SPATIAL ANALYSIS OF HOLLOW WAYS IN THE HILDESHEIMER WALD MOUNTAINS (LOWER SAXONY, GERMANY) AS A MODEL FOR MOUNTAINOUS REGIONS OF CENTRAL EUROPE

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With 7 figures and 1 table

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Summary: The Hildesheimer Wald is a subdued mountain range situated at the northern transition from the Central German Uplands to the North German Plains. Widespread hollow way systems are distinctive anthropogeomorphic features documenting the historical importance of the region in terms of traffic and land use issues. In this manuscript we focus on the detection of hollow ways and the quantification of the surface area affected by hollow ways. Therefore, we used i) pedo-morphological field mapping in two selected areas of the central Hildesheimer Wald Mountains. These two areas were additionally surveyed using ii) a semi-automated GIS-based modelling approach to compare both mapping methodologies. The analysis of the calculated hollow-way-affected surface areas shows only minor differences (2.8 % and 0.7 %) indicating the overall high potential of this GIS-approach to map and outline hollow way systems. The pedological investigations in the two selected areas demonstrate that the soilscape is largely transformed where hollow ways frequently appear. During the development phase of hollow ways, concentrated surface runoff led to strong erosional processes at the hollow way bottoms and subsequently relatively shallow soils. In consequence, there is a remarkable loss of forestry area at degraded hollow way bottom sites, suggesting reduced usability for commercial forestry. In the second part of the study we used the GIS-mapping approach to calculate the hollow-way-affected surface area for the forested area of the entire Hildesheimer Wald Mountains. We ascertained an area of 183 ha representing approximately 2.2 % of the total mountain range. Due to methodological limitations in very shallow pronounced hollow way sections it is very likely that this value is a rather conservative approximation of the real extent of hollow way systems. Since hollow ways represent preservable environmental archives storing information on cultural landscape development, we are strongly in favor of the implementation of protection measures in these specific areas. Hollow way systems should be managed adequately to avoid further degradation and additionally increase the quantity and quality of wildlife habitats.

Zusammenfassung: Der Hildesheimer Wald ist ein Mittelgebirgszug, gelegen im Übergangsbereich von der Mittelgebirgsschwelle zum Norddeutschen Tiefland. Weitverbreitete Hohlwegsysteme sind ein charakteristisches anthropogeomorphologisches Merkmal und belegen unzweifelhaft die historische Bedeutung der Region als Verkehrsraum sowie eine umfangreiche Landnutzung der Region.Der vorliegende Beitrag widmet sich der Erkundung von Hohlwegen und der Quantifizierung der von Hohlwegen beeinflussten Flächenanteile. Dafür wurden in zwei ausgewählten Gebieten des zentralen Hildesheimer Waldes i) bodengeographisch-geomorphologische Geländekartierungen durchgeführt. Des Weiteren wurden diese beiden Gebiete ii) mittels eines halbautomatisierten GIS-basierten Modellansatzes untersucht, um die Ergebnisse der genutzten Kartierungsmethoden vergleichend zu bewerten. Der Vergleich zeigt nur geringfügige Unterschiede der ermittelten Flächenanteile (2,8 % bzw. 0,7 %) zwischen den Geländekartierungen und den GIS-gestützten Kartierungen, was auf ein insgesamt hohes Potenzial des verwendeten GIS-Ansatzes zur Kartierung und Darstellung von Hohlwegsystemen verweist. Die bodengeographischen Untersuchungen zeigen, dass die Bodenlandschaft in Gebieten mit einer hohen Hohlwegdichte deutlich verändert, in der Regel degradiert, wurde. Konzentrierte Oberflächenabflüsse führten während der Hohlwegnutzung zu erheblichen Erosionsprozessen an der Hohlwegsohle und bedingen dort folglich flachgründige Böden. Die Eignung solcher degradierten Standorte für die kommerzielle Forstwirtschaft ist deutlich herabgesetzt und die erzielten Erträge geringer. Eine forstliche Nutzungsaufgabe ist für die betroffenen Flächen naheliegend. Im zweiten Teil der Studie wurde der GIS-Ansatz aufbauend verwendet, um die hohlwegbeeinflussten Flächenanteile für den forstwirtschaftlich genutzten Hildesheimer Wald zu berechnen. Dies ergab eine Fläche von 183 ha, was ca. 2,2 % des gesamten Hildesheimer Waldes entspricht. Aufgrund methodischer Einschränkungen in sehr flach ausgeprägten Hohlwegabschnitten ist es sehr wahrscheinlich, dass dieser modellierte Wert eine eher konservative Annäherung an die realen Flächenanteile darstellt. Da Hohlwege erhaltenswerte Umweltarchive darstellen, die Informationen über die Entwicklung der Kulturandschaft speichern, wird sich nachdrücklich für die Umsetzung von Schutzmaßnahmen in entsprechenden Gebieten ausgesprochen, um eine weitere Degradierung der Standorte zu vermeiden und darüber hinaus die Quantität und Qualität von Habitaten in der Landschaft zu erhöhen.

Keywords: hollow ways, digital terrain analysis, openness, historical soil erosion, Hildesheimer Wald Mountains

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1 Introduction

Hollow way from the Anglo-Saxon term 'hola weg' means something like a harrowed path or a well-trodden road. The geomorphological term 'hollow way', also known as "linear hollows" or 'sunken lanes', refers to an erosional, mostly linear depression in the landscape, thought to be triggered by continuous passages of human and animal traffic and path related maintenance measures (Linke 1976; Wilkinson 1993; Müller 2005; David et al. 2011). Their formation is mainly caused by the degradation of vegetation cover and soil compaction along the ancient road or path networks. Due to these processes surface runoff is accelerated and concentrated, which consequently leads to linear erosion and the lowering or incision of a hollow way (Fig. 1). Depending on the natural setting (e.g. parent material, relief, intensity and purpose of use) the morphology of hollow ways may differ greatly, ranging from rather wide (> 100 m) and shallow (0.5 to 1.5 m) structures (e.g. Ur 2003) to small-scale (< 2 m) and deeply incised (> 10 m) landforms (Denecke 1969, this study).

