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SOIL, WATER, AND TOPOGRAPHY: DECODING SETTLEMENT LOCATION PREFERENCES IN EARLY MEDIEVAL LEIBNITZER FELD (AUSTRIA)

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Abstract

The study investigates settlement location preferences during the Early Medieval period in the Leibnitzer Feld microregion of southeastern Austria, focusing on soil, terrain, and hydrological characteristics. Utilizing LiDAR data and Digital Elevation Models, the research examines the spatial distribution of settlements relative to agricultural potential and non-agricultural activities. The analysis reveals a distinct pattern of settlement locations influenced by soil quality including its ability to retain water. Settlements with access to high-fertility soils, primarily eutric brown soils, suggest an agricultural focus. Conversely, settlements on high ridges or with no access to fertile soils indicate non-agricultural functions. Some of those have been identified as potential mining settlements, highlighting the region's economic diversity. This study underscores the importance of integrating geospatial technologies with archaeological data to enhance our understanding of historical settlement dynamics.

Keywords: archaeology, Early Medieval settlements, site location analysis, landscape archaeology, LiDAR data, DEM analysis.

1. INTRODUCTION

The purpose of this chapter was to spatially analyse Early Medieval sites in the Leibnitzer Feld microregion (see Štular, Lehner 2024, Fig. 1 in this volume) by observing soil and terrain characteristics within site catchments for each archaeological site. The approach is based on the well established assumption that predominantly agricultural societies made their living primarily within the site's hinterland known in archaeology as site catchment (Lozić 2024b in this volume). This method enables us to discern, in a given region and time period, between the sites that have an easy access to the fields, and those that don't. In the case of the latter, non-agricultural motives can be assumed for their choice of location. Another goal of this method is to analyse the environmental variables that were crucial to the choice of settlement location.

The Early Medieval economy in the region was predominantly based on agriculture and animal husbandry, which has recently been illustrated by a meticulous analysis of two Early Medieval refuse pits containing archaeozoological and archaeobotanical assemblages discovered in Kleinklein, just outside our study area. Meat consumption was based on domestic animals (pigs, cattle, chickens, sheep, and goats) and to a lesser extent on game (deer and wild boar) (Toškan 2019). The diet was based on a rather limited selection of crops, consisting of barley (*Hordeum vulgare*), broom millet (*Panicum miliaceum*) and probably rye (*Secale cereale*) (Kiszter et al. 2019). Recent research elsewhere has also demonstrated the importance of rivers for the supply of proteins related to fishing and gathering activities (Rihter 2019; Wawruschka 2009; evidence for fishing: Nowotny 2016).

Previous research efforts conducted in the Leibnitzer Feld and its surroundings have provided important contributions and valuable insight regarding Early Medieval populations that inhabited Austrian Styria (Gutjahr 2018c; Gutjahr et al. 2024 in this volume; Koch 2024 in this volume).

However, if the sites are analysed in isolation, the microregional settlement model is difficult to discern. Thus, in this chapter, we have observed Early Medieval settlements in the Leibnitzer Feld in the landscape context. Given the dynamic relationship between the many environmental variables and the scarce archaeological data, this was a formidable task. Fortunately, geographic information systems (GIS) technology provides mechanisms to manage the data and study correlations between the various components of a complex environment and archaeological sites.

2. MATERIALS AND METHODS

2.1 STUDY AREA

The study area, the so-called Leibnitzer Feld, is located in the Mur/Mura valley in Styria in southeastern Austria (*Fig. 1*). The area covers approximately 280 km^2. To the north, the mountain formation of the Buchkogel, including the elongated range of the Wildoner Schlossberg and the Bockberg, separates the Grazer Feld from the Leibnitzer Feld. It is known collectively in the Middle Ages as 'Hengist'. This area has been the subject of considerable research interest (Gutjahr et al. 2018), as shown by the impressive bibliography compiled on the subject (e.g. Gutjahr 2013; 2014; 2015; Gutjahr, Trausner 2009; Roscher 2001). It ends in the south on the west bank of the Mur, with clearly discernible remains of the Roman town *Flavia Solva,* in present day Wagna (Groh 1996; Hinker et al. 2014; Groh 2021). This particular study area was chosen because of the relatively high number of Early Medieval sites compared to the rest of Styria. An important aspect of the choice was the fact that some of them were discovered during rescue excavations (Komberg, Weitendorf, Rohr bei Haslach) and provided organic material for the radiocarbon dating.

2.2 ARCHAEOLOGICAL DATA

Scarce data are problematic in Early Medieval archaeology in this region in general, and even more so in Leibnitzer Feld. Due to the perishable building material used for such settlements, the Early Medieval settlements can only be detected by archaeological excavations (Štular, Lehner 2024 in this volume). Furthermore, in this particular area, an additional factor for poor preservation of the archaeological remains is intensive modern farming. This is especially true for the eastern part of the study area, where remains associated with dwelling sites seem to be largely absent. For these reasons, we cannot overstate the archaeological significance of the few known settlement sites. These are starting points for "reading" and understanding the natural parameters that were decisive for the choice of the location of the settlement.

To select the relevant archaeological sites for this study first the data quality was re-evaluated (see *Appendix 1* for description of sites with references). The final selection was comprised of settlements (*Table 1:* A–F) and cemeteries (*Table 1:* G–J). However, because of their paucity we also included the artefacts classified as so-called stray finds, that is, artefacts found outside of a distinct archaeological context (Darvill 2008). In our case, the stray finds are pottery fragments (*Table 1:* L–N), as well as jewellery (*Table 1:* K, O, P) and dress accessories (*Table 1:* R). We argue, that stray finds are indirect indicators of occupation, signalling either possible dwellings or burial sites in the vicinity (see Dzieńkowski 2018). However, in the analysis confirmed settlements were considered as a separate category.

2.3 LiDAR AND DEM DATA

Prior to archaeological interpretation, the original Lidar dataset (1000 km^2 point cloud in "*.las" file format with accompanying orthophotos) was obtained from the Provincial Government of Styria (Das Land Steiermark) for the *Hengist Best-of* project (Gutjahr et al. 2018). The original data set was processed and filtered according to the archaeology-specific method (Lozić, Štular 2021; Štular, Lozić 2016). The test of the data processing method was performed on a smaller area (4 km^2), in case adjustments of the methodological approach would be necessary. The real value of the re-processed point cloud and re-interpolated digital elevation model (DEM) was revealed by the use of different visualization types (hillshade, openness, difference from mean elevation, sky view factor). It resulted in improved quality and "sharpness" of data and thus in better visibility of the possible archaeological features (Štular, Lozić 2020). The use of different visualization techniques is necessary to obtain the maximum information about possible archaeological sites visible on the surface (Lozić, Štular 2021).

One of the key products of LiDAR data for archaeology and geosciences is DEM (Štular et al. 2021). The DEM dataset is provided as gridded elevation data in a raster structure that represents the surface of the terrain. It contains *x*-, *y*-, and *z*-values, which represent *x*- and *y*-coordinates and elevation information, respectively. Digital Terrain Analysis can be used to

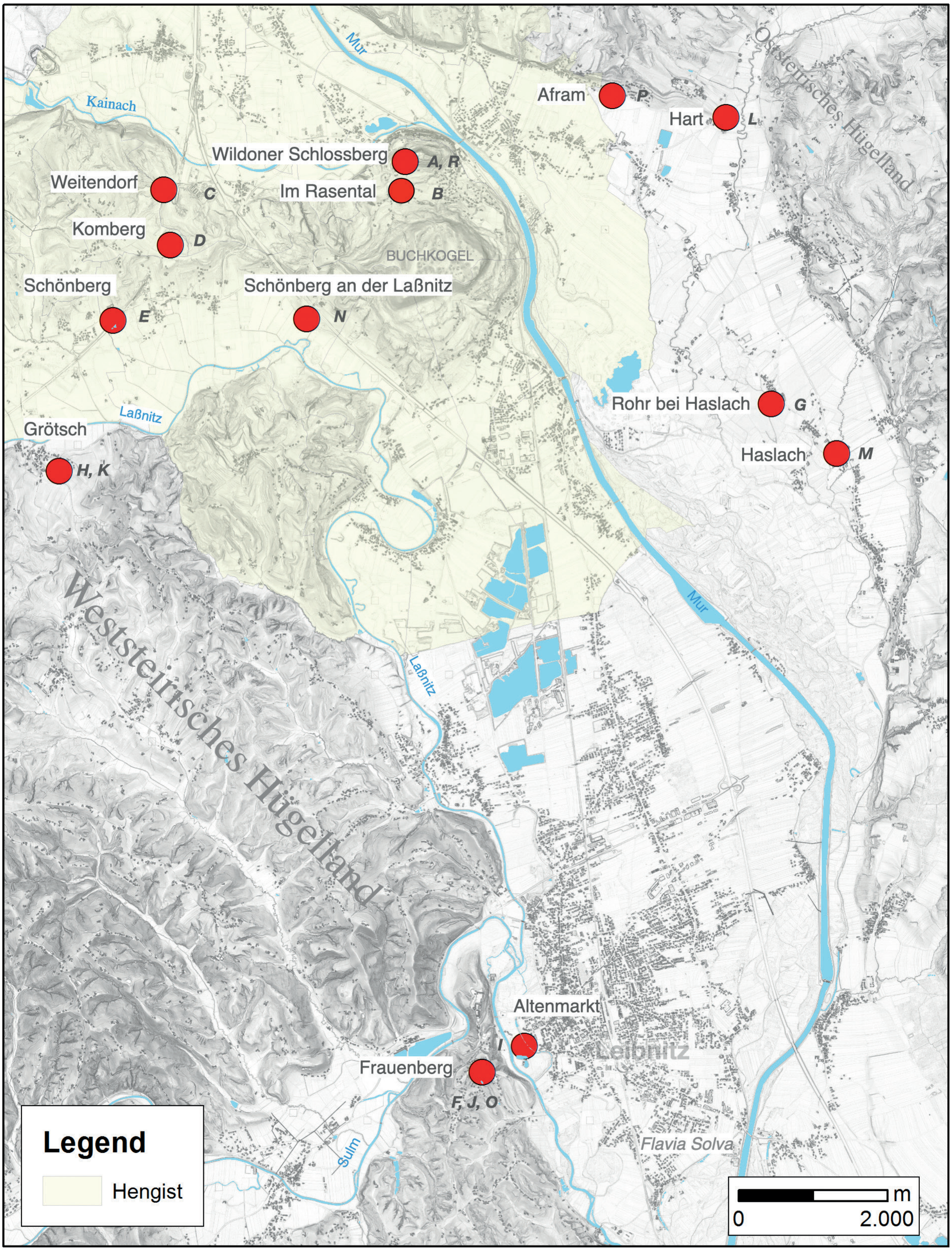

Fig. 1: Leibnitzer Feld study area with Early Medieval sites. Yellow is the approximate area of Hengist (sources: Zbiva; Gutjahr et al. 2018), defined by today´s borders of five municipalities organized in the "Kulturpark Hengist". The proper borders of the medieval Hengist county are unknown in detail.

