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AGRICULTURAL DRAINAGE SYSTEMS IN THE CZECH LANDSCAPE - IDENTIFICATION AND FUNCTIONALITY ASSESSMENT BY MEANS OF REMOTE SENSING

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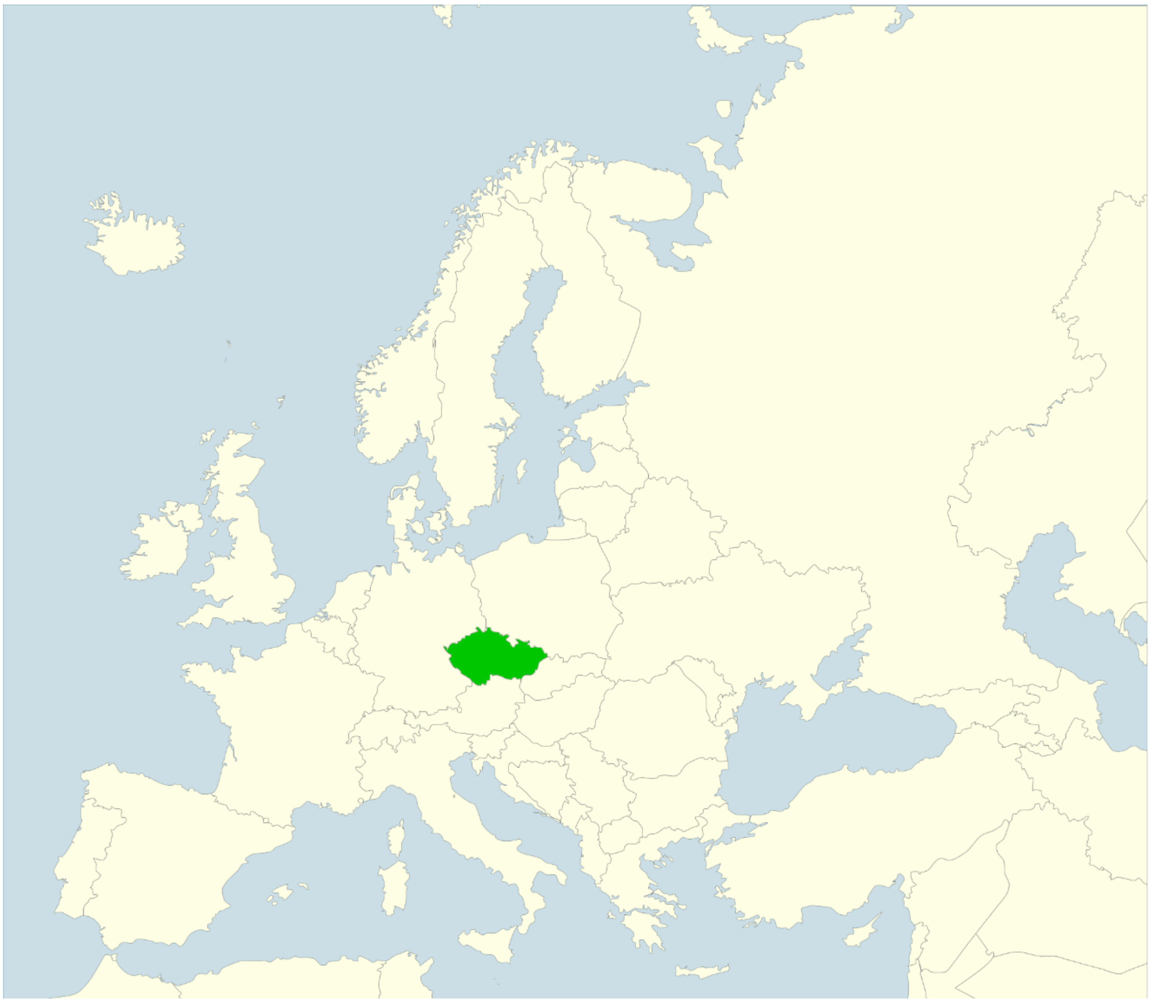

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Abstract: Subsurface drainage systems are among the most important meliorative measures taken in the Czech Republic. Nevertheless, their functions are perceived rather differently by Czech society. Perspectives differ among landowners, farmers, water managers, and environmentalists. With changing climatic conditions and new agricultural practices, the conditions of the existing drainage systems must be reassessed, particularly in relation to future strategy for funding and management. In this regard, the main decision makers in the Czech Republic are the farmers, rather than the state or landowners who would probably be more suitable. This paper presents the results of a survey of the conditions of drainage systems, their maintenance and their defects. New technologies, mainly remote sensing, and their use for the identification and survey of drainage systems are also presented. Land drainage measures have changed the entire landscape in the Czech Republic (agricultural intensification has caused the loss of a number of natural habitats and natural water flows). In the context of increasingly common occurrences of hydrological extremes and the aging of the drainage systems, the existence of such systems must be reconsidered. Either they should be preserved for agricultural production purposes, or, on the contrary, gradually eliminated to promote the recovery of natural habitats. The best solution for each part of the Czech Republic will differ according to the landscape characteristics of the given area.

Key words: amelioration, survey flight, phytoindication

Abstrakt: Drenážní odvodnění je v podmínkách ČR plošně velmi významným melioračním opatřením. Jeho funkce jsou ve společnosti vnímány diametrálně odlišně. Rozlišujeme pohled vlastníka pozemku, hospodařícího zemědělce, správce vodního díla nebo ekologa. Tak, jak se mění zemědělství i klimatické podmínky, je nutné posoudit I změněné podmínky ve vztahu k existujícímu odvodnění. S tím souvisí i další strategie jejich podpory a správy. Dominantní roli v ČR v tomto ohledu sehrává uživatel pozemku, nikoli stát nebo vlastník, jak by bylo zřejmě správné. V příspěvku jsou dokumentovány výsledky provedených šetření k popisu stavu drenáží, způsobů jejich údržby, četnosti výskytu závad a možnosti využití moderních technologií a metod DPZ pro jejich identifikaci i pro analýzu odvodněného území v širších souvislostech. Výstavba odvodnění zásadně změnila ráz české krajiny. Podpořila intenzifikaci zemědělství, a tím i úbytek řady přírodních stanovišť a přirozených vodních toků. Zvyšování extremity hydrologických jevů a stárnutí těchto vodohospodářských děl zvyšuje naléhavost řešení jejich další existence v různých částech ČR: zachování pro zemědělskou produkci i postupný útlum až likvidaci pro obnovu přirozených stanovišť.

Klíčová slova: odvodnění, snímkování, fytoindikace

1. Introduction

Since a landscape cannot be defined as the mere sum of its natural components, water as a “component” of the landscape reflects the situation and relationships in the landscape as a whole. The source of the water in the network of rivers and water bodies is the landscape, the catchment area, from the micro-range level in the form of soil water molecules (associated with the status of the soil “component”) to the various order macro-range level of the catchment area.

The primary goal of increasing water retention in the landscape, retarding its runoff (namely accelerated surface runoff), increasing its infiltration, and increasing percolation into deeper layers (thus improving the supply of underground water) is to alter the landscape structure. This means making alterations in favour of refining the landscape texture and increasing the shape variability of land parcels (LP) so that they then better correspond to the natural character of the wildlife habitats – in general, increasing the variability in both spatiotemporal organization and management (Stejskalová et al. 2013; Cushman et al. 2007; Zonneveld 1979).

The agriculturally exploited landscape, which plays an essential role in biodiversity, faces two main problems: structure and agricultural management.

Unfortunately, the landscape structure, under the associated agricultural management, has been experiencing a trend of progressive deterioration (after initial improvement in the 1990s, which was however very short). In this regard, the landscape texture has become rougher (very extensive LP) and there has been an increase in uniformity and monotony in the geometry of the landscape matrix (Tlapáková et at. 2013). This has been due to the intensification of agricultural production in every sense, i.e., including the very high input of chemicals and industrial fertilizers associated with the production of crops not primarily intended for food purposes (rape seed, corn). The land is considered a means of production rather than a natural resource. The cultivation of these crops represents an extremely significant burden on the environment, not only due to the xenobiotic input, but also due to the deterioration of both quantitative and qualitative soil and water parameters. This is inevitably accompanied by the devastation of the biological component of the agricultural landscape.

Agriculturally managed areas require a higher variability of crops in arable land and increased diversity of both species and natural cover in perennial grasslands achieved by differentiated mowing, grazing and differentiated fertilization. The differing heights of various plant species influence water infiltration, evapotranspiration and runoff as well as the life cycles of both vertebrates and invertebrates. Variability of landscape elements is also required, including their spatial organization aimed at the best possible effect on the particular natural conditions.

