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The application of the Geographic Information System and remote sensing in identification of the flooded and waterlogged areas

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Abstract: This paper concerns the application of remote sensing and the Geographic Information System (GIS) to the identification of standing water bodies during floods and the differentiation of landforms in flooded areas. The methodology was applied to the flood plain of the Morava, south of the vilage Vysoká pri Morave, Slovakia, with respect to the August 1985 flood.

Key words: aerial photographs, flood plain, river Morava, flooded and waterlogged areas, abandoned arms and meanders, oxbow lakes

Introduction

The study deals with the application of remote sensing and GIS methods to the identification of flooded and waterlogged areas in flood periods. Research into these phenomena was directed to the identification of landforms in flood plains. The different degrees of flooding or waterlogging can disclose or indicate fluvial landforms, which were partially covered or simply not mapped before.

The study emphasizes the following possible applications of aerial image interpretation and GIS technology:

i) the identification of spatial extent of flooded and waterlogged areas corresponding to a particular N-year discharge during floods,

ii) the specification of fluvial relief forms and the recognition of small terrain irregularities, which are not always precisely represented on existing 1:10 000 scale topographic maps.

The method was applied to the Slovak–Austrian boundary reach of the Morava river fluvial plain from Vysoká pri Morave, where it is about 5 km long, and in places 3 km wide. The flood plain is bounded by the river Morava, the dike and the channel of the Malina. Also, because the Morava channel represents a state border, and was therefore a strictly guarded area until 1989, the flood plain area preserves a largely undisturbed natural complex. It displays the forms typical of fluvial morphology and only minimal traces of anthropogenic activity.

The Morava floods this area annually, at which times it is almost inaccessible. Thus, identification of the extent of the flooding is impossible using conventional methods of field research. The dominant function of a flood area is retention or drainage of the flood water, though the grassland on the Morava flood plain is regularly mown for agricultural purposes.

Methodology

When applying remote sensing data at a research level such tasks as the identification and surveying of flooded and waterlogged area require the use of GIS technologies. These enable the integration of extensive data sets from several thematic layers and they permit a comprehensive solution to the problem. The density of information, the situational accuracy and the accessibility of the required information at times when field research is not possible represent the chief usefulness of these techniques. Their principal drawback may be the difficulty of harmonizing the imaging interval with the flood event. Clearly, the ideal situation is when flexible imaging is possible during a flood.

Aerial images make it possible to obtain data concerning a short-term landscape-changing event such as a flood, and simultaneously provide information describing dynamic phenomena (for example, changes in the flood-affected ground), when serial records of the ground are obviously desirable. As one of the possible data source, black-and-white images provide the required information on the spatial extent of floods and can also be used in the creation of a map of the flood-affected area. Aerial images not only record the contemporary fluvial morphology of the flood plain and short-term terrain modifications (deposition, landsliding, erosional furrowing, bursting of dikes, etc.), the frequent consequences of flood, they also facilitate recognition and differentiation of the first order fluvial morphological events and small terrain irregularities, which have not previously been precisely surveyed. The latter occur during floods and may remain filled with water for some time after the main phase of drainage of the standing water from the flood plain. The choice of images must, of course, be based on the harmonisation of the imaging interval with the flood. The first step, therefore, is to find a flood, with which there are matching aerial images of model territory being investigated.

As well as the 1997 and 1998 floods, which for the river of Morava represent ten-year events, there have been three other important floods in the last 25 years: February 1997 ($Q_{max} = 998$ m^3.s^{-1}, which is regarded as a 10-year event) and in August 1985 ($A_{max} = 881$ m^3.s^{-1}, a 5-year event discharge, which was recorded at the Moravský Ján station). During a third flood in August 1991 the river level of the Danube affected flows on the Morava up to the 15 km from the confluence.

The investigated area was imaged only 8 times in the years 1969–1995, and only in August (1985). It thus shows some of the effects of flooding in the Morava floodplain. Positive copies of the aerial panchromatic images of area investigated at a scale 1:10 000 were bought from the Topographic Institute in Banská Bystrica. Aerial images are the main source of information concerning the scale and intensity of flooding. Supplementing information were provided by watermanagement and topographic maps at 1:50 000 and 1:10 000 scales, and by field surveying. Precise interpretation requires proof of the validity of interpretation scheme adapted in the field. Without this the interpretation necessarily implies certain degree of uncertainty and error. The work was based on older studies, e.g. Feranec & Kolář (1988) and Cebecauer (1997) who surveyed barren waterlogged lands in the Eastern Slovakia lowland by means of multispectral satellite images.

