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AGRICULTURAL DYNAMICS OF BLED MICROREGION (SLOVENIA)

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Abstract

The study examines Early Medieval agricultural land use in the Bled microregion of Slovenia using LiDAR data combined with archaeological, geological, and soil data. The research employs LiDAR-derived digital elevation models to analyse landscape variables influencing land use. Four geomorphological zones were identified, demonstrating that Early Medieval settlements predominantly occupied areas with moderately steep slopes and soils with high capacity to retain water. The results indicate a preference for agricultural settlements with limited diversification. This approach highlights the utility of LiDAR in archaeological landscape analysis and underscores the potential of integrating open-access environmental data with traditional archaeological methods.

Keywords: airborne LiDAR, airborne laser scanning, GIS analysis, Early Medieval archaeology, geoarchaeology

1. INTRODUCTION[1]

This chapter presents an innovative approach to using LiDAR data as a means of discovering, documenting, and interpreting agricultural land use systems (Lozić 2024 in this volume). We searched for variables – significant environmental differences within the landscape – that have influenced land use. In doing so, we combined information from LiDAR-derived digital elevation models (hereafter DEM) with archaeological, geological, and soil data. Whereas this study shared the approach with the previous chapter (Lozić, Koch 2024 in this volume), the specific methods used were different.

The aim was to demonstrate the Early Medieval land use system in the Bled (Slovenia) microregion. The Bled microregion is uniquely suited for such research due to the simultaneous availability of high quality archaeological and historical records for the Early Medieval period as well as LiDAR data, which is a rare combination in the region (*Figs. 1, 2*).

2. MATERIALS, METHODS AND RESULTS

2.1. ARCHAEOLOGICAL CONTEXT OF THE BLED MICROREGION

The Bled microregion (80 km^2) is located in the northwest of Slovenia, in the subalpine area of Julian Alps. The microregion is bounded by the confluence of the rivers Sava Bohinjka and Sava Dolinka in the east, and by the high mountain plateaus of Pokljuka and Mežakla in the west and north (*Fig.* 3). The area is notable for its intensive fluvio-glacial geomorphology. The archaeological significance of this microregion lies in the fact that it encompasses the entire territory of

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[1] This chapter is an abridged version of the previously published article by Lozić (2021). We have reproduced sections describing materials, methods and results as these are essential to the integrity and flow of this volume.

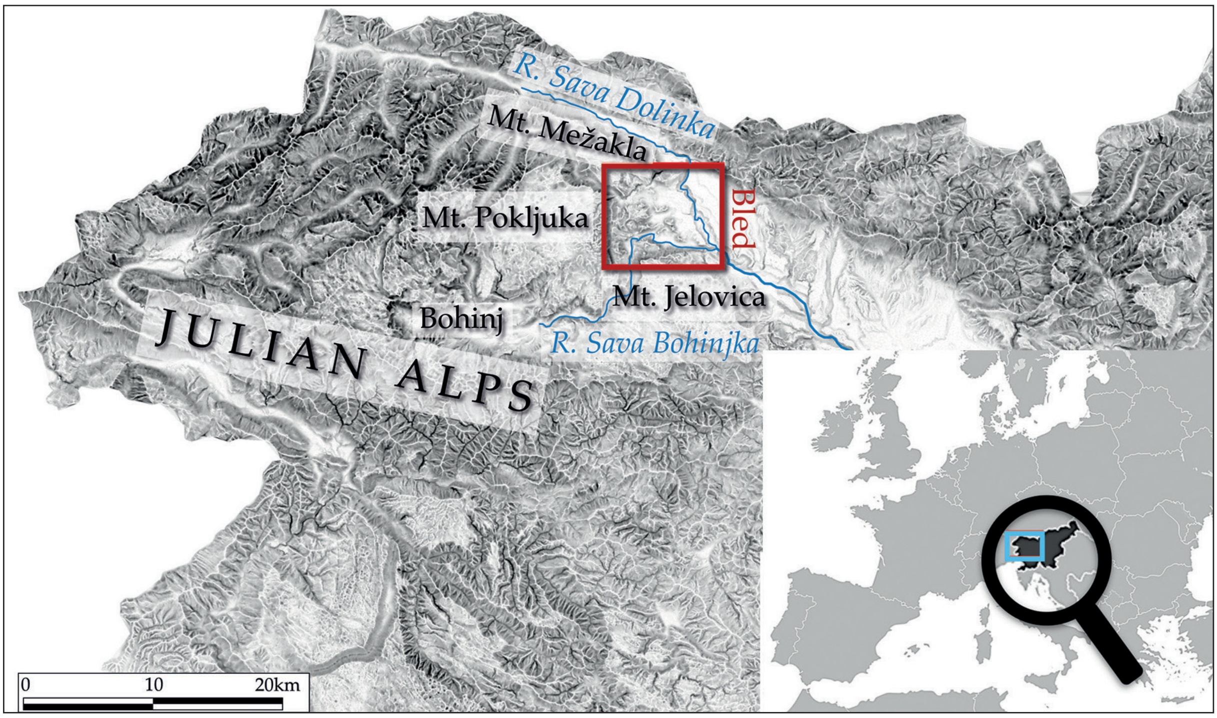

Fig. 1: Location of the study area with the most relevant topographic features mentioned in the text (decimal longitude and latitude coordinates of the map centre: 14.1949; 46.1168).

Fig. 2: Regional map of locations and sites mentioned in the comparative studies (decimal longitude and latitude coordinates of the map centre: 17.8173; 47.8235).

No.	Name	Type	Chronology	Zbiva ID
1	Pri Turku	Cemetery	750–970	10000779
2	Omruževa hiša	Settlement	790–1100	10002357
3	U hribeh	Hoard	820–820	10000981
4	Na Žalah	Cemetery	800–960	10000953
5	Pristavski grič	Communication	676–1100	10000950
6	Pristava at Bled	Communication	676–1100	10000770
7	Pristava at Bled	Cemetery	500–960	10003456
8	Pristava at Bled	Settlement	620–960	10003538
9	Grad (Bled Castle)	Settlement	780–1100	10002452
10	Sedlo on B. Castle	Cemetery	800–960	10000769
11	Sv. Martin in Bled	Cemetery	960–1100	10000801
12	Brdo	Cemetery	640–800	10000771
13	Bled Island	Cemetery	920–990	10000767
14	Bled Island	Church	1004–1100	10004042
15	Vadiše	Cemetery	700–870	10000774
16	Dlesc	Cemetery	820–960	10000911
17	Došca	Cemetery	769–901	10003275

Table 1: Early Medieval sites in the Bled microregion; numbering refers to *Fig. 3*. The year 1100 indicates an arbitrary end of the Early Medieval period, but the site in question continues to exist after this date (source: Pleterski 2016).

župa, which was the smallest administrative entity of the Early Medieval Slavs (Pleterski 2013a; 2013b). Bled has long been the focus of both archaeological and historical research and from the point of view of Early Medieval archaeology, it is the best researched microregion in Slovenia. Since the 1880s, and most intensively in the 1970s and 1980s, 17 noteworthy Early Medieval archaeological sites have been documented by archaeological excavations (Kastelic 1960; Kastelic, Škerlj 1950; Knific 2004a; 2004b; 1983; Pleterski 2008a, 2008b;2010; 2013a; Pleterski, Belak 1995) (*Table 1; Fig. 3*).

Only one settlement in the Bled area has been fully excavated (Pristava at Bled) and further two (Grad and Omruževa hiša) have been confirmed by excavations, but the chronology of several others could be inferred from their respective cemeteries. Remaining settlements were dated by a date before provided in written sources or inferred indirectly from the landscape analysis and retrograde analysis of the historical cadastre (*Table 2; Fig. 3*). However, no detailed and systematic archaeobotanical research has been carried out in the Bled microregion to date, and there are no published palynological results dealing with the Early Medieval vegetation in this area yet. Similarly, extensive underwater archaeological investigations of the Lake Bled yielded minor Early Medieval finds (Gaspari 2008; Gaspari et al. 2022), but as yet no significant findings of relevance to this study. Similar can be said for the most recent analysis of the cemetery on the Bled island (Štular 2022).

Three decades have passed since the last comprehensive analysis of the Bled microregion, in which A. Pleterski combined archaeology, written sources, and retrograde analysis of historical cadastres (Pleterski 1986; 2013a). He reconstructed the arable areas, which occurred in small patches scattered in the valley plains (*Appendix: Map 1*). His key conclusions were that most settlements were continuously inhabited from the Early Medieval period to the present time; the economic model was dominated by agriculture, with little developed crafts (Pleterski 2008b). Therefore, each settlement was located adjacent to soils suitable for agriculture. Moreover, most settlements had a cemetery nearby. The validity of the original study was subsequently confirmed with archaeological excavations on three separate locations in Žale near Zasip (Knific, Pleterski 1993), Zasip and Došca (Modrijan 2020). Pleterski was therefore able to infer where and when the settlement took place with a great level of confidence, but not why and how.