Designing measures associated with water in the landscape absolutely requires consideration of and reflection on the existing agricultural drainage systems (ca 98% executed by systemic tile drainage). This drainage covers as much as a third of currently or formerly agriculturally managed land, measured as a surface area of ca 1.1 mil. ha (Fig. 1).

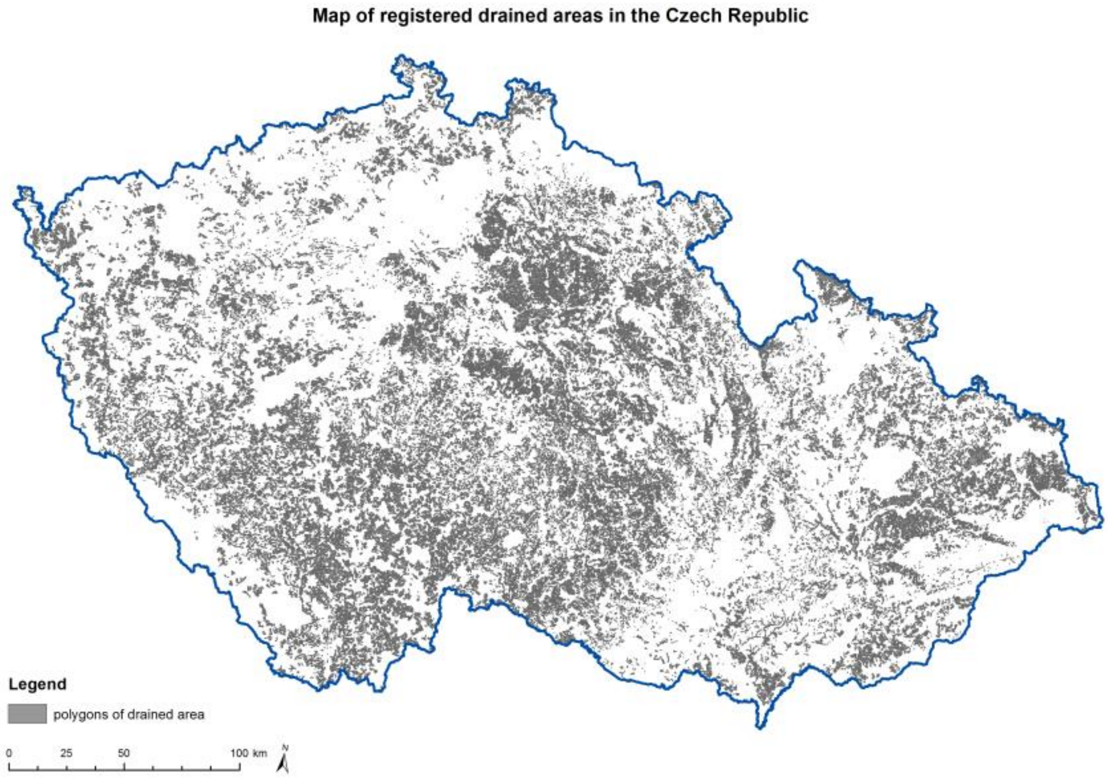


Fig 1. Map of registered drained areas in the Czech Republic. Source: RISWC, Ministry of Agriculture

The drainage systems work as large water collectors which shorten residence time conducting the water directly into a recepient (Zajíček et al., 2016) without further use or retention in the landscape. The presence of drainage interferes with all supported activities aimed at restoring wetlands and small water bodies, revitalizing water courses, etc. with significant impacts. In drained areas, such activities cannot be implemented in the same manner as in undrained land. Damage to drainage resulting from these activities leads to changes in its function and consequently the deterioration of soil properties due to unwanted waterlogging and the initialization of soil erosion by water as a subsurface runoff product (Kulhavý and Fučík 2015; Spaling and Smit 1995).

Besides quantity, drainage also affects water quality (Fučík et al., 2015). Ignoring the presence of drainage may result in serious pollution of drainage water and subsequently surface water, e.g., by inappropriately placing dunghills or applying chemicals, fertilizers, or digestate from biogas plants.

At present, no competent institution is taking full responsibility for the systemic drainage. However, the topic of water in the landscape and the strategies for fighting drought represents a live issue in professional, political and media circles without taking into account this totally indispensable aspect (Government Decree No. 620, 2015).

This contributes to the lack of knowledge and reduced importance regarding this topic from both the side of competent institutions, designers, etc. on the one hand and entrepreneurs and physical entities on the other hand. The only exceptions are owners and users of drained LP, who face the problems associated with the presence of such water management systems on their land. They have to cope with the altered functionality caused by the absence of systematic maintenance of the detailed drainage and receptacles of these systems, resulting in operating defects and attempts to solve the problems ad hoc. In the vast majority of cases, the assumed cause of the non-functionality of these systems has been their advancing age, but this assumption has been proven untrue. Surveys of these systems have shown (Kulhavý et al. 2007; Kulhavý et al. 2007; Kulhavý et al. 2013) that even drainage systems from the time of the First Republic are still functional and that their defects are only local and can be eliminated by repairs. Their deteriorating condition is rather a consequence of the absence of maintenance due to the transfer of this state investment to land owners (despite the fact that one DS may affect tens of LP) without transferring the documentation on their placement in the terrain and respecting these systems when continuing development (by-roads, line buildings, housing), forestation or the sowing of fast growing trees on the drained areas resulting in all related consequences.

Also in light of climatic changes and the increasing frequency of extreme climatic events (Daňhelka et al. 2015; Brázdil et al. 2008), these aspects of the issue of “water in the landscape” can no longer be ignored.

2. Theoretical and methodological background

The Czech Republic is unique due to the topology and technical complexity of its agricultural drainage systems, not only because of natural conditions (geological, pedological, geo-morphological diversity) but also because of the changes in land ownership. In the first half of the 20th century the land was divided into small private properties before it was collectivized and ownership was transferred to the state and large-area management after the year 1948 (Kulhavý and Fučík 2015). After 1989, another wave of land ownership reorganization took place, including the drainage systems (Act No. 92/1991, Act No. 229/1991). Along with that, a period of inadequate or absent maintenance and repairs of these systems began (and still continues), resulting in various degrees of their degradation with negative effects on their functionality.

The altered functionality of drainage systems is thus increasingly manifested in drained areas by drainage water accumulation, emergence, or more or less permanent waterlogging of the partially drained LP. To improve and correct this situation, the primary task required is to obtain precise documentation on the actual placement of the drainage systems and their functionality for further maintenance and management of the drained parcels (TNV 75 4922) corresponding to the current use of the drained area and its potential development over the long term. This unsatisfactory situation could be documented by the results of the survey described in the section Results. Subsurface drainage systems can be identified and their condition assessed using various methods, preferably in combination. These methods may be destructive (direct manual or machine-operated uncovering of the drainage, a pedological survey) or non-destructive (based on indirect techniques – distant, optical, electric resistance, sonic or geo-seismic, electromagnetic, biological) (Nováková et al. 2013; Svobodová 1990). The best distant method is remote sensing. A literature review of relevant domestic and international sources focused on the investigations and applications of RS methods performed so far on agricultural drainage has been published by the authors (Tlapáková et al. 2014) with the aim of providing a more detailed analysis of the data in order to achieve maximum efficiency in the survey.

The identification of subsurface drainage using RS methods is based on the specific spectral behaviour of water, which significantly differs from other natural as well as artificial compounds. Due to the nature and position of the drainage objects under the earth's surface (the depth of tile or plastic drains is usually 0.6–1.5 m), the initial conditions, disposition, and practical possibilities for the direct imaging and interpretation of these objects are rather limited. The current approaches in passive RS, which utilize registered records of reflected or emitted radiation from the visible (VIS) and infrared (NIR) spectrum field (Fig. 2) to detect landscape objects, do not enable recording under the soil and vegetation cover and thus cannot provide direct data on objects in the subsurface zone.

