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THESES OF DOCTORATE (PhD) DISSERTATION

POSSIBLE WAYS OF APPLICATION OF GEOINFORMATICS IN THE MANAGEMENT OF ENVIRONMENTAL CONFLICTS

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Precedents of the study

In order to reconcile nature conservation and agriculture, the development of an EU-conform land-use zone-classification for Hungary, conceptualising and applying a methodology of classification by taking the production and non-production potentials of various regions into consideration, was completed in 1997. This work represents the agricultural potential-environmental sensitivity zone classification of each spatial unit in the whole area of Hungary. This zonality is the basis for the Hungarian National Agri-Environmental Programme making the frames for the agricultural development, in accordance to the spatially differentiated and multifunctional agriculture (Ángyán et al., 1999).

Questions on the transformation of the agriculture's structure (therefore the spatial structure of land-use) were also conceived in the National Rural Development Plan (2004) and in the Developing Rural Areas Strategy (2005). Based on the survey of rural regions, development priorities with the two statements made below included were conceptualised in accordance to the rural development strategy of the European Union for the period between 2007 and 2013 (FVFS, 2005):

- 'There is an exaggerated production-centeredness – in many cases not adapted to the endowments of production – typical in the agriculture whereas the utilisation of potentials in the increase of economy, the use of the environmental potential, the preservation of the rural way of life and the improvement of life-quality are less manifested.
- The ratio of areas vulnerable to environmental problems (deflation, erosion, inland water and other factors of soil destruction) is extremely high, as two third of the water bases are located in a susceptible geological environment.'

It is a well-known fact that water regulation works carried out during the 19th century caused complex environmental-ecological problems in the catchment areas. About one fourth of Hungary's area is lowlands from which water is not drained in a natural way. Approximately 10-15% of the nearly 5 million hectares of regularly cultivated plough-lands is intermittently covered by detrimental surface water, even annually. According to the data assessment of several years, an average of approximately 130,000 hectares is inundated by inland water for a period of 2-4 months each year. In the frequent occurrence of inland water, not only water regulation works played a determining role

but also the intensive agricultural production during the socialist era and the change in the estate structure following the transition of the political system. An obstacle to the development of the optimal land-use spatial structure is the unavailability of an exact source of information for the decision-makers of the branch accomplishing all terms below, i.e.:

- Extending to a significant geographical spatial unit;
- Including data with a homogenous structure spatially;
- Being based on integrated databases of the level of farm management;
- Containing a spatial analytical methodology based on scientific methods.

The application of spatial scientific methods is inevitable in modelling the monitoring of environmental elements. According to the theory of exact research, such model-surveys can promote our work only when based on detailed spatial resolution information. It is especially the case for plainland areas, the state, movement and characteristics of surface and underground water have different characteristics regarding both the given spatial segments and instants.

In the light of the problems explaining the changes of the rural spatial structure, a number of surveys intended to find a solution to establish a land-use structure adapted to the optimal environmental conditions by applying the available technical conditions. Responses to the questions to be answered can be given by obtaining the broadest possible knowledge on the environmental conditions and by applying spatial scientific methods.

Aims of the study

During the study, the propositions made were as follows:

1. To demonstrate the development of a geoinformatic system, that includes an extensive geographical area and is applicable to the modelling of the state of environment, from the model production to the application of the databases on the level of analysis. Also, the problems and possibilities of producing and managing large quantity, large-scale and various geographical data are presented in detail.

2. To determine the risk of inland water inundations and the impacts of ecological factors playing a role in causing them, due to the plainland water regulations in the given sample area.
3. To represent the stability values of land-use based on the studies of significant (235-year-long) time-series spatial changes.
4. To analyse the spatial correspondence between areas formerly inundated either permanently or intermittently and current land-uses based on a database developed from the maps of the first military survey.
5. To represent the spatial values of the environmental transformation of the land-use structure based on the micro-relief, land-use analysed by time-series, soil genetic conditions and inundation risk in a plainland sample area with low discharge values.

Methods

The research area

The spatial frame for the research was provided by the geographical micro-landscape of the Bihari Plain (Figure 1), surrounded by the River Berettyó from the North-Northwest, the River Sebes-Körös from the South and the state boundary between Hungary and Romania from the East. This micro-landscape, regarding its appearance, façade and physical geographical-hydrological features, can be classified as a unit; it is a typical example of the plainland impact areas of the river regulations carried out in Hungary, as environmental conflicts being more common today (land-use conversion problems, inland water-vulnerability) occur here more frequently. The research area in total is 866.5 km^2, being nearly 1% of the territory of Hungary and approximately 2% of the area of the Great Hungarian Plain. Plough-lands at the Bihari Plain are 1.4% of all plough-lands in Hungary.

