Inland excess water hazard on the flat lands in Hungary

Csaba BOZÁN[1] – János KÖRÖSPARTI[1] – Gábor ANDRÁSI[1] – Norbert TÚRI[1] – László PÁSZTOR[2]

1: National Agricultural Research and Innovation Centre, Research Department of Irrigation and Water Management (NAIK ÖVKI), H-5540 Szarvas, Anna-liget 8.; E-mail: bozan.csaba@ovki.naik.hu

2: Hungarian Academy of Sciences, Centre for Agricultural Research, Institute for Soil Sciences and Agricultural Chemistry, Department of Soil Mapping and Environmental Informatics, H-1022 Budapest, Herman Ottó út 15.; E-mail: pasztor.laszlo@agrar.mta.hu

Abstract: Inland excess water is surplus surface water forming due to the lack of runoff, insufficient absorption capability of soil or the upwelling of groundwater. This interrelated natural and human induced phenomenon causes several problems in the flat-land regions of Hungary, which cover nearly half of the country. Reasonable and preventive management of agricultural areas requires satisfactory information on the spatial and temporal distribution of excess water. Excess water is a complex process whose characteristics can only be determined through taking numerous factors into consideration. GIS together with large-scale spatial information on those factors, which significantly affect formulation of excess water, can provide suitable background for the compilation of hazard map. One well-defined and quantified parameter representing the affect of relief, groundwater, agro-geology, hydrometeorology, land use and soil properties on the formulation of excess water was defined and derived. Multiple linear regression analysis was used for modeling the joint effect of the selected environmental factors on inundation. The result of the applied regression kriging process is a map which spatially predicts inundation frequency. The final hazard map can be used in spatial planning, as it is valuable in numerous land-related activities (land use and agricultural planning, water management procedures, water-oriented cultivation systems, wetland restoration, etc.).

Keywords: excess water, hazard, land use, GIS

Introduction

Inland excess water is surplus surface water forming due to the lack of runoff (Rakonczai et al., 2011). This water related phenomenon causes several problems in the agricultural lands in Hungary. Most of the excess water definitions have a common part that inland excess water is a temporary water inundation that occurs in flat-lands due to both precipitation and groundwater emerging (water uprush) on the surface as substantial sources (Pálfai, 2001). Damage caused by excess waters can be occurred about 1.8 million hectares, from which 60% is located in the arable-land. The area affected by inundation in every 5 years is 150000 hectares on average. The possibility of the amount and distribution of extreme precipitation is increased in Hungary, as it is written in VAHAVA (Change-Effect-Response) project (Várallyay, 2007). Extreme precipitations of recent years have made seasonal and permanent waterlogging the most serious agro-environmental problem in the Great Hungarian Plain (Koncsos, 2011). As a consequence, preventive management of land requires sufficient information on the spatial and temporal distribution of inland excess water (Bozán and Tamás, 2008). 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). Mapping of excess water hazard is a great challenge since excess water is a complex process. Its characteristics can only be determined by taking numerous factors into consideration. Geographical Information System (GIS) together with large-scale spatial information on those factors, which significantly affect formulation of excess water, can provide suitable background for the compilation of maps with the expected accuracy. Due to the more than 10 years research and development work, the NAIK ÖVKI compiled the Hungarian Excess Water Hazard Map for the lowlands which can suitable for numerical characterization of the hazarded areas by excess water. Our further research and development have placed great emphasis on the consideration of other influential factors (additional variables) in order to refine the sensitivity of mapping (e.g. confined groundwater, irrigated and meliorated areas, NATURA2000, discharge of canal networks, excess water regulation, excess water retention reservoir, etc.).

Materials and methods

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. The effect of soil on the formation of inland excess water was modeled and spatially represented by the soil's water management characteristics, i.e. soil water conductivity. The effect of (agro)geology was modeled and spatially represented by a complex index, taking into consideration the depth and thickness of the uppermost aquitard. The effect of groundwater was modeled and spatially represented by the standard depth of groundwater, i.e. the average of its ten highest values within the last 50 years. The effect of land use was modeled and spatially represented by a numeric coefficient based on the National CORINE Land Cover database (Büttner et al., 2004) and individually attributed to its categories using expert judgement. The effect of hydrometeorology on the formation of inland excess water was modeled and spatially represented by a humidity index (10% possibility of occurrence of root square of sum of monthly weighted precipitation and sum of monthly weighted potential evapotranspiration ratio). A map displaying the relative frequency of inland excess water events was also compiled. Its source was the seasonal mapping of areas damaged by inland excess water. Data were provided by the responsible Water Directorates from the period between 1962 and 2010. Multiple linear regression analysis (MLRA) was used for modeling the joint effect of the selected environmental factors on inundation. First, principal component analysis (PCA) was performed on the affecting environmental auxiliary information and the resultant principal components (PCs) were used in the further procedures. Since PCs are orthogonal and independent, they satisfy the requirements of the MLRA and decrease multicollinearity. The PCs were used as explanatory variables and the inundation data as response variable in MLRA, applying stepwise selection at the 0.05 significance level. The coefficient of determination varied between 0.15% and 0.25% in the course of the 100 runs. The best performing case was selected for further processing. MLRA only partly explains the spatial variability (pattern) of the distribution of inland excess water. On the other hand, taking the role of environmental factors by the linear model into account, it eliminates the trend. Kriging of the MLRA residuals provides the stochastic component. Kriging requires knowledge of the spatial auto-correlation, estimated by the semivariogram of the variable to be spatially predicted, which in our case is the MLRA residual. An exponential semivariogram model was fitted to the experimental semivariogram (range ¼ 10,623 metres, sill ¼ 24.5 and nugget ¼ 17.2), which was then applied to calculate the kriging weights in the spatial interpolation. Superposing the