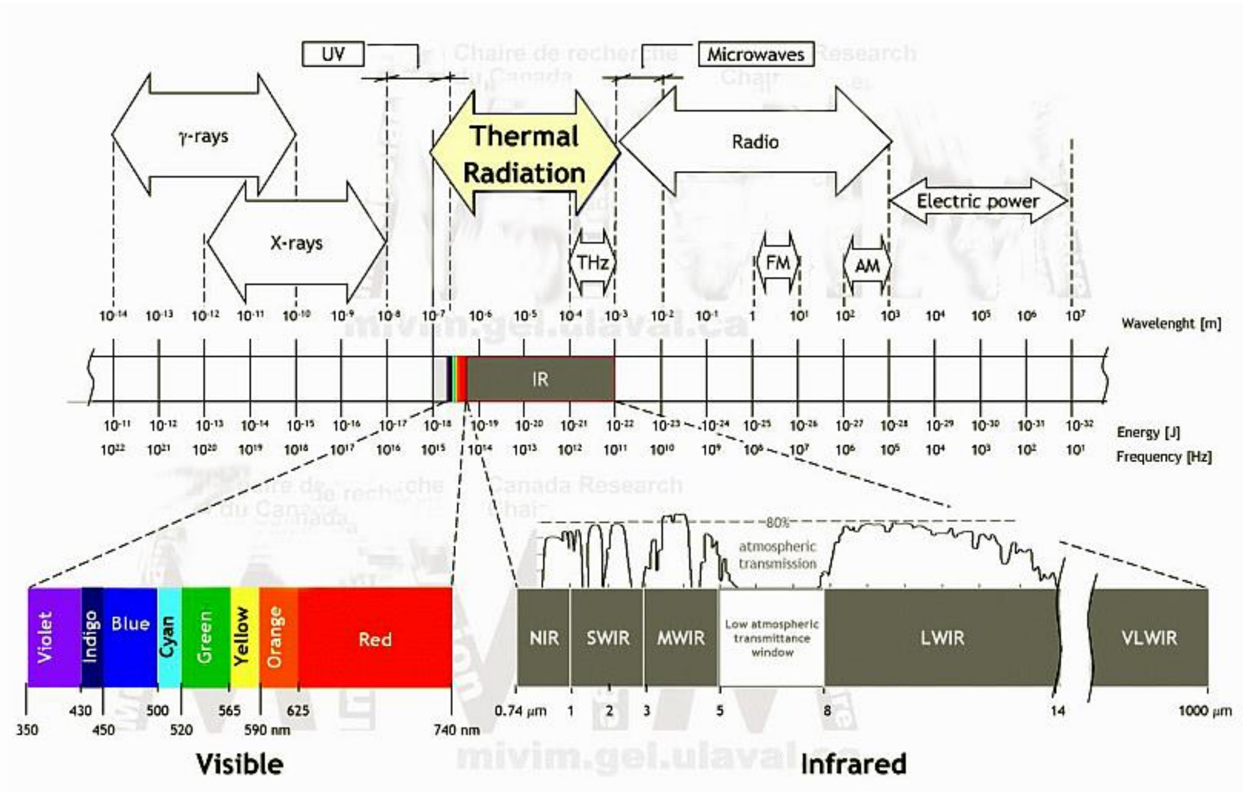


Fig 2. Electromagnetic spectrum. Source: www.wikiskripta.eu

Subsurface drainage therefore represents an object that using standard optical RS methods can be identified and studied only indirectly. By means of spatial hydro-indicative associations between the relief, soil, and vegetation, various parameters such as heterogeneity of soil characteristics, vegetation nature, relief predisposition, etc. can be defined. The application of RS methods consists in the identification of subsurface drainage objects, typically as an indirect manifestation of the existence of the drainage groove or a hydrological association of the tile drainage element with the terrain surface in the recorded images (differences in moisture, temperature, the condition and vitality of vegetation, etc.). The RS recordings are analysed both to identify the drainage systems themselves and to locate sites of altered functionality. These sites can usually be detected owing to drainage water accumulation, i.e., waterlogging or soil erosion caused by water, depending on the particular conditions at the time of recording.


Photos 1, 2 – Examples of drainage system malfunctions – drainage water emergence with the water erosion caused. Source: Z. Kulavý, M. Čmelík – RISWC


Photos 3, 4 – Examples of drainage system malfunctions – footstalks and roots in the pipes. Source: M. Čmelík – RISWC

Information about the drainage systems' functionality is another type of source data which should be taken into account during the synthesis of limits and measures of agricultural management. As part of the LPIS server[2], it should provide more details on the existence of drainage systems and their functionality. For example, records of waterlogged sites provide more detailed information on the extent of soil excluded from management due to the impossibility of necessary agro-technical interventions (sowing, tillage, cutting, etc.). No DZES or PPH provision takes into account drainage and the existence of drainage systems (DS) in LP. A direct relationship can be found between the DZES 3 provision "Protection of underground water against pollution with hazardous compounds", which among other things includes farm fertilizers and their deposits, and organic fertilizers, including digestate. Additionally, there is DZES 5 "Minimum level of land management aimed at reducing erosion", which should eliminate agro-technical interventions during waterlogging or water saturation except in crop harvests. If the particular LP contains a DS that for some reason is partially non-functional, water accumulates and stagnates on the surface or saturates the water profile to such an extent that attempts at standard land management in these blocks are directly opposed by these provisions. Land parcels that are waterlogged as a result of drainage system defects display a different time course than undrained land, which again has not been reflected in this particular provision in any way. After repeated attempts at management (over the course of several consecutive years, depending on the annual water content), the condition of the soil deteriorates and via a feedback mechanism contributes to

[2] http://eagri.cz/public/web/mze/farmar/LPIS/

the reduced function of the existing DS. This DS is no longer capable of draining such compacted soil as in the original technical parameters proposed for the conditions determined at the time of its construction.

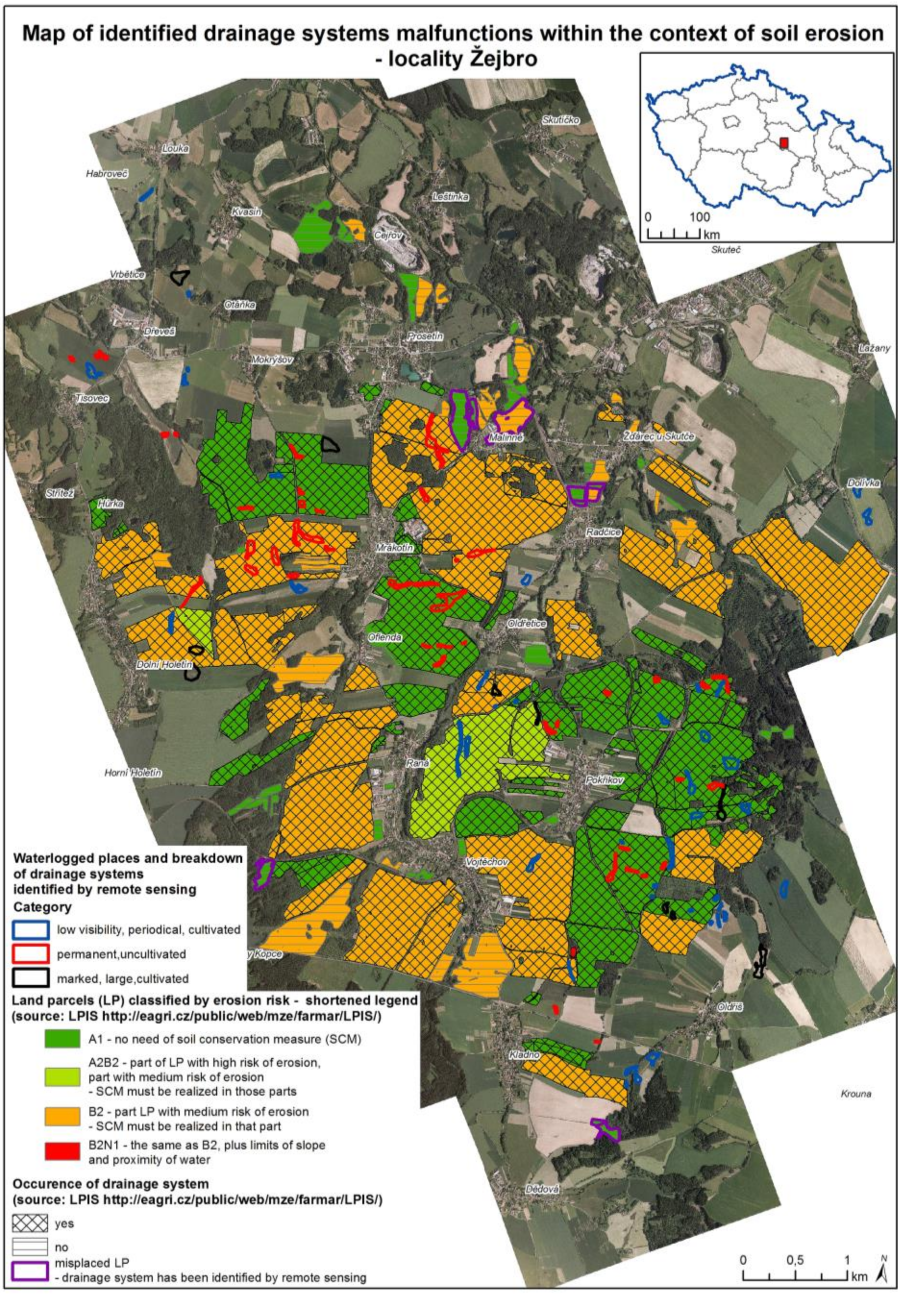


Fig 3. Map of identified drainage system malfunctions within the context of soil erosion. The map shows waterlogged parts of drainage systems as identified by remote sensing against a background of a thematic map layer from the LPIS. The LPIS contains no evidence of drainage system malfunctions or their effect on erosion risk (mainly water erosion). The map shows land parcel classification regardless of waterlogging caused by the drainage systems. This is associated with the incorrect classification of occurrences of drainage systems in land parcels in the LPIS. Source: RISWC