2.2. LiDAR DATA

The airborne LiDAR data used in this study was acquired in 2014. These data have a nominal density of 5 points/m^2 and an estimated horizontal and vertical root mean square error of 0.09 m and are distributed via the eVode webservice (Triglav Čekada, Bric 2015; Štular, Lozić 2020; for correlation between point cloud density and DEM quality see Štular et al. 2021b). The data were processed using an algorithm developed specifically for archaeology (Štular et al. 2021b). The relevant metadata and paradata have been presented elsewhere (Lozić, Štular 2021). The main product used in this study is 0.5 m DEM with archaeology-specific off-terrain features included.

ID	Name†	Established (approx.)	Dating source‡
A	Višelnica	830	Indirect
B	Zg. Gorje	830	Indirect
C	Poljšica	10th c.	Inferred
D	Sp. Gorje	750	Cemetery
E	Podhom	10th c.	Inferred
F	Zasip	800	Cemetery
G	Mužje	920	Cemetery
H	Grmišče/Rečica	960	Direct
I	Pristava at Bled	620	Excavation
J	Grad 1	640	Cemetery
K	Grad 2	800	Cemetery
L	Grad 3	before 1050/60	Written sources
M	Želeče	9th c.	Inferred
N	Zagorice	before 1070/90	Written sources
O	Mlino/Zazer	8th c.	Cemetery
P	Koritno	before 1065/75	Written sources
R	Zg. Bodešče	820	Cemetery
S	Sp. Bodešče	960	Cemetery
T	Sp. Bohinjska Bela	10th c.	Inferred

Table 2: Early Medieval settlements in the Bled microregion; ID refers to *Fig*. 3. Modern names of the villages are used that have been recorded in similar form in medieval written sources. Dating sources: cemetery – based on the adjacent cemetery (after Pleterski 2013a, Modrijan 2020); indirect – inferred indirectly, based on the landscape analysis (after Pleterski 2013a); written sources – terminus ante quem from written sources (after Pleterski 2013a).

As already mentioned, in archaeology, processed LiDAR data are mostly used for interpretative mapping of archaeological features, i.e. feature detection. In this case study, however, we have used the data for what is termed integrated multi-scale ‘deep’ interpretation, which aims to deepen the understanding of archaeological features in their landscape context (Lozić, Štular 2021). In this case, the digital terrain model is treated not just as a set of elevation values, but as an important habitat descriptor. The specific tools to achieve this are described below in more detail.

2.3. GEOLOGICAL DATA

The Bled area is divided in four geomorphological areas: the high alpine karst plateaus, the intramountain area, the till plain, and the marshy area. The high alpine karst plateaus of Pokljuka (852–1630 m), Mežakla (776–1593 m), and Jelovica (900–1411 m) were formed by glaciers in the Pleistocene (*Appendix: Map 2*). The area is composed of Middle Triassic dolomites and limestones. Sedimentary deposits on the Quaternary slope cover the intramountain area between Poljšica and Podhom, which slopes gently towards the alpine Radovna River valley and the glacial Lake Bled (lithostratigraphic unit al. – alluvium). The Bohinj and Radovna glaciers had a particularly strong influence on the geomorphology and postglacial fluvial processes, with strong glacial activity leading to the deposition of a till plain with up to several 10 m of Quaternary sediments, and with a small marsh basin in the northeast part of Lake Bled (lithostratigraphic unit, pr. – till; b – marsh deposits). The marshy area between Lake Bled and the stream Rečica was formed during the last glaciation.

A characteristic feature of the Bled landform is the frontal moraine on the northeast edge of the lake and the dome-shaped monadnocks rising above the general level of glacial deposits (Bavec, Verbič 2004; Serianz 2016; Serianz et al. 2020). Bled Castle is located on one such cliff-like dome-shaped monadnocks (Ogorelec 1978). The Pleistocene fluvioglacial sediments formed the terraces of Sava Dolinka and Sava Bohinjka Rivers (lithostratigraphic unit al. – alluvium and pr. –till). An important aftereffect of the underlying geological conditions in the study area is the lack of perennial water and permanent water streams (see *Fig. 1* and *Fig. 3 f*or the locations mentioned in the text).

Of particular relevance to our case study is the overall glacial nature of the area, which is clear evidence that the geomorphology has not changed significantly since the Pleistocene, let alone since the beginning of the Early Medieval period.

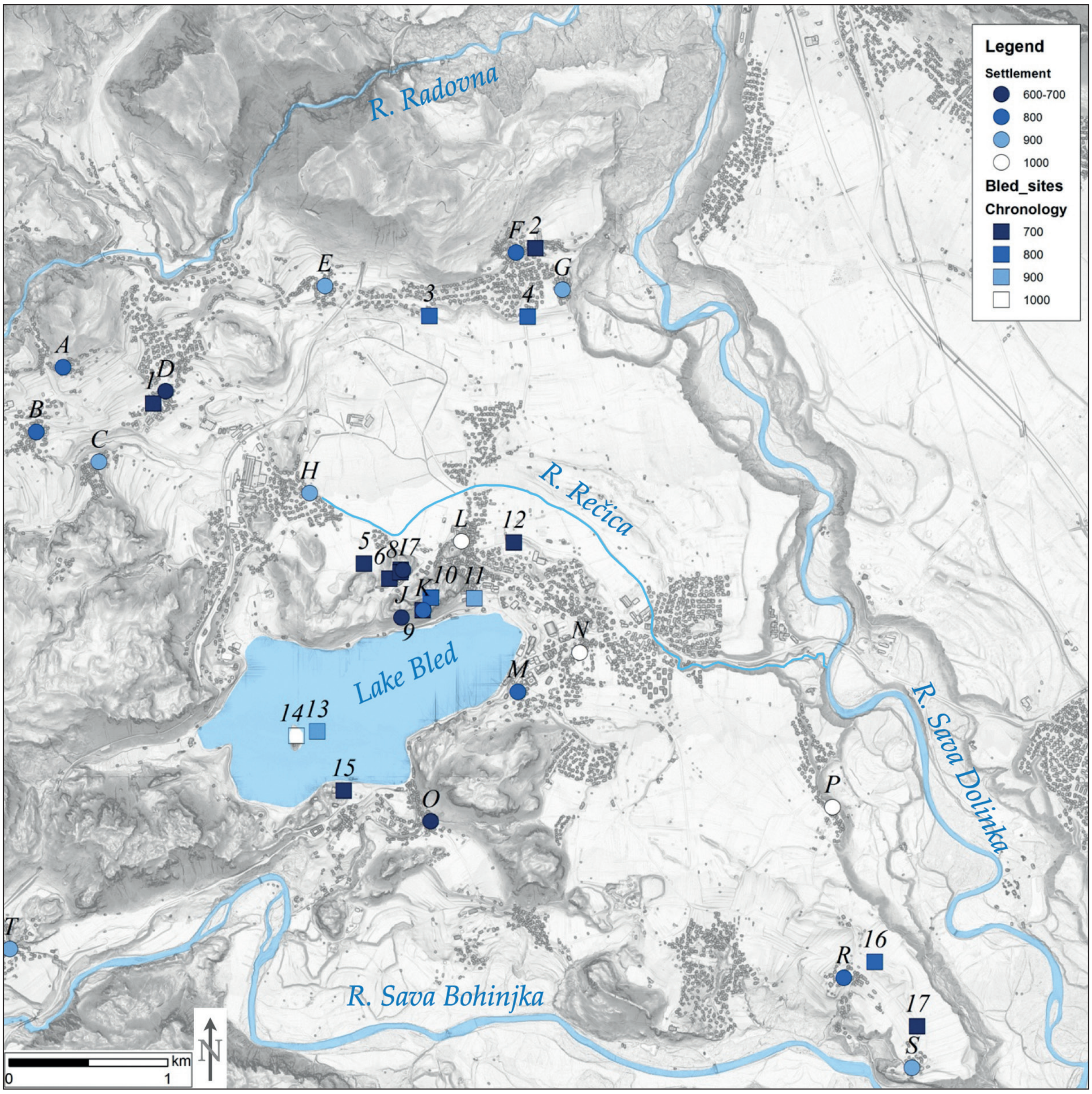

Fig. 3: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), the Early Medieval sites (numbers refer to *Table 1*) and settlements (letters refer to *Table 2*) in the Bled microregion. The colours refer to the century of foundation (labelled as year AD in the legend).