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regression and interpolation results provided the overall RK prediction of the inundation hazard (Pásztor et al., 2016).

Results and discussion

Regression kriging is a spatial prediction technique that combines the regression of the dependent variable on auxiliary (additional) variables with kriging of the regression residuals. The resulted final map is the Complex Excess Water Hazard Map (Figure 1.) is suitable for comparing different kind of areas and determining the relationship between different influential factors. According to the final map the Hungarian lowland areas are hazarded by excess water inundations in different rates. Highly and extremely hazarded areas can find along the rivers and the Great Hungarian Plain in Upper-Tisza region (Bereg, Tisza-Szamos köz, Szamos-Kraszna köz, Rétköz, Bodrogköz, Taktaköz), Hortobágy river valley, Jászság and Nagykunság, Körös River valley, Lower-Tisza valley, and west part of Danube-Tisza Interfluve. The Little Hungarian Plain (Fertő-Hanság) belongs to this category, meanwhile from the Transdanubian region there are some small places where the excess waters can cause damages (Sárvíz). Moderate hazarded areas can find on the plateaus (Danube-Tisza Interfluve, Nyírség), but excess water inundations can appear on the Békés-Csanád Loess Plateau due to the water uprush.

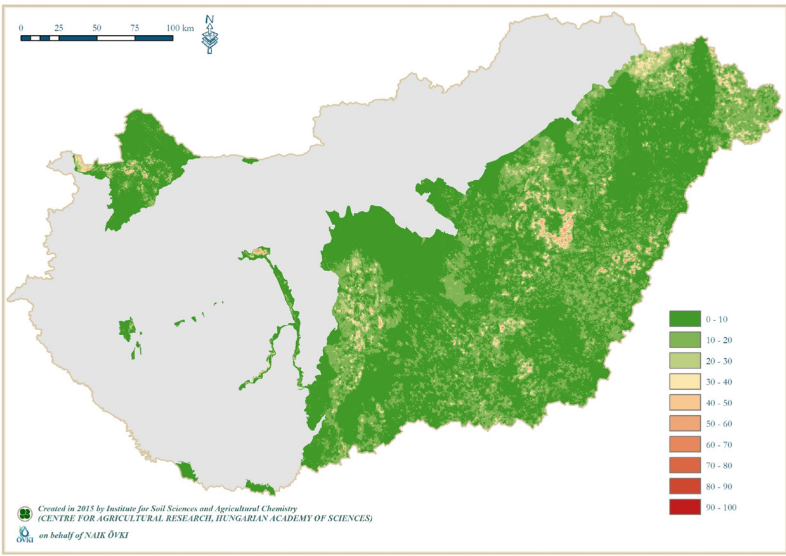

Figure 1. Complex Excess Water Hazard Map

Conclusions

Reasonable and preventive management of agricultural areas requires satisfactory information on the spatial and temporal distribution of excess water. Excess water is a complex process whose characteristics can only be determined through taking numerous factors into consideration. Due to the more than 10 years research and development work the NAIK ÖVKI compiled the Hungarian Excess Water Hazard Map for the lowlands which can suitable for numerical characterization of the hazarded areas by excess water. The result of the applied regression kriging process is a map which spatially predicts inundation frequency. The final hazard map can be used in spatial planning, as it is valuable in numerous land-related. The presented method could be further refined. The application of regression kriging together with the applied multiple, virtual sampling allows the consideration of multiple data layers for each affecting factor. The environmental correlation expressed by multiple linear regression could be substituted by further, knowledge based, data mining methods for improving the modeling of the complex relationship between inundation and its affecting factors. Our further research and development have placed great emphasis on the consideration of other influential factors in order to refine the sensitivity of mapping. The groundwater factor can refine with the database of confined groundwater and flow system. It is important to develop the land use factor, because there are so many additional variables which have direct and indirect effects on the development of excess water inundation (i.e. irrigated and meliorated areas, NATURA2000, discharge of canal networks, excess water regulation, excess water retention reservoir, actual agricultural techniques, etc.). Remote sensing data services are becoming more and more affordable, improved reference data series on the spatial distribution of inland excess water events could be incorporated.

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