GIS-BASED MAPPING OF EXCESS WATER INUNDATION HAZARD IN CSONGRÁD COUNTY (HUNGARY)

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Abstract

The average annual precipitation may show extremely high territorial and temporal variability in Hungary. In the flat-land regions the excess waters cause several problems and damages mainly in the agricultural areas. In this paper GIS based mapping of excess water hazard and some related influential factors are presented in Csongrád County (4,263 km^2). Limited numbers of affecting environmental factors were considered, and information on these factors was collected and arranged. The affects of soil, agro-geology, relief, groundwater, land use and hydrometeorology were represented by one parameter. In this way the formation of excess water was defined and quantified. Each factor was spatially represented by: soil infiltration capacity; a complex index considering the depth and thickness of the uppermost aquitard; relief intensity; the average of the ten highest groundwater levels within 50 years; a numeric coefficient of land use based on CORINE Land Cover (CLC100) database and individually attributed to its categories; humidity index (10% possibility of occurrence of root square of sum of monthly weighted precipitation and sum of monthly weighted potential evapotranspiration ratio). The values coming from the regression equation were multiplied by and added to a constant value, resulting in the Complex Excess Water Hazard Index. The values provided by the equation were then used to compile the excess water hazard map based on more detailed original map layers. As a consequence the resulted risk map and integrated database can be utilised in numerous land related activities (e.g. land use and agricultural planning).

INTRODUCTION

The Great Hungarian Plain (43,600 km^2) is the largest lowland of Central Europe. It has continental climate, but it is also exposed to oceanic and mediterranean effects. The average annual precipitation may show extremely high territorial and temporal variability. Under such conditions a considerable part of precipitation is lost by surface runoff, downward filtration and evaporation, but principally in the flat-land regions the excess waters cause several problems and damages mainly in the agricultural areas having basin-bottom character. Damage caused by excess waters can be occurred about 1.8 million hectares, from which 60% is located in the arable-land of the Great Hungarian Plain. According to Pálfai (2000) the area affected by inundation in every 5 years is 150,000 hectares on average. The highest inundations (above 300,000 ha) were registered in 1940, 1941, 1942, 1966, 1999 and 2000 as indicated by Figure 1.

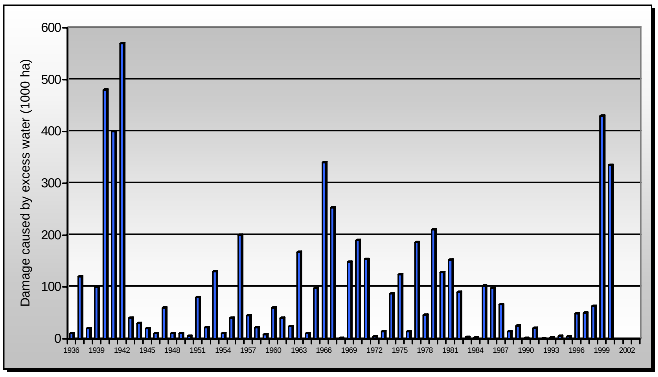

Figure 1: Average excess water inundations of the Great Hungarian Plain
Source: Pálfai (2000)

The term excess (inland) water defines the occurrence of inundations outside the flood levee, in the protected area (from sources other than flood overflow). According to Pálfai (2001) most of the definitions have a common part, namely, that excess water is a kind of temporary water inundation that occurs in flat lands. Many of the definitions emphasise that in addition to precipitation and snow melting the other substantial source is the groundwater, which emerges on the surface (so called underflooding). More recently the over-moistening of the soil of arable land is also considered excess water, as it also causes damages.

Basically the development of excess water inundations has two main reasons. On the one hand the constant factors (i.e. geological structure, soil conditions, relief, dead river beds), which create the conditions of development of excess water inundations, and on the other hand the variable factors (i.e. weather and groundwater conditions) and human factors (land use, water management, agricultural techniques, land degradation, over-irrigation and so on), which generate this phenomenon. In hydro-meteorological respect there is a great importance of the extreme meteorological situations (accumulation of previous precipitation, low air temperature and sunshine duration and low intensity of evaporation periods). The non-uniform distribution of atmospheric precipitation combined with heterogeneous relief and soils with unfavourable physical/hydrophysical properties are the reasons of extreme moisture regime: the simultaneous hazard of waterlogging or over-moistening and drought-sensitivity in extensive areas, sometimes on the same places within a short period (Várallyay, 2003, 2004). The most significant excess water hazards were determined by the previous long rainy periods. For this reason the groundwater level can also rise progressively which is able to cause excess water inundations, mainly on those areas where not to be found impermeable layer above the groundwater level.