2.4. SOIL CONDITIONS

The underlying lithology (bedrock) described above is one of the diagnostic criteria for the variety of soil types in the study area, which are briefly summarized here. Rendzinas formed on limestone, dolomite, moraines, and talus deposits. Dystric brown soils formed on carbonate and siliciclastic rocks. All are mostly suitable for forest and alpine pastures. Eutric brown soils formed on moraine and talus deposits and on fluvioglacial sandy gravel sediments. Small patches of rendzinas that formed on limestone mostly support forests and meadows. Brown soils on fluvioglacial sandy gravel sediments are among the most fertile soils in subalpine areas. They occur in the plains, are well drained, sufficiently deep, and have favourable physical and chemical properties for intensive cropland. However, the brown soils formed on moraine and talus deposits are of limited use as arable land for modern agriculture, as the soil skeleton consists of moraine loam and stones. A notable depression with hydromorphic soils (hypogley) formed on a Pleistocene clay and loam northeast of the Lake Bled; it is mostly suitable for grassland. The areas adjacent to the riverbeds of Sava Bohinjka and Sava Dolinka are dominated by

FC class	mm-mm	Description
1	< 30	Very low
2	30-80	Low
3	80–150	Medium
4	150-230	High
5	> 230	Very high

Table 3: Classes of soil's effective field capacity (FC) used in the Soil map of Slovenia.

undeveloped soils on alluvial river deposits that have been frequently flooded in the past. Suitable land uses here are riparian forests and grassland (Vidic et al. 2015) (*Appendix: Map 3*).

2.5 EFFECTIVE FIELD CAPACITY OF SOIL

For agricultural use, arguably the most important soil property is its ability to retain water. This quality is defined as the soil's effective field capacity (hereafter FC). FC depends on soil texture, depth, and organic matter content, and is measured as the water content of a soil after gravity has drained as much water from the soil as possible (Bleam 2012). The higher the FC value of a soil, the more water it is able to retain and the less susceptible it is to drought.

For mapping purposes, soil types are defined as discrete pedocartographic units and FC is one of the criteria used. In the Soil map of Slovenia (Vidic et al. 2015), which holds the best available data for the Bled microregion, FC is part of the description of pedocartographic units and is presented in 5 classes (*Table 3; Appendix: Map 4*). From the perspective of archaeology, the problem with soil maps is that they are produced on a small or medium scale. This is also the case with the Soil map of Slovenia, which is designed for use at 1:25,000 scale, which is somewhat coarse for our purposes. To improve this, further analyses can be undertaken, such as the wetness index described below.

2.6. MODIFIED LANDFORM CLASSIFICATION METHOD

The landform or morphological classification of DEM, also termed geomorphology or morphometry, provides an objective and quantitative description of landform shapes, defined as specific geomorphic features, for example, plains, mountain ranges, hills, and valleys. The available methods have mostly been developed for geomorphological analysis of the terrain and are based on advanced spatial statistics (Pike 1988; Wood 1996; Tagil, Jenness 2008). We applied an automated landform classification method, topographic position index based landform classification (hereafter TPI), implemented as a module in SAGA GIS (Gallant, Wilson 2000; Böhner, Selige 2006). TPI provides a simple and powerful means of classifying the landscape into morphological classes. It is calculated as the difference between the elevation of a cell and the average elevation in large- and small-scale neighbourhoods. Positive values indicate that the cell is higher than its neighbours, while negative values indicate that the cell is lower (*Fig.* 4) (Guisan et al. 1999; Weiss 2001; Tagil, Jenness 2008).

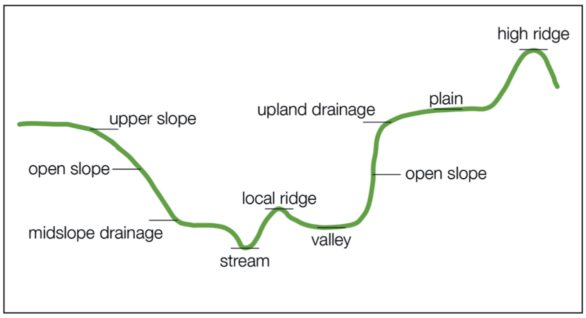

Fig. 4: A schematic depiction of the morphological classes detected by the SAGA GIS module Topographic position index based landform classification.

TPI has proven to be one of the most important predictive variables for vegetation species distribution. For example, in a study of plant distribution in the Spring Mountains of Nevada (USA), TPI was second only to elevation as the most important predictive variable (Guisan et al. 1999). In other words, in a typical landscape, TPI classes are informative not only of landform classes but indirectly also of plant communities. This demonstrates the importance of TPI for all landscape-aware human decisions, including the choice of Early Medieval settlements in the Eastern Alpine region (hereafter EMS) location.

In our application to archaeology, the results of TPI have presented significant challenges to analysis (*Fig. 5*). The areas of moderately steep slopes and till plain were clearly defined, but the mountainous plateau and river terraces were not. Therefore, an additional visual geomorphological analysis was carried out. For this purpose, hypsometric tinting of DEM, transparently (60%) superimposed on a hillshade visualisation of the same DEM, was used to improve terrain classification and visualise relief differences more clearly. The most important criterion was the height above sea level. Applying this additional analytical step we were able to precisely describe the mountainous plateau and the Holocene river terraces (*Appendix: Map 5*).

Our modified landform classification is thus a combination of TPI and visual geomorphological analysis that incorporates height above sea level. It allowed us to define quantified catchment descriptors of landscape

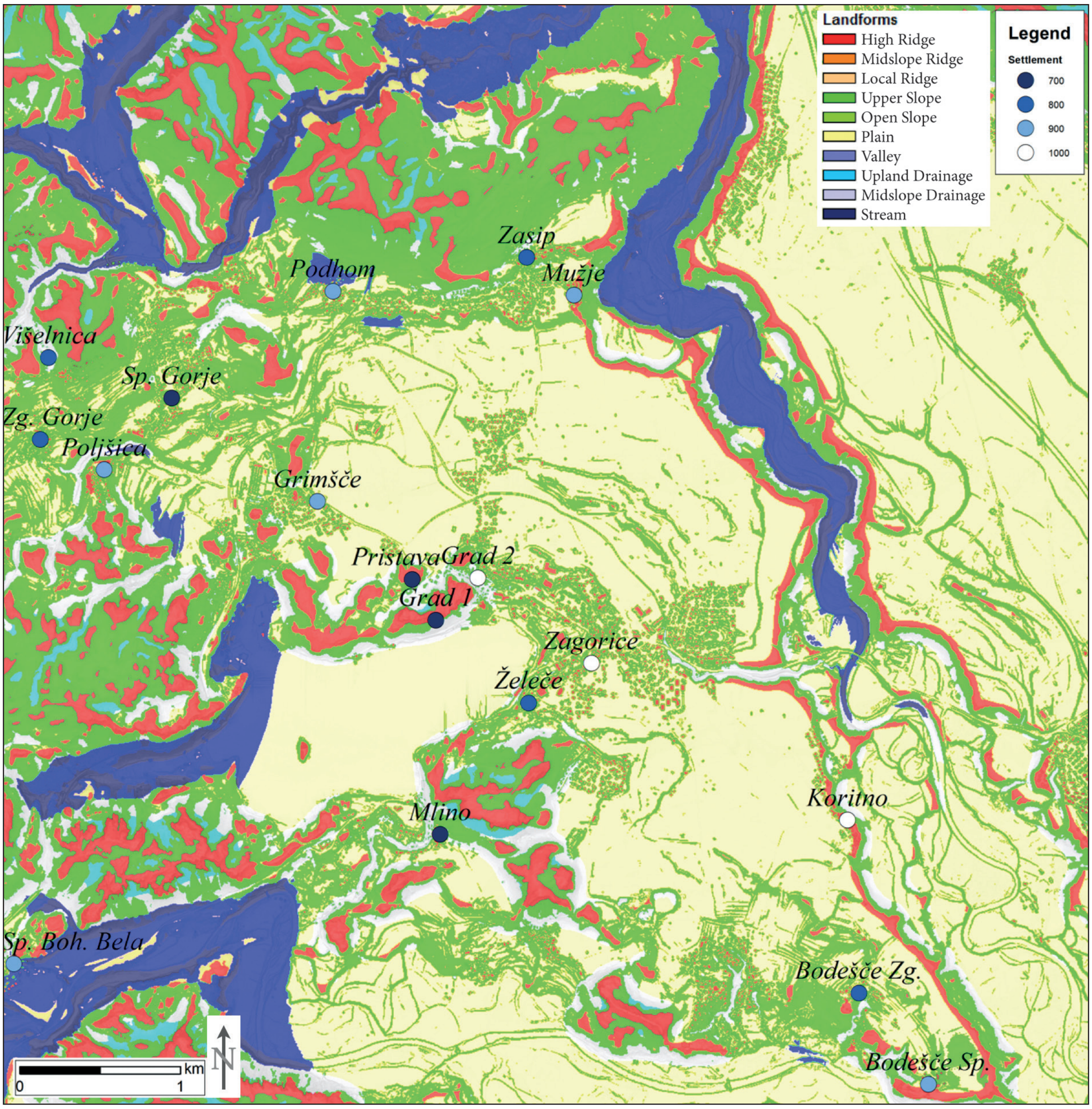

Fig. 5: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), topographic position index based landform classification.

morphology, which we termed Zones. Defined in this way, Zones represent two of the most important predictive variables of plant species distribution: TPI and height above sea level (Guisan et al. 1999).