The present contribution is an extension to existing research into flood plain of the Morava south from Vysoká p. Morave. This area has been selected as the archetype for the application of remote sensing data and GIS in the analysis and registration of physiognomic vegetation forms and land cover (Feranec et al. 1993; Oťaheľ *et al.*, 1994).

Characteristics of the study area

The procedure outlined here was applied to the southern part of the Morava delineated by the road, which connects the river with the dike in the vicinity of Marchegg, which forms part of the eastern bank of the river between 10.6 and 15 river km of the confluence with the Danube (Fig. 1). The study area is part of the Záhorská nížina lowland. The accumulation of the Quaternary sediments is the result of past climatic changes and tectonic movements which are ongoing. An 85 m thick layer of Quaternary sediments (Kullman, 1980) has been confirmed in the Zohor-Marchegg depression, which partially overlaps with study area. Repeated climatic changes in the Pleistocene led to cyclic sedimentation of fluvial sediments in the researched stretch of the Morava. Nine cycles of fluvial sediments have been identified (Vaškovská, 1963).

The modern relief of fluvial plain is, of course, the result of accumulation, erosion and transport activity of the river in the past. The monotonous and flat flood plain is locally differentiated by a network of old river arms in various stages of development, by oxbow lakes and by numerous depressions with typical wetland vegetation. The Morava channel is well graded and of low gradient (approx. 0.2‰). Thus, in the recent past it has meandered, shifted its bed course and regularly flooded the surrounding area. The river changed its bed almost after every flood, as indicated by the many abandoned arms and meanders along the whole length of the stream.

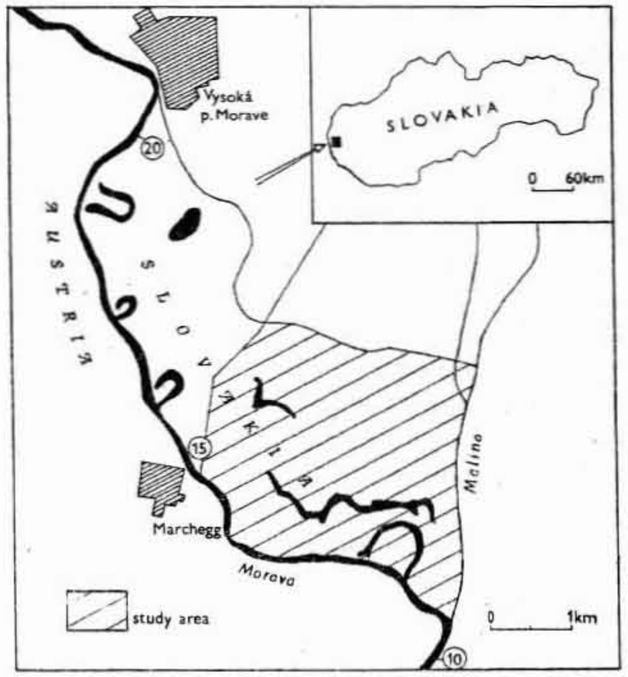

Fig. 1. The location of the study area

When fully developed meanders were breached, the stream straightened and shortened (Grešková, 1998). This was how the discharge concentrated into the main bed and the earlier-formed meanders lost their „reservoir" function during floods. In the present study area there is a particularly prominent meander cut off at 12 km. The entire Slovak–Austrian boundary section of the Morava became constricted by dikes on both sides of the river into a narrow flood area, which widens only in the study area, i.e. south of Vysoká p. Morave. Here, typical fluvial morphology with its typical forms survived in contrast to the area beyond the dike where they have been altered by anthropogenic activity.

Evaluation of hydrological/meteorological situation

The meteorological conditions during the study year have been evaluated, special attention being paid to the rainfall before and during flood. In terms of the annual total rainfall, 1985 was a year, which slightly exceeded the average. The annual precipitation total registered at Malacky was 651 mm and that at Zohor, 686 mm. The bankful water level of the Morava was preceded by heavy rainfall, which began at the end of July and ended on August 10th. The highest monthly precipitation totals were registered August that year. (Malacky, 135 mm and Zohor, 162 mm).

