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USE OF REMOTE SENSING FOR IDENTIFICATION AND DESCRIPTION OF SUBSURFACE DRAINAGE SYSTEM CONDITION

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Abstract

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The paper presents basic facts and knowledge of special survey focused on detection and evaluation methods of subsurface drainage systems by means of remote sensing. It is aimed at the complex analysis of applied processes in spatial localization, classification or assessment of subsurface drainage systems' actual condition by means of distance research methods.
Data collection, their analysis and interpretation have been shown in seven experimental areas in the Czech Republic. Mainly it means determination of potential, application principles and limits of pracical use of different technologies and image data obtained by remote sensing in solving questions.

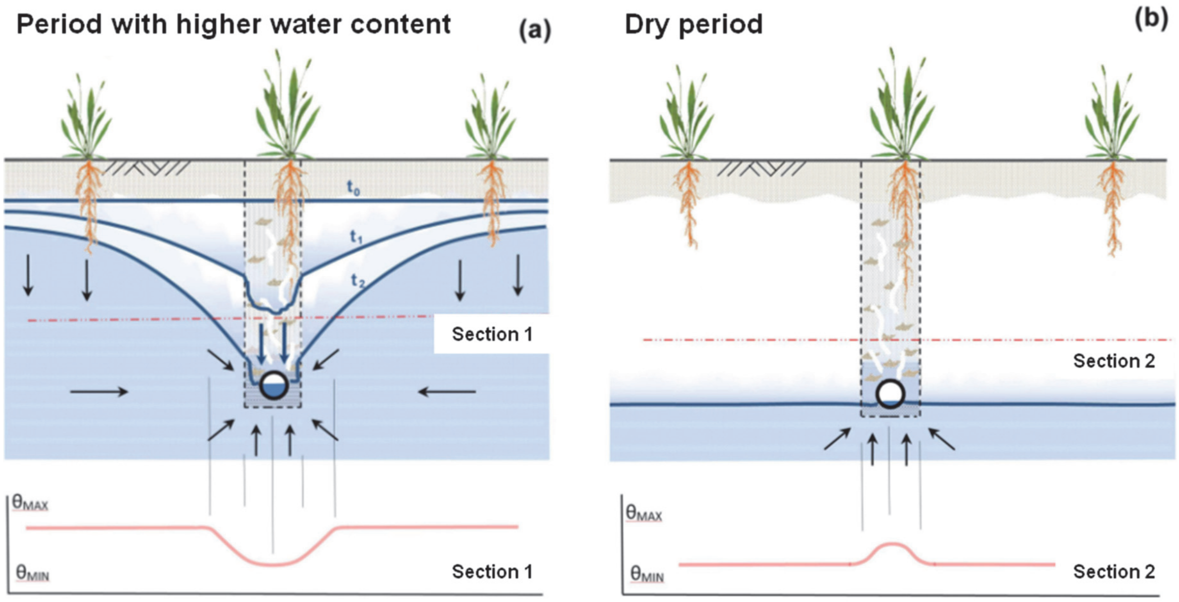
Keywords: remote sensing, RPAS, aerial image interpretation, subsurface drainage

INTRODUCTION

The identification method applied in this work is a remote non-destructive approach based on Remote sensing (RS) in combination with multifunctional tools of geographic information systems (GIS). This method allows effective identification of the entire subsurface drainage system (DS) and assessment of even very large localities with high precision, corresponding to both executive and alignment project documentation of the system. Information on their present condition and functionality is of high importance, beside their current planimetry. Identification of subsurface drainage using the RS tools uses remote investigation of hydrologic objects based on specific spectral properties of water, which differ significantly from those of other natural or man-made objects, i.e. landscape elements and components (soil, rock, vegetation, buildings, etc.). The overall low reflectivity of pure water decreases with increasing wavelength, while the basic course of the spectral curve (with the minimum in infrared spectrum) in natural conditions is additionally significantly modified by the conditional properties of water and environmental effects. In soils as highly heterogeneous compounds, the spectral properties of their abiotic and biotic components are combined. In general, the overall soil reflectivity grows with increasing size of soil particles characteristic for the particular soil type. Increased soil moisture results in its lowered reflectivity, with apparent absorption bands close to the proximal and central IR wavelengths (1.4 and 1.9 µm). The soil moisture content often strongly correlates with the soil texture. Coarse-grained sandy soils are usually easily drained, with resulting low soil moisture content, and therefore high reflectivity. Finely textured soils with difficult drainage will generally display low reflectivity; clay soils will therefore typically appear darker than sandy soils (Dobrovolný, 1998; Žaloudík, 1994). In remote investigations of hydrologic soil parameters, one should discriminate between surface soil waterlogging (oversaturation of the soil surface layer by water and ensuing accumulation of free water on the surface – in a particular form, quantity and duration) and soil moisture and water regime (i.e. water content in the entire soil profile and its changes). Assessment of the intensity or qualitative degrees of surface soil waterlogging and their spatial distribution based on common RS materials is usually associated with direct interpretation methods evaluating significant moisture conditions on the uncovered soil surface. The direct interpretation of the soil moisture conditions is based on evaluation of the correlation between the spectral reflectivity of the uncovered soil surface and its moisture (in general, the reflectivity decreases with increasing moisture). The soil moisture status recorded immediately on the soil surface is then used for direct determination of the amount of soil subsurface water, based on the genetic relationship between subsurface and surface soil horizon conditions. However, these approaches can only be used in specific technical, weather and positional conditions (drainage type, readout time and technology, duration and intensity of precipitation, favourable conditions of the soil surface). However, even the direct interpretation itself of the relevant soil characteristics is often complicated in natural conditions. The reason is that the spectral reflectivity of the investigated soil complex and the recorded differences in surface waterlogging of the drained soils in the images are influenced, beside soil moisture, by additional soil properties, complicating both the exact assessment of the moisture parameters and their correct spatial extrapolation (e.g. mineral and chemical composition, humus and soil pigment contents, texture, surface coarseness (Lipský, 1990; Plánka, 1983; Šefrna, 1986).