The main benefit of utilizing data obtained by RS methods (Lipský 1990; Naz 2009) is the ability to document the unequivocal link between DS presence in LP and the negative manifestations due to their altered/reduced functionality requiring repairs, i.e., the removal of the cause of waterlogging. Based on these data, soil-protective technologies, or anti-erosive measures, should also include technical measures aimed at repairing DS defects, thus removing the causes underlying the negative waterlogging, potential erosion, and varying degrees of pedological characteristic deterioration in LP.

For example, the classification of LP with registered DS defects among LP at risk of erosion with all the ensuing requirements would not lead to an improvement in erosion risk because, again, the current measures would not deal with the real cause, i.e., the DS defects (Fig. 3). The list of soil-protective technologies should also include technical measures for DS handling in respect to their current condition and functionality. The map outputs (Fig. 3) show that both the frequency and extent of DS defects at the identified sites are not negligible, and if this situation is not dealt with, one can expect they will continue to increase (Tlapáková 2015).

3. Empirical knowledge and methodology

The bulk of the research and experimental work consists of the application of remote sensing methods and their utilization in investigating the areas of interest – the indirect identification of subsurface drainage objects via drainage grooves or the hydrological association of tile drainage elements with the terrain surface in materials obtained by RS methods (differences in temperature, moisture, vegetation condition and vitality, etc.) (Krusinger 1971). This allows the development and practical validation of the available modern distant non-destructive technologies for positional identification and the precise localization of drainage systems (RS, GPS and GIS methods and materials) (Northcott et al. 2000). These activities are accompanied by proposals for methods using information technologies (digital GIS databases) and other territorial documents (maps, designs and technical documentation for water management systems). The methodology of DS identification is primarily based on the use of appropriate geodata and RS materials (multi-sensor aerial data – standard or specialized images and monitoring) (Goettelman et al. 1983; Verma et al. 1996; Naz 2009).

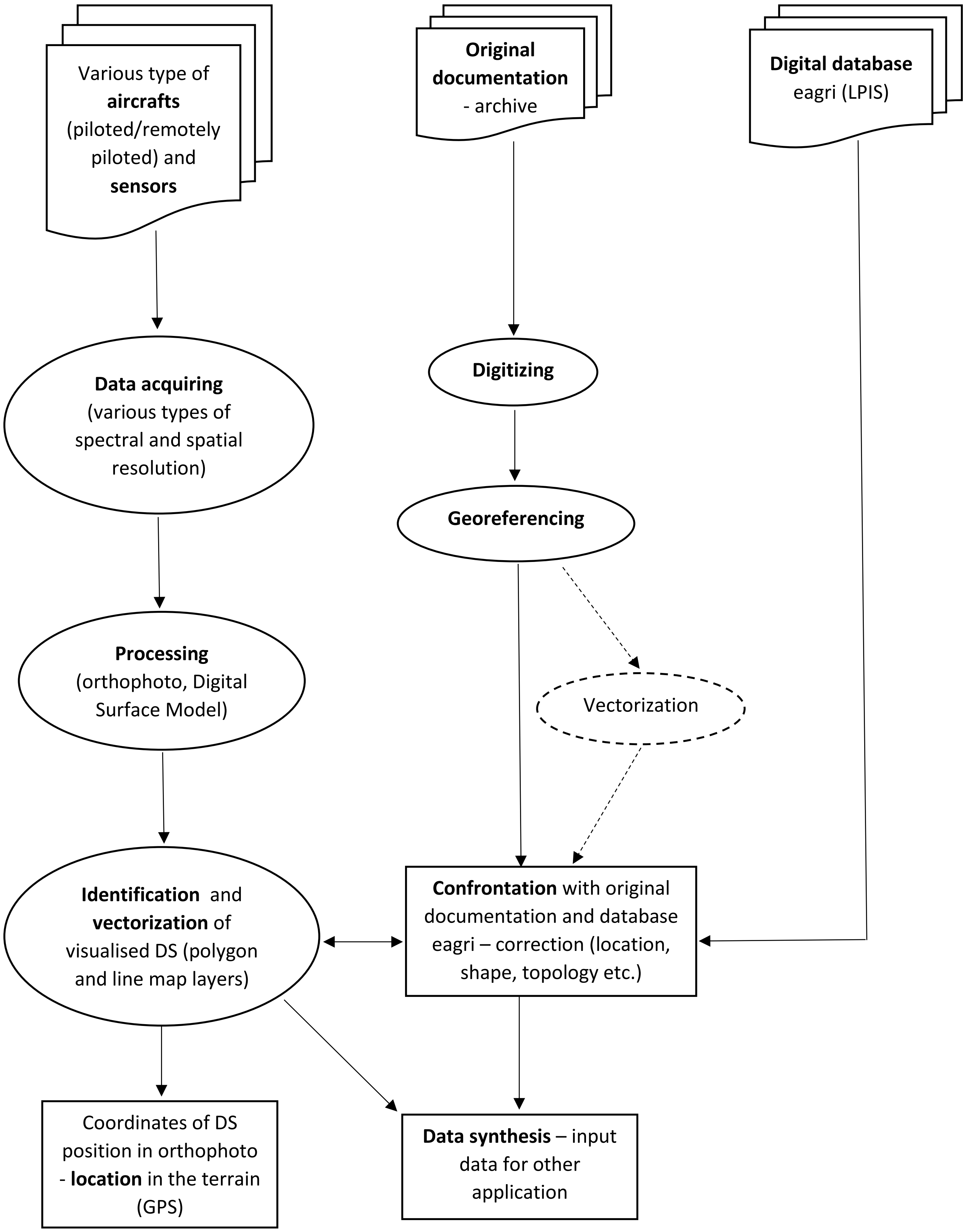
The identification method is developed based on targeted aerial data with the use of novel technologies (remotely piloted aircraft systems (RPAS) and various sensors). Their development and use significantly advances both the research of this issue and the application of the methods and results achieved in the practice of almost any field.

Remote sensing methods used for the identification and mapping of DS

RS images are no longer used in the way they were originally intended for DS identification. RS images were initially used to determine local moisture changes in land surface mapping. This method presumes the influence of line drainage components on the drying-out of the part of the soil profile over the drain, marked with a coloured sign on the RS images. These manifestations are based on local changes in soil heat conductivity owing to water saturation at the time the snow melted, drying out immediately after precipitation. However, for practical use, visual manifestations in the images are hampered by quite a wide variety of effects within rather narrow time limits. In their previous analyses, the authors created an indirect interpretative method based on a phyto-designation principle. This principle utilizes local differences in plant growth as a dominant effect of the drain which optimises the water-air regime of the soil profile for that part of the selected cover crop. The drain effect appears as a line, in many cases clearly distinct in the images. The processing of the survey photographs lays the foundations for very precise DS identification in the terrain. Subsequent localization is possible for large DS whose local efficiency of coverage for the drained area identified is 75–90%.

As shown by the experimental recordings, the drainage systems can be identified in practically all the types of distant records tested with significant variability in the sensor used, i.e., spatial and spectral resolution. When visualizing DS manifestations for all these types of data, it is essential that the conditions are optimal for mediating their manifestation on the surface recorded. This requires targeted determination of the recording date for capturing the required manifestations on the one hand, and on the other hand it allows the identification of drainage systems in images acquired primarily for other purposes, but (accidentally) at optimal conditions for the visualization of the drainage systems.

Scheme 1. Scheme of the main points of the applied methodological approach.



To determine these optimal conditions and the criteria underlying the identifiable manifestations of drainage systems, three spheres or levels acting co-ordinately were defined to provide the required manifestations of the drainage systems in the images obtained by RS methods. They are indispensable for applicable utilization of the developed method in generally valid conditions.