ID	Name*	Type	Chronology (AD)**	Chronology Confidence Level***	Zbiva ID
A	Wildoner Schlossberg[1]	Settlement	750–1000	2	10001857
B	Im Rasental[1]	Settlement	700–1000	3	10002886
C	Weitendorf	Settlement	750–860	3	10002796
D	Komberg	Settlement	625–675	3	10002344
E	Schönberg	Settlement	600–800	3	10003649
F	Frauenberg[2]	Settlement	600–1100	1	10001862
G	Rohr bei Haslach	Cemetery	665–1035	2	10002488
H	Grötsch[3]	Cemetery	750–850	2	10001838
I	Altenmarkt, Leibnitz	Cemetery	800–1600	3	10001830
J	Frauenberg[2]	Cemetery	900–1000	2	10001851
K	Grötsch[3]	Undefined	670–700	1	10004069
L	Hart	Undefined	700–800	1	10002605
M	Haslach	Undefined	600–850	1	10002442
N	Schönberg/Freybühel	Undefined	600–1000	1	10003648
O	Frauenberg[2]	Undefined	900–1000	1	10003647
P	Afram	Undefined	900–1000	1	10001822
R	Wildoner Schlossberg[1]	Undefined	400–700	1	10004056

[1] Wildoner Schlossberg, Im Rasental; [2] Frauenberg; [3] Grötsch: for the purpose of site catchment analysis the location of sites and stray finds located nearby have been treated as a single location.
** See online Zbiva database (https://zbiva4.zrc-sazu.si) for further details on how the chronology was determined for each site.
*** 1 – poor; 2 – good (e.g., diagnostic artefacts); 3 – excellent (e.g., stratigraphy and C14 dates).

Table 1: Early medieval sites in the Leibnitzer Feld micro-region. ID refer to *Fig.* 1 (source: Zbiva database). Note: The year 1100 indicates an arbitrary end of the Early Medieval period, but the site in question continues to exist after this date.

perform information extraction that derives terrain parameter computation and feature extraction from DEMs (Zhou 2017). Attributes computed with DEMs can be derived directly, as single or primary attributes, or compound/secondary attributes, which are functions of two or more single attributes.

From DEM primary topographic attributes, such as slope, specific catchment area, aspect, and plan and profile curvature, can be derived for each cell as a function of its surroundings. The secondary attributes, which are computed from two or more primary attributes, are important because they offer an opportunity to describe pattern as a function of process. Those attributes that quantify the role of topography in the redistributing of water in the landscape and in modifying the amount of solar radiation received at the surface have important hydrological, geomorphological, and ecological consequences in many landscapes. These attributes may affect soil characteristics (because the pedogenesis of the soil catena is affected by the way water moves through the environment in many landscapes), distribution and abundance of soil water, the susceptibility of landscapes to water erosion, and the distribution and abundance of flora and fauna. Among the secondary topographic attributes we have used landform classification and soil moisture (see below).

2.4 TOPOGRAPHIC AND GEOLOGICAL CHARACTERISTICS OF THE STUDY AREA

The Liebnitzer Feld is enclosed in the west by the uplands of the Weststeirisches Hügelland, which are cut by wide valleys of the rivers Sulm, Laßnitz and Kainach. From the Wildoner Buchkkogel the Leibnitzer Feld extends in a north-south direction and reaches the modern Austrian-Slovenian border in the south (*Fig.* 1). In the east, the study area is bordered by the edge of the Oststeirisches Hügelland. Today, the entire region is characterized by intensive agricultural use.

The western part of the study area is part of the Central Styrian high geologic formation also known as Middle Styrian Swell (subdividing the Styrian Basin), which is a geologic formation of Paleozoic (Middle Miocene) metamorphic rocks containing phyllite (Flügel 1960; Flügel, Neubauer 1984a; 1984b). The eastern margins belong to the Miocene formations (mainly sandstone) and Neogene carbonates (Leitha Limestone), which occur in a narrow and isolated area from Wildon in the north almost down to Spielfeld/Šentilj. The outcrops of Karstified Neogene carbonates (Leitha Limestone) are important, especially the area of Wildoner Buchkogel and Sukdull, because they were probably sourced for stone building material in Roman times (Bauer, Weissinger 2020). The Mur valley was

Interval (Penck, Brückner 1901/1909)	Type Unit of Glacial Stages	Type Locality
Würm	Niederterrasse (Lower Terrace, NT)	
Riss	Hochterrase (High Terrace, HT)	Helfbrunner Terrasse
Mindel	Jüngerer Deckenschotter (Younger Cover Gravel, JDS)	Schweinsbachwaldterrasse
Günz	Alterer Deckenschotter (Older Cover Gravel, ADS)	

Table 2: The Alpine Glacial Stages. The four classical glacial stages, Würm (W), Riss (R) Mindel (M), and Günz (G), and the three interglacials Riss-Würm (RW), Mindel-Riss (MR), and Günz-Mindel (GM) were named by Penck after the four Bavarian tributaries of the Danube (Donau) and Isar (Penck and Brückner, 1901). The system was later extended by adding two earlier glacial stages – Donau and Biber, and two corresponding interglacials – Donau-Günz (DG) and Biber-Donau (BD)(Eberl, 1930; Schaefer, 1953).

formed through fluvial incision and terrace development by the Middle Pleistocene to Holocene (Rabensteiner et al. 2019). Well-developed stepped fluvial terrace systems connected to terminal moraines of Quaternary glaciations formed from four individual Alpine glacial events (Penck, Brückner 1901) are characteristic also for this area (Winkler von Hermaden 1955). The geological subsoil in the Mur valley consists of early Tertiary sediments overlain by a series of stepped Quaternary gravel terraces (Suette 1986) (*Table* 2, *Fig. 2*).[1]

The system of three gravel terraces can be observed throughout the valley (*Fig. 3*). First from the eastern edges is an active flood plain of the Laßnitz river, extending to a maximum of 1 km in width to the Upper Pleistocene terrace (Würm). At its northern edge, just south of the Wildoner Buchkogel, part of the Middle Pleistocene (Riss) terrace occurs. The Middle Pleistocene (Riss) terrace extends about 5200 m to the east, where it reaches the edge of an active floodplain of the Mur River (about 3 km wide). Within the study area, the Middle Pleistocene (Riss) terrace emerges in a relatively narrow strip (1.5 km wide) again in the eastern part of the Mur floodplain, where it reaches the margins of Mindel terraces, and in the southern part also the Middle Pleistocene Terrace (Riss). A characteristic distinguishing feature between the Würm terraces, and the older ones (Riss, Mindel), is the clay layer over the gravel on the latter. On the Lower Terrace (Würm) and the present double (Mur/ Laßnitz) floodplain the clay layer is missing, which is an important fact affecting soil formation (Suette 1986). The vertical distance between the Upper Pleistocene (Würm) and the Middle Pleistocene (Riss) terraces in the study area is 5–10 m, and the vertical distance between the Middle Pleistocene Riss and Mindel terraces is especially large, reaching 23 m. The two sub-corridors of the Würm terrace (A, B) differ in water regime and soil cover. The sub-corridor A lacks perennial water and permanent water streams, its soil cover with a thickness between 0.2 and 2.5 m consists primarily of loamy sands with high field capacities and high permeability under saturated conditions (Eisenhut et al. 1992). The sub corridor B is covered with proluvial deposits, with permanent water streams coming from the East Styrian hills. In general, it has a fine sediment cover up to approx. 1 m thick, from which brown earth could often form (Untersweg 1984; 1985).

[1] Digital geological maps in a scale 1: 50.000, additionally the explanatory table necessary for the interpretation were used for the data source (https://gis.stmk.gv.at/).

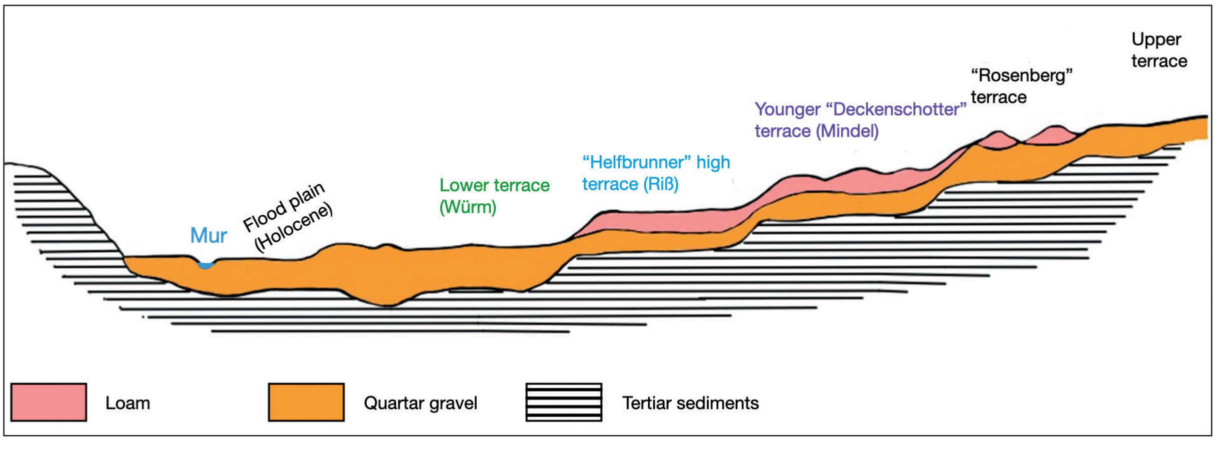

Fig. 3: A schematic section through the terraces of the Leibnitzer Feld. The Quaternary deposits comprise a series of terraces that rise in steps (modified and redrawn by E. Lozić after the Lower Mur valley terrace sequence by Fabiani (1978 Abb. 4)).

