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First attempt at mapping the historical spatial distribution of rice cultivation after 1945 in Slovakia from military topographic maps

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Abstract

We present the first Slovak national-scale reconstruction of post World War II rice cultivation in Slovakia using two military cartographic series (Military topographic mapping 1:25,000 – VTM25, 1952–1957; and 1:10,000, 1958–1971 – VTM10). Rice-field polygons were manually digitized strictly where the specific rice symbol occurs. We further verified the cartographic interpretation via a hydrotechnical case study (Zalaba project plans) and screened national WMTS tiles with a high-recall YOLOv5 utilized as a completeness check. We also cross-checked for positional error using independent church-tower control points (RMSE ≈ 18.5–21.5 m). We delineate 434 fields in 50 municipalities (2,297.7 ha) on VTM25 and 147 fields in 10 municipalities (254.34 ha) on VTM10, revealing a sharp post-1960 contraction with only ~11% of area persisting. LiDAR (1-m DTM) confirms preserved irrigation system fragments at several sites. Together, these lines of evidence show a brief expansion peak in the late 1950s followed by an abrupt termination, likely driven by policy and economics rather than local feasibility alone. We also highlight data limitations (symbol generalization, sheet-year asynchrony) and provide conservative area estimates. This national inventory provides a baseline for Central-European comparisons and for heritage-oriented conservation of agro-hydrotechnical relics.

Key words:
rice fields, Slovakia, historical, military topographic maps, spatial distribution

1 INTRODUCTION

Oryza sativa L., belonging to the *Poaceae* family, is one of the two domesticated species of the genus *Oryza*. Today, it is a globally widespread cereal and one of the most important food crops, especially in Asia and Africa (Gnanamanickam, 2009; Fuller & Castillo, 2014; Shaheen et al., 2022). Domesticated rice comprises multiple genetic lineages, the two main subspecies are ssp. *japonica* and ssp. *indica*, with the aus group considered a distinct cultivation lineage of *indica*. Genomic studies indicate multiple simultaneous domestication processes with substantial gene flow (introgression), resulting in high variability of biological and ecological traits (Sweeney & McCouch, 2007; Choi et al., 2017; Das & Khanda, 2020). From original primary centres of domestication in East and South Asia, rice cultivation spread south and westward into Southeast Asia, Central Asia, and the Middle East (Choi et al., 2017; Spengler III et al., 2021). In the European context, rice is currently grown predominantly as *japonica* and, to a lesser extent, *indica* variants adapted to cooler conditions than those in the tropics, namely in Spain, Greece, Portugal, Bulgaria, and Italy, which is the largest producer of rice in Europe with an area of 227.49 thousand ha in 2025 (Eurostat, 2025). In the Central European context, rice cultivation is relatively rare, but it has some historical basis. Hungary, which represents the area of rice cultivation closest to Slovakia, cultivates 2,920 ha in 2025, predominantly at sites with preserved historical infrastructure (Apáti, 2003; Eurostat, 2025). They grow mainly local varieties for example Dunghan shali, Kákai 203, Oryzella, and Sandora, which are adapted to local conditions. The variable microclimate creates limiting conditions here, the greatest risks are cold and severe drought. Hungary lies at the northern limit of rice cultivation in Europe as of today (Jancsó, 2024). The two main rice-growing locations in Hungary are the counties Jász-Nagykun-Szolnok and Békés (Szuts et al., 2021).

Rice was also cultivated in the past on the territory of Slovakia. We do not precisely know the exact area or the individual municipalities where rice cultivation historically occurred. The main aim of this article is to map rice fields in Slovakia in the period after 1945 by means of manual (literature, archival research) and automatic (with the help of ML) analysis of nationwide historical cartographic works. We aimed to identify the places and forms of rice cultivation in Slovakia in the period after 1945. With this methodological approach, we will attempt to identify all mapped rice fields shown on military topographic maps at scales 1:25,000 and 1:10,000 produced in the 1950s and 1960s, with a temporal dimension for the interval of rice cultivation within Slovakia. We proceed from the premise that contemporary account of Fekete (1952) captures only the beginning of the post-war experiment. We expect that military maps from the second half of the 1950s will already depict a larger and more spatially contiguous extent of rice fields. The assumption is that, between the work of Fekete (1952) and the later maps, the dynamics of postwar expansion and rapid decline will be evident. A partial objective is an attempt to identify fragments of irrigation-canal systems that have been preserved to the present. With this contribution, we add to knowledge on the little-explored history of rice cultivation in Europe, specifically in Central Europe and in Slovakia.

Rice grows in diverse environments: in irrigated areas, on rainfed lowlands, in deep water in wetlands, on elevated drier soils, and in tidal marshes. Irrigated rice cultivation requires substantially more water than other crops—approximately two to three times the consumption of other cereals. Under the conventional transplanted-rice system, an average of about 2500 litres of water is used to produce one kilogram of paddy rice (Cordero-Lara, 2020). For the *japonica* variant, during the period from sowing to emergence, the base temperature for germination is 11 to 12 °C, the cultivation optimum 24 to 28 °C, and the maximum 35 °C. Low temperatures can damage the crop at any growth stage and reduce overall yield (Ferrero & Nguyen, 2004). Water, together with temperature, is the most important factor in rice cultivation. Among other things, it satisfies physiological needs such as crop growth and development, acts as a thermal regulator, and is the most evident and important thermal protection in the initial phase of the cycle as well as during flowering. Rice is mostly grown submerged and is actively flooded in the early stages of growth (Jancsó et al., 2017; Ferreira et al., 2023). Three planting methods predominate: dry-seeded, wet-seeded, and water-seeded. Wet-seeded planting is used most extensively, but dry-seeded planting has also begun to be adopted more recently due to lower water use; however, the paddy must then be irrigated (Kumar et al., 2023). So-called aerobic rice is also used, which is not directly flooded, yet the supply of a certain amount of water is still necessary, especially by irrigation canals at the paddy level (Jancsó et al., 2022; Bo et al., 2025). Because the crop requires irrigation, substantial interventions in the local landscape are necessary to build terraces or canal irrigation systems. Terraced rice fields are built at high elevations and on steep slopes; their main function is to retain water. Canal irrigation systems are constructed in flat and moderately elevated localities (Chen et al., 2014). In the European context, canal irrigation systems predominate, bringing water from rivers or mountain streams (Kraehmer et al., 2017; Gómez de Barreda et al., 2021; Bo et al., 2025). Rice cultivation has historically been, and remains today, labour-intensive, despite extensive mechanization of some operations (Hoki, 1977; Hoque et al., 2023).

Specific historical land use and land cover (LULC) types can be examined at a nationwide level by studying country-wide historical map or map series. In the Central European context, specifically Slovakia, most notable and useful for national level analyses from the early modern period are the First, Second, and Third Military surveys of the Austro-Hungarian Empire, mainly for their wide coverage and a rich legend. More modern and highly valuable are national topographic maps from 1950s to 1970s, capturing land use and landscapes in transitional periods (MŽP, 2022). In recent years, automated analyses of historical maps have become increasingly common in the study of large cartographic corpora. Numerous studies have demonstrated automated methods for various landscape features on historical maps – from classifying large areal land-cover regions to pinpointing small point symbols and text labels. For instance, color-based unsupervised classification has been used to automatically extract extensive features like 19th-century forest cover (Herrault et al., 2013), and deep learning segmentation can delineate complex areal features such as historical wetlands with high accuracy (O'Hara et al., 2024; Vynikal et al., 2024). Likewise, line features such as roads or boundaries can be traced via either classical image processing or modern convolutional neural networks – recent approaches include both fully convolutional segmentation of road pixels and object-detection of road intersections for network reconstruction (Saeedimoghaddam & Stepinski, 2020; Jiao et al., 2022). Point symbols (e.g. icons for structures or land elements) are typically detected as objects, for example, Mask R-CNN models have achieved high accuracy in identifying multiple topographic point symbols on historical map sheets (Vassányi & Gede, 2021). Meanwhile, map text (labels and toponyms) can be handled by optical character recognition (OCR) preceded by tailored text-region detection to improve results (Schlegel, 2021). Table 1 is intended as a compact guide to established tools and workflows for automated vectorisation/detection in historical cartography, with examples covering areal classes, linear networks, symbols, and map text.