They are as follows:

1. aboveground – aerial space between the aerial device, i.e., the carrier of the utilized sensor, and the recorded surface (meteorological data, climatic conditions), the type of device and sensor (type, quality, spatial and spectral resolution of the acquired data)
2. on the surface – vegetation cover, soil cover, status and activities occurring on the recorded surface (growth analysis – phenophase, crop type, involvement of vegetation cover, agro-technical interventions related to growth and periods without growth, etc.)
3. underground – hydro-pedological characteristics, drainage groove, construction technology, the DS itself, its condition and functionality (destructive methods, detailed verification)

Besides defining these three levels, we must take into account the principle by which the manifestation of subsurface drainage systems is mediated in the recorded surface. This manifestation is based on the principle of phytoindications in the vegetation cover, on the principle of differences in moisture associated with the hydraulic activity of the drainage groove in a surface totally devoid of cover or in phases without the involvement of cover and thus without changes in the behaviour of bare arable land and on the principle of moisture changes related to temperature, wind, and other phenomena directly impacting the soil surface.

Local conditions are essential criteria for the selection of the recording date (with the same vegetation cover, same weather course, verified drainage water runoff from the system). These conditions include the:

- Status of the drainage groove
- Growth phenophase and moisture conditions (precipitation regime), especially in the case of properly applied fertilizer
- Phasing of agro-technical interventions associated with management methods, and in cases of differences in bare arable land, namely harvest and autumn processing before the next sowing

These criteria are evaluated in subsequently acquired images, namely from detailed targeted recordings.

To interpret the selected scale, the recorded areas are primarily divided into two groups:

1. with vegetation cover

   - at a further classification level in areas of arable land

   - the interpretation of the manifestation based on the phytoindication principle is more complicated and requires multiple classification levels

2. without vegetation cover, bare soil cover

   - practically exclusively in areas of arable land

   - the manifestation of the principle of moisture differences makes it less complicated to select the classification

This categorization into groups aims to evaluate the success and effectiveness of both principles and to assess the requirements for achieving the visualization of DS manifestation during the vegetation period and outside of it.

However, this analysis is also limited primarily by natural factors, namely climatic, which are variable both spatially and temporally in particular years and must be processed adequately.

4. Results

A very important factor in phytoindication is scheduling conditions with favourable moisture in particular phenophases according to their type, i.e., the quantity of precipitation, temperature conditions, and related agro-technical interventions, namely fertilization. If these factors are combined at an appropriate time, they improve the conditions for mediating information on the subsurface drainage systems. Besides current and running precipitation, the analysis must include the long-term situation regarding moisture balance and the degree of water saturation of the soil profile related to the vegetation cover.

The criteria for basic specification are categorized according to whether they identify DS manifestation via phytoindication or via differential soil moisture.

Tab 1. Overview of the main criteria and conditions for the visualization and identification of drainage systems by means of remote sensing

1. phyto-indication				2. moisture differences	
1a – permanent grassland	**weight 1a /***	**1b – vegetation-covered arable land**	**weight 1b**	**2 – vegetation-free land**	**weight 2**
Climate		**Climate**		**Climate**	
characteristics of precipitation, temperature,	2	characteristics of precipitation, temperature,	2	characteristics of precipitation, temperature,	3
long-term trend in moisture conditions (year/inter-year)	2	long-term trend in moisture conditions (year/inter-year)	3	**Agricultural management**	
Vegetation cover		**Vegetation cover**		postharvesting management,	3
permanent grassland	2	type of crop-plant, phenophase	3	harvesting, tillage, harrowing etc. in relation to precipitation	3
pasture (grazing/ungrazing)	2	**Agricultural management**		fertilization	3
Agricultural management		fertilization in relation to precipitation	3	**Drainage system**	
grass cutting, fertilization, grazing	3	**Drainage system**		characteristics of drainage groove	3
Drainage system		characteristics of drainage	3	building technology	3
characteristics of drainage groove	3	building technology	3	presence of drainage water in drainage system	3
building technology	3	presence of drainage water in drainage system	2		
presence of drainage water in drainage system	1				
/ weight: 1 to 3 = low to high*					

Each criterion on this basic scale is weighted differently according to its classification related to either the phytoindication or differential moisture principle. Meaning that in different groups the same criteria will be weighted at different values. The weighted values were defined on a scale of 1–3. Research has shown that the essential weight is decided by the character of the drainage groove while the material used for conducting and collecting drains practically does not play any role. The presence of water in the DS at the time of recording does not have to be primarily decisive. This is valid for recording in the RGBI spectrum range, and probably also for hyperspectral (HS) data. In contrast, while using thermal zone and thermocamera recording, the presence and quantity of water in DS plays an essential role in the tile temperature (Zajíček et al. 2011) and in the increase of contrast with the terrain outside of the drain. Again, this depends on the date of recording and the air temperature. This effect is easiest to observe at extreme values, either of air temperature or quantity of drainage water flow. These extremes provide maximum contrast between DS manifestation and the surrounding growing cover. This was verified by recordings captured with a thermocamera at various localities and in different conditions, with the greatest success obtained by recording at ca 35°C a week after a 100 mm precipitation when all DS in the entire flow-through profile were traversed by drainage water (Fig. 4).

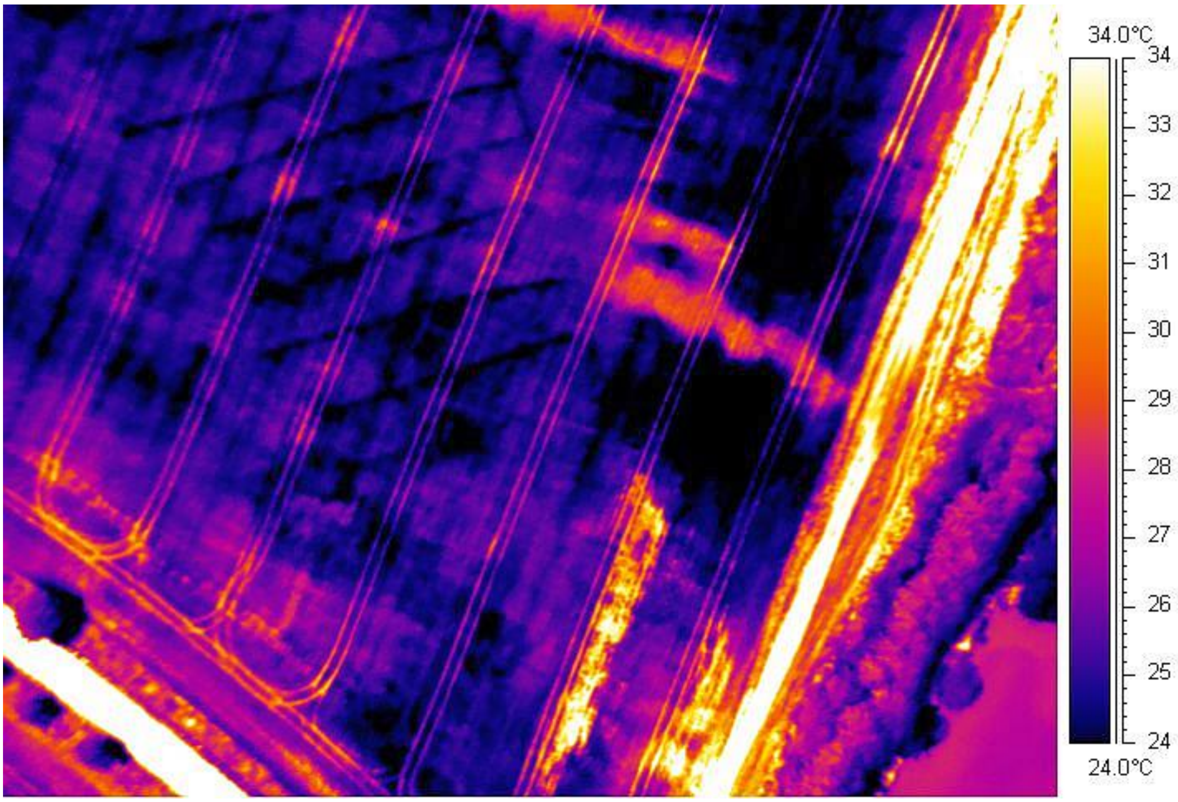


Fig 4. Exemplary thermographic image of infrared spectrum: temperature spectrum 24 - 34 °C, spatial resolution 30 cm (locality Domanín, South Bohemia, 2 July 2013) with visualised drainage system: dark lines display the cooling effect of drain tiles full of water. Source: ENKI, o.p.s.