Due to the nature and localization of the monitored drainage objects under the ground surface (tile drains usually deposited in 0.6–1.5 m depths), the initial conditions, disposition and practical feasibility of direct imaging and interpretation of these objects are rather limited and complicated. The common methods of passive RS, utilizing for detection of landscape objects the recorded data of reflected or emitted radiation from the visible and infrared spectrum, do not enable intervention under the soil and vegetation cover and thus cannot provide direct information on the objects located in the subsurface zone.

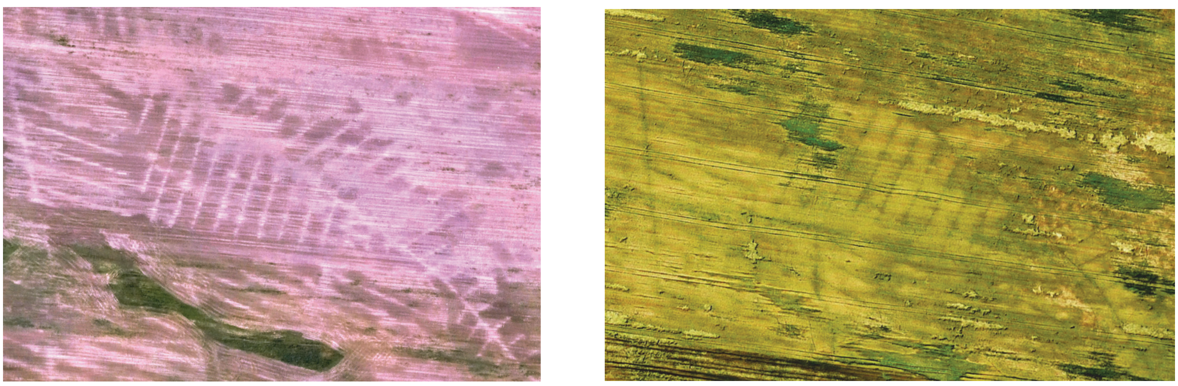
Therefore, in most cases, the subsurface DS represent objects that can be more reliably monitored and studied by standard optical RS methods only indirectly, by using territorial hydro-indicative relationships between the relief, soil, and vegetation – e.g. heterogeneity of soil properties (moisture, temperature, mineral composition and porosity, water permeability, humus content), vegetation characteristics (specific features due to altered positional conditions), relief predisposition (geomorphologic microforms), etc. The indirect interpretation method thus consists in diagnostics of the soil moisture differences based on the corresponding geo-indicators, evaluation of their relevant interpretation signs, and localization in the images. The correct interpretation of these manifestations recorded in the RS images may only be done with knowledge of the basic principles and specifics of functioning of the DS in the soil environment – i.e. recognition of the main hydrologic processes influencing the particular positional conditions in the drained soil profile (above the drain and outside it). The key role is played by understanding the principle of the monitored phenomenon and the correct interpretation of the local relationships among the cause, participating factors, and their significant consequences in the given conditions (marked manifestations of the existence and functioning of DS identifiable in the images), in changing temporal, climatic and positional conditions of the monitored agricultural land. In vegetation-covered surfaces, the most suitable indicator seems to be



1: *The description and functioning of DS in various specific conditions* the vegetation cover, reliably indicating the degree of waterlogging, the depth of the underground water level, as well as the soil water regime. This assessment is based on the natural correlation of the vegetation (condition and species distribution) on the quantity and quality, physiological accessibility and regularity of the changes in water and nutrient content in the soil (Lipský, 1990). The description and functioning of DS in various specific conditions is given in the illustrative scheme in Fig. 1 (adopted from Tlapáková, 2014).