While hollow ways in loess regions of Central Europe are accepted as important ecological habitats and cultural and natural monuments which need to be preserved (e.g. Poesen 1989; Wolf and Hassler 1993; Ambos and Kandler 1999; Dotterweich et al. 2012), hollow ways in the subdued mostly forested mountainous regions of Central Europe have received much less attention. Some former geographical studies (e.g. Hempel 1957; Mortensen 1963; Denecke 1969) mainly deal with the morphology and genesis of hollow ways to reconstruct historical road networks. More recent case studies from the Taunus mountains (Stolz 2011), the northern Odenwald (Moldenhauer et al. 2010) or the Palatinate Forest (Förster 2012) rather focus on spatiotemporal budgeting of sediment fluxes in areas affected by hollow ways. However, reliable information as to the extent to which the surface area of a mesoscale landscape, like a subdued mountain range in Central Europe, is affected by hollow ways is not yet available. In this context, several observations in the mountainous regions around Hildesheim (Lower Saxony, Germany) indicate that hollow ways or hollow way systems are widely distributed and represent an important element of the cultural landscape (Dannemann and Herrmann 2014; Sandner et al. 2014; Lahmer 2017). Moreover, the existing studies show that many morphological varieties of hollow ways can be found and that therefore their identification can be difficult. Tab. 1 summarizes criteria which can be used to distinguish hollow ways from other linear erosion features like e.g. rills, gullies or skidder trails.

With this study, we aim to draw a comprehensive picture of the morphology of two representative hollow way systems in the central Hildesheimer Wald Mountains, firstly, based on detailed pedo-morphological explorations. Secondly, we want to assess the accuracy of the field mapping results compared with estimations of a semi-automated GIS approach, using a LiDAR (Light Detection and Ranging*)* derived digital elevation model (DEM). Based on the aforementioned, we finally want to map and estimate the surface area affected by hollow way structures for the forested area of the entire Hildesheimer Wald Mountains, and thus develop a possible model for other subdued mountain regions in Central Europe. This is important e.g. regarding forestry issues or for understanding historical traffic and trade relationships on a regional to sub-regional scale. Finally, a detailed hollow way map for the entire mesoscalic landform of the Hildesheimer Wald Mountains provides the opportunity to find systematic patterns which may explain the distribution and purposes of such anthropogeomorphic landforms.

2 Study area

The Hildesheimer Wald is a subdued mountain range situated at the northern transition from the Central German Uplands to the North German Plains (Fig. 2). It is a section of the Innerste Uplands bordered by the valleys of the Leine River and Despe stream to the west, the Innerste River to the north and the Nette River to the east. The highest peak in the Hildesheimer Wald is the "Griesberg" with 359 m a.s.l. A mean temperature of 9.2°C and annual precipitation of 708 mm (Mühr 2007) classify the regional climate as temperate (Cfb), according to the Koeppen-Geiger climate classification.

The petrography of the NW-SE striking Hildesheimer Wald is mainly characterized by mesozoic formations overlying Zechstein evaporites (Bartels 1967a; Semmel 2002). The center of the complex anticline structure is built up by lower triassic formations (Bunter Sandstone, German: Buntsandstein), followed by middle (Muschelkalk) and upper triassic (Keuper) strata. Due to salt tectonics, subrosion and denudation, the center of the structure is moreover characterized by a depression in the northwestern part, which is drained by the Beuster River (Bartels 1967a; Semmel 2002). This has resulted in two facing homoclinal ridges (Bartels 1967a; Spönemann 1966, 1989).