2.7. MODIFIED WETNESS INDEX METHOD

Topographic modelling of soil moisture conditions can help alleviate the scale limitations of standard soil maps. Such modelling based on DEM is possible as water tends to flow and accumulate in response to gradients in gravitational potential energy (Murphy et al. 2009). The algorithms, commonly referred to as topographic wetness index, describe how susceptible specific areas in a study region are to become saturated (Murphy et al. 2009; Olaya, Conrad 2009). They calculate for each cell of the grid the relationship between the specific upstream catchment area and the slope (Böhner et al. 2002; Mattivi et al. 2019). The first defines the potential of water intake (rainfall) and the latter the ability to discharge the water downslope (runoff; formula: TWI = ln [Catchment Area/Slope]). One can think of these as a rainfall-runoff model (*Fig. 6 a–c*).

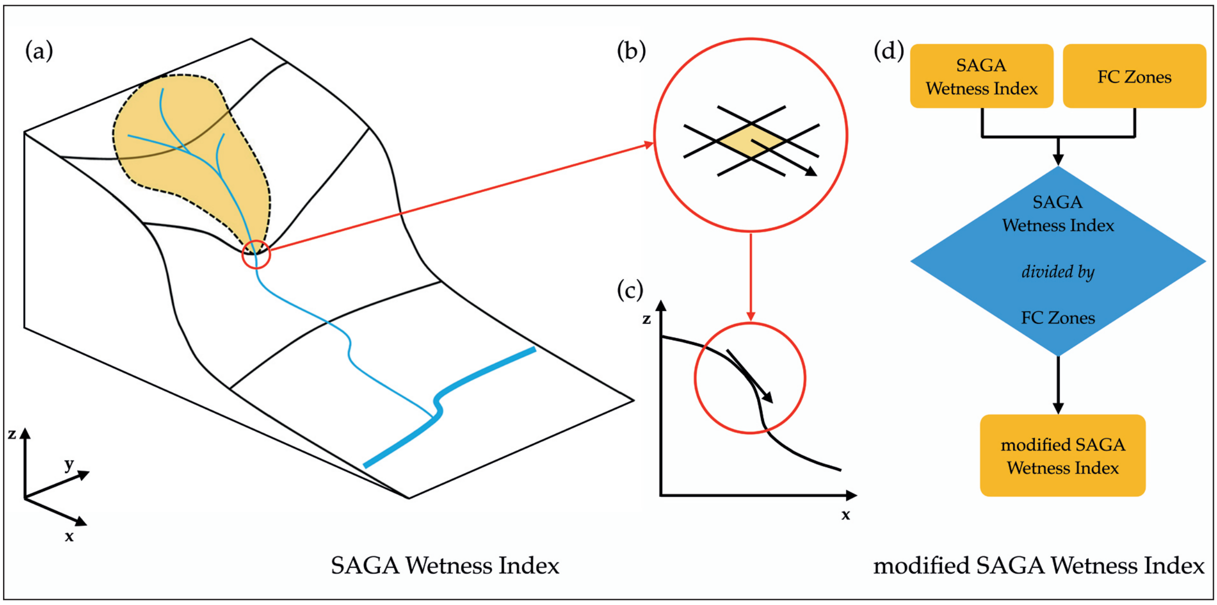

Fig. 6: Topographic wetness index: a – flow accumulation area; b – flow direction, and the corresponding flow width for a DEM cell; c – tangent of slope angle; d – custom algorithm for modified SAGA wetness index (a–c adopted from Mattivi et al. 2019, Fig. 1, published under CC-BY 4.0 licence).

Methods differ primarily in the way the upslope contributing area is calculated (Sørensen et al. 2005). We used the SAGA wetness index (hereafter SWI), because it does not think of the flow as a very thin film and hence it predicts more realistic (higher) potential soil moisture for valley floors (Böhner et al. 2002). The field tests demonstrated that SWI in combination with LiDAR derived DEM is the best existing predictor of soil wetness (Kienzle 2003; Murphy et al. 2009; Kemppinen et al. 2017).

Another advantage of the SWI is that it can be refined by setting the suction index (Bock et al. 2007). Unfortunately, the suction index function is poorly documented in the SAGA GIS software used and the best available description is in the source code (Conrad et al. 2015). In addition, the suction cannot be adjusted locally. Therefore, we developed custom modified SWI (hereafter mSWI) by using the FC value extracted from the Soil map of Slovenia (Vidic et al. 2015) as weighting index (*Fig. 6d*). mSWI was calculated with map algebra using SWI and FC classes as an input.

In this way, we obtained mSWI (*Appendix: Map 6*) which combines the accuracy of the FC with the precision of the fine relief resolution of the SWI and is a very realistic predictor of soil quality. This method is similar to the topographic wetness index used in the Leibnitzer Feld case study (Lozić, Koch 2024 in this volume), but the two methods differ in details.

2.8. GENERAL METHODOLOGICAL REMARKS

There are three general methodological remarks to be made. First, our method of combining soil data with TPI and mSWI analysis is based on the premise that soil conditions in the Early Medieval period were similar to those of the modern period. This is justified in this particular case study by the fact that hydrological and surface conditions were subject to similar geomorphological processes throughout the Holocene and that the relationship between land surface properties (e.g., soil, vegetation, and lithology) was not very different in the Early Medieval period. In this particular case study, the stability is the result of the underlying lithology described above. Consequently, this method is only suitable for areas where either soil conditions have not changed significantly between the archaeological period under investigation and the time of soil data collection, or relevant soil data have been obtained through palaeoenvironmental analysis. This is not always the case, for example, in urban areas soil properties changed significantly (*Fig. 1:* Zagorice, Želeče, Sp. Bohinjska Bela, Pristava). However, in our case study the urban areas are relatively small and did not have significant influence on the results.

Second, the selection of methods used in this case study is indicative, but by no means exhaustive. For example, slope and aspect can also be used as predictor variables for plant species distribution. In addition, climate (temperature, precipitation) and human impact are also very important for the distribution of plant species,

Zone	m a.s.l	TPI	Lithostratigraphic Units	Soil type	Land Use	EFC[1]	No. EMS
1	580–931	High Ridges, Midslope Ridges, Local Ridges	T2/1; T2/2-Middle Triassic dolomites and limestones	Rendzinas on limestone and dolomite, and on moraines and talus deposits; Dystric brown soils on pyroclastic rocks, and on mixed basic and non- carbonate rocks	forest, alpine pasture	3	0
2	511–570	Upper Slopes, Open Slopes	al-holocene alluvial deposit	Eutric brown soil on moraine and talus deposits	meadow, arable land	3	16
3	480–510	Plains	pr-holocene alluvial deposits	Eutric brown soil on glaciofluvial sand gravel deposits or alluvial fans	intensive arable land	2	3
				Hydromorphic Soils (Alluvial soils, Hypogley, Amphigley)	grassland	4	
4	450–470	Upland Drainages, Midslope Drainages, Streams	pr, al-holocene alluvial deposits	Undeveloped soil on alluvial deposits	riparian forests.	1	0

Table 4: A habitat descriptor for the defined zones within the Bled case study area.

as are many other factors. Alternative types of similar predictor variables include airborne LiDAR-derived feature detection used to identify landslides (Li et al. 2015), spectral parameters of airborne LiDAR data applied for detection of glacial landforms (Janowski et al. 2021), and object-based image analysis applied for volcanic and glacial landforms mapping (Feizizadeh et al. 2021). Furthermore, TPI and mSWI methods in no way intend to compete with verified and established methods of environmental archaeology, such as archaeopalynology, archaeobotany, or archaeozoology (e.g. (Dincauze 2000; Jones 2002; Evans 2003; Reitz et al. 2008; Reitz, Shackley 2012; Andrič et al. 2016). Rather, the aim is to introduce and test additional methods and, perhaps more importantly, to add LiDAR as a new data source for the archaeological analysis of past human land use. The suggested good practice would be to use TPI and mSWI in combination with other methods. However, in this case study, on the one hand, LiDAR and soil data are the only data currently available to the author, and on the other hand, TPI and mSWI were sufficient to provide new insights into the archaeological landscape in general and EMS in the context of agricultural land use in particular.

Third, the theory of central land cores has been applied implicitly to this study. That is, we know from previous studies that all relevant settlements in the Bled area are within a 7-minute walk of the field cores (Lozić 2024 in this volume with references).

3. RESULTS

Our modified landform classification is, as mentioned, the combination of TPI and visual geomorphological analysis, which resulted in the definition of four Zones. Below, each Zone is described (*Fig. 7; Table 4)*.

Zone 1 is defined as a mountainous plateau with steep and very steep slopes (TPI classes: High Ridges, Midslope Ridges, Local Ridges; 931–580 m a.s.l.). Middle Triassic dolomite and limestone bedrock prevail (*Table 4:* T2/1; T2/2) and two soil types occur. The first are rendzinas and the second dystric brown soils. The latter have a higher FC (FC index 3; mSWI index: 0, -5). Nowadays the area is forested and suitable for alpine pasture. There are no EMS in Zone 1.