Distant data acquired so far with various sensors in different spectrum parts (RGBI, HS, thermal, including parallel RGBI + HS recording on the same date in identical conditions) at different spatial resolutions from all completed recording campaigns (10 x large-area air-raid, 32 x RPAS and a number of additional small-extent air-raids) represent a unique temporal array of recordings acquired exclusively for the purposes of DS identification. This in itself is an invaluable basis for argumentation for the further investigation of all issues associated with the work performed so far and supporting its complexity at all levels such as the:

- Absence of available records in digital form comparable with records of other subsurface systems
- Absence of documentation corresponding to the actual execution of the system and documentation on its present condition and functionality (repairs done at random, often by lay people, without a recording, survey, etc.)
- Lack of respect or even ignorance when manipulating the drained LP, which is unthinkable in cases of other officially approved structures that are subject to valid legislation
- Complicated property rights – one DS may extend to tens of LP and thus have tens of owners; separated ownership of detailed drainage facilities (DDF) and main drainage facilities (MDF); no link to the real estate register, etc.
- A number of inaccurate, although repeated, assertions related to the natural aging of the drainage, loss of function due to age, sites waterlogged as a result of DS defects mistaken for natural wetlands, etc.
- Limited options for effective handling of drainage water collected by these systems, which to a large extent represent a very important component of the entire runoff, namely in the context of the much discussed extreme drought (Doležal et al. 2003, 2004) and insecurity in climate development in future years
- No consideration of DS existence in the rules for agricultural management (DZES, PPH, PEO, PRV, allocation of funds, etc.)

The above-mentioned points correspond to the survey aimed at users of drained LP and their opinions on the conditions of the drainage systems, their maintenance and defects.

The results of the survey could be listed in basic points as follows:

- Total number of participants: 30 users – 76% farmers (farm-rented land)
- Information on DS: 33% from locals, 17% from landowners, 7% from building records, 43% from other sources
- Cognizance of DS information acquisition: 37% NO, 33% YES, 20% do not know, 10% data not provided
- Their own documentation on DS: 53% YES, 47% NO
- Their opinion on DS condition: 63% corresponds to DS age, 30% bad
- Waterlogging occurrences: 60% YES, 40% NO
- DS inspection frequency: 68% regularly, 21% occasionally
- Frequency of DS maintenance: 57% YES – regularly, 23% YES – less than once every 3 years, 10% NO
- Increase in time for maintenance: 54% YES – increasing, 21% NO – has stayed the same
- DS documentation correspondence to the actual execution of the DS: 20% corresponds, 50% only partly (depending on location), 17% data not provided
- Benefits of DS documentation: 70% data not provided, 20% necessary, 10% unnecessary
- Satisfaction with MDF maintenance: 59% mostly NO, 17% mostly YES, 7% only partly (depending on location), 17% data not provided

In addition to the method we have developed, we have created and continue to supplement and update a unique geodatabase of data on drainage systems in the GIS environment. This, or rather these geodatabases allow one to work simultaneously with all types of collected data in the following basic structure:

- Raster data:
    - Current distant recordings acquired by RS methods exclusively for the implementation of the project: in the structure of raster catalogues of orthophotos, digital surface models, subclassified according to the surveyed locality and dates
    - Archived LMS acquired for other purposes: in the structure of raster catalogues of georeferenced aerial photographs, subclassified according to the surveyed locality and dates
    - Archived design documentation for drainage systems: in the structure of a file directory of georeferenced projects, subclassified according to the surveyed locality and the year of construction
- Vector data
    - Map layers in the form of polygons created by direct vectorization of orthophotos obtained by recording campaigns of identified DS surfaces and identified lines of conducting and collecting drains (with the attributes: date of flight, type of manifestation, category of identified DS, land use, and optional note)
    - Map layers or further information layers identified based on the same orthophotos (sites of waterlogging, defects, erosion manifestations, etc.) – monitoring and overlay analyses of DS functionality assessments
    - Thematic map layers associated with the investigated topic that are included in running analyses (e.g., LP from LPIS with a wide range of attributes related to the developed method, data on the terrain and experimental research and measuring, external data sources and databases)
- Outputs of analyses – sublayers and databases processed for the final methodological description and results for specific purposes
    - Raster of processed DEM, spatial analyses, etc.
    - Vector layers as outputs of all analyses completed
    - Processed final versions of map outputs for presentation of the achieved results and their potential uses – e.g. as “mapbooks”, Figs. 5, 6
    - Follow-up analyses for purposes of complex landscape measures, Fig. 7, Charts 1, 2

Fig 5. Exemplary map sheet from the libraries created for the registration and classification of identified drainage systems (drainage systems are classified according to the type and extent of their identified manifestation and the type of land use) – discrepancies in registered drainage areas in the national register and drainage areas identified by means of remote sensing (locality Maleč, East Bohemia). This drainage system is not registered in the national register, and moreover, the original documentation of this structure is not available. In this case, remote sensing has provided information and confirmation of the drainage system location in the land parcel. Source: RISWC

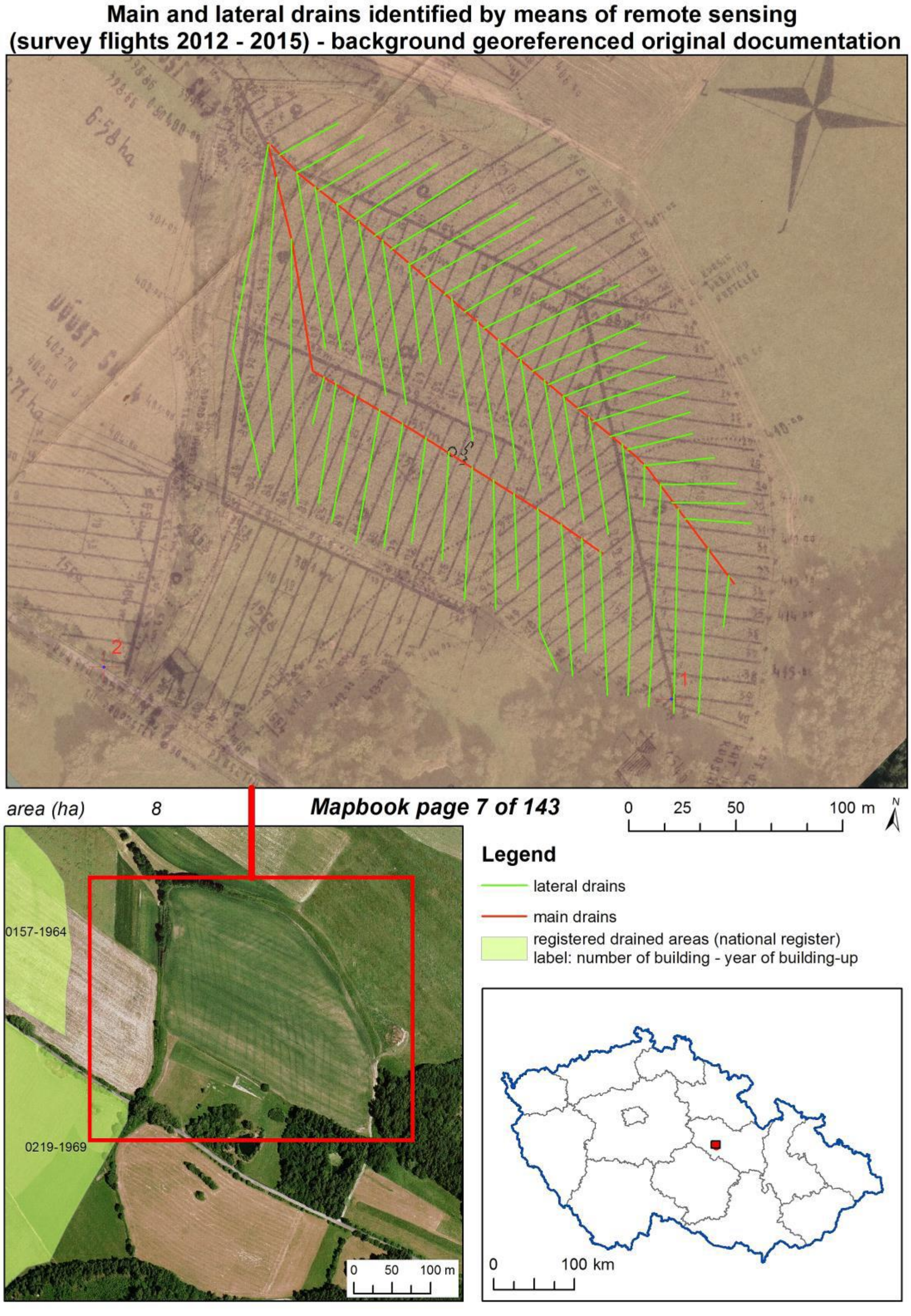


Fig 6. Exemplary map sheet from the libraries created – comparison of drainage system data sources: original documentation and remote sensing identification – plotted drain lines and a comparison matching the georeferenced drainage system construction documentation to the aerial photo (locality Žejbro, East Bohemia). This drainage system is not registered in the national register; the original documentation of this structure is available but does not display the real location of the drains in the land parcel. Source: RISWC