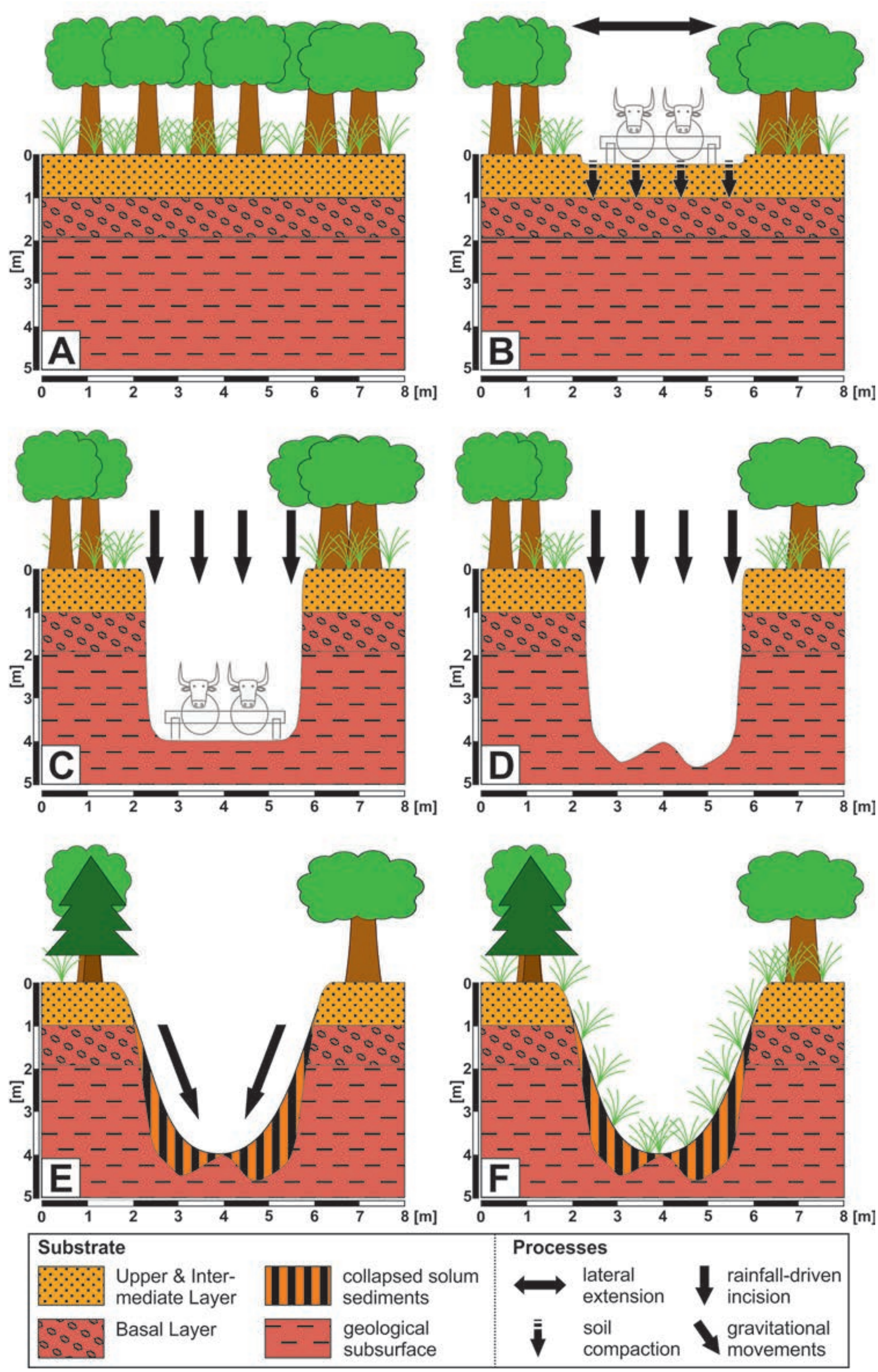

Fig. 1: Hollow way evolution model in subdued mountainous regions. A: Initial situation before hollow way formation, B: Forest clearance and road construction led to soil compaction, C: Accelerated and concentrated surface runoff caused incision of the path, D: Impassability led to abandonment of hollow ways, E: Partial infilling with collapsed solum sediments from adjacent scarps, F: Recent situation with stabilized slopes (see Fig. 4).

Tab. 1: Field criteria used for hollow way detection based on Denecke 1969, Hassler 1993b, Ambos and Kandler 1999, Müller 2005, Moldenhauer et al. 2010 and own field studies.

Geomorphic position	Topography	Pedological features	Vegetational features
located outside of hydrological channels	relatively straight patterns (plan view)	disturbed subsurface with eroded soil horizons/layers	sickle-shaped trunk growth at the sides (German: "Säbelwuchs")
running along slope spines, mountain ridges, spures and crestline gaps	confluence-diffluence junctions (plan view)	often preserved ancient ruts at the hollow way bottom	scarce vegetation and especially no or stunted trees in depression line
mostly cutting contour lines in wide angle	precipitous and sometimes steep flanks (sectional view)	Very seldom preserved historical artefacts (e.g. horseshoes) at the hollow way bottom	
often located in the proximity of historical pathways/roads	triangular to trapezoidal/ conical shape (sectional view)		

Soil formation is clearly determined by the distribution of periglacial cover beds, which modify the geological sub-surface (e.g. Bartels 1967b; Rausch 1977; Kleber et al. 2013; Dannemann and Herrmann 2014; Sandner et al. 2014). These deposits show a layered vertical structure, consisting of a Basal Layer (BL), a locally preserved Intermediate Layer (IL) and an Upper Layer (UL). The BL represents the solifluidal reworked bedrock of the surrounding area and in general contains minimal or no aeolian matter. In contrast, aeolian material is an important component of the IL (if preserved) and the UL (Kleber et al. 2013; Semmel and Terhorst 2010). In the Hildesheimer Wald Mountains, UL and IL combined show thicknesses from 30 cm at the upper slope to about 200 cm at footslopes (e.g. Bartels 1967a, 1967b; Sandner et al. 2014). During the Holocene soil genesis in the UL mainly led to the development of Luvisols (German: Parabraunerden) or rather variations of Luvisols, providing high potential for forestry use (Sandner et al. 2014; NIBIS Mapserver 2019).

As Fig. 2 shows, the region around the Hildesheimer Wald is densely settled and most settlements were founded before or in the Middle Ages (Meier-Hilbert 2001). In those days, the Hildesheimer Wald Mountains were used to gain firewood and raw materials like timber or stones, but also for wood pasture and livestock farming in the Middle Ages and modern times, resulting in degraded and even non-forested situations (Gebauer 1944; Köppke 1967; Germer 2008). For people in those days, the Hildesheimer Wald Mountains were the major morphological barrier which needed to be crossed by pathways to transport people and goods. The present-day land use in the Hildesheimer Wald Mountains is dominated by forestry, which in combination with ownership structure and the variable soil conditions results in a small-scale mosaic of naturally dominant European beech with subordinate oak trees and areas of spruce monoculture (Hofmeister 2017).

3 Material and methods

3.1 Pedo-morphological field mapping

In the central Hildesheimer Wald Mountains two selected areas with widespread hollow way structures were mapped using GPS (Fig 2b). For cross-sections depth and width were measured using a laser distance meter. Depths were classified into the classes 0-1 m, 1-2 m, 2-3 m, 3-4 m, 4-5 m, 5-6 m, 6-7 m and 7-8 m. The surface area affected by hollow ways was calculated based on this GPS mapping. Therefore, we used a 3 m buffer which represents the mean width of all field mapped hollow ways. Furthermore, soil pits were dug in proximity to hollow ways and described according to the German Soil Mapping Manual (Ad-hoc-AG Boden 2005) and Munsell Soil Color Chart (Munsell 1994).

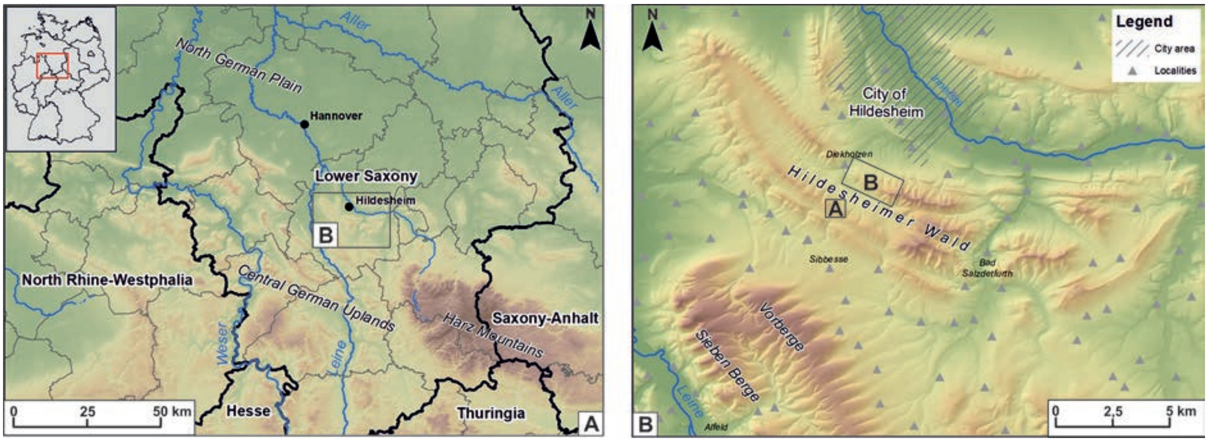

Fig. 2: A: Hildesheimer Wald Mountains (framed) at the northern transition from the Central German Uplands to the North German Plains, B: Detailed study areas A and B are located in the central part of the Hildesheimer Wald Mountains. The settlements in the region (gray triangles) date from at least the Middle Ages.