Mapping the historical extent of rice fields is known, for example, from the USA (Hanks et al., 2021). Systematic examination of the environmental and economic aspects of rice fields in the European part of the Ottoman Empire in the Early Modern period was undertaken by Shopov (2019). Studies more often focus, for instance, on the typology of rice fields (Tabayashi, 1987) or on the management of flooding canals (Masseroni et al., 2017), harmful weeds lowering yields (Kannan et al., 2017), and the

Tab. 1. Summary of tools for automated approaches for detecting or extracting different features in historical cartographic sources

Tool	Mapped features	Automated approaches	Study
Historical Maps Vectorization Toolbox (HMVT)	fluvial corridors	Colour-based classification; preprocessing; postprocessing; raster to vector	García et al., 2020; Dunesme et al., 2022
MapKurator	text labels (toponyms)	OCR on map images, linking of text to spatial data	Schlegel, 2021; Kim et al., 2023
U-Net	wetlands	Deep convolutional neural network for semantic segmentation	O'Hara et al., 2024; Vynikal et al., 2024
YOLO-based	map symbols and icons denoting land use	CNN object detection using YOLO (You Only Look Once)	Smith & Pillatt, 2023; Pai et al., 2025
SegFormer (Transformer)	road networks	Transformer-based semantic segmentation (SegFormer) to classify pixels	Sertel et al., 2024

optimization of flooding methods (Zhang, et al., 2020; Lee, 2022). In Slovakia and in the broader Central and Eastern European region, systematic historical-geographical research on rice fields practically does not exist, creating a significant knowledge gap about these agroecosystems. The goal of our study is to fill this gap by combining historical maps and LiDAR data that represent the current state to reconstruct and analyse defunct rice fields, thereby offering a new geographical perspective on their extent and legacy. By integrating historical cartographic sources with modern geoinformation techniques, we build on proven approaches and aim to contribute insights into the historical spread of rice cultivation in the region with systematic mapping. We hope to record almost lost part of Slovak agricultural history and preserve the knowledge connected to rice cultivation.

2 History of rice cultivation in Slovak context

The general history of rice cultivation is relatively complicated. Some of the earliest archaeological evidence for the domestication of rice dates to around 9000 BP in China (Zheng et al., 2016; Zuo et al., 2017). In the Mediterranean, the first grains of rice in archaeological excavations are documented to the 12th century BCE (Before Common Era) from the palace of Tiryns belonging to the Mycenaean culture, and it later appears in the 1st century CE at various sites of the Roman Empire, including north of the Alps. Only small quantities of seeds were documented at individual sites, and from different contexts we know that rice seeds were used for medical and religious purposes. In this period, rice was most likely not cultivated in the Greco-Roman world and was imported from the East. From the early 7th century begins the so-called Arab Green Revolution, which brought several new cultivated plant species to the Mediterranean, including rice (Muthukumaran, 2014). In a later period, rice played a marginal role in the Byzantine Empire, but by around the 10th century it was already present in texts concerning diet (Kokoszko et al., 2013). Rice probably reached Europe by several routes: from Greece or Egypt to Spain and Sicily in the 8th century, and from Persia to Spain in the 8th century, from where it spread to Italy between the 13th and 16th centuries (Chang, 2000). Italian varieties are genetically related to the North Chinese varieties of the *japonica* subspecies (Cai et al., 2013).

It is questionable whether the Ottomans cultivated rice in Hungarian or Slovak territory during the occupation between the 16th and 18th centuries, as mentioned by Csapody (1953). Sert (2021) does not mention Hungarian localities, although Temesvár (Timisoara) is mentioned, where rice cultivation was introduced by Italian entrepreneurs/settlers under the reign of Maria Theresa and Joseph II (Büchl, 1976). It is documented that in the southern Balkans, for example around the city of Niš the Ottomans cultivated rice intensively, but Hungarian areas are not mentioned in Amedoski (2017), even though Szuts et al. (2021) state that there is evidence of rice cultivation by the Ottomans in the 14th century; however, this does not correspond to the period of Turkish occupation in the Kingdom of Hungary in the conservative interval 1526–1699 (Pálffy, 2001). Pinke et al. (2014) writes about the Italian origin of rice cultivation in Hungary in the 18th century, which would correspond to the timeline from Temesvár. From the available sources we can verify that rice cultivation in territory of today's Hungary began certainly sometime between the end of World War I and the end of World War II, but likely earlier. By 1946, however, rice cultivation was undergoing in the territory of present-day Hungary (Simon-Kiss, 1997; Gombos, 2008). From 1947, rice cultivation began in the territory of then Czechoslovakia; it was brought to southern Slovakia by resettlers from Hungary (Česká televize, 2013a; Fekete, 1952).

At present, large-scale rice cultivation is not present in Slovakia, as evidenced by the fact, that no area in category 213 Rice fields in CLC2018 is found in Slovakia (CLMS, 2020). The only relevant academic source on the cultivation of rice in Slovakia is the work of Fekete (1952), which describes this phenomenon in its historical period, as well as various climatic, technical, and social characteristics of rice cultivation. It states that the first trials on Slovak territory took place during the World War II the Danubian Lowland under the supervision of Hungarian farmers. This claim is questionable at best. It further states that full-scale rice cultivation in Slovakia began in 1947, and that repatriates from Hungary had a significant share in the development of rice cultivation. This form of farming was highly labor-intensive. In the Slovak context, this period also mentions combined rice cultivation with fish and poultry rearing. The two main cultivation localities in the Danubian Lowland are given as the municipalities on the lower Hron near the Perec channel and the area around Kolárovo–Kameničná. To a lesser extent, it is cultivated in the Potiská nížina (Eastern Slovak Lowland), the Intravulkanická brázda (possibly within the Southern Slovak Basin), and other parts of the Danubian Lowland. The area in the text is given as approximately 400 ha. Csapody (1953) states that in Hungary the variety *Oryza sativa* (subsp. *japonica*) cv. Doungham Shali was cultivated, and Fekete (1952) also mentions that this variety (or its equivalents?) was adopted from Hungary and the USSR. The varieties adopted for cultivation in Slovakia were selected for their relatively short vegetation period and cold tolerance. This was largely an ideologically motivated activity, since in the early 1950s there was a prevailing motivation for agricultural production self-sufficiency in Czechoslovakia. Another motivation was the cultivation of otherwise unproductive marshy soils (Česká televize, 2013b). According to anecdotal testimony from contemporaries, people working in agriculture viewed the experiment of rice cultivation sceptically, mainly due to climatic conditions (Teliščáková, 2017). During our historical research, we spoke with two contemporaries that remember rice cultivation from their childhood in 1950s in municipality Dedina Mládeže and Zbrojníky.

3 MATERIAL AND METHODS

Study area

According to Fekete (1952), the localities of rice cultivation are concentrated in the southern parts of western, central, and eastern Slovakia, in the local lowlands. The boundary of our study area is the northern limit of the possibility of rice cultivation, based on estimates from the trials conducted (Fig. 1).