Among the environmental conflicts of a plainland area, the cumulative impacts of the former water regulation works can be considered as the most significant. Most of the environmental conflicts typical in the region can be traced back to them. Thus, the modern and recent landscape evolution of the research area is presented in the

dissertation in detail; focusing on the process of surface water regulation works playing a key role in the evolvement of the current environmental problems, as well as the features of the changes in land-use.

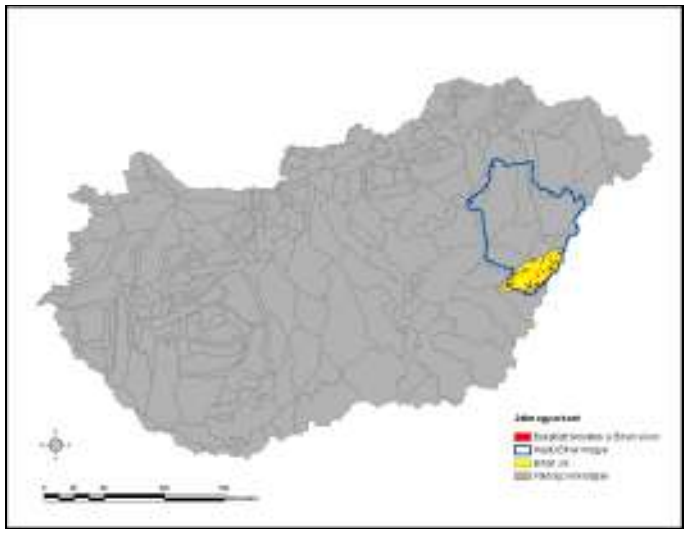

Figure 1 Location of the research area in Hungary

Input data used for the analyses

To the experimental model to be complied for the geographical area of the Bihari Plain, a high-resolution integrated geo-database, consisting of the elements below, has been established:

- A relief model, produced based on the contour lines and spot heights of topographic maps with a scale of 1:10,000.
- A soil genetics database, produced based on genetic and land-assessment maps, both with a scale of 1:10,000 and records of laboratory tests.
- A topographical database containing planimetry information included in the topographic maps with a scale of 1:10,000 used as a source.
- An administrative – statistical database, of which graphical data were produced based on topographical maps with a scale of 1:10,000, whereas the attributive data were generated by the T-Star database of the Hungarian Central Statistical Office.

- A data series database including land cover, of which sources were, on the one hand, historical maps with a scale of 1:28,800 (The First and Second Military Surveys), and geoinformatical layers produced by the assessment of satellite images (Corine CLC-100, CLC-50), on the other.
- An integrated hydrological database containing the course lines of surface watercourses and channels, the area of surface still-waters (data source: topographical maps with a scale of 1:10,000), the location (as located by GPS) of and the values observed by the ground-water monitoring network of wells, as well as the maximum geographical extent and frequency of inland water inundations in a scale of 1:50,000, on the layer-level (data source: Trans-Tisza Region Environmental and Water Directorate).
- A nature conservation database produced based on estate cadastre maps with a scale of 1:10,000 (data source: Hortobágy National Park Directorate).

The software environment applied

To the development of the databases, the ESRI software environment, applied for the studies, primarily uses a vector approach data model however also supports raster layer technique. To the modelling of environmental analyses, mainly the layer-approach was applied, taking advantage of the raster-vector interface functions of the software used.
To analyse environmental conflicts and to detect their phenomena, complex models are required. Such questions can be answered more effectively by applying geographical information systems and decision support systems based on geoinformatics with the theory of the least environmental risk kept in view, as GIS-systems and models based on natural resource management are effective tools to both analyse and tackle multi-factorial complex problems.
The modules applied during data collection, data integration and spatial analysis are:

ArcView 3.3 (ArcGIS 9.x)	main module
CAD Reader	DWG, DXF data exchange option
Dialog Designer	application development,
Digitizer	digitalisation support,
IMAGINE Image Support	ERDAS data exchange option,
ECW	ECW format management,

Geoprocessing	spatial operations,
3D Analyst	3D analysis options,
Spatial Analyst	spatial analyses,
Network Analyst	analysis of linear networks.

Analysis methods

To the study of environmental land-use, two outstandingly important phenomena were examined: the risk of inland water occurrence and the characteristics of the land-use.

In the hydrological practice, nomograms, tables and numeric methods are applied to determine the inland water discharge of the area studied. However, a detailed spatial analysis of the triggering factors and the comparison of that with the potentially available inundation maps are considered to be more exact, thus, more expediential.
During this study, three research methods to determine the risk of inland water were applied and compared:

- Risk-assessment based on the frequency of inundations: the frequency of the occurrence of inland water inundations were studied by water authority maps recording such phenomena;
- Empirical theoretical risk-assessment: the conjunct impacts of the triggering and influencing factors were studied at the sample area aiming the localisation of the potential sites of inland water occurrences;
- Risk assessment based on water-balance calculations: the amount of the resultant inland water was quantified and associated with certain spatial units, which aimed to define the time dimension of the phenomenon.