The schemes in Fig. 1 show various mechanisms of effects of the soil water regime caused by the existence of the line drainage element. The ground in the draining groove differs from the surrounding soil by both physical and biochemical properties due to mixing with the excavated material during the construction works. This is manifested by long-term changes in hydro-physical properties (permeability, porosity and volumetric weight, organic mass content, temperature conductivity) caused by the hydromelioration intervention and the consequent processes (biological, hydrological, pedo-genetic, etc.). This identification approach must first consider all the conditions and relationships in the area, including partial geo-factors and anthropogenic activities, which play a decisive role in the typical visual manifestation and potential reliable DS identification from the RS image recordings according to the selected interpretation pattern (based on pedo- and phyto-indications). The key relationships assessed in the area during the interpretation and spatial analysis of subsurface drainages are, in particular, the conditionality and variability of the optical manifestations of soil (uncovered soil surface) and vegetation in the evaluated temporal images (spectral/density, i.e. tone – colour, brightness and texture parameters), both theoretically and practically (experimentally and verified in the field). For the individual distant recording types, the main criteria and factors required for the correct visual interpretation and positional localization of subsurface DS in the selected RS image materials are gradually selected and verified. At the same time, individual exemplary types of the visual drainage manifestations in selected standard or special aerial images are categorized and explained. The examples of characteristic manifestations of subsurface drainage systems in colour aerial images are documented in Fig. 2. The basic type variants of the tree structure of drainage grooves were captured in the images of the same land plot in locality 2 – Žejbro on June 12, 2013 (a), closed corn stand, 20-day phenophase – growth of leaves (light bands of faster drying soil above the drains after precipitation) and on July 7, 2014 (b), closed stand of spring barley, 55-day phenophase (darker lines compared with the surroundings – denser, higher and more vital stand of maturing cereal above the drainage groove, period without previous precipitation) (data source: UpVision, s. r. o.).

The most frequently used above-ground distant methods and RS image material mentioned as the most suitable for identification of subsurface DS include colour aerial IR images in analogue or digital form (colour infrared – CIR), which usually display higher contrast allowing better spatial delineation of the drains. However, colour or BW panchromatic photographs are also acceptable and very well usable for the detection. Spectro-zonal CIR images are highly informative (they are particularly sensitive to the soil water content and to chlorophyll in the vegetation cover), while image materials from the visible part of the spectrum (VIS – namely aerial measurement images in natural colours) are more descriptive and accessible. Moreover, these images can in fact also be used for common agricultural and land improvement practice (they provide a more complex information). These conclusions have also been confirmed by a number of international and national studies focused on large-area monitoring of drained agricultural surfaces (namely exposed soil surfaces before vegetation involvement – (Goettelman *et al.*, 1983; Krusinger, 1971; Northcott *et al.*, 2000; Spreckels, 1995; Swiatkiewicz, 1994; Verma *et al.*, 1996), study of drainage and soil moisture conditions using RS (analysis of local



(a) (b)

2: *Typical visual manifestations of the operating DS in an aerial image of (a) nude arable land with unclosed vegetation cover (light lines), or (b) area with cereal cover (dark lines)* hydro-indication relationships and manifestations of DS – (Lipský, 1990; Svobodová, 1990; Tlapáková *et al.*, 2014; Vinogradova, 1995; Žaloudík, 1994)), RS image processing in GIS – automatical drainage systems delineation and hydrological modelling (Ale *et al.*, 2006; Naz *et al.*, 2009; Tetzlaff *et al.*, 2009) or inventory of the status and function of subsurface DS during specific agro-aerial surveys (Tlapáková *et al.*, 2009; Tlapáková *et al.*, 2008)).

MATERIALS AND METHODS

Description of the Study Areas

The practical RS potential for DS identification has been tested in seven selected experimental areas in the Czech Republic (East and South Bohemia), which are characterized both by variable natural conditions and differing land management in the monitored localities.

The basic characteristics and situation of the monitored study areas are given in Tab. I and in a comprehensive localization map (Fig. 3).

The individual localities represent different climatic degrees with differing geological and hydro-pedological characteristics of the environment (e.g. sub-montane locality 4 – cold degree vs. locality 6 – warm climatic degree in the River Labe region) and land use (e.g. locality 4 – almost exclusively pastures, locality 3 – prevailing permanent grasslands in the form of meadows vs. localities 2, 5 and 1 – intensively managed arable land with a significant proportion of technical crops).

The selected localities differ in their surface (10–80 km^2), as well as in the proportion of drainage (18–52% of the total surface according to available data) and the period of its construction. This is also related to their differing surface and form, finishing (exclusively excavating technology), extent of their servicing or current functionality. All these parameters play a role in DS visualization in RS images and are involved in the establishment of suitable criteria for the visual interpretation. All study areas have been monitored by remote sensing since 2012, both during the vegetation and extra-vegetative period, with multisensory data of various types and resolution (VIS, NIR, thermal) acquired from different available carriers (aircraft, RPAS, mobile posts).

The summary of the dates and types of RS image recordings is given in Tab. II.

The dates of individual recordings are primarily based on the conditions favourable for photographing, i.e. the current state of weather, long-term precipitation trend (characterized by the index of previous 30-day precipitation period – IPP_{30}) and related soil saturation. This has been monitored in relation to the cover condition and the expected DS manifestation in the acquired images. For this purpose, all study areas have been provided with meteorological stations for continuous monitoring of precipitation and air