Registration was not continuous at the Vysoká p. Morave gauging station during 1985 so for the purposes of this research, the water levels and discharges registered at Záhorská Ves (0 gauge = 139.86 m a.s.l.) have been adopted. In 1985, the Morava culminated at Záhorská Ves on August 13th with a discharge of $Q = 845$ m^3.s^{-1}. Aerial imaging took place on August 24, 1985 when the following values were registered: $Q = 265$ m^3.s^{-1} $H = 342$ cm. Of course, the standing water remains in flood plain long after the water level of the channel has fallen. This is as true for the southern part of the Morava flood plain, as any other.

Interpretation of aerial images

The analogue (visual) method for the interpretation of aerial panchromatic images was used. This applies an extensive scale of interpretation criteria (Šúri, 1996). Fairly acceptable (in terms of homogeneity) classes of different rate of surface flooding and waterlogging were identified by interpretation of black-and-white aerial images. The classes of rate of surface flooding and waterlogging rates were distinguished in the process of analogue interpretation relying on physiognomic traits. Physiognomic traits of the identified classes of surface flooding and waterlogging rates are for the purpose of this study significant characteristics of appearance (the tones of gray, texture, brightness). Manifestations of surface changes (identifiable on the images as typical homogeneous patterns) are also defined as physiognomic traits. The process of identification consisted of distinguishing, classification, and establishment of borders of the flooded and waterlogged areas on photomaps.

In case of standing water bodies, there is a very low risk of misinterpretation, but it may occur. This may be due, for instance, to waves on the water surface, in which case the water does not appear to be homogeneous on the images. As in the case of terrestrial imagery, it is usually easy to differentiate standing water bodies from waterlogged ground. But it is not easy to differentiate different degrees of waterlogging, and, in such cases, the interpreter has to apply his or her best judgment. The following classes of flooded and waterlogged areas were distinguished in the air photograph analysis:

1. Territory with higher level of flood

The ground surface lies deep below the water table and it is covered by a relatively thick layer of water (darker).

2. Territory with lower level of flood

The terrain lies close below the level of the water table, it is covered by a thinner and therefore lighter layer of water. This particular class occurs, for instance, inside meander loops and it was identified on relatively higher situated spots with thicker fluvial deposits.

Classes 1 and 2 represent flooded areas covered by continuous water table. Classes 1 and 2 are comparatively easily identified on aerial images. They differ from the water surface of a stream and that of meanders by tones of gray, brightness and texture. Solitary trees and shrubs often protrude from the water.

3. Territory with very waterlogged surface

An intensely waterlogged area is defined as ground where standing water is discontinuous. Inside these areas water may be concentrated in small shallow depressions along the network of abandoned arms. Bodies and standing water smaller than 1x1 mm (10x10 m in the field) are categorized as Class 3 areas. If larger, they are Class 1 or 2. Field roads are usually covered by water during floods.

4. Territory with waterlogged surface

Class 4 areas often grade imperceptibly into those of Class 5, but, owing to pronounced difference of tone of gray on aerial images, it is easy to differentiate them from Class 3 areas.

5. Relatively dry territory

These areas are never flooded. They are often similar to those of Class 4 but may have a distinctive feature, which may be attributed to the farming activity, e.d. striped ground following mowing and the farming activity. It is the case of mown meadows with distinct strips after mowing and with presence of field footpaths.

In the identification process also abandoned arms and meanders (6) and oxbow lakes (7) were distinguished. The abandoned arms and meanders are in an advanced stage of development, being silted-up and overgrown, often fringed by vegetation. In flood times they are normally filled with water. The boundary between Classes 6 and 7 is often gradational. Hydrophilous plants inhabit the more recently abandoned arms or meanders of the old river system of the Morava and there are often semi-permanent ponds. Except at time of flood, they are part of a well-preserved system of oxbow lakes, which documents the past development of the Morava fluvial plain. Woodlands, solitary trees and shrubs, water streams and channels, standing water (the Hajbrodské Jazierko Lake) and the dike which border the area, were also identified. It was not possible to differentiate between the flooded and unflooded forest but it seems that at least some of the woodland bordering the Morava and the Malina were also flooded.

Results of interpretation were processed into a scheme at scale 1:10 000, scanned, georeferenced, and adapted by means of identical ground control points into the national cartographic coordinate system (S-JTSK), which also contains topographic elements. Vectorisation of the interpretation scheme was achieved by means of the *r2v* semiautomated programme (Able Software Company). Then polygonisation and identification of closed polygons were carried out by designating to each of them a digital code, which corresponds to the identified class. The interpretation is given as the digital map of flooded and waterlogged areas in ArcView GIS (Fig. 2).