This Slovak "rice belt" consists of two contiguous areas with a total area of 12,808.5 km² (≈ 26.1% of SR; EPSG:5514). The south is the warmest part of Slovakia, and the lowlands also concentrate numerous watercourses that supply the water needed for irrigation. The dominant geomorphological unit is the Podunajská rovina (Danubian Lowland), including Žitný ostrov; the Podunajská pahorkatina (Danubian

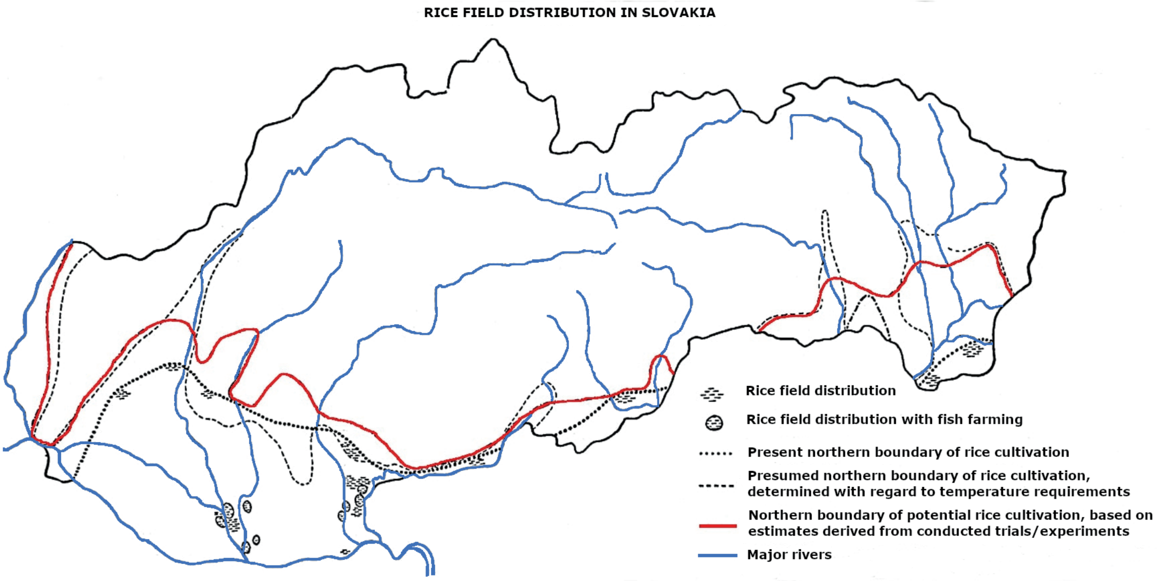

Fig. 1. Distribution of rice fields and cultivation limits in Slovakia according to Fekete (1952). Red line – northern limit of the possibility of rice cultivation, based on estimates from the trials conducted. Original figure was translated and edited for better readability

Upland), for example in the sub-unit Sikenická mokraď (Sikenica wetland); the Východoslovenská rovina (Eastern Slovak Lowland); and, to a lesser extent, the Juhoslovenská kotlina (South Slovak Basin) (Kočický & Ivanič, 2011). The study areas fall within the catchments of the Malý Dunaj, Váh, Nitra, Žitava, Perec, Sikenica, Hron, Ipeľ, Rimava, Bodva, Bodrog, Veľká Krčava, and Latorica Rivers, which fed the irrigation canals used for rice cultivation. The areas belong to warm districts according to the Atlas krajiny Slovenskej republiky (Hrnčiarová, 2002). Of soils suitable for rice cultivation, the floodplains and terraces of these watercourses are dominated by Fluvisols to Chernozems. The main indicated localities are the vicinity of Kolárovo, the Pohronie region, the vicinity of the Perec stream, and in eastern Slovakia Streda nad Bodrogom and the vicinity of the village of Leles.

Military topographic maps 1:10,000 and 1:25,000

As the primary source for the spatial distribution of rice fields in Slovakia, we used historical military topographic maps at 1:25,000 (1952–1957) and 1:10,000 (1957–1971) scales (hereafter VTM25 and VTM10), based on the corresponding map symbols. We obtained raster data via a WMTS (Web Map Tile Service) service in the EPSG: 5514 coordinate system, relying on the provider's existing georeferencing (MŽP SR, 2022b; MŽP SR, 2022a). We consider this source of information to be highly reliable. It was a detailed mapping of the landscape at various scales, with an emphasis on the tactical needs of the army (Govoruchin et al., 1977). Notably, VTM10 was recently used by Vynikal et al. (2024) for the automated vectorization of wetland LULC symbols (in this study abbreviated as TM10).

We considered as an unambiguous rice field only those areas that contained the corresponding map symbol for rice, which is identical in both map series (Fig. 2). Present are features suggesting that they served as rice fields, but without the corresponding symbol we cannot verify this; therefore, we did not include such areas in the results. Through archival research we determined the years of production of individual map sheets, which enabled temporal analysis of the occurrence of rice fields. For the initial manual identification of localities, we used the work of Fekete (1952) and then we inspected municipalities mentioned in press and archival documents. The identified localities were manually vectorized by individual map sheets in the EPSG: 5514 coordinate system in ArcGIS Pro 3.4.0. The vectorized polygons of rice fields encompassed the entire areas delineated by the corresponding map symbol. When counting the number of rice fields per municipality within current administrative boundaries, we treated each separate polygon as one field. Areas were computed in aggregate for the entire municipality. Names and borders of municipalities were used as they are at present. Manual vectorization was chosen for its precision and reliability, as supported by earlier studies (Piškinaitė & Veteikis, 2023; Kratochvílová et al., 2025).

To assess the positional accuracy of the historical topographic maps (VTM25 and VTM10), we used church towers as independent check points (ICPs), as these features are consistently represented on both historical maps and present-day datasets. Present date ICP in form of churches were derived from orthophoto imagery (GKÚ & NLC, 2023) and manually marked position of tower. For each study site, three to five nearby churches were selected, aiming to surround the rice fields from different directions whenever possible. The displacement between historical and reference locations was calculated separately in the x and y directions, and root mean square error (RMSE) was computed following standard formulas. ICPs were used for both VTM10 and VTM25 to calculate global RMSE.

Rice field technology – Case study Zalaba

Based on historical cartographic sources and archival documents, we can identify two primary ways of constructing irrigation systems in Slovakia: a simple method of building fields enclosed by simple irrigation channels, and a more complex method involving embankments and feeder channels (in slovak: náhony). We use plans from the municipality of Zalaba as an "anchor" to bridge between the cartographic symbol on the VTM and the actual system of hydraulic-engineering works. We have an overview plan at 1:2,880 and a site plan at 1:1,000, technical details of feeder channels and sluice gates (section and detail drawings), longitudinal profiles, earthwork volume calculations, and a set of illustrative photographs

(GEOPLAN, 1952). The site plans were georeferenced to EPSG: 5514 (positional ties to stable object points) and used exclusively to interpret and compare the hydraulic-engineering works shown in the plans against the cartographic depiction in the map series.

LiDAR identification of technological remains of rice fields

To identify the technical remnants of historical rice fields in the present-day landscape, the vectorized areas were compared with a 1 m-resolution digital terrain model (GKÚ, 2024). Morphological features corresponding to irrigation channels or embankments/feeder channels were visually identified and recorded as indications of preserved elements of the rice-field infrastructure. Based on visual analysis of the DTM, sites were classified into two categories: (i) detected fragments, where the presence of anthropogenic structures is unambiguous and well distinguishable, and (ii) indicated fragments, where morphological traces are weaker, incomplete, or ambiguous and their interpretation requires field verification. The inspection of forms was carried out within the localities identified on the historical maps. We compared the overlay of the vectorized rice fields from VTM25 and VTM10 against the above-mentioned DTM. Where possible, we attempted at least a naive estimate of area differences between preserved rice fields captured in the DTM and the vectorized polygons captured in the map series, which are subject to cartographic generalization.