3: *Localization map*

I: *The basic characteristics and situation of the monitored study areas*

Study area	Surface (km²)	Drainage surface (km²)	Proportion of drained area (%)	Climate	Geology	Soil
1 Maleč	81.42	14.36	17.64	MT10MT2MT3	Mesozoic minerals (sandstone, claystone), orthogneiss, granulites and very advanced Moldanubic and Proterozoic migmatites, Proterozoic minerals with Assynth folding, with various intensity of variss metamorphosis (slates,phyllites,mica schists to paragneiss), repetitive series of Moldanubic minerals (schist gneiss, paragneiss to migmatites), granodiorites to diorites (of tonalite series)	Dystric Planosol, Eutric Cambisol, Eutric Gleysol, Dystric Cambisol, Eutric Fluvisol, Calcaric Regosol, Albic Luvisol
2 Žejbro	71.15	22.66	31.85	MT10MT2MT3CH7	Proterozoic minerals with Assynth folding, with various intensity of variss metamorphosis (slates,phyllites,mica schists to paragneiss), granodiorites to diorites (of tonalite series), Mesozoic minerals (sandstone, claystone), folded and metamorphed Paleozoic minerals phyllites, mica schists), granites (granite series)	Eutric Cambisol, Eutric Gleysol, Dystric Planosol, Eutric Fluvisol, Cambic Arenosol, Calcaric Regosol
3 Zderaz	27.84	5.82	20.92	MT10MT2	Mesozoic minerals (sandstone, claystone), Proterozoic minerals with Assynth folding, with various intensity of variss metamorphosis (slates, phyllites, mica schists to paragneiss), orthogneiss, granulites and very advanced Moldanubic and Proterozoic migmatites, granodiorites to diorites (of tonalite series)	Dystric Cambisol, Eutric Cambisol, Dystric Planosol, Eutric Gleysol
4 Lipka	25.73	13.19	51.27	CH6CH7	Mesozoic minerals (sandstone, claystone), Quaternary minerals (loams, loess, sands, gravels), Tertiary minerals (sands, clays), Proterozoic minerals with Assynth folding, with various intensity of variss metamorphosis (slates,phyllites, mica schists to paragneiss), orthogneiss, granulites and very advanced Moldanubic and Proterozoic migmatites	Dystric Planosol, Dystric Cambisol, Eutric Gleysol
5 Černíkovice	11.62	5.89	50.71	MT11	Mesozoic minerals (sandstone, claystone), Quaternary minerals (loams, loess, sands, gravels)	Luvisol, Gleyic Fluvisol, Eutric Fluvisol, Eutric Cambisol, Dystric Planosol, Calcaric Regosol, Stagno-gleyic Cambisol
6 Strašov	22.48	8.16	36.30	T2	Mesozoic minerals (sandstone, claystone), Quaternary minerals (loams, loess, sands, gravels)	Cambic Arenosol, Eutric Cambisol, Calcaric Regosol, Calcaro-gleyic Regosol, Fluvi-gleyic Phaeozem
7 Domanín	10.03	3.82	38.12	MT10MT5	Tertiary minerals (sands, clays), Mesozoic minerals (sandstone, claystone)	Dystric Cambisol, Eutric Gleysol

II: *The summary of the dates and types of RS image recordings*

year	2012			2013																			
term	**18. 5.**	**17. 10.**	**14. 11.**	**17. 4.**	**24. 4.**	**26. 4.**	**12.–15. 5.**	**18. 5.**	**19. 5.**	**12. 6.**	**27. 6.**	**28. 6.**	**2. 7.**	**17. 7.**	**22. 7.**	**24. 7.**	**29. 8.**	**30. 8.**	**1. 10.**	**2. 10.**	**25. 10.**	**27. 11.**	**4. 12.**	**16. 12.**
type	**VIS, CIR**	**VIS, CIR**	**VIS, CIR**	**VIS,DSM, thermal**	**VIS**	**VIS, CIR**	**VIS**	**VIS**	**VIS, CIR**	**VIS, DSM**	**VIS, DSM**	**VIS, DSM**	**VIS, thermal**	**VIS, CIR**	**VIS**	**VIS**	**VIS, DSM**	**VIS**	**VIS**	**VIS, DSM**	**VIS**	**VIS**	**VIS**	**thermal**
image																								
1. Maleč	15/*	15	15			15																		
2. Žejbro	15	15	15						15															
3. Zderaz	15	15	15						15															
4. Lipka	15	15	15													15								
5. Černíkovice	15	15	15													15								
6. Strašov	15	15	15			15																		
7. Domanín														12,5	20									
detailed image (RPAS)		**VIS, DSM**																						
1. Maleč											18–20						18–20							
2. Žejbro		10		10						13–20		19–21								21		22	20–23	15
7. Domanín					15		15	15					10–20					10–15	10–15		10–15			

/* – resolution of acquired images (cm/px),
VIS – visible spectrum,
CIR – colored infrared spectrum,
DSM – digital surface model