3.2 Digital terrain analysis and calculation of hollow-way-affected area

In the first step we derived the forested area of the Hildesheimer Wald Mountains using CORINE land cover data (EEA 2019). Subsequently, a LiDAR derived, high-resolution DEM (LGLN 2018) with a spatial resolution of 1 m was used to calculate relief parameters and hydrological parameters in ESRI ArcGIS 10.6.1 and SAGA GIS (Conrad et al. 2015). An openness analysis (Yokoyama et al. 2002; Doneus 2013) was then undertaken using SAGA GIS to detect linear surface structures that might indicate hollow ways (Fig. 3). Consequently, negative openness values describing potential morphological features of hollow ways (high values: bottom of the structure, low values: shoulder) were extracted from the classification by reclassifying openness values to classes. To derive coherent linear structures from the high-resolution analysis, raster values were converted to polygon features and buffered with 1 meter. The dissolved area was the base for further analyses.

To avoid misclassification, an erase data set was created to exclude irrelevant structures from evaluation. Due to the morphological similarity of natural streams and hollow ways in openness signatures, a hydrology analysis was conducted. Natural streams were calculated and buffered with 5 m. As a threshold to identify main natural streams we used a flow accumulation value of 20,000, which was validated via visual interpretation in the two intensively field mapped areas (Section 3.1). This was necessary because even hollow ways show flow accumulation in analysis results. Moreover, anthropogenic structures and some geological features were buffered based on empirical knowledge (own observations, Schmidt et al. 2018) and added to the data set. Buildings, industrial complexes, railroads, roads and paths were buffered with 10 meters. Two geological units (Muschelkalk and Keuper) were completely added to the erase data set due to a high number of quarries which also show similar openness signatures. The resulting buffered area was erased and therefore excluded from further analyses. Additionally, very small landscape features (e.g. windthrow depressions) with comparable openness values were also excluded by using a threshold value of 100 m^2 as the minimum feature size. The findings were validated with visual interpretation and field mapping results (Section 3.1).

4 Results

4.1 Morphology of hollow way systems in the central Hildesheimer Wald Mountains

In the central part of the Hildesheimer Wald Mountains two areas with well-developed hollow way structures have been selected to determine the extent of hollow way systems in the region (Fig. 2). Area A is located south of the village of Diekholzen and has a size of approximately 21.8 ha. Elevations range from 243 m a.s.l. in the southernmost crest area to 173 m a.sl. in the northeastern part. The regionally important road L 485 passes through the area and connects Hildesheim and Alfeld. Historical sources from around 1440 already mention a path in this specific area, underlining its historical significance in terms of transportation (Köppke 1967).

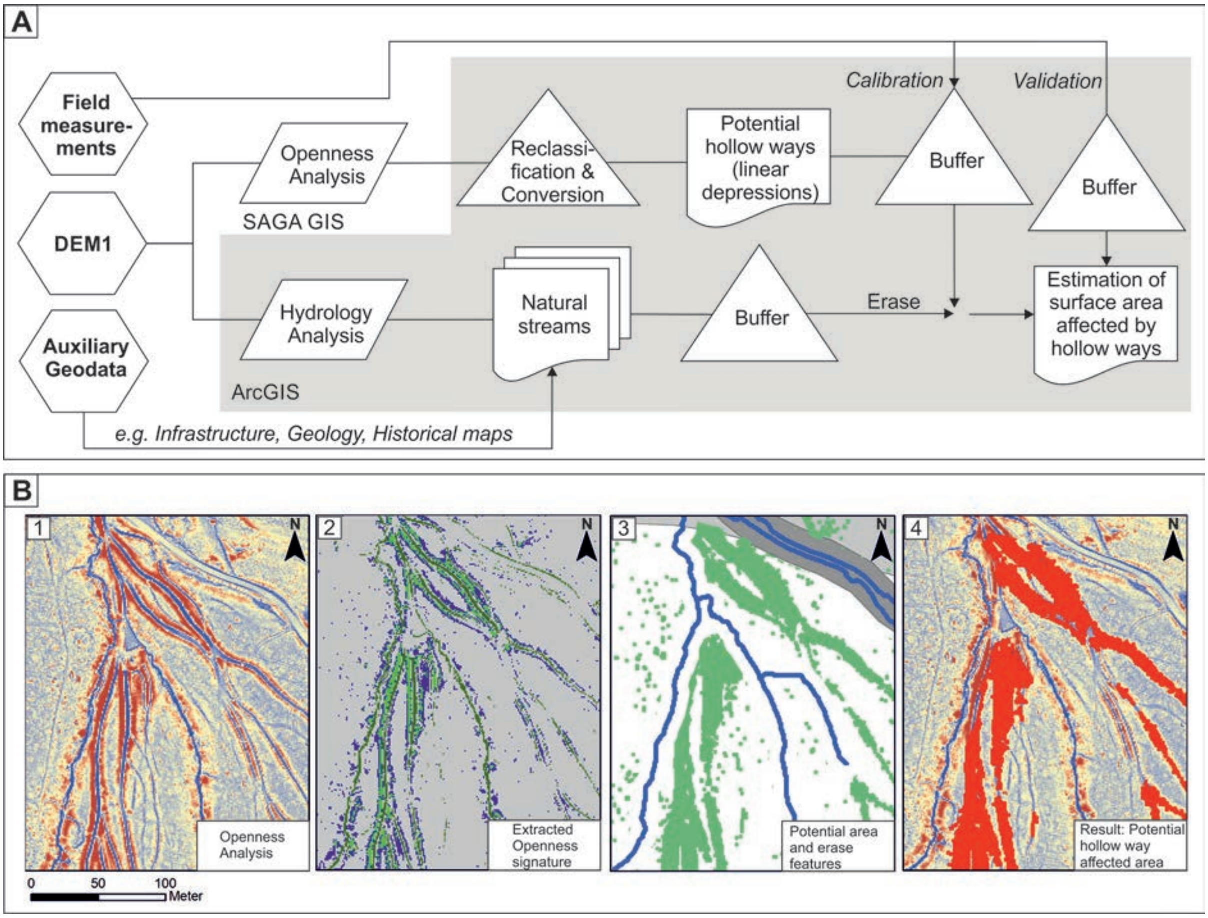

Fig. 3: A: Schematic workflow for calculation of surface area affected by hollow ways; B: Visualization of the workflow (1) Results of openness analysis (Doneus 2013) ranging from high (blue) to low (red) negative openness values. High values representing the bottom of structures, low values showing e.g. shoulders of hollow ways or valleys. (2) Classified and extracted signature of potential hollow ways. (3) Potential area (green) and erase features like natural and anthropogenic drainage systems (blue) or infrastructure (grey). (4) Results showing the potential hollow-way-affected area (red) overlaying the openness results.