Machine-learning verification of completeness

In automated analyses of historical cartographic works, it is useful to distinguish between feature extraction and feature detection. Extraction aims to delineate spatially continuous geometries across a map sheet (e.g., polygons or networks) and is typically most effective for classes with a relatively consistent cartographic signature that can be pre-processed reliably, such as forests, hydrographic elements, or wetlands (Herrault et al., 2013; Dunesme et al., 2022; Vynikal et al., 2024). In contrast, detection identifies discrete occurrences of a target representation (commonly as points or bounding boxes) and is particularly suitable when the mapped phenomenon is expressed by a distinctive symbol or repeated pattern, such as symbols or text (Schlegel, 2021; Pai et al., 2025). Several modern approaches have demonstrated high success rates in automating feature extraction from historical maps. For example, U-Net–based segmentation methods can achieve very high accuracy (overall F1-scores around 90% or more) when identifying specific map features like wetlands (O'Hara et al., 2024), and custom YOLO-derived detectors for map symbols have reached near-perfect detection performance (~98% mAP for tree symbols) (Smith & Pillatt, 2023). Transformer-based models such as SegFormer further push the state of the art, yielding significantly improved segmentation metrics (high IoU and F1) in tasks like historical road network extraction (Sertel et al., 2024). Traditional toolkits and pipelines (HMVT toolbox) also report robust overall accuracy in vectorizing map elements from scans, underscoring the effectiveness of both classical and deep learning techniques in this domain (Dunesme et al., 2022). Because rice fields in the VTM map series are depicted using a specific symbol pattern, we employed symbol detection as a systematic screening step to reduce omission errors when locating rice-field occurrences. Field extents were subsequently digitised manually as polygons (Fig. 2). Our deep-learning workflow follows the general symbol-detection strategy described by Pai et al. (2025), but here it was applied to a single feature class.

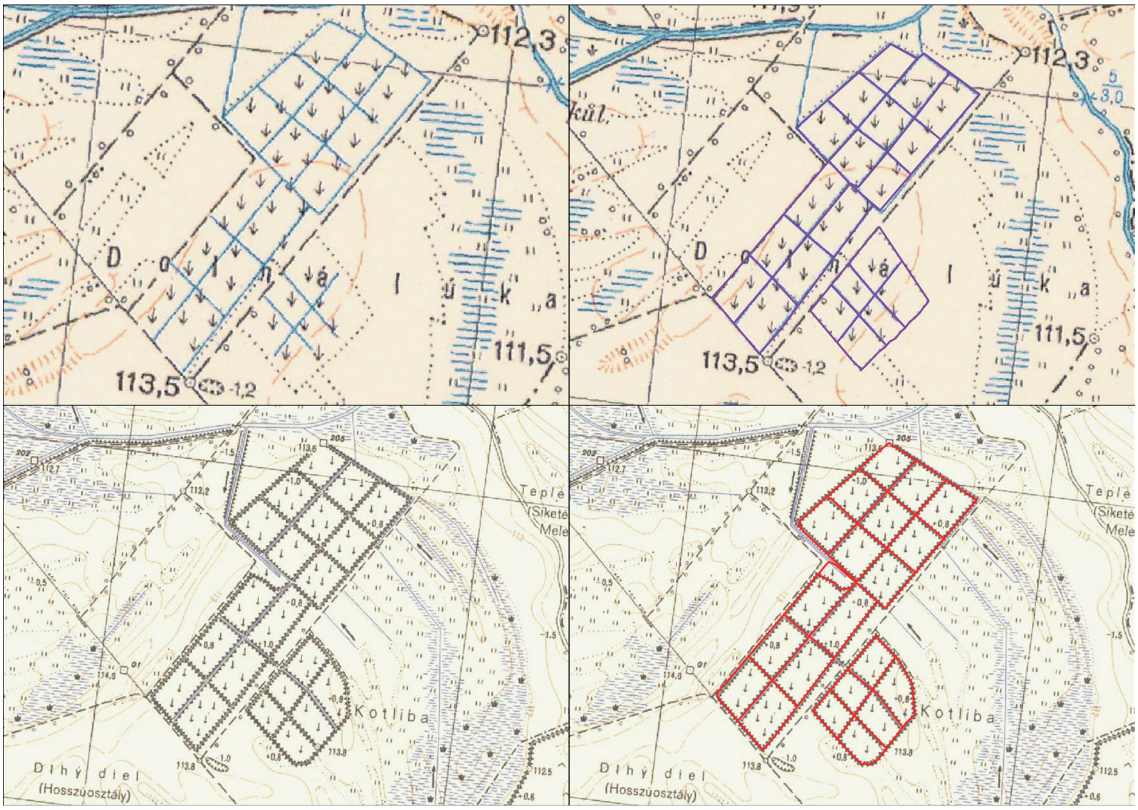

Fig. 2. Example of manual vectorization of the same complex of rice fields in the municipality of Gabčíkovo on two map series: VTM25 (1:25,000; 1952–1957, top row) and VTM10 (1:10,000; 1958–1971, bottom row) (MŽP SR, 2022b; MŽP SR, 2022a). On the left are excerpts from the original maps; on the right is a manual interpretation of the outlines of the individual paddies (purple on top, red on the bottom)

We used a single-stage object detection model (YOLOv5) implemented in Python 3.12 using the Ultralytics framework, executed via custom runtime scripts to manage input/output paths and inference parameters. Raster map content was accessed as WMTS tiles (Fig. 3) derived from the VTM10 and VTM25 series (MŽP SR, 2022a; MŽP SR, 2022b). Using the WMTS tiling scheme (tile size 256 × 256 px), we generated a georeferenced tile-index vector grid in a GIS environment. Each tile footprint was assigned a unique identifier following a column–row convention (e.g., the tile in the first column and first row is coded as 1_1) to enable unambiguous linking of model predictions to spatial locations.

Training tiles were selected from locations where rice symbols had been identified manually. Selected tiles were annotated in LabelImg (Tzutalin, 2018) by drawing bounding boxes around complete rice symbols only (single class: rice). We trained separate models for VTM10 and VTM25 due to differences in scale and cartographic representation, using an 80/20 train–validation split (Tab. 2). Model training used a batch size of 16, an input image size of 640 px, and up to 250 epochs. The 640-pixel input size was used in both training and inference because the native tile resolution renders individual symbol elements comparatively small; therefore, tiles were resized to the network input size as part of YOLO preprocessing.

During inference, detections were generated at 640 px input resolution using a confidence threshold of 0.74 and non-maximum suppression with an overlap threshold of IoU = 0.45. Tile IDs with positive detections were exported to CSV and joined to the georeferenced tile-index grid in ArcGIS Pro 3.4. We then manually inspected candidate tiles, excluded false positives, recorded newly identified rice field occurrences by vectorizing extents. Model performance summaries are reported in the Results section.

Given data availability, for VTM25 we used a lower zoom level when extracting tiles, which led to a smaller number of processed tiles compared to VTM10. The input counts of tiles and ground-truth symbols (labels) are given in Table 2.

4 RESULTS

Positional accuracy of historical map series

Using a common set of 132 independent check points (church towers) georeferenced in EPSG: 5514 against contemporary orthophoto (ZBGIS), we estimated systematic shift and random planimetric error for both series. Mean offsets are highly consistent - Δx ≈ +13 m (east) and Δy ≈ −5 m (south), suggesting a stable, series-agnostic bias in the WMTS georeferencing rather than sheet-specific warping. Dispersion is lower for VTM10 (RMSE_total = 18.53 m) than for VTM25 (RMSE_total = 21.54 m), as expected from its larger scale. In practical terms, feature overlays should anticipate ≈20 m radial position uncertainty for both series, with a directional trend towards E–SE relative to the modern reference.