Zone 2 consists of gently sloping terrain at the foothills. It occurs mostly in the western part of the study area, on the low hills surrounding the Lake Bled and above the river terraces (TPI classes: Upper Slopes, Open Slope; 580–510 m a.s.l.). The bedrock are mostly Holocene alluvial fan deposits. Prevailing eutric brown soils were formed on talus slopes mixed with moraine material and deposited directly on inactive alluvial fans (Novak et al. 2018). These soils have high FC (FC index 3; mSWI index: 0, -5). The area is mostly suitable for arable land and meadows. 16 out of 19 EMS are located within Zone 2.

Zone 3 represents a large till plain formed in postglacial fluvial processes that deposited up to several tens

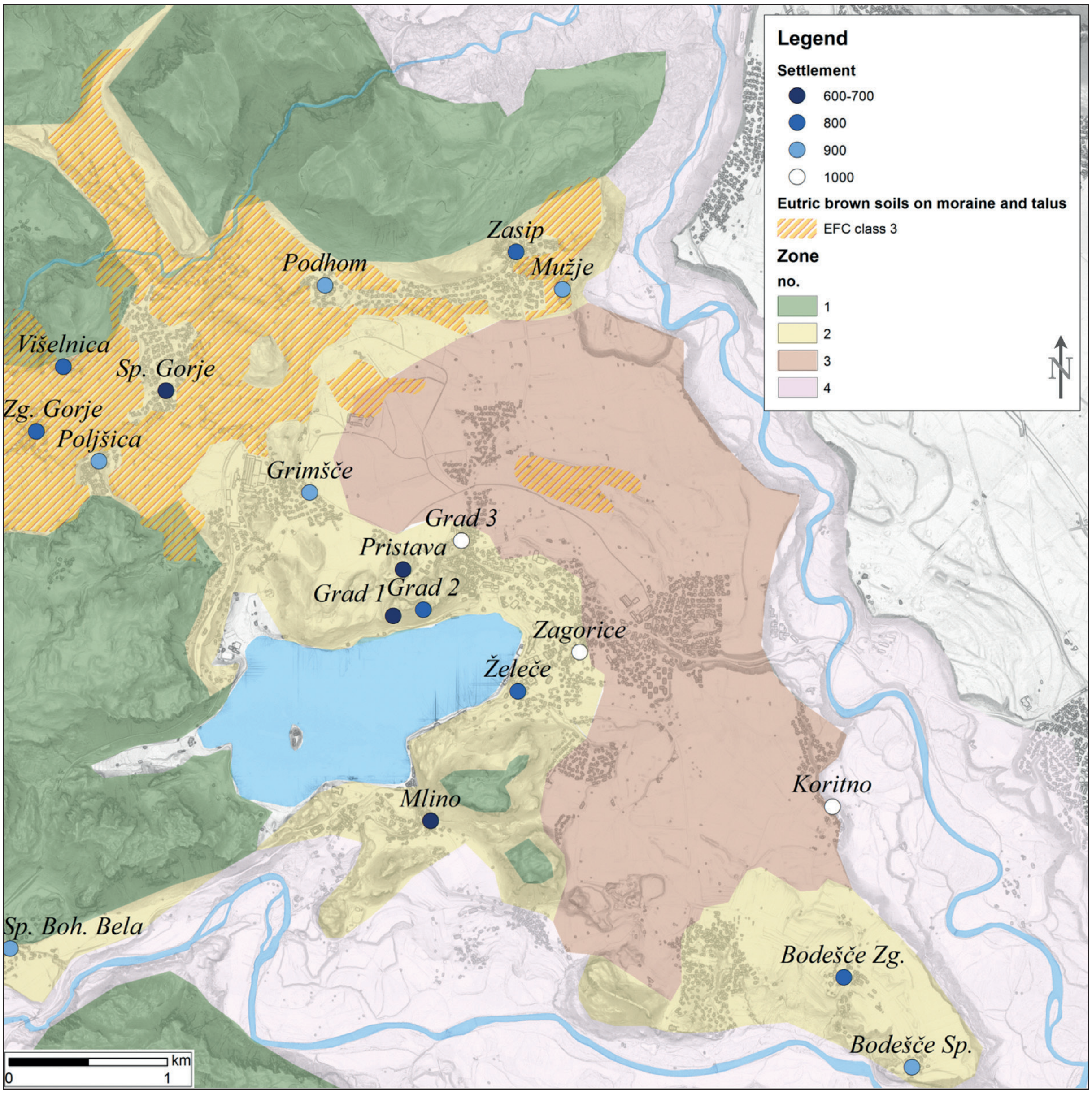

Fig. 7: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), brown soils with high capacity to retain water (marked with dashed lines) and physiographic zones. The areas most suitable for Early Medieval agriculture are located at the intersection of the dashed lines and yellow Zone 2.

of metres of Quaternary sediments. It is limited by the riverbeds of Sava Dolinka and Sava Bohinjka (TPI class Plains; 510–480 m a.s.l). Over the glaciofluvial sand gravel deposits (*Table 4:* pr), fertile deposits of brown soils developed. However, due to the high porosity of Holocene sediments, the FC is low (FC index 2; mSWI: 0.7), which means that the entire area is exposed to drought. This is exacerbated by the absence of permanent surface water. Nevertheless, there are small patches of hydromorphic soils (Alluvial soils, Hypogley, Amphigley) with high FC (FC index 4; mSWI: 0,-5). Their formation was possible due the glacial activity and postglacial fluvial processes, which have resulted in deposition of clayed sediments north of the Lake Bled (Serianz et al. 2020). The brown soils in the Zone 3 are the most suitable soils for modern agriculture in the area (Vidic et al. 2015), providing that drought effect can be mitigated (for example, by irrigation or drought-resistant crops). Only three EMS, all established only in the eleventh century, are located in Zone 3.

Zone 4 is an area of multiple alluvial terraces covered by Quaternary sediment (till, fluvio-glacial sediment, and slope sediment) deposits rising above adjacent active floodplains (TPI class Upland Drainage, Midslope Drainage, Streams; 480-450 m a.s.l). The area is characterized by undeveloped soils formed on alluvial deposits with very low FC (FC index 1; mSWI: 0, -11). It is overgrown with riparian vegetation. There are no EMS in Zone 4.

It can be concluded that the preferred landscape type for EMS was moderately steep slopes and brown soils with high FC, defined here as Zone 2 (*Fig. 7:* Zone 2). This is the case for most EMS in our case study (*Fig 3:* Višelnica, Zgornje in Spodnje Gorje, Poljšica, Grmišče, Zasip and Mužje). The location of two other EMSs (*Fig. 3:* Zg. Bodešče and Sp. Bodešče) fits the landform classification criteria, but not the soil conditions as depicted on the pedological map. We explain this by the fact that the existing soil map is not detailed enough to show the microlevel differences. Indeed, the area is full of glacial moraines and micro valleys, and under such conditions water-rich and marshy soils tend to develop. Their presence in this particular area is confirmed by the historical field names ("V blateh", "Curkovca", "Pretaka", "Nad potokam", which means "In the mud", "Stream", "Flow", "Above the stream" respectively; after Pleterski 2013a, 45–54).

The only other landscape context where three EMS exist is large till plain with fertile brown soils with low FC, defined here as Zone 3. However, all three (*Fig. 3:* Zagorice, Grad 3, Koritno) have only been established in the eleventh century.

The above presented focus of EMS on a landscape characterised by moderately steep slopes and brown soils with high FC is consistent with previous research on EMS in similar landscape conditions by Wawruschka (2009). Her mountainous or hilly areas fit well with the description of our Zone 2, although some of the data (e.g., m a.s.l.) cannot be directly compared.

The most important result of this analysis is the definition of the ecological niche that was preferred by the EMS and is based on the agricultural land use. The importance of this lies in the scalability, i.e., this result can be directly applied to regional studies of the Early Medieval settlement in Eastern Alpine region and possibly other regions with subalpine climate.

The results also enable new insights into the Early Medieval Bled microregion by characterizing the individual EMS. Exclusive preference for Zone 2 prior to the eleventh century strongly suggests two key points. First, these are primarily agricultural settlements. There are two exceptions (*Fig. 3:* Grad 2, Mlino) where the landscape morphology does not allow for the presence of significant arable land and non-agricultural function seems probable (Pleterski 2013a, 72–78 and 94–98). Second, the relatively narrow scope of agricultural land use, as can be inferred from the exclusive occupancy of Zone 2, suggests a not overly diversified agricultural land use system, possibly based on a single staple crop.