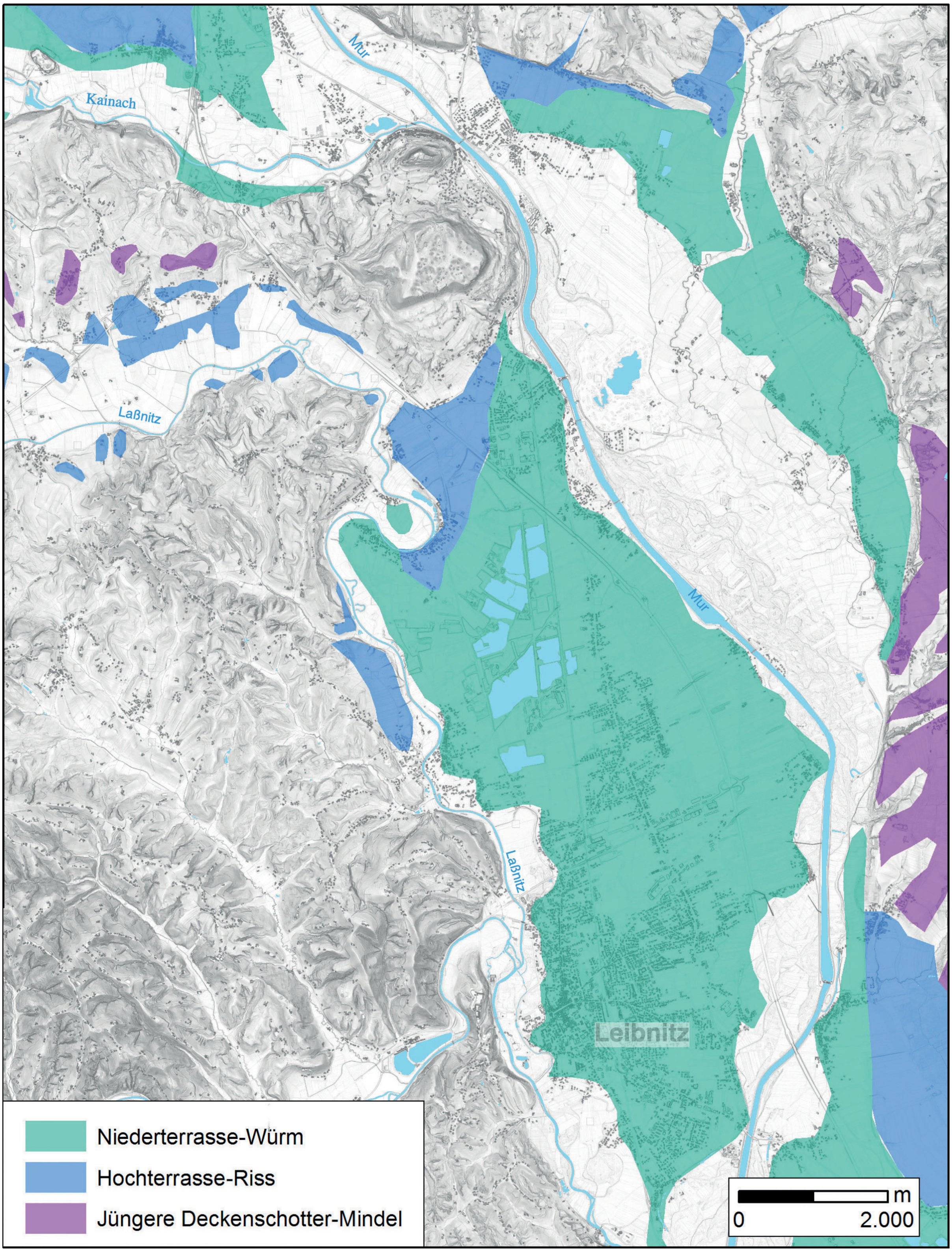

Fig. 2: Leibnitzer Feld study area, terraces from the Quaternary era.

2.5 SOIL CHARACTERISTICS

The quality of the soil is of key importance for the possibilities of agricultural production. Agriculture played an important role in the organization of economy and society in the Early Medieval period. As all sedentary farmers they were interested in occupying the best land for crop production. For this reason, we have focused on the observation of the soil characteristics of a selected region to observe the preference of the location of the settlement site. Since there is no direct evidence of the Early Medieval fields in the study area, we are drawing on the closest analogy from the Bled microregion, where it has been shown that fields were probably located within 7 min radius from the settlements (see below).

Soil data were obtained from the digital soil map[2] based on the Austrian System of Soil Classification (Fink 1969). The data are vector-based thematic representations starting at a scale of 1: 30,000. The eBOD web GIS application[3] represents the web version of the digital soil map and allows all the location properties of agriculturally usable and mapped soils.

For the purpose of this analysis, we mapped and plotted the most common soil types in the study area. According to the data three main types of soil occur within the study area (*Fig. 4*). First type are Alluvial soils (fluvisols; in the cited source marked as soil unit: *Auboden: ID 31001*), which are relatively young and undeveloped soils that were formed in frequently flooded areas by repeated deposition of sediments on alluvial deposits along the river and stream channels. These areas are usually part of the active floodplain and are vegetated by riparian forest or wetland habitat containing a combination of trees, shrubs, and/or other perennial plants (Suette 1986, 8). If the areas of parent material are loamy and silty-loam deposits that form on Early and Middle Pleistocene glaciofluvial conglomerates, they may be used as cropland or meadow.

The second type are Pseudogley soils (planosols; soil unit: *Pseudogley: ID 31013*). Their parent materials are the Pleistocene and Pliocene deposits. Due to their low infiltration capacity, they are only suitable for arable farming if they are deeply tilled and raised in the middle of the field to allow meteoric water runoff. In archaeology this type of soils are often referred to as heavy soils and the tilling as ridge and furrow. Where the water level is high (near the rivers Mur, Sulm, Laßnitz), the pseudogleyic soils are abundant. The main agricultural use is grass cultivation as meadows, forest, or arable land.

The third type are eutric brown soils (cambisols; soil unit: *Lockersediment – Braunerde: ID 20016*). In the study area, they form on sandy gravels of glacial-fluvial carbonate that cover the bottoms of the river valley and on Quaternary gravel terraces. They are used for intensive croplands because they are the most fertile soils in the area, which are well drained, sufficiently deep, and have favourable physical and chemical properties. The downsides are high stone content and low water retention capacity. We can conclude that within the study area these are most suitable soils for agricultural production.

2.6 SITE CATCHMENT ANALYSIS

The Early Medieval period is known for its self-sufficient economic model, based on agriculture and animal husbandry. Choosing a location for a settlement must have therefore been governed by physical settings important for agriculture. This means that determining (natural) factors, such as arable and grazing land, and perennial source of water, had a great effect on the settlement pattern in the landscape. Some resources, such as water, are so basic and so vital that the distance to obtain them must be minimized. In other words, those where important attributes for the selection of the location of the settlement.

The locations of known settlements are therefore a good starting point for detecting ("reading") the natural parameters that were decisive in choosing the location of the settlement. To this end, based on analogy from Bled, the time-distance parameter of 7 minutes was used for site catchment calculation sites within the Leibnitz region (Lozić 2024a in this volume with references). After establishing the site catchment area for each site (*Fig. 5*), these areas were further analysed for soil characteristics and all other available environmental variables.

2.7 DEM ANALYSIS AND TERRAIN MORPHOLOGY (Ger. Landschaftskategorien)

The morphology of the study area has been analysed using the Topographic Position Index (TPI) based Landform Classification (SAGA GIS v8). The analysis has been conducted on DEM with a resolution of 10 m, which was obtained by aggregation from the original LiDAR data. The same method has been used in the Bled microregion case study, where it is described in more detail (Lozić 2024b in this volume).

From a geomorphological point of view, the study area is characterized by the presence of two macrotopographical units (*Fig. 6*, *Table* 3): the hilly landscape (an appendix of the south-western hills that extend up to the uplands between the rivers Laßnitz and Sulm called Sausal) and the plateau landscape (naturally connected to the plain south of Graz district through the Mur river).

The Early Medieval sites tend to concentrate in the *Plain* class (altitude band 260–320m a.s.l). This is the

[2] http://bfw.ac.at.

[3] Digitale Bodenkarte, https://www.data.gv.at/anwendungen/digitale-bodenkarte-ebod/.

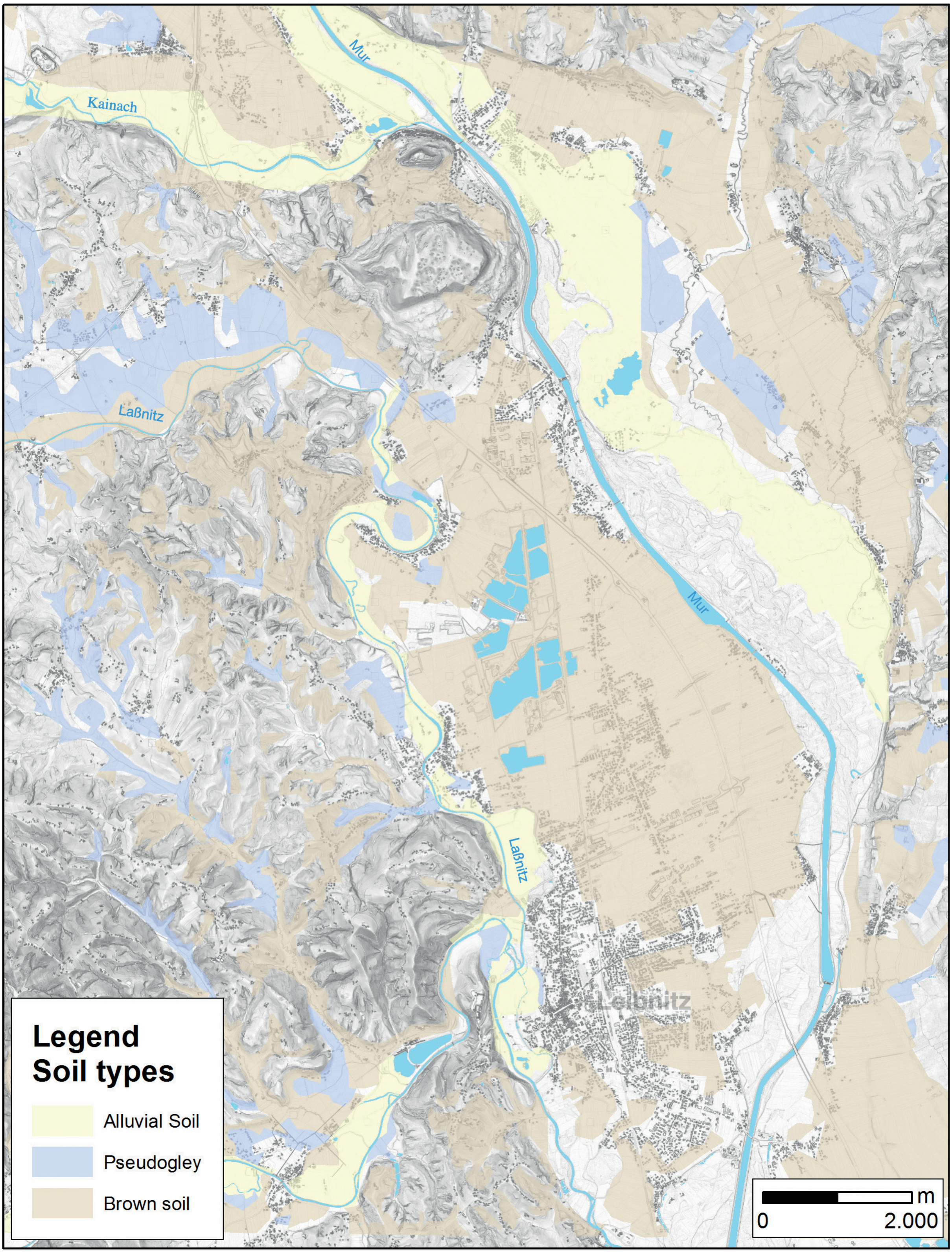

Fig. 4: Leibnitzer Feld study area, soil types relevant for archaeological analysis of the study area (source: http://bfw.ac.at).