Tile-level ML screening performance

To gauge the effectiveness of the ML pass as a completeness check, and its impact on curation workload, we evaluated tile-level screening performance at fixed operating thresholds with a design goal of high recall. We report the fraction of tiles flagged, precision/recall against known positives, and the average number of tiles requiring review per confirmed hit for VTM25 and VTM10 (Tab. 4). Tile-level screening at operating thresholds conf. = 0.74 and NMS IoU = 0.45 flagged only a small share of tiles - 0.18% on VTM25 (181 tiles) and 0.12% on VTM10 (456 tiles), which kept the scope of manual review low. On VTM25, of these flagged tiles, 145 were true positives (including 9 new beyond the original manual) and 36 were false positives. This corresponds to precision tile = 0.801, recall tile known = 0.993, and on average 1.25 reviewed tiles per hit. On VTM10, the detector captured all known positive tiles (recall tile known = 1.00), but with precision tile = 0.096 it required approximately 10.36 reviewed tiles per hit (TP = 44 including 7 new; FP = 412). These figures confirm that the setting was deliberately oriented toward high recall as a “safety net” for retrieving candidates. All positive detections were subsequently verified

Fig. 3. Tiles from the WMTS and the scale of the rice-field cartographic symbol shown in black squares. Left: 256×256 px grid (tile footprint) and an example tile (red frame). Center: detail of the tile; Right: zoomed-in rice symbol, red boxes illustrate typical labels used for training the detection model

Tab. 2. Input datasets for ML-based screening of rice-field symbols on VTM25 and VTM10. Listed are the WMTS zoom level (z) and nominal ground sampling distance (GSD), the total number of tiles analysed, and the counts of ground-truth (GT) tiles and symbol instances. The GT set was split into training and validation subsets (values shown as [tiles/symbols])

map series	zoom	GSD [m/px]	tiles analysed [n]	GT total [tiles/symbols]	train [tiles/symbols]	validation [tiles/ symbols]
VTM25	9	4.0	98,566	34/872	27/763	7/109
VTM10	10	2.0	394,264	39/789	32/686	7/103

Tab. 3. Summary of the planimetric accuracy of the VTM25 and VTM10 map series relative to the ZBGIS reference: mean offsets in the x/y axes (Δx, Δy), axis-wise errors (RMSE_x, RMSE_y), and total 2D error (RMSE total); calculations from a common independent check points (ICP) set in CRS EPSG: 5514

map series	[n] of ICP	mean Δx [m]	mean Δy [m]	RMSE x [m]	RMSE y [m]	RMSE total [m]
VTM25	132	12.83	-5.70	19.18	9.80	21.54
VTM10	132	12.97	-4.29	17.60	5.80	18.53

Tab. 4. Tile-level screening performance. TP = true positive; FP = false positive; FN = false negative

Map series	Tiles flagged	TP known	TP new	TP total	FP	FN known	Precision tile	Recall tile known	Flagged fraction	Tiles per hit
VTM25	181	136	9	145	36	1	0.801	0.993	0.18%	1.25
VTM10	456	37	7	44	412	0	0.096	1	0.12%	10.36

Tab. 5. Number of delineated fields and municipalities and the sum of areas (ha) by map series in which the rice symbol occurs in the given series. The field area includes the entire symbolized block (including embankments and canals)

Map series	N fields	N municipality	Total area (ha)	Years of mapping	Rice field present
VTM25	434	50	2297.7	1955-1957	1955-1957
VTM10	147	10	254.34	1958-1968	1958-1960

manually. Precision on VTM10 was markedly lower because the higher zoom (z = 10; 2 m/px) reveals finer symbology, increasing confusion with non-target map symbols and thus false positives.

Inventory of mapped rice fields

The inventory summary shows that on VTM25 sheets (1955–1957) we delineated 434 fields in 50 municipalities with a total area of 2,297.7 ha (Tab. 5). The municipality names we considered and used for purpose of this study are present ones and, in some cases, can differ from names on VTMs. On VTM10, rice fields occur only in the years 1958–1960 (although the map sheets for the indicated municipalities extend to 1968), and in total we identified 147 fields in 10 municipalities with an area of 254.34 ha. Taken together, the two series capture a temporal sequence: VTM25 represents the peak phase of the late 1950s, whereas VTM10 documents a limited continuation with a sharp termination ("cut-off") after 1960. Fekete (1952) reports approximately 400 ha of rice fields; in our inventory, however, two of the localities he mentions do not appear, while we record several that are not noted there (e.g., Rimavská Sobota and Gabčíkovo). These differences in area and listed localities likely result from the temporal mismatch between the text and the production of the map series.

In the first mapping, Kolárovo has the largest area of rice fields (296.66 ha), followed by Leles (140.84 ha), Klin nad Bodrogom (105.51 ha), and Topoľníky (97.31 ha). Notably, Topoľníky attains a large area with a low number of fields (6), which suggests larger parcels than in the core localities of the Danubian region. The northernmost documented occurrences lie outside the main Danubian Lowland area, Budmerice (8.00 ha; 3 fields) represents the northern boundary locality at the 48°21′ N parallel, equivalent to northernmost rice producing province in China Heilongjiang (Lu et al., 2017). In the second mapping, only ~254 ha persisted from the original ~2,298 ha; distinct "islands" of continuity are concentrated mainly in Čiližská Radvaň (118.95 ha) and Gabčíkovo (43.13 ha), with smaller residuals in Dolný Štál (15.30 ha), Horný Bar (6.67 ha), Michal na Ostrove (4.78 ha), and Baloň (2.17 ha). The spatial retreat is thus nearly nation-wide, except for a few centres in the lower Žitný Ostrov and Leles in east.

Green polygons mark localities captured only on VTM25 (≈1955–1957), orange polygons mark localities captured only on VTM10 (≈1958–1971), and purple polygons indicate localities present in both mapping series. The left panel shows the western and central part of the study area, while the right panel shows eastern Slovakia. The blue network represents major watercourses, and black lines delineate administrative boundaries. Taken together, the maps reveal a strong concentration of sites in the Danubian Lowland, especially on Žitný ostrov and adjacent anabranching system. In the Eastern Slovak Lowland (catchments of the Bodrog and Latorica), with more isolated occurrences near Budmerice, Slovenské Ďarmoty or Janík (Fig. 4).

Analysis of the digital terrain model (DTM) derived from LiDAR data confirmed the presence of remnants of rice fields at several localities. In the municipalities of Kolárovo, Leles, and Boťany, fragments of the original parcel layout were unambiguously detected, whereas at other sites (Topoľníky, Komárno, Veľký Kýr, Dunajský Klátov, and Branč) fragments were only indicated. Detections were made from 1-m DTM derivatives (hillshade, slope, curvature) and cross-checked against the mapped extents from VTM25/VTM10.

The mapped fragments should be treated as provisional and require field verification and/or more advanced analyses, because land grading, ploughing, and subsequent urbanization have removed the surface expression of most former rice fields. Where rice cultivation is reported by secondary sources but is not depicted in the analysed map series, future work could extend the evidence base through targeted archival research, particularly in historical agronomic records held by local, still-operating agricultural cooperatives (formerly JRD - Unified Agricultural Cooperative) or by successor institutions of ŠM (state agricultural farms). One such case is Zlatná na Ostrove mentioned by Teliščáková (2017), which we were unable to independently corroborate using the available map sources. Also, there are couple of municipalities with earthworks symbols present in rice fields but without rice symbol, it could be interesting to start future archival in these locations, if available.

Case study Zalaba

Archive drawings divide the infrastructure into the main supply canal, secondary laterals, and a system of manually operated sluice gates. The water intake from the source was elevated above the rest of the irrigation system, and by gravity the water spread into the canals. In some cases, the canals were bordered by embankments. A system of manually operated gates was used to regulate the inflow of water. The canals admitted water via top-operated gates (sluices).