III: *The summary of the main criteria*

Study area	predominant age of DS	the most effect season for identification of DS	vegetation, land cover	moisture period
1 Maleč	more than 60	spring, autumn	all types	humid
2 Žejbro	more than 20	spring	all types	humid + dry
3 Zderaz	more than 40	spring	permanent grassland	dry
4 Lipka	more than 30	spring, summer	permanent grassland	dry
5 Černíkovice	more than 30	spring, summer	all types	dry
6 Strašov	more than 60	spring, autumn	all types	humid + dry
7 Domanín	more than 20	spring, autumn	all types	humid + dry

temperature, which primarily influence the water and air regimes of the soil and differing phyto-indication manifestations of the drainage groove and the surrounding terrain. In cooperation with the local managing agricultural subjects, the sowing schemes with dates and methods of agro-technical operations have been recorded. The knowledge of the plant cover species and phenophase at the time of aerial recording, along with factors influencing the moisture and nutrition regime (fertilization, tillage, cutting), provides important data for identification and specification of the main criteria underlying the visual manifestation of drainage in the images. Beside targeted large-area photographing in seven study areas, detailed investigations and supporting research are also conducted in the selected parts of localities 1, 2 and 7. Selection of these localities is based on differences of the characteristic of their DS, natural conditions, agricultural management and, moreover, availability of other necessary data. Simultaneously with aerial recordings, in selected dates and localities (1, 2, 3) samples were collected to establish the volumetric soil moistures in the drain positions, in the centre between the drains, and in a position of the drained surface where the existing DS has not been identified in the available RS materials.

Methodology Basis

The method of assessment is based on the configuration of several levels of analysed data with the aim to detect their mutual interactions. These levels are gradually configured and corrected according to the level of obtained knowledge and current results:

Scope level:

1. Classification and description of different variants of the visual manifestation in the RS image materials;
2. Establishment of the criteria and specifics of the manifestation in arable land and permanent grasslands in the RS image materials;
3. Correlation between the natural conditions and successful identification, based on laboratory processing of collected soil samples, continuous monitoring of precipitation and air temperature, and evaluation of the supplementary survey;
4. Monitoring of agricultural management of the study areas and its manifestation in the RS image materials.

Spatial level:

1. Vertical – mineral stratum – soil (including soil surface) – vegetation cover – atmosphere);
2. Horizontal – experimental survey and collection of samples in the drain position and outside the drain;
3. Technical – differences in the visual manifestation of drainage related to the utilized method and various types of acquired RS data.

Final synthesis:

1. Assignment of weights to particular criteria with the aim to increase the probability of visual manifestation in RS image materials;
2. Formulazing of the methodological procedure and recommendations for the best identification of DS in the RS image materials within the main points of view.

Data Sources and Analysis

The key data for all interpretation analyses were obtained as images of the study areas (RS image recordings) acquired continuously to varying extent, by varying means (RPAS), at varying dates, spectra (VIS, CIR, thermal) and spatial resolution on various recording materials. The acquired images have then been photogrammetrically processed into orthophotos and they serve as a raster data for editing and evaluation of the study areas with regard to DS identification. All analyses and processing of the remote and underground geodata have been completed in the GIS environment. Both the source data and the results of spatial analyses are kept in the form of geodatabases structured according to the spatial and subject groups. The DS identified visually in RS materials are first vectorised into a polygon layer (with attributes describing the intensity, extent and type of their manifestation at the particular photographing date). The type of plant cover and other potential positional specifics are also included. To evaluate the quantitative parameters of the extent and topology of individual DS construction elements (collecting and conducting drains), DS parts identified in the RS recordings are vectorised in the selected areas into line trajectories allowing unequivocal evaluation of the actual position of these construction parts in the terrain.

Basic utilized classification:

a) according to the extent and clearness of the visual manifestation in aerial images: 1 – complete system, clearly visible; 2 – incomplete system, clearly visible; 3 – incomplete system, moderately visible; 4 – incomplete system, low visibility; 5 – incomplete system, very low visibility;
b) according to the manifestation in the images: 0 – without manifestation; 1 – light lines; 2 – dark lines; 3 – part of the system as light lines, part as dark lines; 4 – plastic manifestation;
c) according to the culture type (basic level): 2 – arable land; 7 – permanent grassland.

(Note: in DS investigated in detail we also monitored the crop species, participation of plant cover, etc.).

Supporting Field Measurements and Analyses (Precipitation – IPP, Moisture and Water Regime)

The current conditions of the upper soil layer during the aerial photographing are described using IPP_{30} (index of previous 30-day precipitation), because it can be easily established in real time or retrospectively for any precipitation-metering station and locality. (Kemel, Kolář, 1982; Kohler, Linsley, 1951) As an additional parameter, we monitored the current soil moisture from samples collected at the time of photographing and established subsequently in the laboratory by gravimetry. Undisturbed soil samples 100cm^3, 2–6 repeating in each tested area were collected and established indexes of soil density (reduced, after exsiccation at 105 °C), soil porosity and soil moisture (relative to the soil porosity, normalized in 0–1).

This index thus reflects the real status of the changing differences in soil moisture conditions (according to the intensity and saturation of the soil profile with precipitation – see Fig. 1), important for notable manifestations of the soil surface water content and successful direct interpretation of the monitored DS. The index of previous precipitation was calculated for all dates of recordings during 2012 and 2013 from daily cumulative precipitation measured at the meteorological stations in the study areas:

$$IPS_{30} = \sum_{1}^{30} S_t \times k^t ,$$

where t is the serial number of the day within the calculated moving interval from day 0 to day 30; k = 0.93 is the evapotranspiration constant.

This value has been recommended for common situations in the Czech Republic. S_t is the total precipitation [mm] on day t. (Kovář, 1990).