These studies were carried out for both winter and summer hydrological half-years as according to the formation of inland water.
During these studies, a detailed spatial analysis of the factors triggering this phenomenon was conducted as well as the spatial analytical methods applied were recited in detail. The factors studied were as follows:

- Relief
- Soil (filtration coefficient, field water storage capacity)
- Ground-water
- Land-use

- Climate (precipitation, evaporation)
- Surface watercourses, channels

The time series research into the land-use had two main objectives:

- To determine the spatial characteristics of land-use stability for each branch of cultivation defining the spatially permanent patches of the environmental land-use structure;
- To delimitate the cultivation branches developed at areas formerly inundated intermittently or permanently indicating the presence of spatial elements for which transition is primarily proposed.

During the analyses carried out, data management and analysis options, projection conversion methods, interpolation procedures (IDW, Kriging, Trend, SPLINE), layer operations (Clip, Union, Dissolve, Intersect), raster-vector conversions, re-classification operations, spatial join, puffering, cell value calculations, spatial statistical calculations, queries and the edition of presentation maps offered by the geoinformatic systems were applied.

Main estimations of the dissertation

Estimation methods for the occurrence of inland water

The results of all three estimation methods were represented for hydrological winter and summer half-years in settlement-level statistical values. For reasons of extent, the spatial patterns, resultant from the three procedures, are not represented in the thesis.

Risk-assessment based on the frequency of inundations

Having the actual inundations in the winter and summer half-years, inundation frequency values for the research area were obtained for all inundated spatial segments both in the winter and summer half-years (Figure 2). The values shown on the map indicate the recurrence of inundations. According to this, a higher frequency value is added to the given spatial unit, the higher is the probability of the occurrence of inland water.

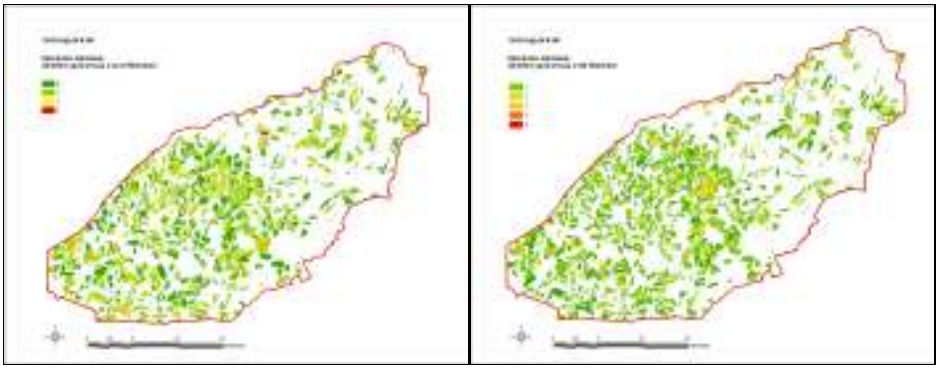

Figure 2 Frequency values of the maximum inundations in the Bihari Plain between 1989 and 2005 during the summer and winter half-years

As seen from the study of the settlement-level spatial statistical values, the analysis of the inundation frequencies indicated vulnerability over the average for the settlements below: Furta, Csökmő, Mezősas, Körösszegapáti, Magyarhomorog, Nagykereki, Újiráz and Vekerd. According to the method, 4.7-21% of the area of these settlements in the Bihari Plain is considered to be vulnerable to inland water all year.

Empirical theoretical risk-assessment

This method is based on the principle of quantifying the factors triggering and modifying the phenomenon of inland water in a spatial division, then are ranked according to the weighed values assigned due to their significance.

The indices obtained were classified by the method of *Jenks* and were ranged, according to the level of vulnerability, to the following categories:

1: not vulnerable
2: moderately vulnerable
3: meanly vulnerable
4: vulnerable
5: extremely vulnerable

The empirical theoretical maps for the research area are shown in Figure 3.

Megjegyzés [Z1]: Ahol térkép van, ott a Figure helyett lehet Map –et használni, csak azt külön kell számozni.