The technical documentation for building the rice fields in the municipality of Zalaba serves as

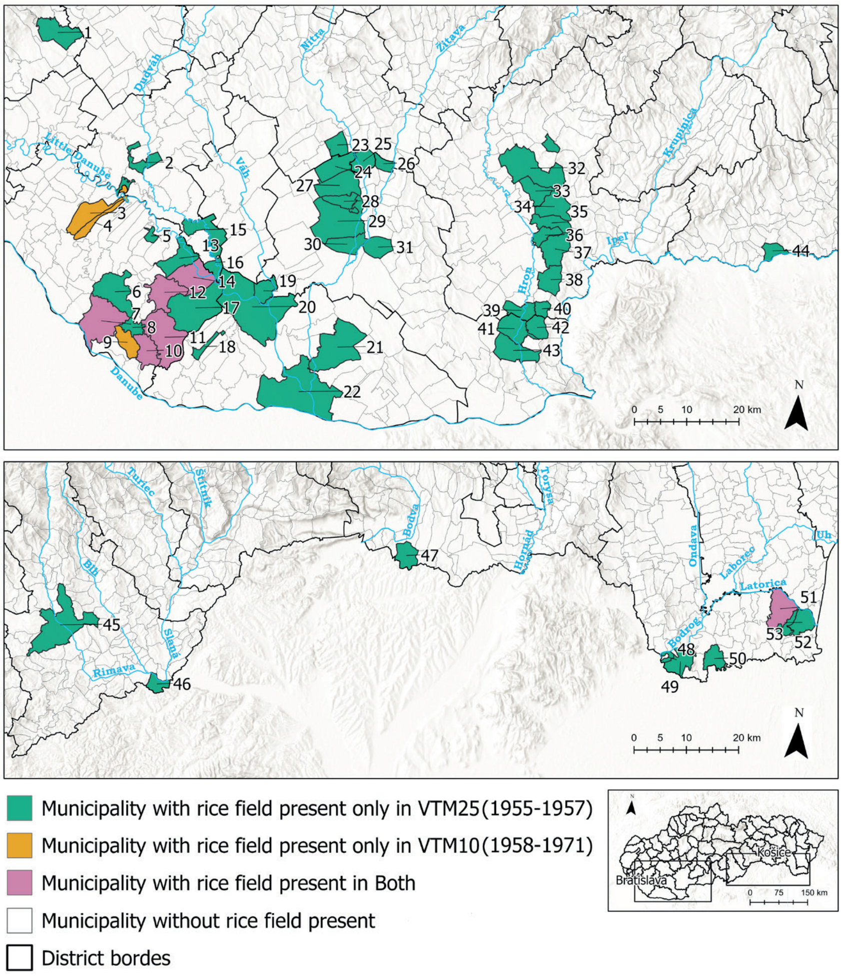

Fig. 4. Spatial distribution of rice-field localities in Slovakia based on topographic maps from two mapping series. VTM25 – Military Topographic Mapping 1:25,000 (1955–1957) and Military Topographic Mapping 1:10,000 (1958–1971). (Source: MŽP SR, 2022b; MŽP SR, 2022a). 1–Budmerice; 2–Čierny Brod; 3–Horná Potôň; 4–Michal na Ostrove; 5–Dunajský Klátov; 6–Vrakúň; 7–Gabčíkovo; 8–Pataš; 9–Baloň; 10–Čiližská Radvaň; 11–Veľký Meder; 12–Dolný Štál; 13–Trhová Hradská; 14–Topoľníky; 15–Kráľov Brod; 16–Dolný Chotár; 17–Okoč; 18–Bodza; 19–Dedina Mládeže; 20–Kolárovo; 21–Hurbanovo; 22–Komárno; 23–Branč; 24–Veľký Kýr; 25–Vinodol; 26–Michal nad Žitavou; 27–Komjatice; 28–Lipová; 29–Šurany; 30–Bánov; 31–Bešeňov; 32–Levice; 33–Mýtne Ludany; 34–Hontianska Vrbica; 35–Zbrojníky; 36–Kukučínov; 37–Sikenica; 38–Šalov; 39–Čata; 40–Zalaba; 41–Bíňa; 42–Sikenička; 43–Kamenín; 44–Slovenské Ďarmoty; 45–Rimavská Sobota; 46–Vlkyňa; 47–Janík; 48–Klin nad Bodrogom; 49–Streda nad Bodrogom; 50–Strážne; 51–Leles; 52–Bačka; 53–Boťany

an independent validation basis. It shows that the map symbol is hydrotechnically interpretable and depicts the agrotechnical system of the rice field. This legitimizes transferring the cartographic interpretation to other localities in the "rice belt," not only based on the symbol shown in the map.

In Figure 5 we see drawings of the technical elements of the rice fields on the construction plans (A, B, C) from the project ,,*Ryžové pole na pozemkoch ČSŠM obec Zalaba*" (Rice field on the lands of the Czechoslovak State Property, Zalaba municipality) (GEOPLAN, 1952) and their depiction on VTM25. Panel A shows the water intake through a regulating sluice into the canal for the Zalaba rice fields from stream Perec. VTM25 introduces a naming discrepancy, labelling the watercourse Sikenica, while otherwise this channel water body is document as Perec, same as in rice field plans. From this point all water feeding the rice field was brought in. The irrigation channel and sluice gate form integral components of the rice field infrastructure, serving to control and distribute water for irrigation across the field system is depicted on the Panel B. The observed elevation difference between the irrigation channel and the rice field demonstrates the gravity-based design of the water conveyance system. In the irrigation system, individual channels were formed by earthworks (Panel C). They were constructed from piles reinforced with sheet piling and a clay core, while the structure was lined with broken stone. The cross-section of the construction was slightly asymmetrical, with water located on the steeper side. As for majority of located sites of rice cultivation, in Zalaba all signs of technical features were lost to melioration.

5 DISCUSSION

The end of the story of rice in Slovakia?

The cessation of rice cultivation likely proceeded at first with lower intensity, gradually, municipality by municipality, between 1955–1960. It is noteworthy that VTM10 map sheets produced after 1960 no longer depict rice fields in localities where they were shown on VTM25. This probably reflects a central directive to halt unprofitable farming, as imported rice was substantially cheaper. Reasons for not continuing in rice cultivation are most probably combination of economic, social and ecological factors. Rapid changes in land use during collectivization are documented in literature (Najdený & Gurňák, 2022) and can be