In this representation, the date of photographing is specified with regard to the nature of the soil moisture regime. The evaluation can mainly provide the relationship between the date of photographing and significant precipitation, i.e. distance between the precipitation and the photographing date. The regime of moisture changes is defined both by the IPP slope (given by the distance between the precipitation and the photographing date) and the absolute IPP value. These data are then compared with the results of laboratory soil testing. Tabulation of the IPP value range in relation with the photographing dates can then point out the similarity or dissimilarity of the conditions of photographing with regard to the soil moisture.

Evaluation of Control Soil Samples Taken on the Dates of Photographing

Analysis of the results of soil measurements confirmed the hypothesis that meadows have lower volumetric weight of the topsoil horizon, given either by the higher proportion of organic mass (roots) or by soil loosening (again by root systems). On the other hand, further study should focus on the land with very compacted to dense soil. In such conditions, the effects and functionality of the drainage system differ from the other localities (the connection of the drainage groove with the soil surface is reduced due to the compacted soil horizon, leading to the risk of surface waterlogging).

RESULTS (IDENTIFICATION OF DS IN RS IMAGES)

The acquired data have been systematically analysed by GIS tools and stored in the form of digitized structured geodatabase. Specific analysis of raster data is based on visual identification of DS line elements and their vectorization. Due to the variability of manifestations and specificity of the DS topology, automated algorithms for image and object analysis cannot be used effectively. The principle of phyto-indication provides a large range of identifiable DS manifestations, which are not defined only by the immediate status of soil moisture, as is the case of photographing soil without vegetation participation. The preferred phyto-indication principle thus provides higher reliability in assigning the corresponding line of direct effect of the drainage groove, improves the accuracy of the drain localization for its subsequent delineation in the terrain, and significantly increases the rate of correct DS identification in the images, because it prolongs the period of visualization by the time exceeding the soil drying after causative precipitation. Evaluation of the interpretation results is done at the above-mentioned levels and classifications, with regard to the specifics of the particular study areas and the dates of photographing (in relation to the nature and status of the vegetation cover).

Interpretation and Evaluation of the DS Condition in RS Images

Identification and evaluation of the subsurface DS condition in the acquired RS images provides the following survey for the particular study areas (summary of the main criteria is listed in Tab. III):

1 – Maleč

Overall balanced representation of the identified drained surfaces is apparent both in spring and in autumn photographing dates (more humid periods, extreme total precipitation 100 mm in two days). So far, this fact seems to be decisive for this particular locality, when a moderately humid or humid period provides better results of visual manifestation in the images than the dry period (verified by repeated photographing in both extremes: waterlogging due to precipitation vs. long-lasting drought). No correlation was found between the cover species and visual manifestation in relation to the success of identification in the monitored dates. Both the range of manifestations and the cover species are thus comparable to the other localities and do not show any specificity. The locality shows existence of relatively old, less surface extensive DS from the first half of 20th century (with considerable variability in form). With high probability, this fact also influences the drainage visualization in the images. Only a minimum of drained surface could be identified repeatedly at different dates to the same extent. Moreover, a number of DS were found that had not been included in the existing inventory of hydromelioration systems. These are probably systems of older date that are often missing in the inventory database.

2 – Žejbro

This locality is in the focus of numerous field and experimental survey programmes, photographing activities and collections of supporting data on the territory because it represents a major experimental catchment, monitored in the long term for the study of the effects of agricultural drainage on the hydrological processes in the landscape (Doležal, 2006). The locality displays the highest surface representation of drained areas (see Tab. II), mainly intensively managed arable land with significant proportion of technical crops. Approximately two thirds of the DS originate from 1970–1989, with the remaining third built in the 1930s. Moreover, the RS techniques have repeatedly detected the presence of 2-storey DS, which were later confirmed by excavation, while the only official documentation of these systems was incomplete. The most relevant dates for identification were again the spring dates (both in 2012 and 2013), belonging to the more humid period, which confirms the presumption of higher success of this detection and interpretation RS method in the spring. However, repeated photographing of smaller surface extent brought very satisfactory results even in other vegetation seasons (after previous less significant total precipitation, i.e. in a dry period). We verified the temporal sequence of the previous causative precipitation, humidity and identifiable manifestation of the DS at various dates (day 4 after measurement of total precipitation for the period early summer – autumn 2013); in the summer the water saturation of the soil profile was higher (total precipitation 63 mm a week before photographing), while the autumn date was preceded by a 20-day dry period. These relationships will be further studied to allow more precise assumptions of the effects of soil moisture (given by the intensity of precipitation and time distance) in order to provide better security of prediction of the visual DS manifestation at the expected date in the images. In the period after very intensive precipitation (relatively dry 14-day period with 3-mm total precipitation followed by a period of intensive 3-day precipitation of 104 mm 2 days before photographing), variable visual drainage manifestation was recorded on different plant covers without apparent significant correlations – i.e. at surfaces sowed with corn similarly as in previous recordings (light manifestation variant), but also at surfaces of cereals and rape (dark manifestation variant). The autumn 2013 recording dates capture a relatively dry period, while the success, surface extent and occurrence of identified manifestations were comparable to the summer dates. The manifestations were recorded both in grasslands and in arable land in all phases (nude, sowed with cereal cover, with grown corn cover). This again confirms the fact that even wide-space crops may mediate the visual manifestation by identifiable drain lines of the dark manifestation type. These signs are more pronounced in the parts of the land plot where the cover is not highly compact (homogenous) and the colour contrast is thus enhanced. Experimentally, the photographing was tested on continuous snow cover (cca 1 cm). The expected total unsuitability of these conditions for the given purpose was not confirmed. DS were confirmed by a whole range of manifestations, both in grasslands and in arable land, both in areas where their presence was repeatedly identified during the vegetation season and in the areas where this was the only date when such visual recording had been captured. Owing to a higher number of repetitions, in most drained areas the recording identified a part of DS in at least one image, in some cases even repeatedly. Again, numerous DS were identified outside the inventory, confirming the need for revision of this all-state inventory and provision of supplementary information on the existing DS.