Area B is situated further north at the so called "Tosmarberge". It has a size of approximately 443.7 ha and elevations range between 310 and 130 m a.s.l. Since decalcified loess deposits almost ubiquitously form the parent material for Holocene soil formation, Luvisols are the common soil type in areas A and B (Fig. 4). However, at a small scale these Luvisols locally show stagnic or podzolic properties. In contrast, the hollow way bottom generally does not show loess-containing slope deposits but rather shallow colluvial deposits covering the BL or solid rock of the geological sub-surface. Moreover, ancient rut structures are preserved sporadically and may indicate maintenance measures undertaken during the period of use to repair the trail.

Fig. 5 shows the field mapped distribution and depth of hollow way structures within the areas A and B. In area A they are mostly oriented north-south and run in more or less parallel lines next to each other. Lengths from approximately 100 to 600 m and maximal widths < 10 m were detected. The pattern of the hollow ways is rather straight with several confluence-diffluence junctions. Confluence predominantly occurs in mid-slope positions, while diffluence dominates in crest and footslope locations. It is striking that hollow ways are more deeply incised in the eastern part of area A, where they can reach depths of up to 7.8 m. In the western part hollow way incision is less deep, reaching maximum rates of 2.7 m. However, the deepest section of a hollow way (8.0 m) is located in the central part of area A and marks the historical extension of road L 485. Especially in the eastern part our data interestingly shows that hollow way incision increases along a slope gradient. Thereby, depths below 2.0 m were mapped for hollow way sections in upper slope ar-

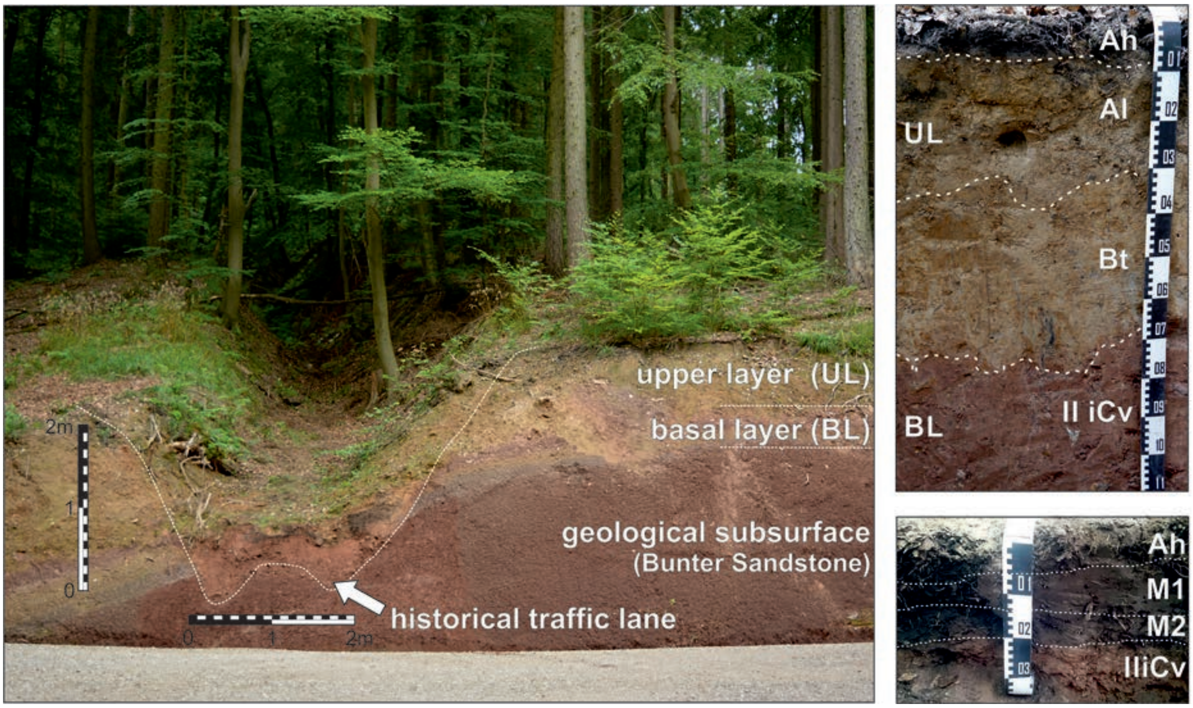

Fig. 4: Left: Characteristic hollow way in the study area with remarkable preserved traffic lanes. Upper right: Luvisol (German: Parabraunerde) developed in periglacial cover beds during the Holocene. Lower right: shallow Leptosol (German: Ranker) frequently appears in hollow way bottom positions.

eas. Incision depth increases in mid-slope positions ranging between 3.0 and 6.0 m. In footslope positions hollow way incisions up to 7.5 m were detected. Based on the field mapping results a hollow-way-affected surface area of 4.0 ha can be calculated, representing 18.3 % of area A.

The hollow way morphology and distribution within area B corresponds well with the criteria presented for hollow way detection (Tab. 1). The historical road network is oriented north-south and has a straight course without any terrain adjustments like serpentines. Furthermore, the course is located outside of the natural channels even though they frequently run in close vicinity and sometimes parallel. Three major hollow way systems with parallel lanes and several rather isolated hollow ways were mapped within area B. The largest system has developed in the western part and extends more than 1.2 km from the northern to the southern edge of area B. Another hollow way system is located in the central section and covers a larger area but with a smaller density of hollow ways. In the eastern part, area B is limited by a fan-shaped hollow way system. In contrast, only very few hollow ways were mapped on the south facing flank of area B. Compared to area A hollow way incision is noticeably weaker in area B and reaches its maximal depth around 4.0 m. The greatest depths occur in mid- to downslope positions whereas hollow ways in upper slope positions or near the crest clearly decrease in depth. The great majority of hollow ways are less than 2.0 m deep. The calculated hollow-way-affected surface area totals 16.5 ha, representing 3.7 % of area B. This has to be regarded as a minimum assumption since some areas were not accessible for field mapping.