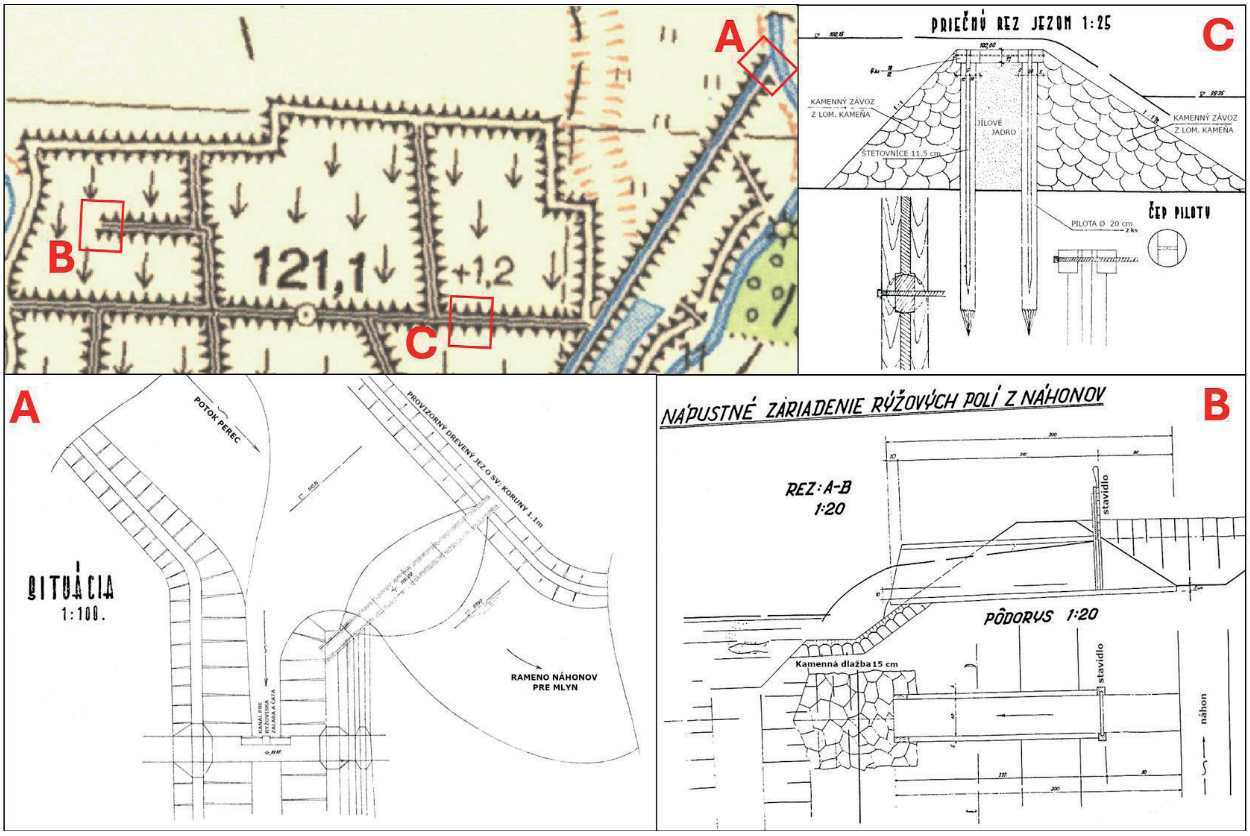

Fig. 5. Linking the map depiction and project documentation of rice fields: upper left, an excerpt from the Military Topographic Mapping 1:25,000 (1952–1957) (MŽP SR, 2022b). A – inlet of the Perec stream into the system of supply canals; B – intake structure (weir) with a sluice gate; C – cross-section through the earthwork (jez). The project plans (GEOPLAN, 1952): “Ryžové pole na pozemkoch ČSŠM, Zalaba” were graphically adjusted for readability; scales/dimensions were preserved

associated with agricultural landforms (Hanušin et al., 2021).

We have indications that a certain set of localities with rice fields was no longer captured on VTM25. We draw on Fekete (1952), where localities such as the vicinity of Leopoldov are identified, yet we did not find them marked with the rice field symbol, not even the technical elements. Another example is the municipality of Ipeľské Predmostie, mentioned in the press as a place where the “rice dream” had faded already in the early 1950s (Teliščáková, 2017). Within the territory of this municipality lies the Ryžovisko Nature Reserve (PR Ryžovisko), where technical relics of the rice field have been preserved. It is one of the few physical remnants of rice cultivation in Slovakia today. A system of supply ditches and canals has survived in a marshy area near the point where the Ipeľ approaches the foot of the Krupinská Planina within several tens of metres. We can only hypothesise that, due to unfavourable terrain, this locality was not subjected to melioration after rice cultivation ceased. At present, PR Ryžovisko serves to ensure the protection of wetland ecosystems in the Ipeľ floodplain, which host protected and endangered species of fauna and flora (ŠOP SR, 2025). Owing to long-term soil inundation, there is potential here for deeper palaeoecological research focusing on the development of land use in a strongly fluvially influenced environment. The research could be complemented by LiDAR micro-morphometry of the ditches and canals to quantify technical parameters and compare them with the available plans from the municipality of Zalaba.

In addition to a possible central directive, we must consider socio-economic and environmental factors: rising labour and energy demands compared to alternative crops, irrigation costs, local soil-hydrological limits, variability in growing-season heat sums and discharges, and pest pressures. Importing of foreign, cheaper rice, starting from the early 1960s could also play a role in cessation of rice cultivation. Archival agronomical sources and production records are crucial for discriminating among these competing hypotheses. For independent verification, we propose using period cadastral and land-reclamation maps, and possibly agronomic statistics from the archives of JRD and ŠM of the identified municipalities. These sources can distinguish whether the absence of the symbol after 1960 reflects a real centrally mandated termination of cultivation, or whether we are observing a gradual abandonment of this agricultural activity.

Today, rice agroecosystems can function as managed, seasonal wetlands: flooding, drawdowns, and post-harvest conditions create microhabitats and concentrated food resources that can be important for waterbirds, which is why rice landscapes are frequently discussed in a habitat-conservation context (Stafford et al., 2010; Suthar & Anderson, 2024). Importantly, potential conservation value extends beyond birds: rice fields can also support diverse aquatic biota, including species-rich microcrustacean communities, highlighting broader wetland-biodiversity relevance (Bisquert-Ribes et al., 2025). At the same time, these anthropogenic wetlands may facilitate non-native taxa, so any biodiversity argument should be paired with explicit consideration of invasion risk and management trade-offs (Bisquert-Ribes et al., 2025). Taken together, evidence from North America and other rice-growing regions suggests that former rice landscapes should not be treated only as a short-lived agricultural episode, but also as a potential conservation and restoration opportunity where hydrological settings and infrastructure persist. In a Central European setting (Slovakia and Hungary), it could therefore be worthwhile to examine whether historical rice cultivation remnants still contribute to wetland habitat networks for avifauna, flora and other taxa, and whether targeted restoration/management could deliver measurable biodiversity benefits. Finally, although any future large-scale return of rice cultivation in Slovakia would depend on multiple constraints beyond climate alone, its feasibility and potential trade-offs would likely be strongly conditioned by the substantial investments required for irrigation and water-control infrastructure.

Data limitations

When interpreting the results, several limitations of the source data must be considered. In both map series there are areas with morphological characteristics typical of rice fields but lacking the corresponding map symbol; these localities could not be confirmed with certainty and were therefore not included in the analysis as rice fields. Manual vectorisation and symbol identification carry a subjective component. The minimum positional displacement of a boundary is determined by the width of the map line in millimetres converted to metres at the given scale. As a rule, the symbol occurs within an area fill bounded by hydrotechnical features or by a dotted line used to emphasise the termination of the vegetation cover. In this regard, the cartographer's subjectivity and the generalisation of individual sheets must be considered.

Temporal consistency is limited by the fact that VTM25 and VTM10 map sheets were not produced in a single year but over a span of several years, which may affect comparisons between the map series as well as within a given series itself. Both maps capture the state of the landscape only as a static “snapshot” and do not account for seasonal or interannual changes in land use. Another limitation is the cartographic generalisation, especially in the case of VTM25, where the smaller scale and simplified symbols may lead to an inaccurate count of identified rice plots and a slight over or underestimation of their number. The areal extent of rice fields is likewise affected by the degree of generalisation in both map series.

The RMSE of map series estimate and reflect a combination of several sources of error: georeferencing uncertainty of the historical maps, cartographic generalization of the church symbols, and residual inaccuracies in the reference dataset. It needs to be taken in to account that all points were created manually, so there is also level of subjectivity here. While church towers are stable landmarks, their representation on historical maps may be displaced by tens of meters due to schematic symbol placement. Furthermore, the distribution of control points was not always uniform, as suitable churches were unevenly available in the vicinity of the study sites. These limitations must be considered when interpreting absolute positional and areal values, although the relative spatial patterns remain robust which minimises the impact of positional error on the main conclusion.