4. CONCLUSIONS

The chapter utilized an existing corpus of open access archaeological database Zbiva (Štular 2019; Štular, Belak 2022), open access remote sensing data and environmental data (geology and soils), as well as open source software tools (e.g., QGIS, SAGA) to reassess existing knowledge on the Early Medieval archaeological landscapes, specifically on agricultural land use. While the importance of free and open source software in science in general (e.g. Pearce 2012), and in the field of airborne LiDAR data for archaeology in particular (e.g. Štular et al. 2021a), is well recognised, we believe that the importance of the increasingly abundant and easily accessible free environmental and archaeological data (e.g. Richards, Niccolucci 2019), is too often overlooked. Hopefully, this chapter is a step towards recognizing the importance that these data sources can have for archaeology.

A novel objective method and, perhaps more importantly, LiDAR as a new data source for the archaeological analysis of agricultural land use systems were presented. The suggested good practice would be to use the method we proposed in combination with existing complementary methods, such as archaeobotanical analyses. However, in this case study, the analysis of LiDAR data was sufficient to provide new insights into the archaeological landscape in general and EMS in the context of agricultural land use in particular.

We used the LiDAR data for what is termed integrated multi-scale 'deep' interpretation, which aims to deepen the understanding of archaeological features in their landscape context. It should be reiterated that, in our opinion, such a use of these data in archaeology remains underexploited despite some promising early studies (e.g. De Boer et al. 2008; Štular 2011; Doneus, Kühteiber 2013). The Bled case study illustrates such potential contribution of LiDAR data to explore landscape gradients that have influenced human activities. We have clearly demonstrated a preference of Early Medieval agriculture for terrain on moderately steep slopes with brown soils that have a high capacity to retain water. Further archaeological implications of this will be discussed in Štular and Lozić (2024 in this volume).

One of the most important methodological contributions of this chapter is the discussion of scale issues. Since the scale of many soil maps is inadequate for archaeological analysis, a method to overcome this challenge is presented using various indices. The solution presented is scalable to other types of landscape and other archaeological periods, as well as to other types of soil data.

In the wider context of LiDAR methodology in archaeology, we have focused on the potential of LiDAR data to provide a source for very detailed landscape description and observe environmental components using GIS analysis, specifically modified landform classification and mSWI. This approach leads to a more detailed and objective analysis of the environment and spatial context of any observed archaeological phenomena. Given the rise of open access data and open access tools there is huge potential for this and similar methods in geocomputational archaeology of the near future.

Data Availability Statement: Airborne LiDAR data used are publicly available at http://gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_Lidar@Arso. Geology data are publicly available at https://ogk100.geo-zs.si. Soil data are publicly available at http://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso.

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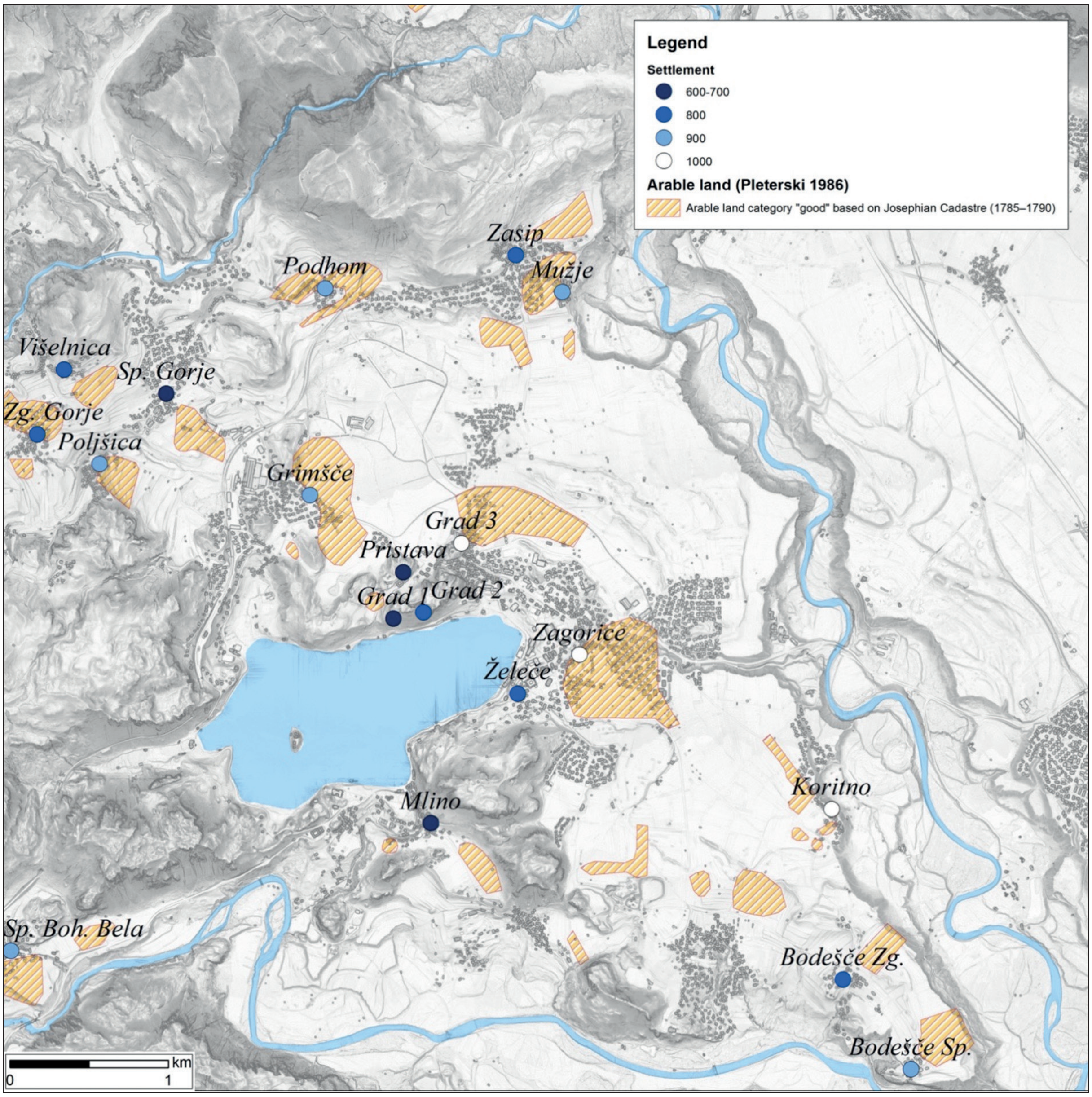
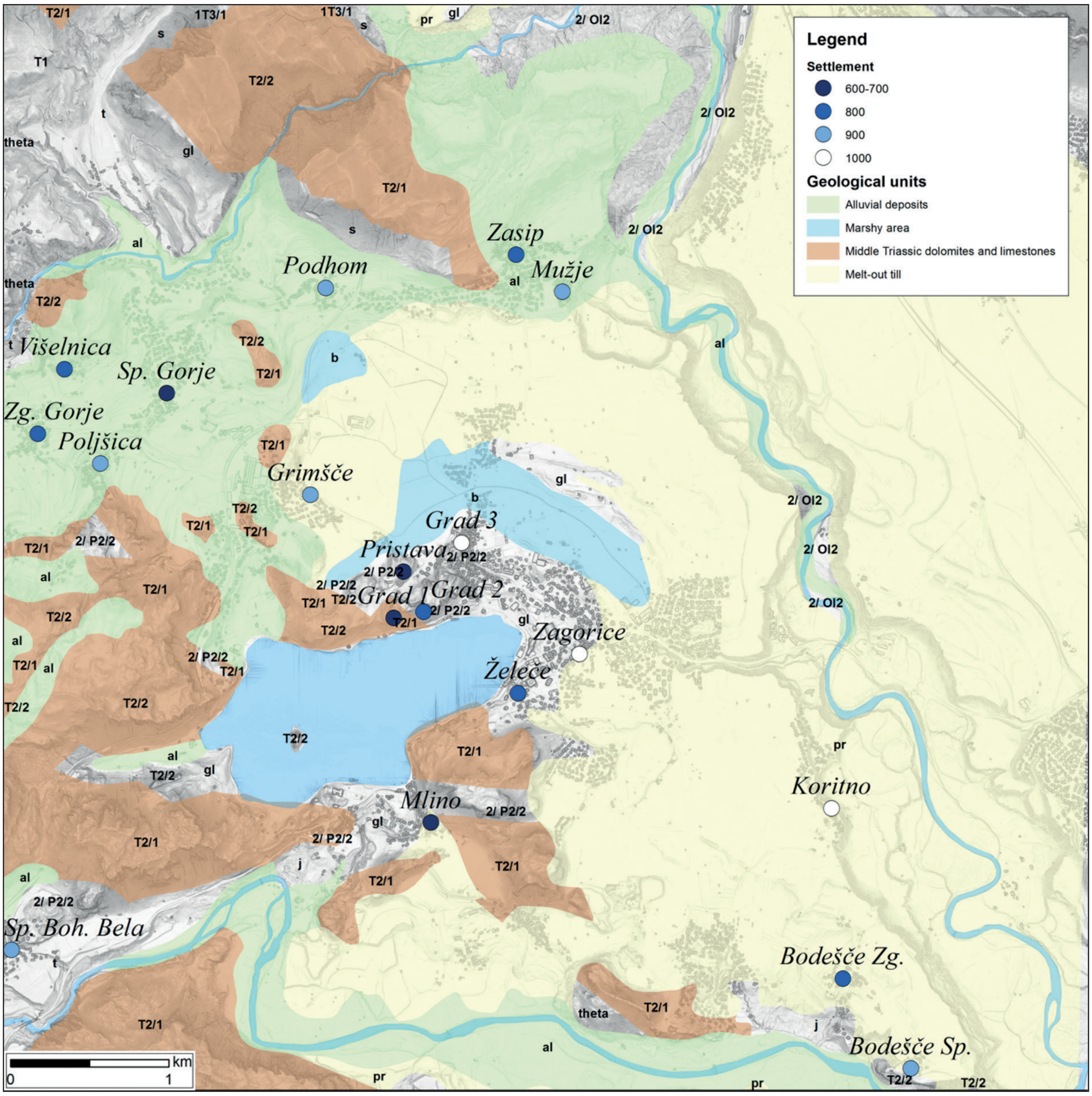
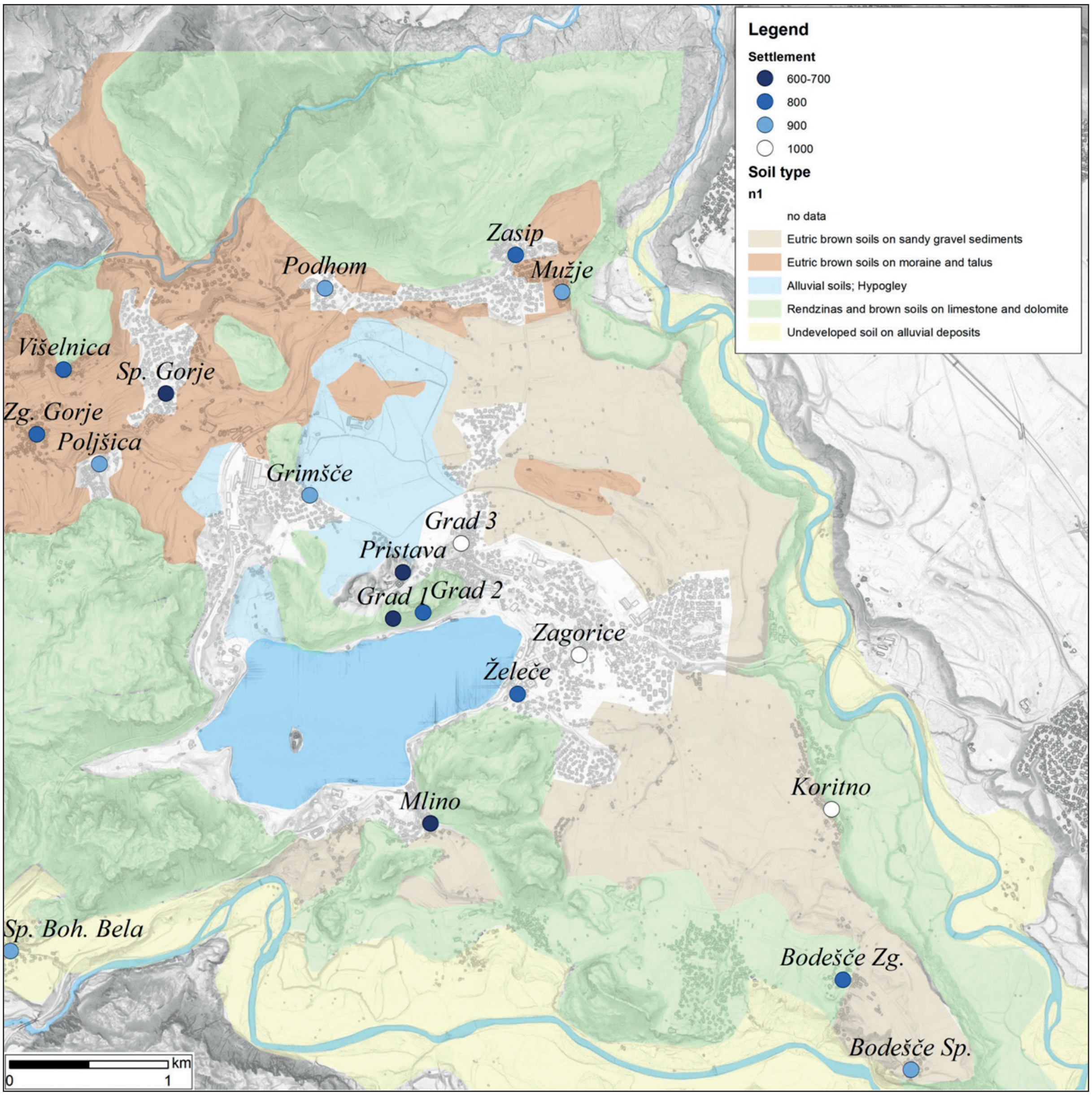
APPENDICES