4.2 Digital hollow way detection

4.2.1 Digital hollow way detection in the central Hildesheimer Wald Mountains (areas A and B)

To test the performance of a semi-automated hollow way mapping approach via GIS (Section 3.2) we modelled the distribution of hollow ways within the field mapped areas A and B (Section 4.1) in the first step. In general, the semi-automatically detected results are in good agreement with the field mapped hollow way distribution and show similar hollow way patterns (Fig. 5 and 6). In area A it is striking that some very shallow hollow way sections (depth class 0-1 m) were undetected using the GIS approach, which is explained by the varying signature in openness analysis. Especially in the western part of area A this resulted in the mapped distribution of the hollow ways appearing scattered and isolated in places. For area A the calculated surface area affected by hollow ways is 4.6 ha (21.1 %) and therefore slightly higher (0.6 ha or 2.8 %) than estimated via the field mapping approach. The main possible reasons for misclassifications (errors of omission as well as errors of commission) in the methodology include: i) shallow hollow ways show a different openness signature and are in some cases not detected, ii) proximity of hollow ways to erased anthropogenic or natural structures or iii) flow accumulation values of hollow ways higher than the chosen threshold value and therefore in places classified as natural streams. However, iv) too low threshold values for flow accumulation would result in the incorrect classification of natural streams as hollow ways.

In area B very shallow hollow way sections were also not detected in some cases and several isolated hollow way features are obvious. However, the semi-automatically produced map also indicates additional hollow way structures not mapped during fieldwork e.g. in inaccessible areas. With 19.3 ha (4.4 %) the calculated hollow-way-affected surface area is once again slightly higher than the estimations made by the field approach (16.5 ha, 3.7 %), providing evidence for the overall good reliability of the applied GIS approach.

4.2.2 Digital hollow way detection for the entire Hildesheimer Wald Mountains

Via the aforementioned CORINE land cover data (EEA 2019) we derived the forested area of the Hildesheimer Wald Mountains which has a size of 83.01 km^2 (8301 ha). For this area we modelled the distribution of hollow ways using the successfully tested GIS approach (Section 4.2.1). The resulting map indicates hollow ways especially in the western part of the Hildesheimer Wald, west of the town Bad Salzdetfurth (Fig. 7). Furthermore, hollow way systems seem to be much more frequent and denser in the northern section of the Hildesheimer Wald close to the city of Hildesheim. Here, particularly in summit areas, multiple hollow way systems were mapped which frequently disappear towards the footslope in the modelled map. Especially in the northern part almost every north-south oriented ridge shows a hollow way system. It is striking that hollow ways in the entire region mostly occur in several hollow lines next to each other. Continuously longer hollow ways were mainly mapped in the vicinity of Diekholzen. In southern sections of the Hildesheimer Wald hollow ways are much less common but were mapped sporadically, too. A comparable low occurrence of hollow ways was also mapped in the east of the city Bad Salzdetfurth (Fig. 7). Summing up, the GIS mapping yielded a hollow-way-affected sur-

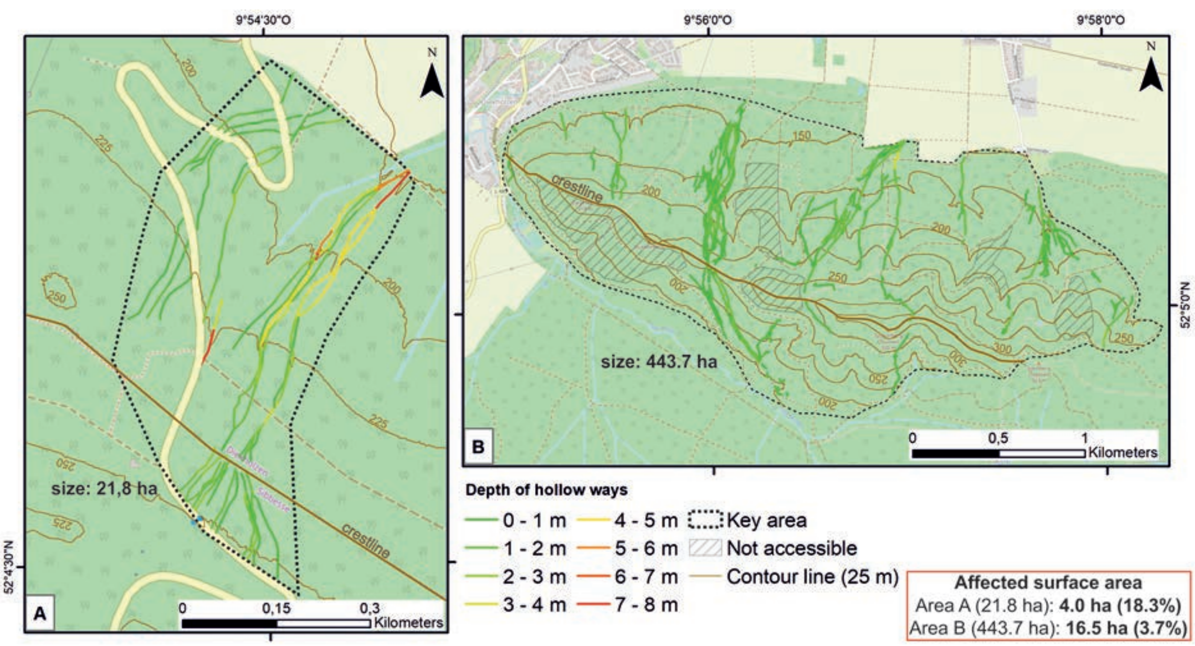

Fig. 5: Field mapping results for areas A (left) and B (right) and estimations of hollow-way-affected surface area. Basemap: © Openstreetmap contributors.

face area of 183 ha, with the great majority being located in its northern parts. That area corresponds to about 2.2 % percent of the entire forested Hildesheimer Wald Mountains.