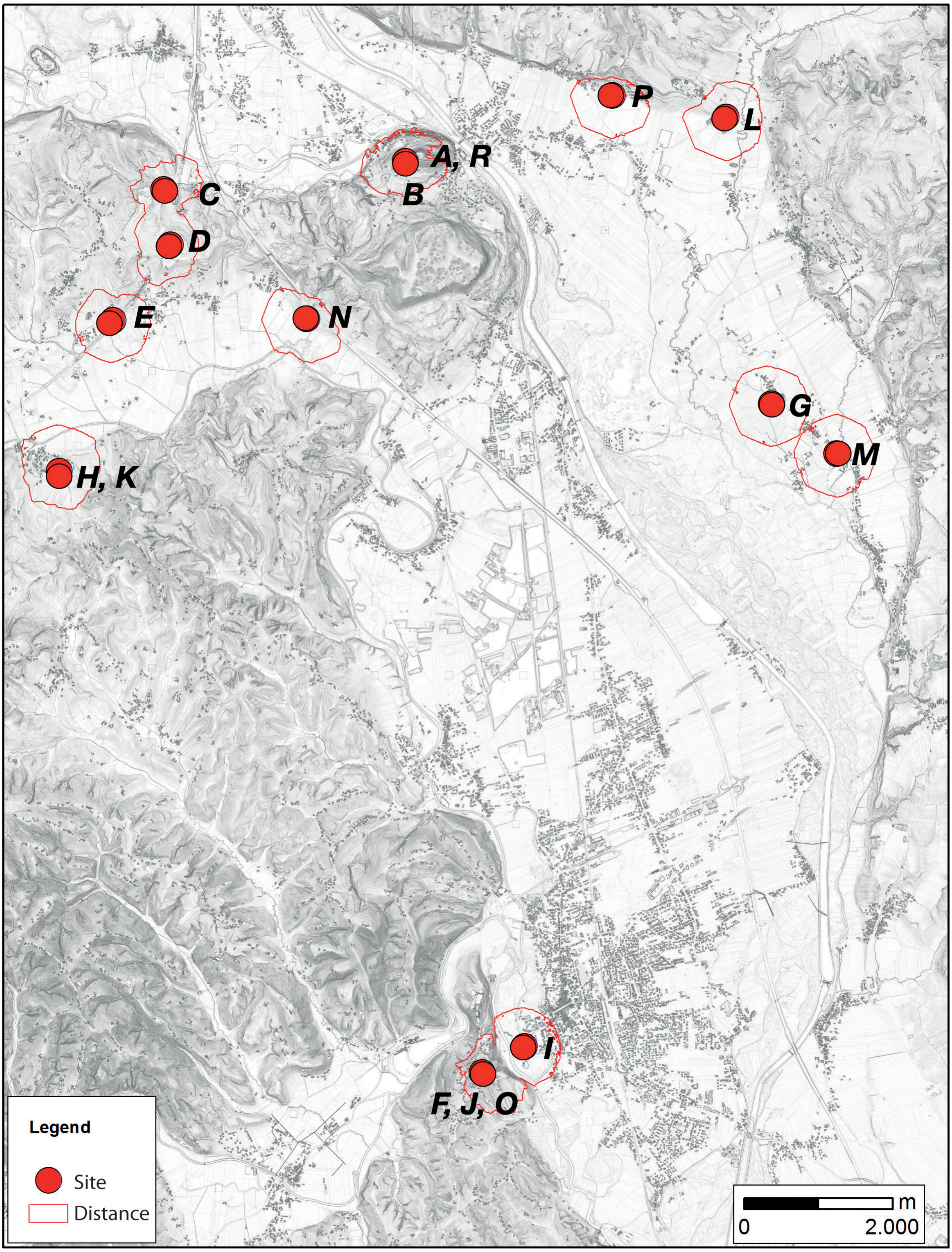

Fig. 5: Leibnitzer Feld study area, site catchment of Early Medieval locations defined as 7 min walking distance. Locations with several sites at the same location (Wildon, Frauenberg, Grötsch) are considered as a single site point (see *Table 1*).

Site	Landform analysis	m a.s.l.
Wildoner Schlossberg (A, R)	High Ridges to Local Ridges	380–420
Im Rasental (B)	High Ridges to Local Ridges	380–420
Weitendorf (C)	Open Slopes	330–370
Komberg (D)	Open Slopes	330–370
Schönberg (E)	Plains	260–320
Frauenberg (F, J, O)	High Ridges to Local Ridges	380–420
Rohr bei Haslach (G)	Plains	260–320
Grötsch (H, K)	Open Slopes to Plains	330–370
Altenmarkt, Leibnitz (I)	Plains	260–320
Hart (L)	Plains	260–320
Haslach (M)	Plains	260–320
Schönberg an der Laßnitz (N)	Plains	260–320
Afram (P)	Plains	260–320

Table 3: Landform classes, height above sea level and prevailing soil conditions for each site.

case with Schönberg (*Fig. 1:* E), Schönberg/Freybühel (*Fig. 1:* N), Altenmarkt bei Leibnitz (*Fig. 1:* I), Rohr bei Haslach (*Fig. 1:* G), Haslach (*Fig. 1:* M), Afram (*Fig. 1:* P). Several sites are found within the *Open slopes* class (altitude band 330–370 m a.s.l): Weitendorf (*Fig. 1:* C), Komberg (*Fig. 1:* D) and Grötsch (*Fig. 1:* H, K). Only two sites can be found in the class *High Ridges* (altitude band 380–420 m a.s.l): the well-known Wildoner Schlossberg (*Fig. 1:* A) and Frauenberg (*Fig. 1:* J).

The most striking result is, that the largest plain in the area between the area of the Laßnitz and Mur rivers is void of sites, which suggest it was not intensively used by Early Medieval communities (*Fig. 7*). The problem we want to tackle here is whether this difference in preference was possibly dictated by the more favourable soil types (see below).

2.8 HYDROLOGICAL PROPERTIES OF THE SOILS

As detailed above, the soils in the area differ due to the underlying lithology, which affects the hydrologic properties of the soils. More specific soil parameters can be obtained by measuring some of the parameters. One of the most important factors for agriculture are hydrological properties of the soils. The plants growing in soil with a high capacity to store the water are less likely to be exposed to water stress during summer droughts or similar events, since such soils have a larger reservoir and can supply water over time when plants need it.

Data on the hydrological properties of soil in the study area has been obtained from the eBOD application.[4] The parameters available to measure hydrologic properties are *soil permeability* and *soil water content* (Basile, Coppola 2019).

Soil permeability measures the ability of the soil to allow water to pass through it. The coefficient of permeability (k) is measured as the volume of water (m^3) that can flow through an area (m^2) per second (m/s) (Carter, Bentley 2016). The soils in the study area fell predominantly into the category of high, medium and low water permeability. For the purpose of this analysis, we have mapped all three classes of permeability that occur within the study area (*Fig. 8*).[5]

Soil water content or soil water holding capacity also known as soil's effective field capacity (hereafter FC) is the amount of water the soil can hold after gravity has drained the soil and until the permanent wilting point, when the soil is so dry that plants die. Sandy soils, for example, which cannot store much water for crops between rains, have low available FC and can be described as dry. Soils with a high FC can be either waterlogged, wet, moderately moist, or well supplied. Data on FC were also obtained from the eBOD application (*Fig.* 9).[6] The soil content categories (high, medium, and low) were also used as weighting parameters for soil moisture (see below).

[4] Digitale Bodenkarte, https://www.data.gv.at/anwendungen/digitale-bodenkarte-ebod/.

[5] The data are available on digital soil map of Austria (categories: 6 categories were joining three: low (Ger. Sehr gerig, gering, gering bis mäßig), medium (Ger. mäßig bis hoch), high (Ger. hoch, sehr hoch).

[6] The data are available on the digital soil map of Austria (categories were joint in to three polygons: moist (Ger. feucht, feucht bis nass, nass)), well supplied (Ger. gut versorgt, gut versorgt bis mäßig feucht, mäßig feucht), dry (Ger. trocken, trocken bis mäßig trocken, mäßig trocken).