To determine areal distortion in the map series, we used preserved relict irrigation earthworks/structures within the Ryžovisko Nature Reserve (PR Ryžovisko) in the municipality of Ipeľské Predmostie. As part of an indicative measurement, we compared vectorized areas of the same features depicted on VTM25 and VTM10 with the objective reality captured in the DTM (GKÚ, 2024) (see in Fig. 6).

By comparing the differences, we obtained a naive indicative estimate of the generalisation of rice-field area (Tab. 6). Compared to the reference DTM value of 237,773 m², VTM25 underestimates the area by 10,955 m² (−4.61%), while VTM10 by 2,723 m² (−1.15%), indicating closer agreement for VTM10. The residual deviations are explained primarily by the difference in scale and generalisation (1:25,000 vs. 1:10,000). We consider the value derived from the DTM to be the most accurate. Considering these findings, the vectorised, map-derived areas reported in this study should be treated as conservative estimates with a certain margin of error, rather than exact metric values.

We are aware that the 1949 Czechoslovak orthophoto map is a useful source for examining historical land use, as evidenced by studies that have used it as a data source (Masný et al., 2017; Žarnovičan et al., 2021). However, upon further investigation, it proved itself unsuitable for our purposes. In the Slovak context, rice fields do not exhibit widely recognised diagnostic features in the orthophoto; the temporal window was too narrow, and the season of acquisition was not uniform, so potential indicators of rice fields were not clearly discernible. Future work should therefore undertake fine-grained analyses of selected localities to assess whether any can be reliably matched to discernible patterns in the 1949 orthophoto map.

6 CONCLUSIONS

This study presents the first comprehensive spatial reconstruction of post- World War II rice cultivation in Slovakia based on two military cartographic series (VTM25, VTM10), combining manual vectorisation with ML-based symbol screening. The result is a national inventory capturing the phenomenon's characteristic temporal signature: rapid expansion in the latter half of the 1950s (predominantly on VTM25 sheets) followed by a sharp decline around 1960 (limited presence on VTM10). We demonstrate that the map symbol is hydrotechnically interpretable (case-study Zalaba) and that preserved technical relics (PR Ryžovisko) provide independent support for the spatial conclusions. At the same time, we explicitly acknowledge limitations: weak temporal comparability of sheets due to non-uniform intervals between mappings, symbol generalisation, subjectivity of manual vectorisation, and positional errors of historical maps (estimated using ICP—church towers). These factors affect absolute areal estimates and the completeness of the set of municipalities with rice fields after 1945, but relative spatial patterns (where rice fields concentrate/vanish) remain robust and constitute the study's main finding. Since Fekete (1952) lists localities that VTM25 did not capture, we must be cautious when extrapolating to the national scale. Incomplete coverage and regional heterogeneity mean our conclusions are robust but not exhaustive. Localities known from independent sources to have been rice fields, but not appearing on analysed maps, are not included in our spatial analysis.

In further research, triangulation with period cadastral–land-reclamation maps and archival agronomic statistics of Unified Agricultural Cooperatives and Štátne majetky is substantively necessary to distinguish the effects of political and economic interventions from local environmental

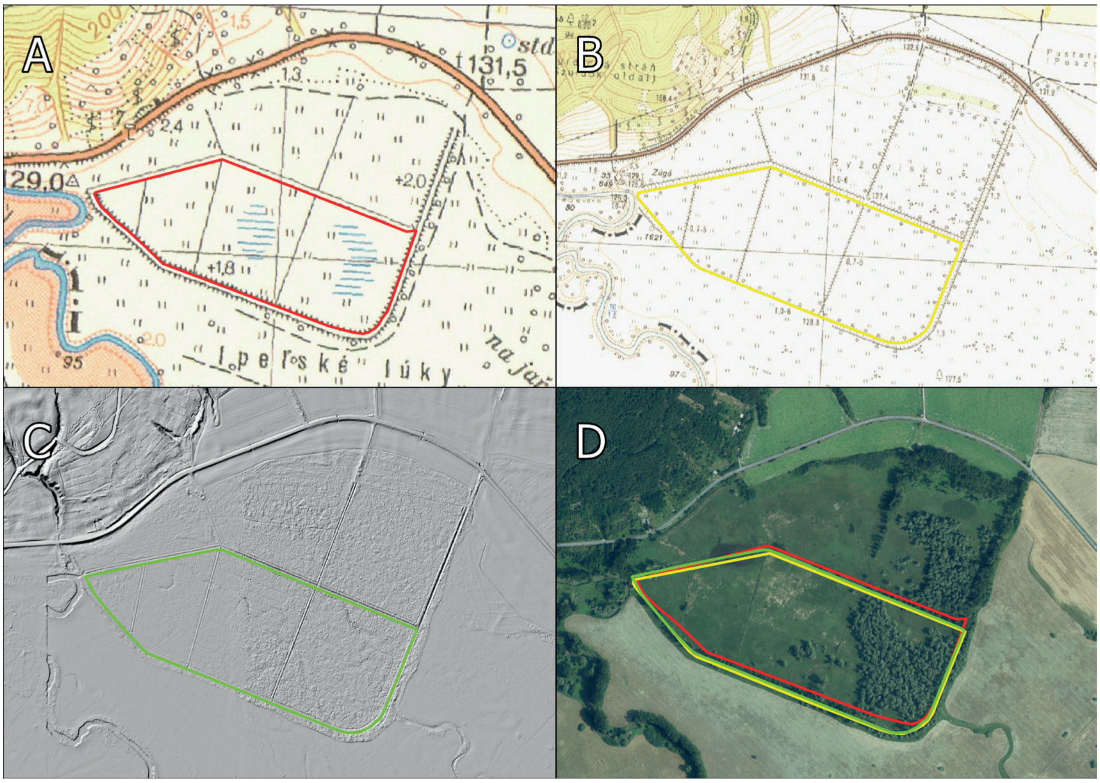

Fig. 6. Comparison of the former rice field polygon in Ipeľské Predmostie across sources: (A) Military Topographic Map 1:25,000 (MŽP SR, 2022b); (B) 1:10,000 (MŽP SR, 2022a); (C) DTM 5.0 (1 m) – multi-directional hillshade (GKÚ, 2024); (D) orthophoto (GKÚ & NLC, 2023)

Tab. 6. Area of the test rice-field polygon across datasets and differences relative to the LiDAR-derived DTM. DTM is the reference (Δ = 0). Δ is computed as dataset − DTM and reported in m² and %. VTM - Military Topographic Map 1:25,000; 1:10,000 (MŽP SR, 2022b; MŽP SR, 2022a)

Dataset	area [m²]	Δ vs. DTM [m²]	Δ vs. DTM [%]
DTM (LiDAR)	237 773.2	0	0
VTM25	226 818.1	−10 955.1	−4.61
VTM10	235 050.7	−2 722.5	−1.15

limits. In the context of historical research, it would likely still be possible—when examining individual localities—to identify eyewitnesses who remember the rice fields from their childhood; these individuals are now approximately 80–90 years old. These individuals could provide valuable information on the details that were associated with rice cultivation, along with first-hand accounts of their experiences, for example what kind of manual work was performed. PR Ryžovisko and analogous sites offer scope for possible palaeoecological soil analysis focused on verifying plant macro fossils (rice and associated weed species) and dating sediments, while LiDAR micro-morphometry can quantify the typology of irrigation systems. Moving beyond the case study toward comparison with the neighbouring "rice belt" in Hungary, would provide a reference framework for the history of rice cultivation in Central Europe and for conserving relics of these specific agro-hydrotechnical landscape features.

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