5 Discussion

5.1 Hollow ways in the central Hildesheimer Wald Mountains (areas A and B)

In the first part of our study we surveyed two areas in the central Hildesheimer Wald Mountains to gather information about the distribution and morphology of hollow way systems and to evaluate the impact of historical traffic use on the local soilscape. Mapping of the former lanes was done using i) a field mapping approach which is certainly a time-consuming task especially for larger areas. In addition, we ii) applied a semi-automated GIS approach for hollow way mapping. The data obtained by our field based and GIS-based modelling approaches both clearly demonstrate that hollow ways are characteristic anthropogenic features in the central Hildesheimer Wald Mountains. They cover larger areas indicating the former importance of this area for transportation, trade and land use issues. Comparison of the obtained mapping results shows a relatively high accuracy of both estimations for areas A and B (Sections 4.1 and 4.2), with only minor differences of 2.8 % (area A) and 0.7 % (area B). This indicates the overall high potential of the applied GIS approach to detect, map and outline hollow way systems. However, limitations exist in very shallow pronounced hollow way sections (depth < 1 m) which were not always detected via the applied modelling approach. In these specific areas detailed fieldwork is required for final validation. On the other hand, the applied modelling approach also has big advantages since we were able i) to obtain information for areas not accessible for fieldwork and ii) high-resolution, systematical mapping can be achieved in a timesaving manner even for larger areas. However, the modelled values for hollow-way-affected surface areas have to be interpreted as a conservative, minimum estimation.

Regarding the measured hollow way depths (< 1 m to approximately 8 m) a clear relationship to the specific geomorphic factors of a site cannot be detected using the applied field mapping in areas A and B. Here, a complex mechanism involving e.g. relief, geomorphic position, operating timespan and purpose of use as well as the erodibility of the subsurface substratum seems to be responsible for triggering incision rates of certain hollow way sections. Our pedological investigations demonstrate that the soilscape is largely heterogeneous in areas where hollow ways frequently appear. In undisturbed sites layered periglacial cover beds form the parent material for Holocene soil formation and Luvisol variations dominate. Concentrated surface

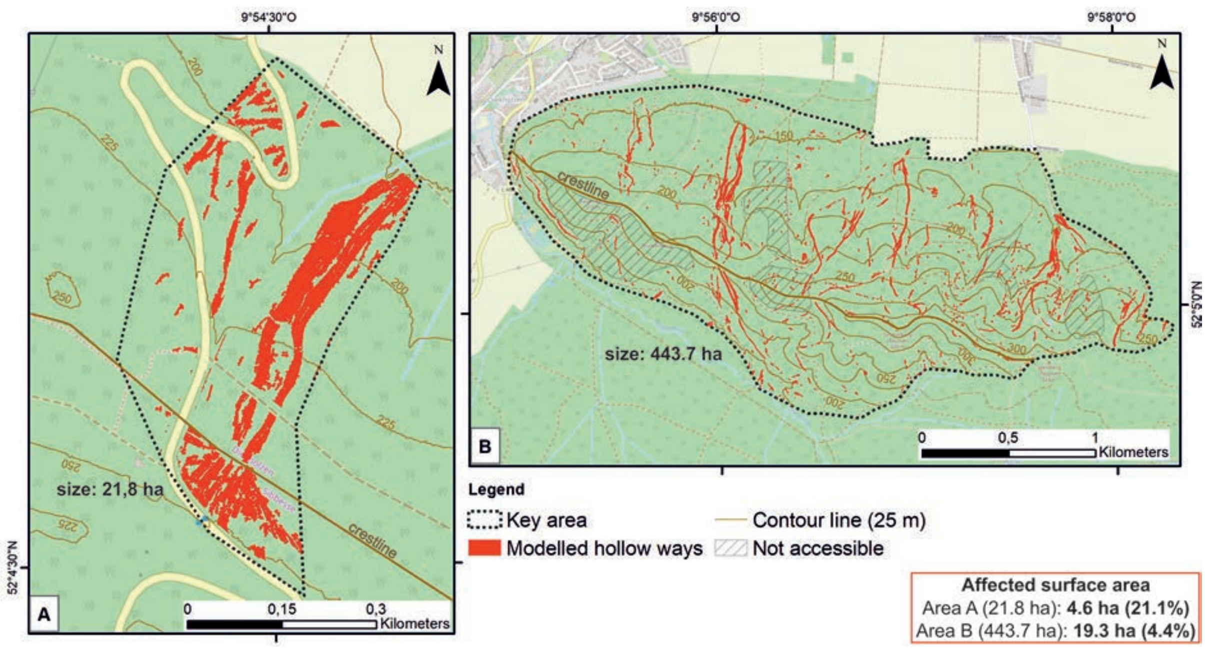

Fig. 6: GIS mapping results for areas A (left) and B (right) and estimations of hollow-way-affected surface area. Basemap: © Openstreetmap contributors.