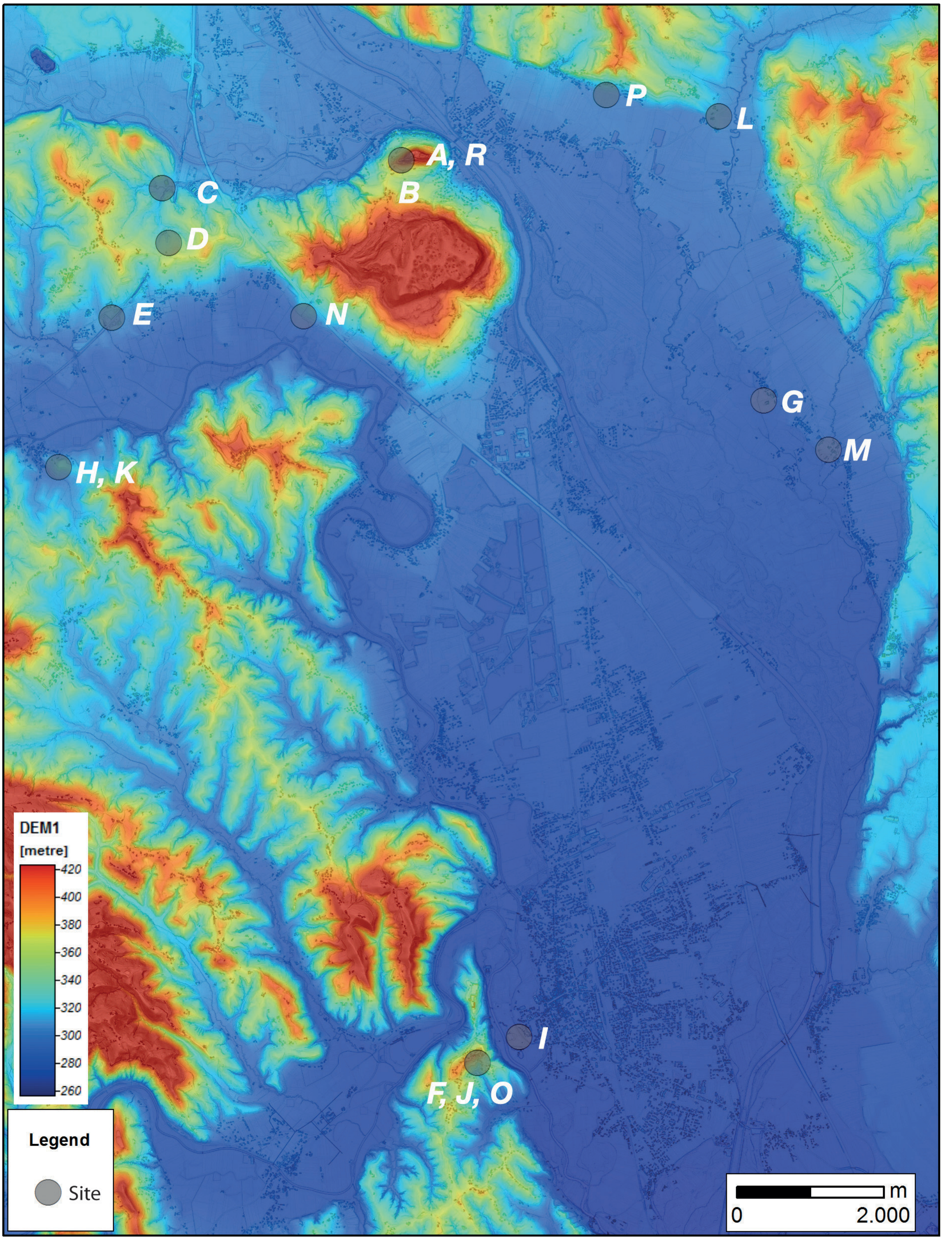

Fig. 6: Leibnitzer Feld study area, two macro-topographical units: plateau landscape (blue) and hilly landscape (other colours). The map depicts height above valley floor, calculated as height above river Mur and its tributaries, as a proxy for macro-topographical units.

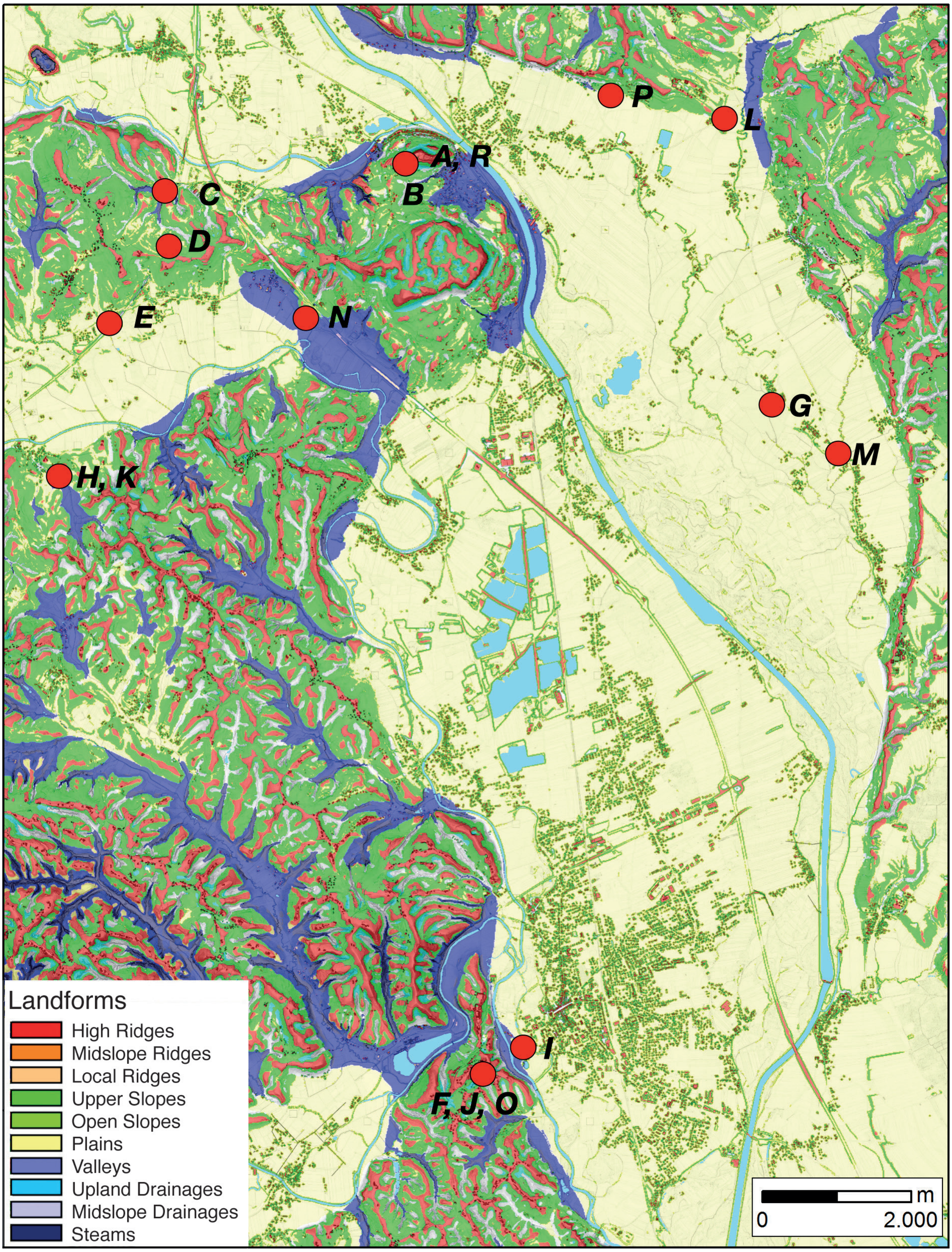

Fig. 7: Leibnitzer Feld study area, topographic position index (TPI) based landform classification (calculated with SAGA GIS v8 from 10 m DEM).

Special conditions that lead to seasonal alternation from wet to dry can be found in some small areas, resulting in a change of the soil's capacity. In this case alternation in soil moisture condition levels can be observed in winter and spring, as well as after longer periods of rain. The result is that the backwater floor or level is high, and consequently such areas are particularly damp. However, in summer and autumn it can completely dry out. The usability of arable land in such areas is limited as it is usually too wet in spring and extensive drainage measures are necessary. Soils in such areas are pseudogley and are only suitable for grasslands or forests.

2.9 TOPOGRAPHIC WETNESS INDEX

As mentioned above, secondary topographic attributes affect soil characteristics, and wetness index is such an attribute. For the present study, a distinction between dry and waterlogged areas was calculated using, as a proxy, the topographic wetness index (hereafter TWI) derived from the digital elevation model. TWI calculates the areas where water potentially accumulates and which are seasonally or permanently wet (Różycka et al. 2017). Regions within a catchment with similar TWI values are assumed to have a similar hydrological response to rainfall if other environmental conditions (such as land cover, soil) are or can be treated as the same (Qin et al. 2011). Whereas most algorithms don't consider the enhancement or impedance of local drainage, the SAGA wetness index which we used does. It is based on a modified catchment area calculation, which does not consider the flow as a very thin film. As a result of this, it predicts for cells situated in valley floors with a small vertical distance to a channel a more realistic, higher potential soil moisture (Böhner et al. 2002).

In this case study only one segment of SAGA wetness index was used: modified catchment area. This parameter reflects the amount of incoming surface water, i.e., it tells how much water flows into each raster cell during the rain (Lozić 2024b in this volume, Fig. 6). The result is represented as a hydrological attribute, that is, as a map of the modified catchment area that is represented as a highly saturated area (value from 24,000 to 16,000 pixels) or an unsaturated area (value from 2,000 to 14,000 pixels) (*Fig. 10*).

The resulting map has clearly exposed a large lowland unsaturated area between the Laßnitz and Mur rivers, i.e., geological colluvial deposits and Würm gravel terraces. By receiving little incoming surface water this area could expose plants to drought stress or water stress, which can cause substantial decline in crop yield through negative impacts on plant growth (Grewal et al. 1984). Regardless, nowadays this area is under intensive arable farming due the high quality brown soil and the favourable lowland terrain.

This was not the case in Early Medieval period, when the avoidance of this area is clearly visible. The proportion of saturated area (values between 24,000–16,000) within the catchment area of sites is very revealing. The sites such as Wildon (*Fig. 1:* A, R), Im Rasental (*Fig. 1:* B), Weitendorf (*Fig. 1:* C), and Komberg (*Fig. 1:* D), Altenmarkt (*Fig. 1:* I), Frauenberg (*Fig. 1:* F), Schönberg (*Fig. 1:* E) seem to be located in less saturated areas (*Table* 4).

3. RESULTS

Due to the complex methodology with many different types of analyses, the results of each method have been presented above for clarity. Here we only comment on the results as a whole.

Data presented above indicates that the preferred soils for agriculture in the study region are brown soils. The analysis of the presented variables within the catchment areas of investigated sites provides clues to the farmland potential (*Fig. 11*) and, indirectly, to the function of the site. It appears that there are three types of sites (*Table* 5). The first type are sites, where brown soil with high FC represents between 67% and 85% of the catchment area (Rohr bei Haslach, Grötsch, Hart, Haslach, Schönberg an der Laßnitz, Afram). The second type has only small patches, about 20% of the catchment area, covered with high FC soil (Wildoner Schlossberg and Frauenberg). The third type are the sites with less than 2% of the catchment area covered with brown soil (Weitendorf, Komberg, Schönberg, Altenmarkt). The latter are mainly covered with soils that are not suitable for cultivation of crops, predominantly pseudogley.