The first attempts to display excess water hazard of lowlands on maps dates back to early ’80s in Hungary (OVH, 1984). National and regional overview maps were compiled based on mainly even frequency records (Pálfai, 1994). There were some pilot scale programs for GIS based mapping of excess water risk by Bíró and Thyll (1999).

MATERIALS AND METHODS

For the whole investigated territory (4,263 km^2) of Csongrád County (Figure 2), situated in the lowland featured Southern Hungary, GIS based quantification and large scale mapping of excess water hazard was carried out. Motivations of the studied area selected were as follows: most part of the region is used for agricultural production; poor vertical drainage of the soil profile due to heavy texture (high amount of expanding clay minerals, low permeability, limited infiltration); meteorological data series are available in the necessary length and quality.

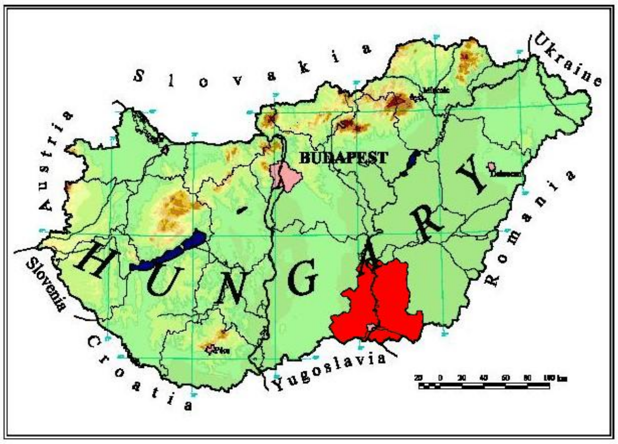

Figure 2: The studied area, Csongrád County

Limited numbers of affecting environmental factors were considered, and information on these factors was collected and arranged. The affects of soil, agro-geology, relief, groundwater, land use and hydrometeorology were represented by one parameter. Essentially each influential factor was typified by only one value at a given place. In this way the formation of excess water was defined and quantified.

Note: Arc/View 3.2 was used for spatial analysis which was carried out in the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences (RISSAC).

RESULTS AND DISCUSSION

Effect of soil (SOIL) was modelled and spatially represented by the water management characteristics of soil (infiltration capacity, mm/h) which based on Kreybig map series (1:25,000) and 1:100,000 scale map of the hydrophysical characteristics of soils (Várallyay et al., 1980). The national soil-mapping project was initiated and directed by Lajos Kreybig in 1937. These maps are still accurate, because the temporal changes in the mapped soil characteristics are not significant. Values of soil factor are shown in Table 1.

Table 1

Values of soil factor

Soil types	Values of soil factor
(1.) sand	5.00
(2.) sandy loam	3.25
(3.) loam	1.25
(4.) clayey loam	0.85
(5.) clay	0.60
(6.) slightly saline and alkali soil, or pseudogleys	0.30
(7.) strongly saline and alkali soil	0.10

The representation of soil factor was worked out by the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences.

Effect of (agro)geology (GEOL) on the formulation of excess water was modelled and spatially represented by a complex index taking into consideration the depth and thickness of the uppermost aquitard (Table 2). The geology factor and map was prepared by the Geological Institute of Hungary.

Table 2

Values of agro-geology factor

Thickness	Depth				
	Aquitard on the surface	<2 m	2-4 m	4-10 m	>10 m
<1 m	0.2	1.8	3.6	4.8	5.0
1-2 m	0.1	1.5	2.7	4.2	5.0
2-4 m	0.1	0.9	1.8	3.4	5.0
>4 m	0.1	0.3	1.1	3.0	5.0

Relief intensity (RELI): Effect of relief on the formulation of excess water was modelled and spatially represented by relief intensity; i.e. variation in elevation per square kilometer. 1:25,000-scale topography map (source: Ministry of Defense) was utilized for the digital terrain model. It was created with digitalizing the contour lines of the investigated area.

Effect of groundwater (GW) was modelled and spatially represented by the standard depth of groundwater; i.e. the average of its ten highest values within 50 years. Spatial analysis of ground water levels was carried out by using long term hydrographical database of Directorate for Environmental Protection and Water Management of Lower Tisza District.