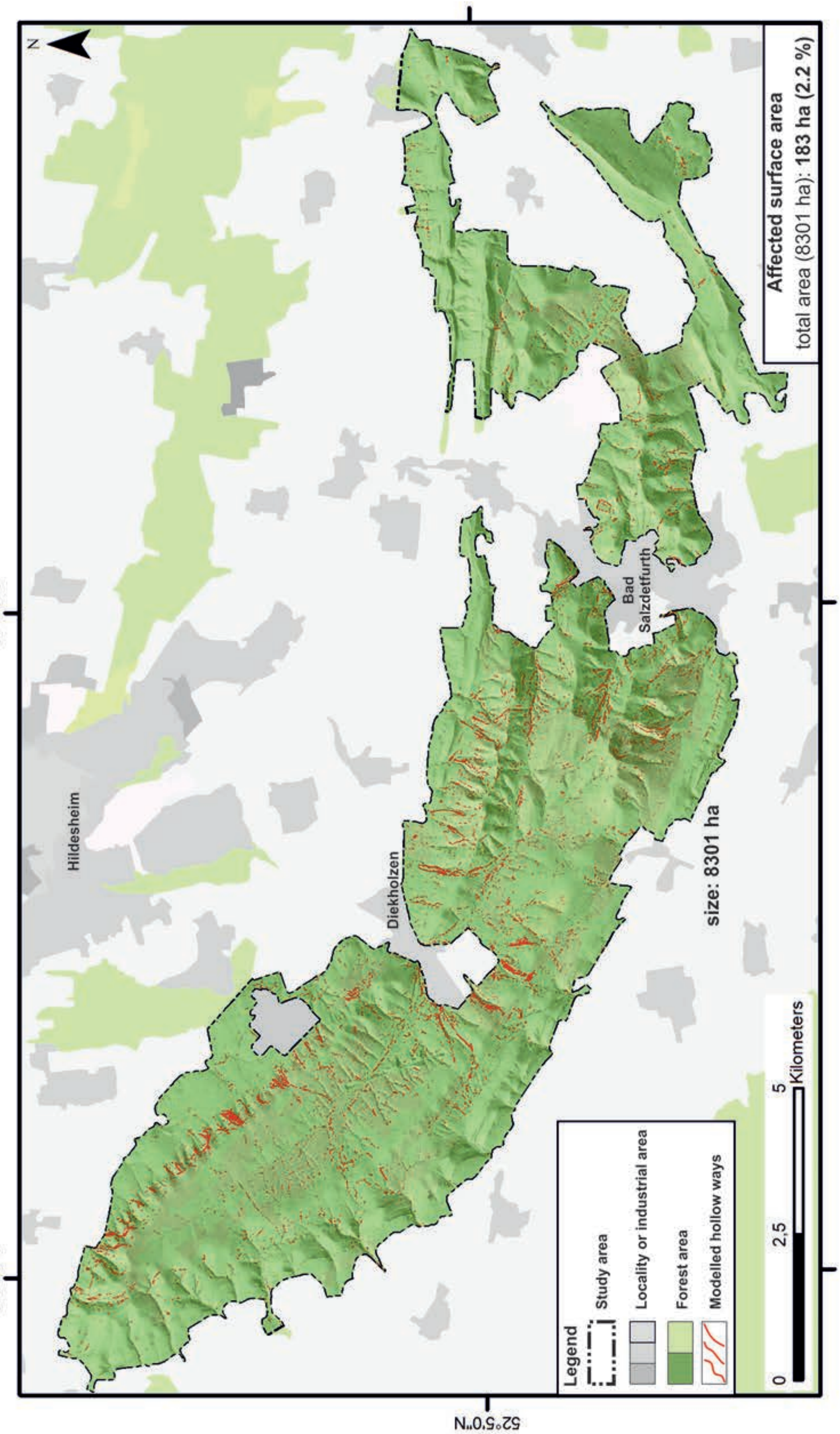

Fig. 7: Hollow way distribution in the forested Hildesheimer Wald Mountains.

runoff led to strong erosional processes at the hollow way bottoms resulting in the loss of periglacial cover beds and consequently relatively shallow colluvial soils covering the solid rocks of the geological subsurface. The physico-chemical properties of these two soils types differ clearly mainly due to the significantly lower soil depth in degraded bottom positions. Here, nutrient and water availability as well as rootability is strongly reduced (e.g. Amelung et al. 2018; Stahr et al. 2012). In consequence, degraded bottom sites show limited plant growth and especially no larger trees. In addition, the accessibility of hollow way sections is at least partly restricted and efficient managing of these areas is rather difficult. The usability of such areas for commercial forestry is strongly limited especially where hollow ways of greater depths occur. Referring to areas A and B, it must therefore be assumed that an area between 18.3-21.1 % (area A) and 3.7-4.4 % (area B) is characterized by reduced usability.

5.2 Hollow ways in the entire Hildesheimer Wald Mountains

In the second part we focused on the entire forested Hildesheimer Wald Mountains (83.01 km^2) to estimate the surface area affected by hollow way structures for a mesoscalic landform for the first time. Using the successfully applied GIS-mapping approach we calculated an area of 183 ha (2.2 %). For the reasons discussed above, this value probably is an underestimation and a rather conservative approximation to the real extent of the hollow ways. Nevertheless, the obtained value definitely demonstrates the considerable impact on the landscape of historical traffic use. It has to be assumed that this area is at least in parts less suitable for forestry since the growth of trees is reduced and/or management is rather difficult due to the deeply dissected terrain in some areas.

Even though a concentration of hollow ways is noticeable in its northern sections, the map (Fig. 7) clearly documents their frequent occurrence throughout the entire mountain range. This is evidence of the numerous purposes of the pathways. Whereas longer hollow ways might have intentionally been constructed to cross the morphological barrier of the Hildesheimer Wald Mountains and to connect the regional settlements, shorter ones might have functioned as rather locally important rural roads providing access to useful raw materials (e.g. timber or stones). However, in most cases it is observable that hollow ways frequently run in more or less parallel lines next to each other. This was already described by Denecke (1969) for some areas in the Solling and Harz Mountains. He uses the German terms “Spurenstrang” and “Spurenbündel” meaning bunched lanes and offers a plausible explanation for this observation. He argues that a multi-lane route is necessary to guarantee smooth traffic flow as it ensures that oncoming traffic can be avoided, overtaking is possible and dilapidated lane sections can be bypassed. Particularly for steep sections he furthermore mentions that a multi-lane course could develop due to the fact that light carts or even riders chose the shortest and steepest way while heavy goods transport had to search for a lane that was less steep but longer. However, while recent roads crossing the Hildesheimer Wald Mountains mainly feature serpentine courses, in historical times relatively straight lane courses were preferred even in steep sections.

6 Conclusions

This study highlights the distribution and impact of hollow ways in the Hildesheimer Wald Mountains, a subdued mountain range typical for Central Europe. Considering the results of our semi-automated GIS mapping we can conclude that the area affected by this anthropogeomorphic landform makes up at least 183 ha (2.2 %) of the entire Hildesheimer Wald Mountains and therefore represents an important anthropogenic landscape element. The presented methodology clearly shows a simple method to map hollow ways and to calculate the area affected by hollow way structures using GIS algorithms. However, local calibration and expertise are necessary to achieve reliable results and therefore we strongly recommend additional fieldwork in order to validate the modelling results. Potential limitations of the methodology were recognized in very shallow hollow way sections as well as in the surroundings of younger anthropogenic disturbance (e.g. roads). In this context, we assume that further methodological advancements could be achieved by statistically determining relevant threshold values for different landscape features. This could lead to the even more effective mapping of elements like hollow ways.

In parts of the mapped areas affected by hollow ways forestry management is potentially less productive and less economical since former soil degradation and terrain incision negatively influence tree growth and terrain accessibility. We recommend that especially areas showing deeply incised hollow ways should be managed very carefully or in exceptional cases taken out of forestry use to avoid further degradation. Since hollow ways also offer numerous ecological niches for animals and plants with very different requirements (e.g. Hassler 1993a) this strategy would also help increase the quantity and quality of wildlife habitats, in addition to the prevention of soil erosion. Another argument for the protection of hollow way structures is their function as archaeological monuments and archives (e.g. Wolf and Hassler 1993). Nevertheless, compared to hollow ways in loess regions of Central Europe the perception of mountainous hollow ways is marginal. This may be due to the fact that they are mainly located in forested areas and therefore are less visible for most people. However, since they store essential historical information on cultural landscape development, we are strongly in favor of the implementation of protection measures in these specific areas.

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