4. DISCUSSION

The sites of Rohr bei Haslach (*Fig. 11:* G), Grötsch (*Fig. 11:* K), Hart (*Fig. 11:* L), Schönberg an der Laßnitz (*Fig. 11:* N), and Afram (*Fig. 11:* P) are located on areas with high FC brown soil (*Fig. 11*), and they seem to belong to an agricultural settlement type. Among those, it should be noted, that the sites Rohr bei Haslach and Grötsch are cemeteries, but their location in the landscape and the abundance of arable land strongly suggest the existence of associated nearby settlements. Similarly, the sites Hart, Afram and Schönberg an der Laßnitz are only known through stray finds, but the above analysis suggest a high potential, that they are indicators of a nearby settlements (*Table* 6).

However, several sites do not have a favourable agricultural hinterland. The first group are the sites that are positioned on hilltops, i.e., landform analysis classes high ridges or local ridges. As a result, they exhibit shortage of soils suitable for arable agriculture within

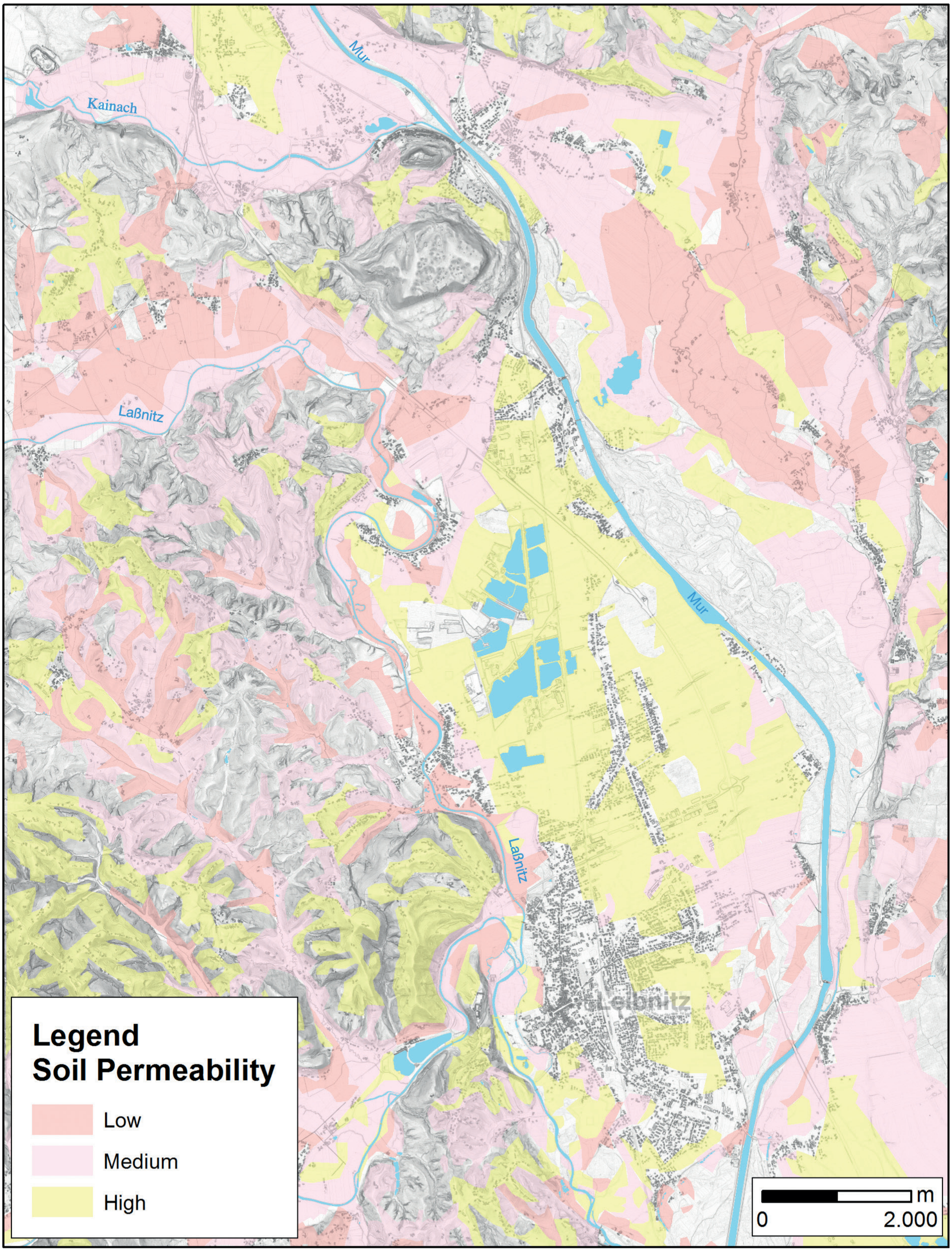

Fig. 8: Leibnitzer Feld study area, soil permeability (the ability of the soil to allow water to pass through it) classified as high, medium and low water permeability (calculated with SAGA GIS v8 from 10 m DEM).

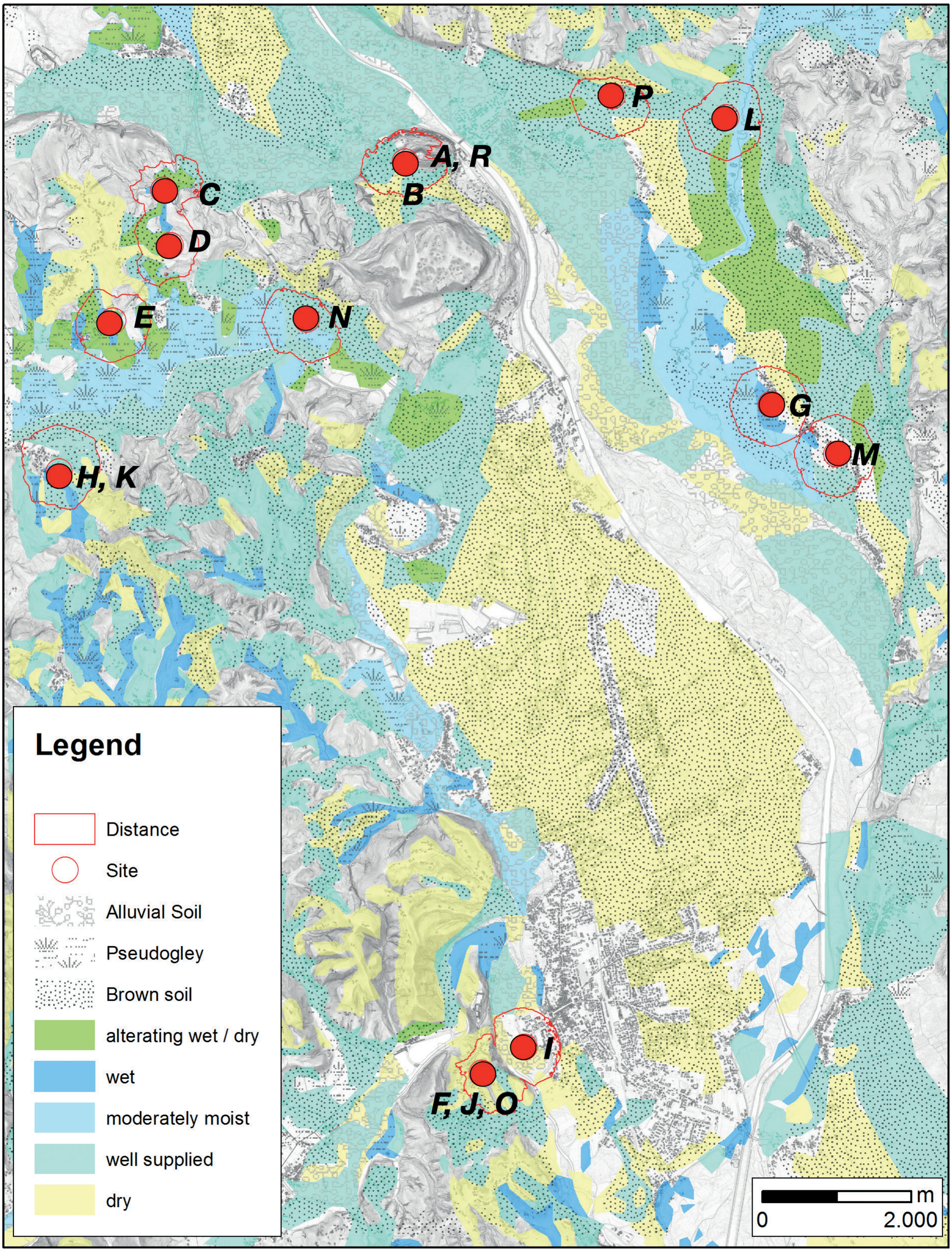

Fig. 9: Leibnitzer Feld study area, soil water content also known as field capacity (FC) classified as alterating wet / dry, wet, moderately moist, well supplied, and dry. Also represented are soil types and site catchment areas (calculated from source data obtained from the eBOD application and from LiDAR-derived 10 m DEM).