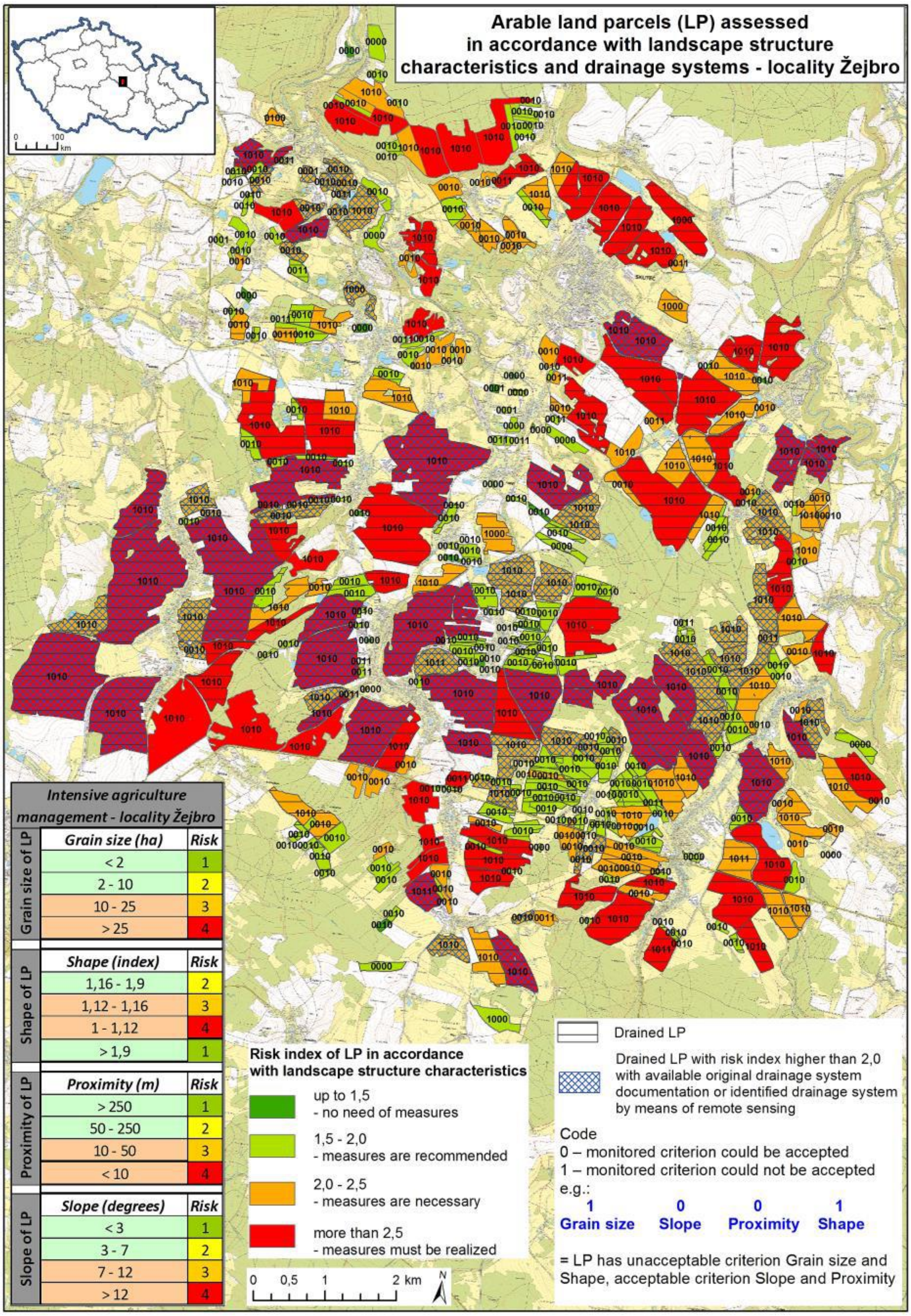


Fig 7. Exemplary map of a landscape characteristic assessment in accordance with drainage areas (locality Žejbro, East Bohemia). Arable land parcels are classified according to the four basic landscape structure characteristics: grain size, shape, proximity and slope. Values have been substituted for these characteristics by risk index, computed by multicriteria analysis, Fuller's method. Information on the drainage systems (original documentation or identification by remote sensing) is provided so that improvement of the landscape structure could also include measures to repair the drained areas. Source: RISWC

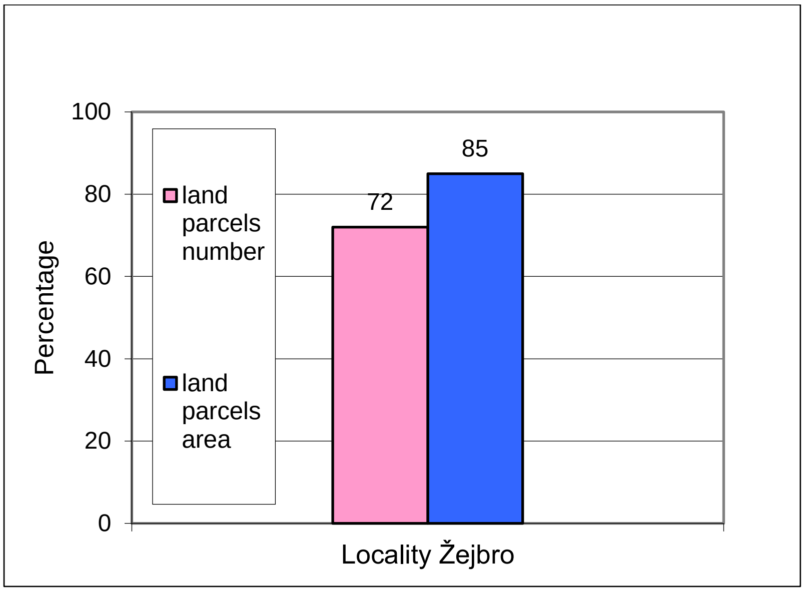


Chart 1. Percentage representation of drained arable land parcels (summary of land parcels and their area, locality Žejbro). Source: RISWC

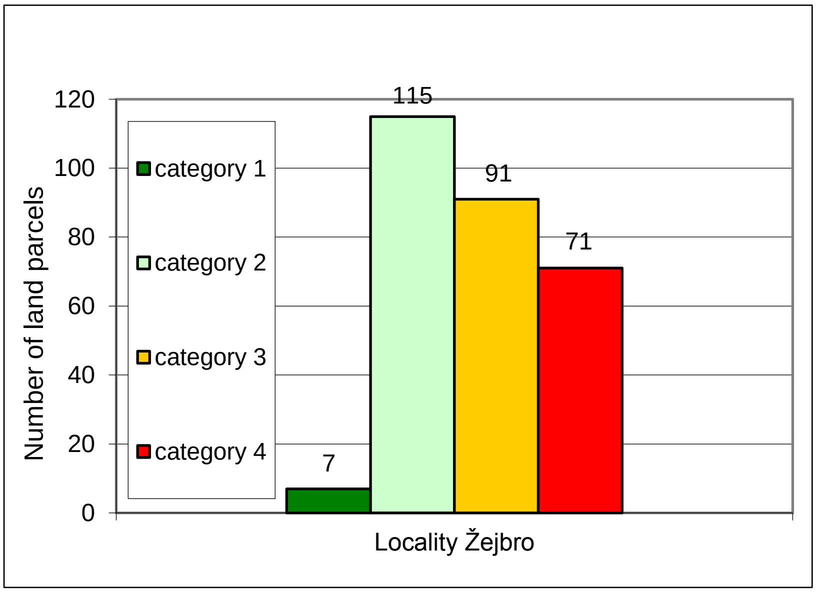


Chart 2. Risk index of drained arable land parcels (summary of land parcels classified into four assessed categories, locality Žejbro). Source: RISWC

5. Discussion

The presence of DDF in LP has not been recorded in the land property register, even though the land parcel owner is also the owner of this system. In the course of land adaptations, new LP are created with new property rights and associated rights of the user, again, without adequate and correct settlement of the existence of DDF in the land parcel. The DDF, even though owned privately, is indivisible from the MDF owned by the state, mostly administered by the State Land Office. DDF (covering ca 1/3 of agricultural land in the Czech Republic) play an essential role in rainfall-runoff conditions, water retention and accumulation, and all related processes (soil erosion caused by water, the distribution of nutrients and pollutants, qualitative and quantitative soil parameters). All this remains inadequately embedded in agricultural management legislation: DZES, PPH, LFA, etc. All DDF manipulations are done based on incomplete, inaccurate or even misleading documentation (the Land Improvement layer in LPIS). The assumption of a direct relationship between system age and decreasing DDF functionality caused by natural aging has not been confirmed. However, its effects on the valuation or devaluation of the land parcel cannot be ignored.