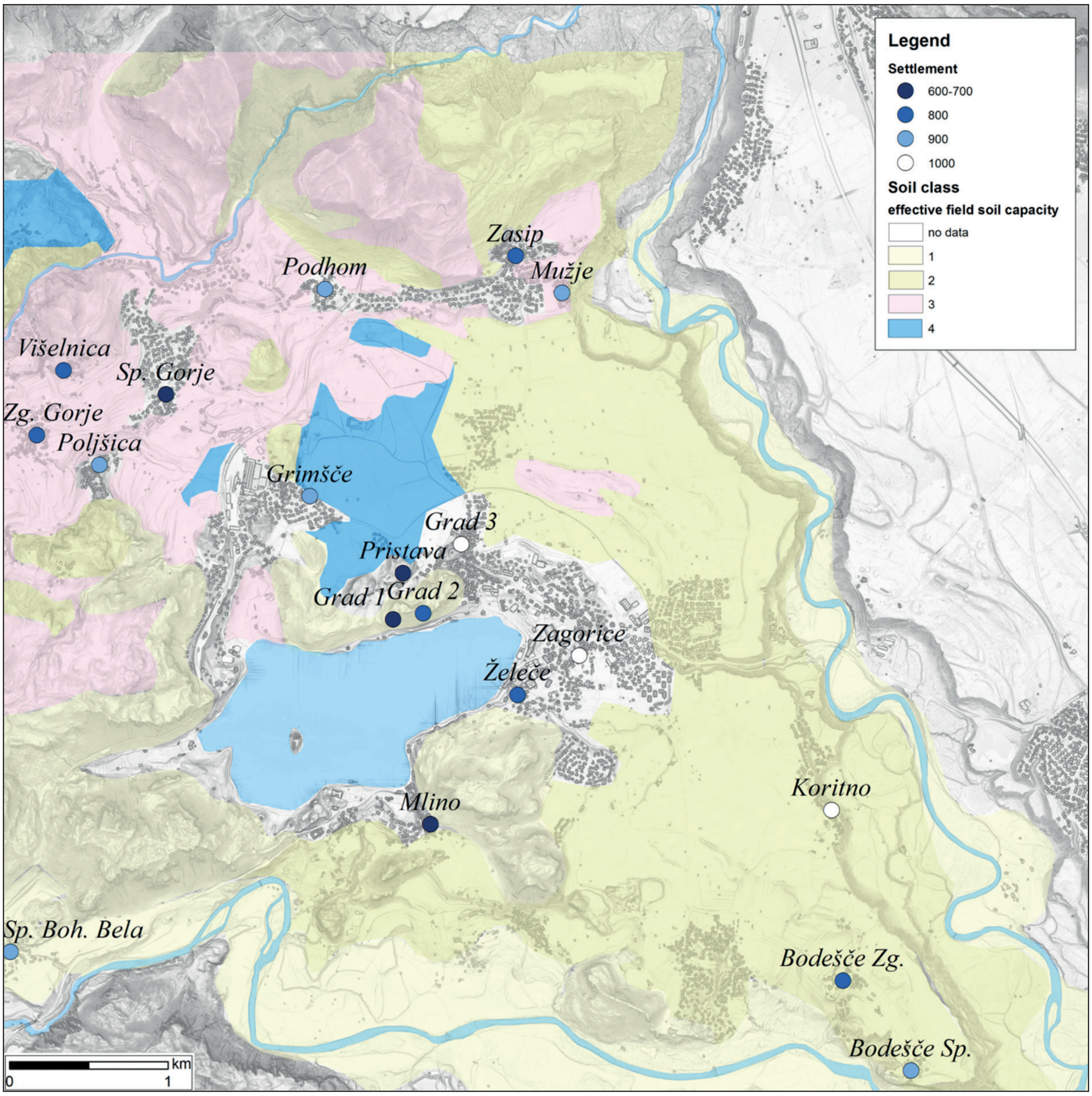
Map 1: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), Early Medieval settlements (letters refer to *Table 2* in the text) and arable land category "good" based on the retrograde analysis of the 19th century Franciscan Cadastre (source data adopted from (Pleterski 2013a).