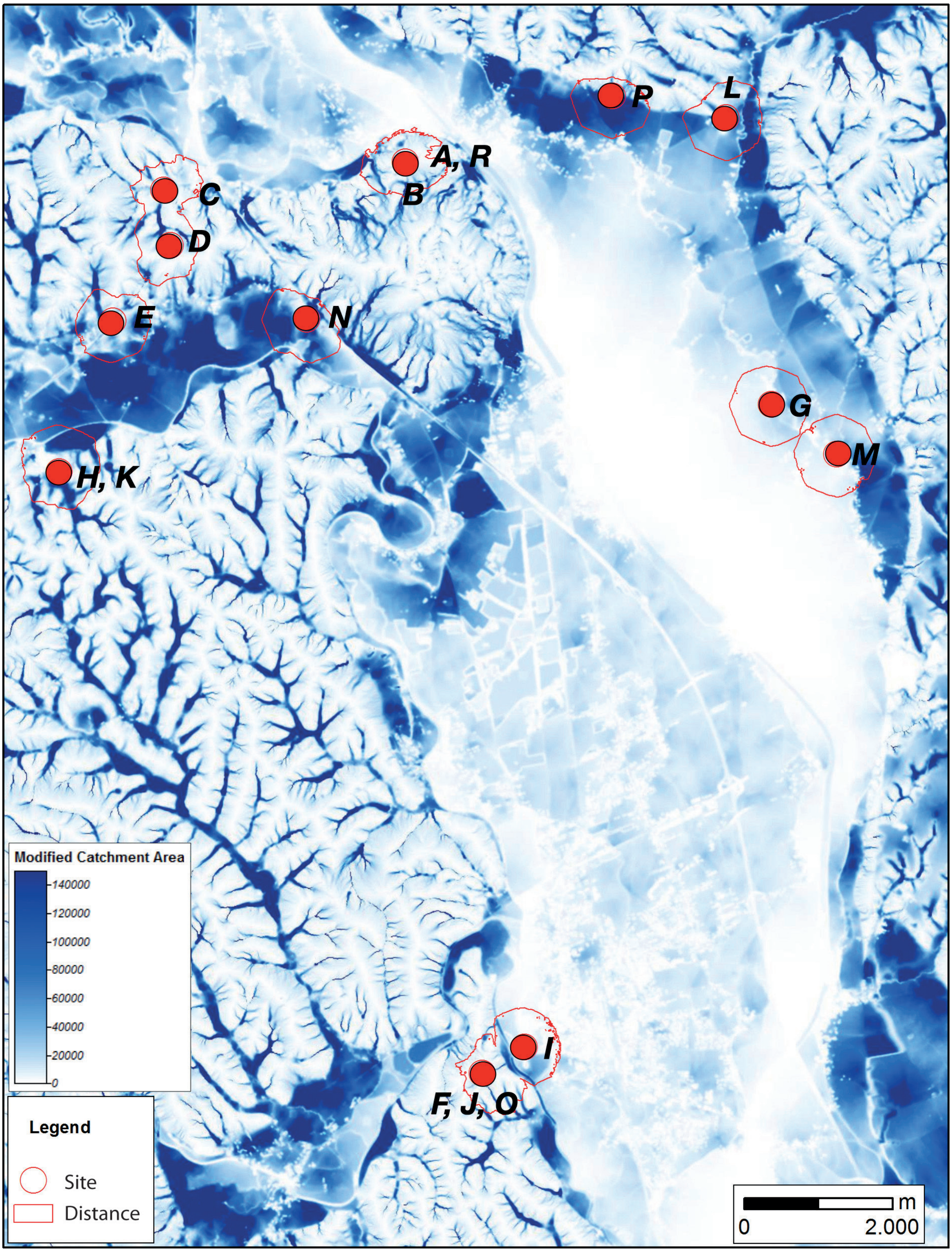

Fig. 10: Leibnitzer Feld study area, modified catchment area as calculated by the topographic wetness index (TWI).

Site	Area (km^2)	Area (ha)	% of saturated within SCA
Wildoner Schlossberg (A, R) / Im Rasental (B)	0.7	72	4%
Weitendorf (C)	0.5	51	1.9%
Komberg (D)	0.6	62	8%
Schönberg (E)	0.7	74	42%
Frauenberg (F, J, O)	0.5	56	1.6%
Rohr bei Haslach (G)	0.8	87	37%
Grötsch (H, K)	0.9	92	43%
Altenmarkt, Leibnitz (I)	0.6	65	7.6%
Hart (L)	0.8	82	73%
Haslach (M)	0.8	89	51%
Schönberg an der Laßnitz (N)	0.7	74	47%
Afram (P)	0.6	64	78%

Table 4: Percentage of saturated area within the site catchment area for Early Medieval sites.

Site	Area km^2	ha	Brown (wet) km^2	Brown (dry) km^2	Brown (wet/dry) km^2	Alluvial (dry)	Pseudogley (wet/dry)	Quality soil with in SCA
Wildoner Schlossberg (A, R) / Im Rasental (B)	0.7	72	0.15 (21%)			0.1 (14%)		21 %
Weitendorf (C)	0.5	51	0.01 (1.4%)		0.06 (12%)		0.3 (60%)	1.4%
Komberg (D)	0.6	62			0.2 (33%)		0.3 (48%)	0%
Schönberg (E)	0.7	74			0.4 (54%)		0.2 (27%)	0%
Frauenberg (F, J, O)	0.5	56	0.1 (20%)	0.02 (4%)				20%
Rohr bei Haslach (G)	0.8	87	0.6 (69%)	0.18 (20.6%)	0.013			69%
Grötsch (H, K)	0.9	92	0.7 (76%)	0.03 (3.2%)				76%
Altenmarkt, Leibnitz (I)	0.6	65		0.02 (3 %)		0.3 (46%)		0%
Hart (L)	0.8	82	0.7 (85%)		0.1 (12%)			85%
Haslach (M)	0.8	89	0.6 (67%)		0.1 (11%)			67%
Schönberg an der Laßnitz (N)	0.7	74	0.5 (67%)				0.2 (27%)	67%
Afram (P)	0.6	64	0.5 (78%)	0.1 (16%)				78%

Table 5: Percentage of soil types within the catchment boundaries.

the site catchment. This is the case for the settlements at the Willdoner Schlossberg (*Fig. 11:* A), the nearby settlement Im Rasental (*Fig. 11:* B) at the southern foot of Wildoner Schlossberg, and the Frauenberg hilltop settlement (*Fig. 11:* F). Therefore, we can suppose that these settlements were not predominantly engaged in agriculture production. Activities such as trade, religious ceremonies, legal proceedings and burying the dead were often undertaken on such sites due to their controllability and arguably, liminal nature. In the Bled microregion this type of settlements was recognised on the Castle hill in Bled (Lozić 2024b in this volume,

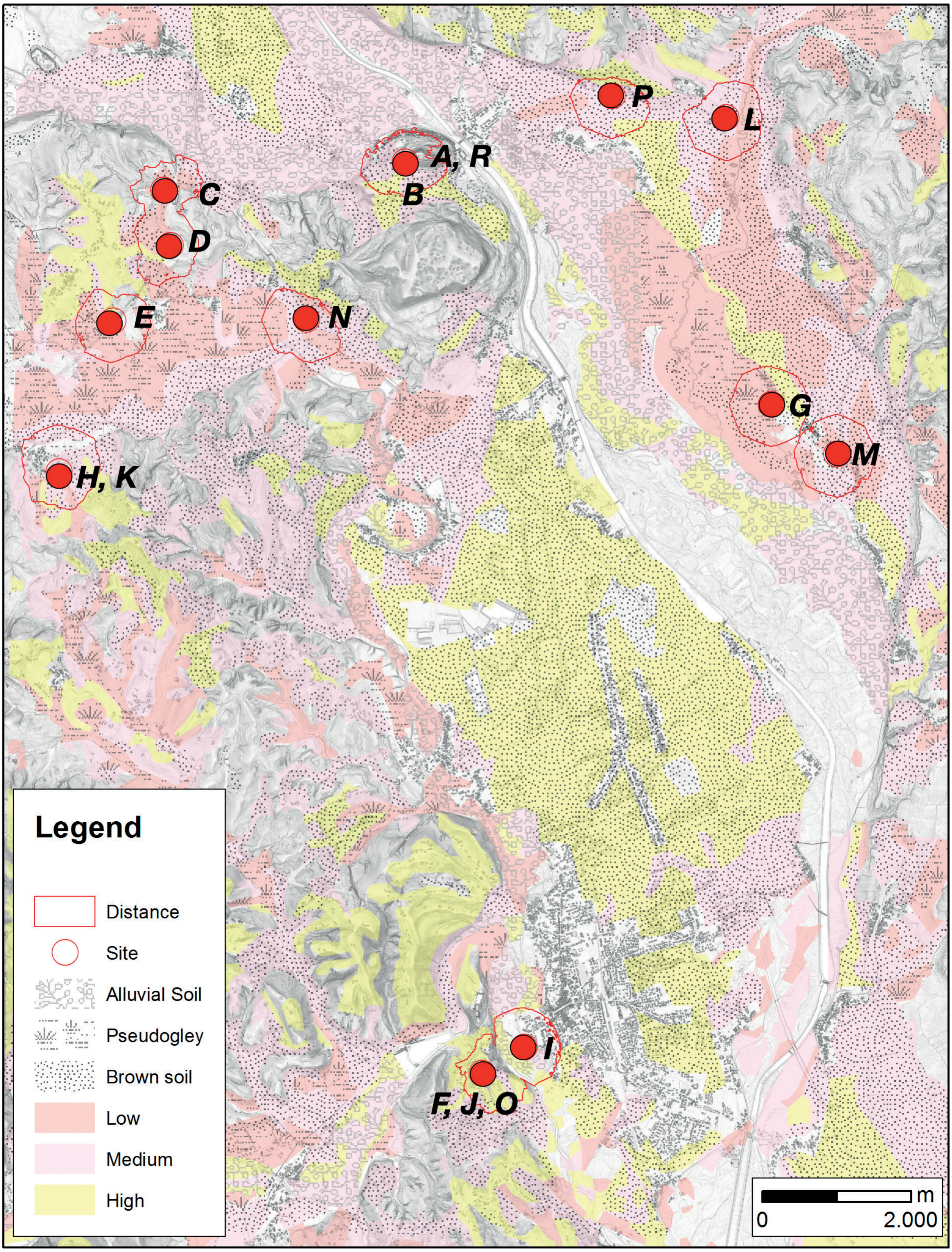

Fig. 11: Leibnitzer Feld study area, soil potential classified as low, medium and high (calculated from source data obtained from the eBOD application).

	Non-Agrarian	Mining settlement	Agrarian Settlement
Wildon Schlossberg (A)	•		
Im Rasental (B)	•		
Frauenberg (F)	•		
Altenmarkt (I)			•
Schönberg (E)		•	
Weitendorf (C)		•	
Komberg (D)		•	
Rohr bei Haslach (G)			•
Grötsch (K)			•
Hart (L)			•
Afram (P)			•
Schönberg an der Laßnitz (N)			•

Table 6: Types of Early Medieval settlements, interpretation according to hydrological properties of the soil in the study area.

Fig. 3: Grad 2). These settlements can be defined as **non-agricultural** settlement type. Possibly, they can be considered as central places that provided administrative and commercial functions.

The second group of sites without favourable agricultural hinterland include Weitendorf (*Fig. 11:* C), Komberg (*Fig. 11:* D) and probably Schönberg (*Fig. 11:* E). Characteristic of this group of sites is the fact that there is no arable land with high quality soils in their catchment area. This is partly due to the location of the Weitendorf and Komberg sites in small depressions separated by hills, and partly due to the fact that almost the entire catchment area is on soils whose water levels can fluctuate greatly during the season, so that agricultural use is severely restricted (*Fig. 8*). This strongly suggests that these sites must have been fully engaged in non-agricultural activities.