3 – Zderaz

This locality was the least successful in DS identification. At practically all dates comparable with other study areas the number of identified DS was the lowest. The spring recording term was apparently the poorest, even though the locality bears the highest representation of grasslands, which generally display better reliability of visual DS manifestations in the images. The highest DS identification rate was achieved in the spring 2013, with photographing taking place practically at the same date as in the previous year (May 18, 2012–May 19, 2013), but in 2013 with ca 2-fold higher success. This may be explained by differing vegetation phase of the grass cover at the time of recording: in 2012 the images were taken just after cutting grass (the cutting was started on May 14), while in 2013 the first cutting was done on June 7 due to belated spring onset. At the time of photographing the cover was close standing, ca 20–25 cm high, which according to initial expectations represents the optimal conditions for DS visualization in the acquired images. Concerning humidity, both recordings were done during a dry period.

4 – Lipka

In this sub-montane locality, the DS were identified with the highest rate and extent during the summer period with lowest total precipitation. The second most successful period was spring, with total previous precipitation of ca 30 mm. On the other hand, the autumn dates show the lowest identification success, even after relatively abundant precipitation (ca 40 mm before

October 14, 2012). Permanent grasslands prevail in this locality (permanent pasture), but with different management than in locality 3 – Zderaz, where these areas exclusively represent managed meadows. Concerning technical conditions, the locality carries a high extent of systemic drainage, established in the period 1968–1991. Practically each polygon of the documented drained area shows a visual manifestation in the acquired images. However, considering the surface covered by the DS and similarity of both natural and technical conditions, this does not represent a methodologically significant parameter.

5 – Černíkovice

Similarly as in locality 4 – Lipka, the most successful period for DS identification was the summer 2013 with practically identical precipitation occurrence (dry period). Both the surface extent and clearness of the manifestation were the best at that time. Again, similarly as in the previous locality, the spring dates of 2012 were successful (also a dry period, ca 13 mm of total precipitation a week before recording). In both cases the DS were identified identically in the same areas, differing in surface extent. Contrary to locality 4, this practically concerns only arable land with various types of agricultural crop in differing phenology phases at the time of photographing. Almost null DS were identified in the images taken during the autumn (dry period). The recorded manifestation type would correspond to the model of drainage groove functioning in the dry period. Considering that this effect was recorded in the summer in an extremely dry period, but not again in the autumn, to better define the suitable conditions for visualization in the images one should take into account a longer period of precipitation and the rate of saturation of the particular type of soil profile.

6 – Strašov

Here, the success of DS identification was balanced in the spring and summer images, showing at the same time the most significant differences in soil characteristics (prevailing Cambisol, Pararendzina and Phaeozem). The DS were identified at different recording dates in different parts of the drained areas, without significant overlapping and without demonstrable causative relationships.

7 – Domanín

The representation of the identified DS is balanced both in arable land and in permanent grasslands. They are shown by clearly visible, significantly darker vegetation bands above individual drains, formed due to faster growth of denser, higher and more vital vegetation, both of agricultural crops in arable land (namely cereals) and in well-developed grasslands (after previous removal of grass biomass by cutting or pasture). Only in isolated cases and temporally, some opposite types of drainage identification manifestations were observed in some continuously monitored areas of arable land both in the summer and autumn periods (before and just after the harvest of the cultivated crops) – i.e. less apparent, larger and not clearly limited light lines of drainage grooves against their surroundings, both in mature cereal crops (related to the changes in physiognomy and appearance of the covers during the plant maturation – earlier maturity with changes in plant colour and water content) and in nude soils before their ploughing (differentiation of the effects of drainage groove during the drainage of the soil profile after previous intensive precipitation). The capacity to identify drainage is negatively influenced by the seasonal agro-technical operations (ploughing and harrowing of arable land or fresh meadow cutting, stomping and pasture exhaustion by cattle), when even previously apparent structures of subsurface drains in the images are partially or totally masked.

