, lowering of the level of underground water-drainage, tillage and creating a deep fallow, fertilization with mineral and organic fertilizers with previous soil fertility control, proper irrigation).

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