Effect of land use (LU) on the formulation of excess water was modelled and spatially represented by a numeric coefficient based on CORINE Land Cover (CLC-50) database and individually attributed to its categories (Table 3).

Table 3

Values of land use factor

Land use category	Land use factor
1. Artificial areas	0.6-1.0
2. Agricultural areas	
2.1. Arable lands	0.3-1.0
2.2. Permanent crops	2.5
2.3. Pastures	0.6
2.4. Heterogeneous agriculture	0.5-2.0
3. Forrest and Natural vegetation	
3.1. Forrest	1.0-5.0
3.2. Other natural vegetation	0.6-3.0
3.3. Without vegetation or open spaces	0.3-0.6
4. Wetlands	0.1
5. Water bodies	0.1

Source: Corine Land Cover database (CLC-50), Institute of Geodesy, Cartography and Remote Sensing

Humidity index (HU): Effect of hydrometeorology on the formulation of excess water was modelled and spatially represented by humidity index (10% possibility of occurrence of root square of sum of monthly weighted precipitation and sum of monthly weighted potential evapotranspiration ratio). Monthly precipitation (P) and potential evapotranspiration (PET) data series covering the period of 1951-2000 from 20 meteorological observing stations were used. The following equation provides the values of humidity index.

$$HU = \left(\frac{P*}{PET} \right)^{0.5}$$

where, P*: monthly weighted precipitation from October to September [mm].
The monthly weighted coefficients are shown in Table 4.

Table 4

Monthly weighted coefficients of precipitation

Month	Weighted coefficient
X	1.0
XI	1.5
XII	2.0
I	2.0
II	2.0
III	1.5
IV	1.0
V	0.75
VI	0.5
VII	0.5
VIII	0.5
IX	0.75

The higher the values of all the above mentioned influential factors are, the more significant the role in excess water development is.

The map of relative frequency of excess water events was also compiled. Its source is the yearly mapping of the areas damaged by maximal inundation from 1951 to 2000. Relative frequency of excess water events can be determined by dividing number of excess water events by total number of examined years. The serial maps were overlaid providing an independent estimation of the spatial distribution of the most risky areas, as well as the dependent variable of a multiple statistical analysis. Since both its spatial resolution and confidence was weaker than those of the above listed factors, generalized versions of the quantified spatial layers (as independent variables) were jointly analyzed with the relative frequency map in a grid with cell size of 1x1 km^2. Multiple regression analysis was used for the determination of the role of various factors in the formulation of excess water thus providing weights for its linear estimation by the applied factors.

The goodness of fit was also considered. According to our experience involving humidity index in multiple regression analysis rather worsened the fitness. As a consequence it was finally used just as a multiplying correction coefficient. Furthermore for the sake of standardization the values coming from the regression equation were multiplied by and added to a constant value, resulting in the Complex Excess Water Hazard Index (CEWHI).

$$CEWHI = (1.6 - 0.007 * GW - 0.15 * SOIL - 0.025 * RELI - 0.17 * LU - 0.04 * GEOL) * 5 * HI$$

Appearance of excess water inundation is dependent upon many factors. The affects of soil, agro-geology, relief, groundwater, land use and hydrometeorology were represented by only one well-defined parameter. In this way the formation of excess water was defined and quantified. Each influencing factor was spatially represented (Figure 3).

The values provided by the equation (CEWHI) were used to compile the excess water hazard map based on a more detailed original map layers (Figure 4).

According to the final synthesis map the spatial distribution of excess water hazard can be studied in details. The most affected regions can be identified and delineated (with red colour).

As a consequence the resulted risk map can be utilized in numerous land related activities: land use and agricultural planning, water management interventions, water oriented cultivation systems, wetland restoration etc.