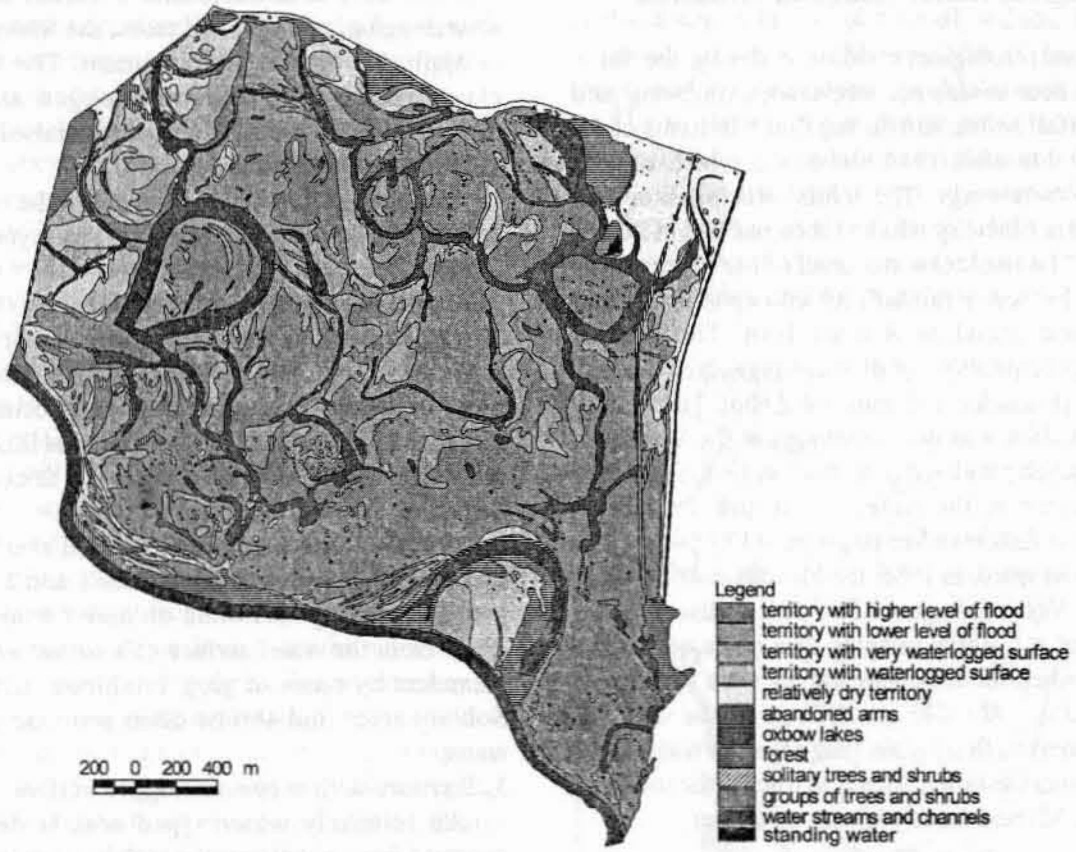

Fig. 2. Flooded and waterlogged areas in the S part of inundation area of the Morava River (Aug. 24, 1985)

Conclusion

Aerial images are now a common source of reliable and precise information at times of flood and they offer a variety applications for flood-protection measures. It is important to realize that the image records an immediate situation. However, changes caused by floods can be detected by comparing images taken at different times. Serial imaging makes it possible to determine the areas flooded only at certain times. Changes can be identified by means of GIS. The information obtained finds a wide use in the prediction of the extent of flooding area, which corresponds to a particular *N*-year discharge (*Q*) or the water level (*H*) during the flood.

It is concluded that interpretation of aerial images in a GIS environment is an efficient means of precisely establishing the extent of flooding and waterlogging at times of flood, as well as enabling the recognition and specification of the fluvial plain morphology. The interpretation of aerial images makes it possible to recognize the courses of old river arms in various stages of their development, and also shallow terrain irregularities, which are filled with water only at times of flood and in the immediate aftermath. The present results emphasize the inadequacies of the existing 1:10 000 maps, which in this case did not exactly represent the locations of the old arms and shallow (up to 0.5 m) terrain depressions.

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