Considering the long-lasting non-conceptual handling of drainage systems (absent and ineffectual maintenance, damage due to development or forestation, unprofessional repairs done without a geodesic survey), establishing their functionality and making predictions for further management is very difficult and differs by locality.

The practice of agricultural management is dependent on and often significantly distorted by the allocation of state subsidies. We have reached a situation where practically all actions are either dependent on monetary support or subject to sanctions. Paradoxically, funding related to drainage systems has not been part of state support since 2007.

Still, drainage systems represent state investments and have an undeniable role in the environment and natural resources.

The procedure recommended for cases of waterlogging in drained agricultural LP:

- The primary responsibility is with the owner, or user.
- The basic information "whether the land parcel is drained" can currently be obtained from the LPIS portal. However, this information is full of errors. Here, it is necessary to first correct the records, at least in the form of supplementing data on older drainage systems, so that this layer corresponds to the final version published by the Agricultural Water Management Administration in 2008 (which can be downloaded without restriction from the website of the Ministry of Agriculture[3]).
- Obtaining design documentation should be in the interest of any owner or user of the drained land parcel. It will allow him to effectively deal with potential system problems (maintenance, repair of defects, change in land use, conflict with other construction, etc.). Even in this phase there may be serious complications, namely with the spatial allocation of the original project in the present landscape. The landscape has undergone significant alterations, and with drainage systems originating from the end of 19th century and the first half of the 20th century, localization of the system without knowledge of its historical state is practically impossible. The simple transformation of the design drawing into the terrain is extremely unlikely. However, this is not an argument against preserving archives of these documents.
- The main drain driving water from the waterlogged locality should be located according to the drawings in the documentation. If the drain is discharged into an open receptacle, the drain mouth should be found and its functionality verified. In the case of damaged functionality, the drain mouth should be repaired, e.g., by perfusion or opening, etc. The recommended procedures for detection, maintenance and repairs are given in TNV 75 4922.
- For the above activities, one must know who is in charge of the recipient (MDF) – Forests of the Czech Republic, respective companies of the catchment area, the State Land Office. Logically, the absence of maintenance of MDF, or generally the DDF receptacle, cannot be neglected when dealing with the problem of systematic drainage, even though the present legal and property right relationships keep causing the unsatisfactory situation in this field to further deteriorate. Concerning the maintenance and provision of data on MDF and small water courses, it would again be desirable to have these map layers included in the LPIS portal. It would enable further proceedings and communication with the respective authorities.

The method of DS identification using RS approaches and the utilization of design documentation allows the application of the above-mentioned points. It enables effective and precise targeting of the subsurface system while minimizing costs and risk of damage to the systems in LP. Both map outputs and documents on the practice confirm the possibility of working with the databases created within the framework of the unified information system LPIS.

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[3] http://eagri.cz/public/web/mze/farmar/LPIS/data-melioraci/

6. Conclusion

The scale of the criteria required for DS visualization in images obtained by distant methods was divided into three basic groups according to the recorded surface and principle of mediating DS manifestations. Besides these specifics, one has to consider the course of the seasons in the particular year and the corresponding meteorological parameters. Broader generalization and simplification of the criteria would mean narrowing the application potential of the developed method. This would mean the elimination of local specifics, which have shown to be of great significance to the manifestations investigated and which with excessive generalization would be undetectable. Moreover, the increasing fluctuations and trends in climatic phenomena, growing instability and advancement towards more extreme values disable the definition of strict criteria without possible adaptation to the variable natural conditions. While this means a certain shift from the original hypothesis for defining the criteria and from the original assumptions, the possibility of recording a large variety of DS manifestations over the course of years allows a trend increasing the effectiveness of image acquisition just because of the monitoring and possible capturing of temporally limited conditions that are essential for the required effect. This advance from large-area solutions to details does not mean that the application to large areas will be reduced. The variability consists in the necessary distribution of image acquisitions to multiple dates based on the particular locality while avoiding increasing costs for such recording by using the RPAS, which despite the extent of the recorded area are sufficient. The end users of the developed method will be able to easily define the optimal conditions for capturing the recordings with the knowledge of the prerequisites defined by us and with a very good and detailed understanding of the managed LP.

Besides differences related to the current state of the construction elements of the drainage, new aspects concerning the existing systemic drainage and influencing the desired approach to their visualization in the RS method-acquired images must also be considered, at least the changes in preferences and supported cultivation methods (advances from the cultivation of food crops to technical crops as an alternative energy source) with the associated distribution of cultivated crops and the impact on large-row crops, along with the repeated application of large quantities of digestate to selected areas in various moisture conditions. All of this may impact the DS visualization and soil properties. These aspects have not yet been evaluated or investigated.

Another aspect is the large scale of the anti-erosive measures, which again are reflected in the distribution of cultivated crops and in the executed agro-technical interventions in these defined areas. As mentioned above, none of these measures respect the existence of the drainage systems. However, all these measures and compliance with the nitrate decree and other measures are associated with possible sanctions on the one hand and the allocation of funds on the other hand. Yet the designation of sites intended for the placement of dunghills without knowledge of the drainage presence in the area may have fatal consequences. This project repeatedly identified DS not in the records (Fig. 5) and repeatedly documented differences between the actual execution and the design of the DS (Fig. 6) (Tlapáková 2015a).

The problem of DS identification can only be solved by a complex approach taking into account the changes in conditions in the agricultural sector, which previously had not been considered in regard to this topic. In combination with different measures applied to different areas, the criteria for the application of the developed method must be differentiated accordingly to be able to correspond to the particular conditions that cannot be neglected.

Analysis and field verification of the mapped localities with DS defects (soil probes, excavation, inspection with a pipe camera) confirmed that the condition and functionality of the drain, drainage groove character, technology of construction, and current soil state (namely its high compaction, density with a minimum proportion of the organic component) represent highly significant factors playing an essential role in DS surface manifestations and their mapping.

Again, an explanation must be sought by combining multiple characteristics, which depending on the nature of the drainage groove can acquire “more extreme” or “more common” appearances. We may assume that the low demonstrability of the drainage groove manifestations in the images will need higher input into, or rather compensation for, the optimal conditions for visualization from other criteria (crop type and surface nature vs. precipitation regime vs. agricultural management). In the case of drainage grooves with higher demonstrability, the need for other criteria may not be so high, increasing the frequency of the identified manifestation in various conditions. The limits for these situations have not yet been precisely defined.

Besides knowing the year of construction (system age), information on the system execution is of key importance. The construction method defines the parameters of the drainage groove (depth, width, mixing) and the way the drainage material is deposited (baked clay tiles, PVC). The manner of covering the groove before embedding, deposition of excavation material, or rate of mixing and heterogeneity of the drainage groove and its hydraulic efficiency (use of gravel and sand fractions for envelope) is related to the surrounding growth terrain as well. These data were part of the original design documentation and their acquisition, similar to the case of the design of drainage objects themselves, is limited both by the availability of archives and by whether or not the design was respected during its execution. Without archived materials, these data cannot be obtained without direct excavation, which represents a rather exacting method limited by the surface.

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Shortcuts:

DDF – Detailed Drainage Facilities
DEM – Digital Elevation Model
DS – Drainage System
DZES – Good Agricultural and Environmental Soil Conditions
GIS – Geographical Information System
GPS – Global Positioning System
HS – Hyperspectral
LFA – Less Favoured Areas
LMS – Aerial Photograph
LP – Land Parcel
LPIS – Land Parcel Identification System
MDF – Main Drainage Facilities
NIR – Near Infrared
PEO – Anti-erosive Measures
PPH – Statutory Management Requirements
PRV – Rural Development Programme
PVC – Polyvinyl chloride
RGBI – Red-Green-Blue-Infrared
RPAS – Remotely Piloted Aircraft System
RS – Remote Sensing
SPÚ – National Land Office
VIS – Visible