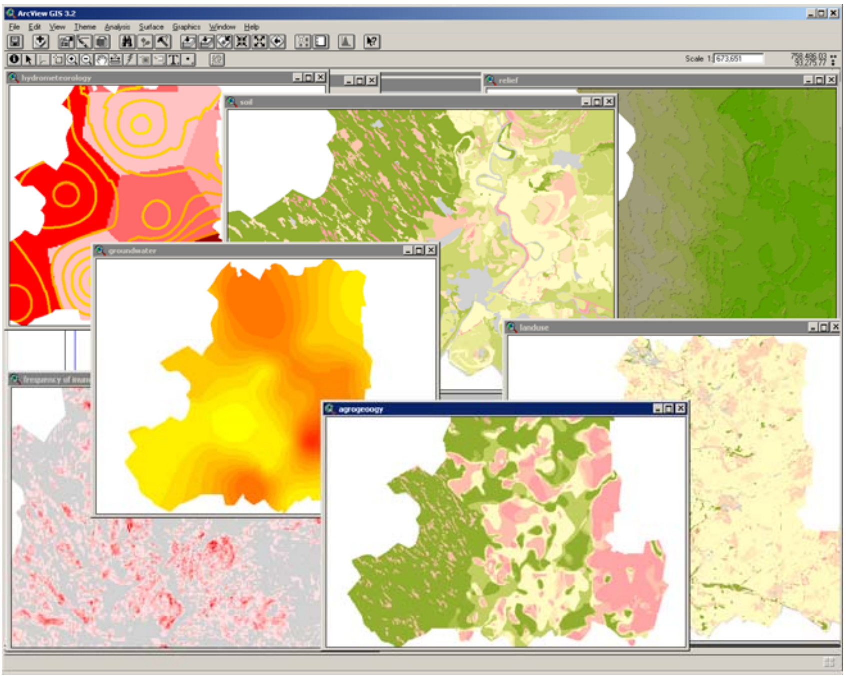

Figure 3: Spatial representation of the influencing factors

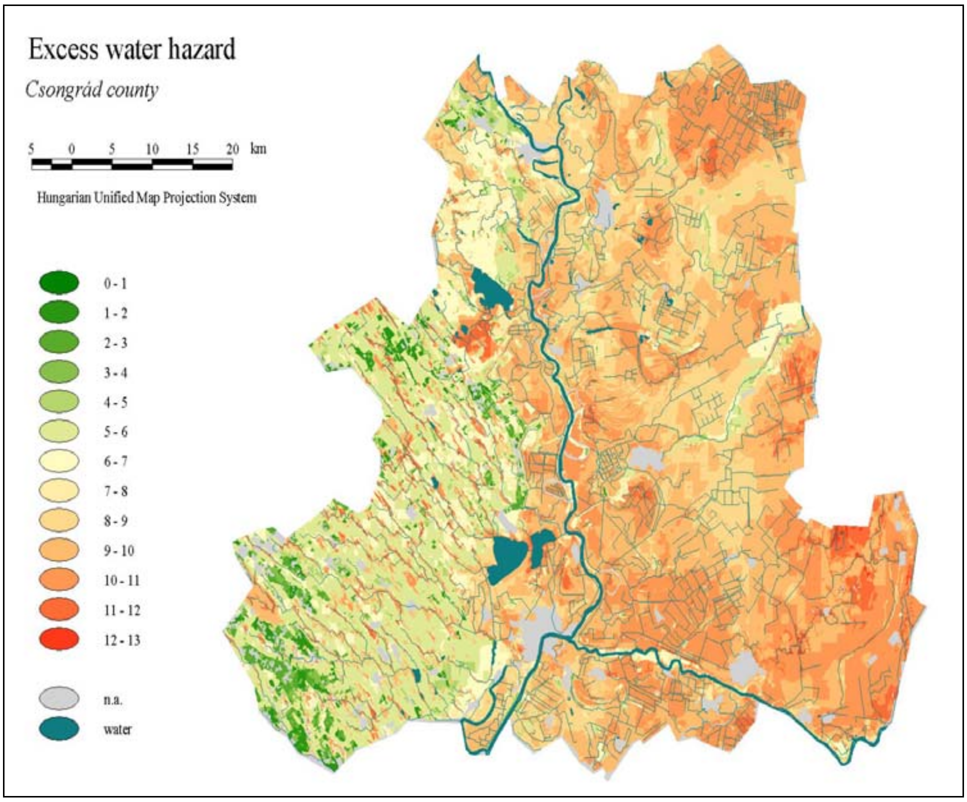

Figure 4: Excess water hazard map compiled for Csongrád County

CONCLUSIONS

Frequent occurrence of extreme anomalies in natural water supply is a great problem for the agricultural production in Hungary. An important step towards an effective solution is the detailed and reasonably accurate mapping of the influential environmental factors of excess water inundation. This study has allowed drawing several conclusions and identifying limitations that would have wide applications in the use GIS methodology for diagnosis of excess water damages.

We would like to note that the accuracy of the presented method and maps will be improved in the near future. In our opinion the presented method could be refined. The resulted map is suggested to be more accurate using more detailed elevation model (based on larger scale topographic maps). Groundwater parameter should be also refined using denser monitoring network and taking into consideration the elevation model during their interpolation.

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