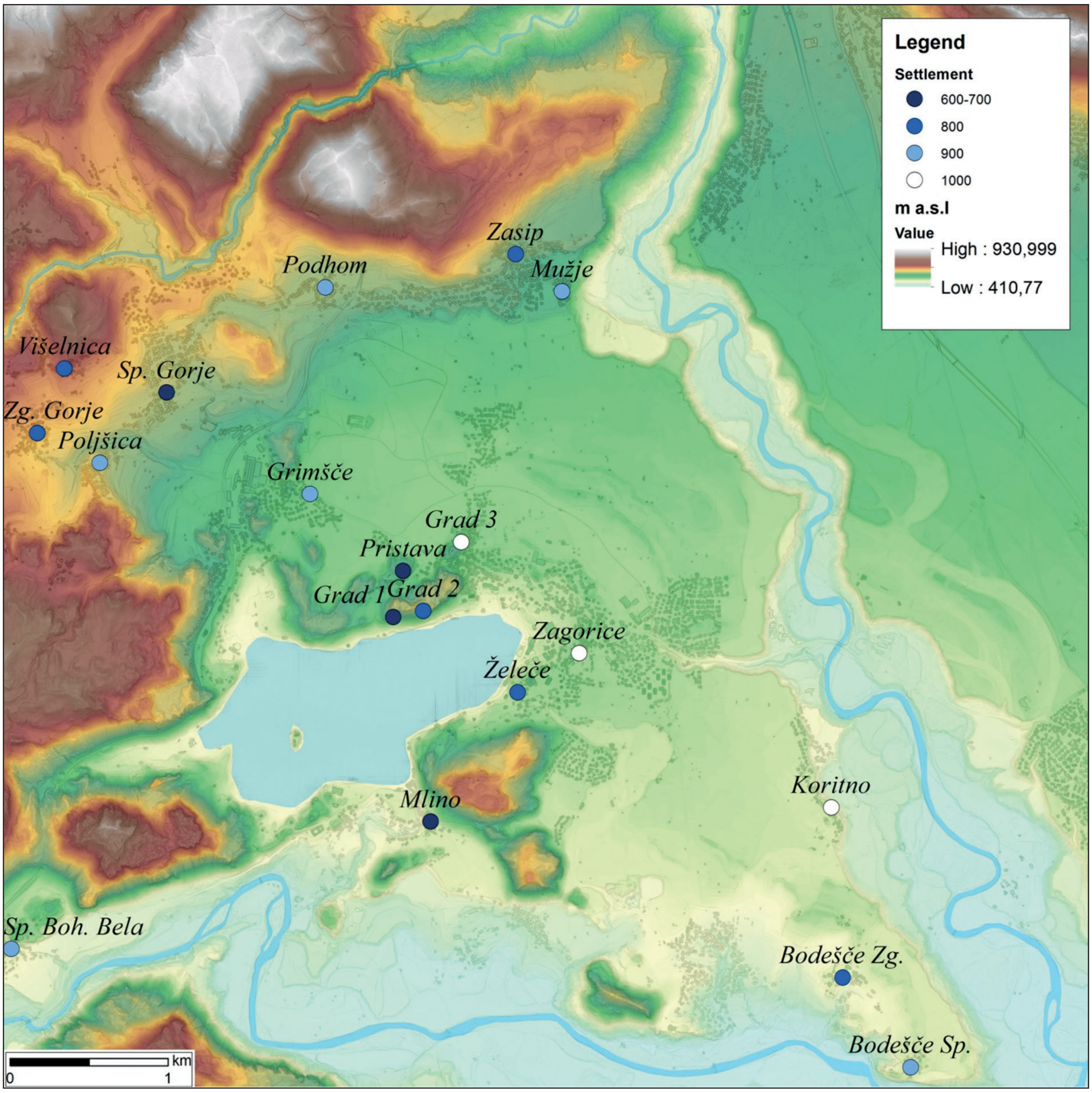
Map 2: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), geological background. The most main geological units prevailing in the study area are presented (source data adopted from Bavec, Verbič 2004; Serianz 2016; Serianz et al. 2020).



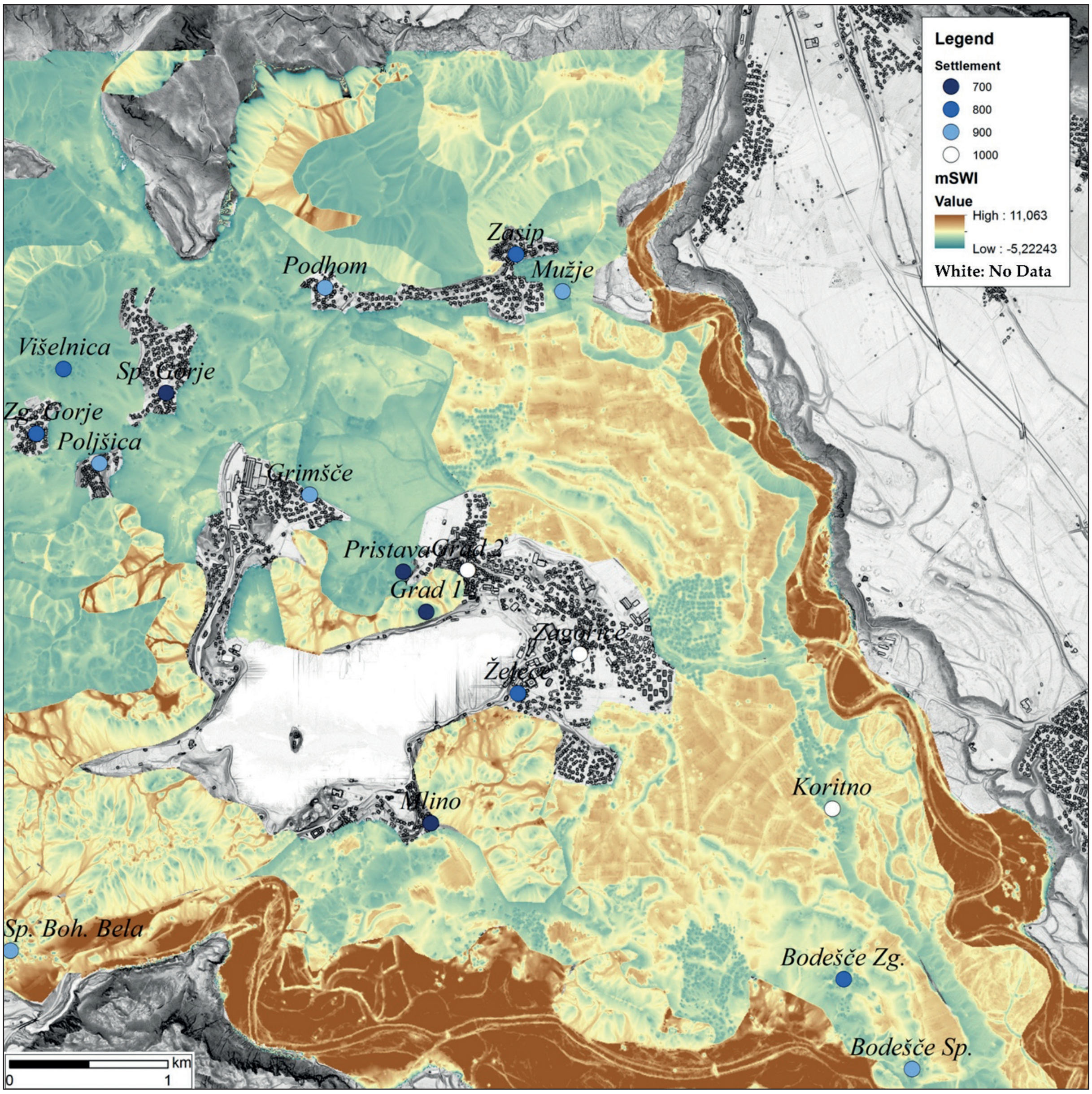
Map 3: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), soil map (source data adopted from Pleterski 2013a).



Map 4: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), effective field soil capacity (FC) classes (source data adopted from Pleterski 2013a).



Map 5: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), visualisation created for visual geomorphological analysis (hypsometric tinting of high-resolution DEM, transparently (60%) superimposed over a hillshaded surface). The highest elevation zone is white, brown represents the mountainous plateau, a darker green for the upper slopes, and light green for the verdant valleys. EMS are represented with points.



Map 6: Bled microregion (decimal longitude and latitude coordinates of the map centre: 14.1139; 46.3752), modified SAGA wetness index (mSWI). The area with modified values between 11 and 0 has a (very) low capacity to retain water (map in yellow and brown), and the area with high capacity to retain water (values 0 to-5, green).