DISCUSSION

So far, the most reliable identification of the DS has been achieved (concerning the representation of arable land and permanent grasslands in the study areas) in intact, cultured permanent grasslands; this is valid for all images from almost all recording periods and in the whole range of the captured manifestations. The type of manifestation captured in panchromatic photos in natural colours is in accord with the type of manifestation identified in the infrared CIR images. No case has been recorded as yet in which the characteristic manifestation type differed between both materials or where the manifestation was found in one of them only. However, there are certain differences in the clearness of the represented identification signs. This again confirms the assumption that in suitable conditions, whose precise criteria have not yet been unequivocally defined, the drainage can be identified with the same success in different image materials using differing detection methods (both above-ground and underground). On the other hand, in unsuitable conditions, none of the so far utilized and tested recording methods has shown better success than the others. Based on the experiments and analyses performed so far, we may conclude that the visual effect of the drainage groove given by phyto-indications can be observed practically in all types of the vegetation covers and crops, of course, in varying degree of "quality" (clearness) and frequency. DS have also been repeatedly identified in covers of wide-spaced and technical crops (grown corn cover, rape cover in all growth phases). Therefore, the assumption that some types of crops are not suitable for DS visualization based on the phyto-indication effect are by definition unsuitable. The type and nature of the vegetation cover, while playing an important role, is not decisive for the resulting representation of significant manifestations of the drainage grooves in the images (in the form of typical tree structures). Beside the type of manifestation, we also evaluated the sharpness of the represented line against the surrounding terrain (towards the space between the drains). The so far recorded range of the image manifestations appears, in the case of typical "light manifestation" (corresponding to gradual differentiation of moisture in the course of drying soil surface after precipitation in arable land, without participation of the vegetation cover), as an unfocused and relatively broad line (ranging from 1 to 3 and more metres). On the other hand, the indication lines identified as typical "dark manifestations" in the vegetation cover are more significantly delineated, appearing sharper, better contrasting, and also more narrow (only of ca 30–40 cm breadth, which better corresponds to the breadth of the drainage groove itself). However, the sharpness and contrast of the represented drainage lines in the images does not represent a principal limitation to the utilization of the described DS identification method, although it may limit the accuracy of their subsequent delineation in the terrain (e.g. during repairs). Nevertheless, even for the larger visualized drainage lines in the images, a satisfactory level of accuracy was achieved in their terrain delineation. The majority of areas with identified DS fall into the category of "incomplete system" (category 2 to 5). So far, only a small proportion (5%) of surfaces with a complete and well-visible DS has been identified. This may be due to the fact that these constructions have ca 25 to ca 90 years of age, and no precise information on their functionality or condition are available. The verification is done by direct excavation of the drains in the terrain, which can only be done locally and not to the extent relevant and comparable with the extent of photographing. The individual localities mainly differ in natural conditions, and thus in the distribution of the DS. Further research should answer the questions whether the extent and distribution, in combination with local altitude conditions, may have a significant effect on the visualization of various DS parts in the images. The altitude parameters in relation to the DS topology might be correlated with repeated manifestation of a certain DS part only (in varying climatic conditions and vegetation cover with its phenophase) or, on the contrary, with the missing manifestation in the other parts of the drained area.

CONCLUSION

In summary, we may conclude that no combination of the monitored factors has been found in the DS manifestations, intensity, and dates of image acquisition that could be unequivocally excluded from further experimental work as totally unsuitable, or, conversely, preferred as suitable. This variability is probably directly related to the current status, functionality and properties of the particular DS, which cannot be generalized and standardized for entire large areas. However, the detailed survey of selected localities pointed out some correlations that may be, to a various extent, also applied to the systems that have not been investigated in detail and on which the information has been obtained only indirectly.

Recommendations for the best identification of DS could be conclude in the following main points of view:

The best conditions differ depending on the type of land cover, resp. vegetation, so that 3 basic types must be distinguished: 1. permanent grasslands, 2. "green" arable land with vegetation and finally 3. "nude" arable land without or with unclosed vegetation.

1. Permanent grasslands – fundamental term of photographing is before the first cutting, in the spring period with higher, long lasting humidity. The most suitable term depends on the previous winter character with its snow cover thickness, its melting and moisture conditions. VIS or CIR images could be done with resolution in 20 cm/px. On the contrary, least convenient term is immediately after cutting grass or pasture improvement and stripping.
2. "Green" arable land – necessity of appropriate combination of the crop phenophase, range and course of precipitation within agricultural management, mainly fertilization. Under these circumstances arable land with cereals cover (approx. 37 to 75-day phenophase) pictures lines of DS the most effectively. In autumn, under the similar circumstances, but with catch crop cover, there is rape (*Brassica napus subsp. napus*) quite reliable type of cover for visualization of DS. VIS or CIR images could be done with resolution in 20 cm/px in both alternatives.
3. "Nude" arable land – efficient term seems to be in early spring or during autumn in optimal off-set of significant precipitation (at least 20 mm) and agricultural management (harvesting, tillage, harrowing etc.). Visual manifestations of the operating DS in taking images are based on different (higher) drying-out of DS lines. VIS or CIR images could be done with resolution in 23 cm/px.

While applying the RS method, the optimal approach seems to be the combination of standard large-area aircraft photographing (gauging images and orthophotos) with supplementary, operative, less extensive specific photographing of land plots using the RPAS means. Fast confrontation of the acquired images with the real state of the covers and recorded surface directly in the field is also important. Creation of a detailed digital model of the surface (e.g. in order to establish the drain sloping and determine the DS topology in case of missing design documentation) and possible more frequent remote DS photographing with lower requirements for stable, suitable weather are helpful as well. This combined image acquisition for hydromelioration detection purposes should help define the relevant criteria and allow repetition, verification and higher reliability of application of the developed identification method.

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