The latter fits very well with the fact that the archaeological finds from the Weitendorf site, including limonite concretions (see *Appendix*), indicate the existence of a settlement with a workshop area for iron ore processing (Fuchs 2008; Gutjahr 2011b; 2018c; Hellmuth Kramberger et al. 2019). In addition, adjacent to the site mining activities in the form of a pit field, so called Pingenfeld, have been documented with the analysis of LiDAR data (*Fig. 12*). It is therefore our interpretation, that Weitendorf is probably a mining settlement, where iron ore mined in the vicinity has been processed.

A similar location preference and soil characteristic at the Komberg site possibly suggests the same settlement type. The same is also possible for the Schönberg site – where an Early Medieval pit and pottery sherds were found on the location of a Roman settlement – which is almost entirely surrounded by unfavourable soils (*Fig. 8*). However, direct archaeological evidence for mining activities at these two sites is currently lacking.

The interpretation of a "mining microregion" is further supported by two specifics. First, the ratio between non-agrarian and agrarian settlements is disproportionately skewed in favour of non-agrarian compared to the micro-regions of Bled (Lozić 2024b in this volume) and the Drava Plain (Dravsko polje; Magdič 2024 in this volume). Second, the study area is a metalliferous region of Styria, which means that iron ore was accessible through an open pit mining.

Contemporary "mining" settlements are scattered throughout Eastern Alps: Pržanj near Ljubljana (Pavlovič 2023), Gorice-Turnišče (Plestenjak 2010, 2007), Rosenburg site in Lower Austria (Wawruschka 2009); in Styria Kirchberg-Deutschfeistritz (Gutjahr 2006) with the only probable Early Medieval blacksmith's forge known so far, and in Tyrol Virgen (Tischer, 2018). Furthermore, the recently discovered burnt layer with iron working debris in the Roman quarry Spitzelofen in Carinthia was dated to the Early Middle Ages with the C14 method (Karl 2021).

Based on the above evidence, it can be assumed that iron production and iron smelting had an important role in Early Medieval Eastern Alps. Iron ore was mined on a small scale, i.e. at a local level. Only in exceptional cases, did it play such an important role in the local economy that a notable proportion of the settlements (and thus the population) were primarily engaged in non-agrarian activities, and this may well apply to the Leibnitzer Feld. The discussion as to whether this was organised by an authority and, if so, whether it involved ecclesiastical, aristocratic or even royal landowners, goes beyond this text. It is likely that the activities related to iron extraction were organised on a seasonal basis, with preparations such as ore extraction, drying and roasting the ore, chopping wood and digging pits taking place in winter, spring and early summer, while the actual production was concentrated in the autumn, as attested for the Medieval Hedmark region in Norway (Rundberget 2015).

Fig. 12: Area north of the site Weitendorf, SVF visualisation of LiDAR-derived 0.5 m DEM (see text for details on data processing). A mining-pit-field or Pingenfeld is clearly detectable in the upper third of the figure (dark circular features).

At the end, the case of the Altenmarkt cemetery must be discussed. This is the only site in this case study whose entire catchment area lies on brown soil with low FC (*Fig. 9:* I). The associated settlement has not yet been archaeologically recognized. Most of the Early Medieval finds from the Altenmarkt cemetery can be dated to the last third of ninth and to the tenth century. More importantly, though, the relatively small size of the Early Medieval part of the cemetery and proportionally high quantity of prestigious grave goods, including a gold-plated disc brooch, suggest that this cemetery was used to bury people with above average social status. In the context of the Early Medieval period, such people are expected to have resided in a separate, primarily non-agrarian settlement. Indeed, such interpretation is in line with the possible connection of this site to the *curtis* (Ger. Hof) *ad Sulpam* that was donated in 860 A.D by Louis the German to the archbishopric of Salzburg (Koch 2024 in this volume, 225–228).

If this interpretation is accepted, it has additional importance for our analysis. If a *curtis* has been established, it signifies a different type of agricultural settlement that introduced different type of agriculture, as was the case in the Bled microregion study (Štular, Lozić 2024 in this volume). There the emergence of new settlements in the 11th century on brown soil with low FC was accompanied by a changing historical context, specifically the donation of land to the bishops of Brixen. The new landlords had the capacity to introduce a new organization of agricultural labour leading to a shift in agricultural practices. Perhaps a similar process was afoot in the case of yet unknown settlement of the *curtis* type associated with the Altenmarkt cemetery. According to the presented analysis, 46% of arable land with low FC is available within the catchment area of Altenmarkt (*Table 5*), which means that it would enable the existence of a wheat-based agricultural subsistence system.

5. CONCLUSIONS

To understand the settlement development of the Leibnitz area and to investigate how the settlement patterns evolved over time, we have carried out various spatial analyses of the available data: Site catchment analysis, DEM analysis and terrain morphology, hydrological properties of soils and TWI. Based on the results, we were able to distinguish between the agrarian and non-agrarian settlements. Among the latter the “mining” settlements are the most important discovery. If we consider the Leibnitzer Feld as a whole, it can be hypothesised to be a “mining microregion”, because the proportion of the presumed “mining” settlements is relatively high. In the context of the currently known archaeological data, which only attests to solitary “mining” settlements scattered throughout the Eastern Alps, the Leibnitzer Feld stands out in this respect. However, further archaeological investigations need to be carried out to confirm the mining activities adjacent to the Schönberg and Komberg sites.

The second important result of this analysis is an indication of the evolution of the archaeological landscape during the Early Medieval period. Again, current data are scarce, but they point to a similar development as in the Bled microregion: a gradual transition from the exclusive cultivation of soils with high FC to the inclusion of soils with low FC, indicating a different type of agricultural system.

Overall, we believe that this study has demonstrated the usefulness of our approach, which combines available data on geology and soils with LiDAR data and an archaeological database.

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APPENDIX

Site	Zbiva ID	Early Medieval Feature, Findings	References
Wildoner Schlossberg (A)	10001857	Displaced finds on the top of the Schlossberg can be dated to the Early Middle Ages ("Horizont XX"). The pottery can be dated to the 8th -10th century.	Bauer 1998; Ebner 1974; Fuchs 1994; Gleirscher 2019; Gutjahr 2018a; 2018b; 2011a; Gutjahr, Roscher 2003; Kramer, Obersteiner 1985; Mader 1986; Roscher 2001; Tiefengraber 2018
(R)	10004056	Enamel disc brooch with eagle motif; cast headdress ring.	Bauer 1998; Ebner 1974; Fuchs 1994; Gleirscher 2019; Gutjahr 2018a; 2018b; 2011a; Gutjahr, Roscher 2003; Kramer, Obersteiner 1985; Mader 1986; Roscher 2001; Tiefengraber 2018
Frauenberg (F)	10001862	"*Carantanian wall*", observed during excavations inside the existing church, it is not possible to verify the dating.	Modrijan 1963; Staudinger 1961; Steinklauber 2013
(J)	10001851	1. An enamel disc fibula and the remains of three human skeletons. 2. In a pit two headdress rings (lunula-shaped temple ring and headdress ring made of non-ferrous metal wire) and a skull were recovered.	Bauer 1998; Ebner 1974; Fuchs 1994; Gleirscher 2019; Gutjahr 2018b; 2018a; 2011a; Gutjahr, Roscher 2003; Kramer, Obersteiner 1985; Mader 1986; Roscher 2001; Tiefengraber 2018
(O)	10003647	Lunula-shaped headdress ring	
Schönberg (E)	10003649	An Early Medieval pit and an Early Medieval pottery fragment.	Gutjahr 2018b; Oberhofer 2012
(N)	10003648	An Early Medieval pottery shard.	unpublished; on the history of the area: Arneitz 2012
Im Rasental (B)	10002886	Several Early Medieval pits, and a post holes, and the small stove. Numerous animal bones (mainly cattle and horses), an iron arrowhead and a large number of Early Medieval pottery fragments.	Bekić 2018; 2016; Gutjahr 2018b; 2018c; Gutjahr, Trausner 2009
Weitendorf (C)	10002796	A total of 34 settlement objects could be assigned to the Early Middle Ages. These were mainly pits, post holes, and two fireplaces. Iron ore concretions with traces of strong heat effects were also found in some pits. Fragments of pottery, a fragment of an iron tangle knife, three ceramic spindle whorls, a stone spindle whorl and a lead spindle whorl, as well as fragments of two small purple pearls with a squat spherical shape made of opaque glass.	Fuchs 2008; Gutjahr 2018c; 2011b
Komberg (D)	10002344	An Early Medieval settlement pit with charcoal, the backfill contained pottery fragments of a few pots and a disc-shaped spindle whorl fragment.	Gutjahr 2018b; Hebert 1996; Pleterski 2010
Rohr bei Haslach (G)	10002488	Two skeletons.	Hebert 2001
Grötsch (H)	10001838	54 documented graves. Pottery vessels, belt buckles, glass beads, finger rings, combs, fire irons and flint stones, headdress rings, spurs, fibulae, animal bones, knives.	Gutjahr 2020; 2018b; Kramer 1981a; Menghin 1985; Vida 2011
(K)	10004069	Disc brooch with an inscribed cross and circular eye decoration made of non-ferrous metal from grave 8 in the Early Medieval graveyard of Grötsch.	Gutjahr 2020; 2018b; Kramer 1981a; Menghin 1985; Vida 2011

Site	Zbiva ID	Early Medieval Feature, Findings	References
Altenmarkt (I)	10001830	Two enamel disc brooches, pottery vessels, headdress ring made of non-ferrous metal, two lunula-shaped headdress rings and a spur. A bangle made of braided non-ferrous metal wires probably belonged to a burial with "mixed inventory" (Ger. "gemischtes Inventar") dated to the 2nd half of the 10th century. A total of about 60–70 burials were found, but only a part of them can be dated to the Early Middle Ages.	Christian 1981–1982; Giesler 1997; Kramer 1988; 1983a; 1983b; 1981b; Modrijan 1963; Staudinger 1961
Hart (L)	10002605	Two Early Medieval ceramic fragments.	Gutjahr 2003
Haslach (M)	10002442	Two Early Medieval ceramic fragments.	Gutjahr 2000
Afram (P)	10001822	A lunula-shaped headdress ring.	Gutjahr 2010; Korošec 1979; Modrijan 1963; Šribar, Stare 1978; 1975; 1974; Steiermärkischer Landesausschuss 1885

Appendix 1: Early Medieval sites in the Leibnitzer microregion. (Source: Zbiva database.)
(Letters in brackets refer to *Fig. 1* and *Table 1*.)