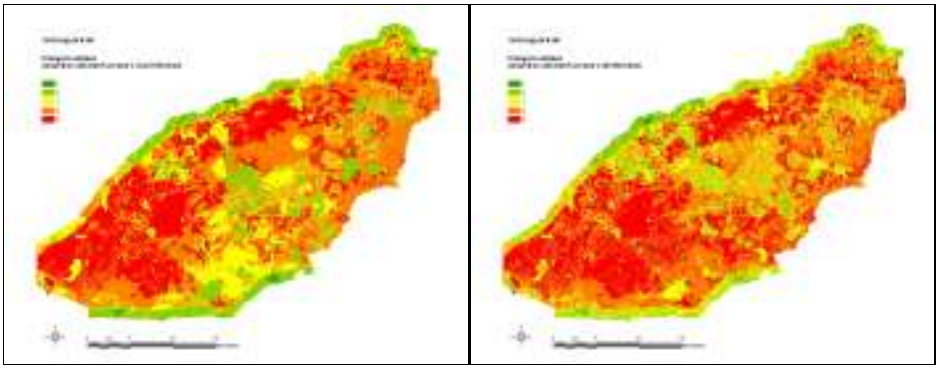

Figure 3 Inland water vulnerability map of the Bihari Plain based on the empirical theoretical risk-assessment of inland water occurring in the summer and winter half-years

It is concluded when studying the aggregate spatial pattern of the inland water vulnerabilities of the winter and summer half-years that extremely vulnerable areas detected in the research area in the two different half-years overlap each other to a significant degree. The high likelihood of the occurrence of inundation by inland water in both half-years can be stated for the following settlements: Csökmő, Darvas, Váncsod and Vekerd. By this method, spatial sub-ratios of 40-80% were indicated for these settlements; the spatial patterns of the risks occurring in the two different hydrological half-years mostly overlap each other.

To validate the method of empirical theoretical risk-assessment, a multivariate main component analysis and a multivariate linear regression analysis were carried out where, as a reference layer, a hydrological authority layer bearing the spatial extension of the actual inundations by inland water were used.

Risk-assessment based on volume calculations

Megjegyzés [Z2]: A felsorolásnál nem ez volt a harmadik

To determine the quantity of inland water arisen during the winter and summer half-years, an area-based water-balance of the catchment area has been calculated. The quantity values resultant indicated the average residue water amount in the catchment area, of which duration (based on evaporation and filtration coefficients) were expressed in calendar days. Results of the risk-assessment based on water-balance are indicated by Figure 4, where the basis of classification is the duration of the occurrence of inland water.

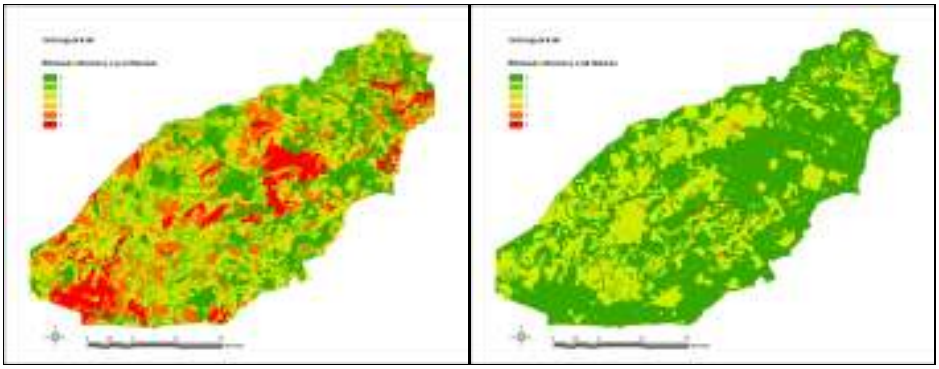

Figure 4 The inland water vulnerability map of the Bihari Plain for the inland water of the winter and summer half-years based on risk-assessment based on volume calculations

According to the results obtained by water-balance calculations, the occurrence of durable inland water has an impact on 30-90% of the area of 13 settlements Csökmő, Darvas, Furta, Komádi, Magyarhomorog, Mezőpeterd, Pocsaj, Szeghalom, Szentpéterszeg, Told, Újiráz, Vekerd and Zsáka).

The occurrence of extremely prolonged (exceeding 27 days) inland water are highly dangerous in the case of several settlements; 46.9% of Mezőpeterd's area, 28.9% of Csökmő's area, 23.8% of Újiráz's area and 22.7% of Told's area falls into this category.

A comparative assessment of the analysis methods

A spatial comparison of the results obtained during the risk-assessments conducted based on the rate of occurrence, the estimation of the resultant water amount and the factors triggering the inland water phenomenon was carried out. The basis for comparison was the vulnerability category values indicated; in all cases, objects with high category values (4-5), as spatial segments mostly vulnerable to inland water were selected. The union of the three layers obtained was carried out for the winter and summer half year target layers has also been carried out, of which results are included in Figure 5 and Table 1. The values included in the figure and in the table (1-3) indicate the cumulated values of vulnerabilities as defined by the research methods. Objectives where the risk of inland water was revealed by all three methods have been represented in an exposed way.

Megjegyzés [Z3]: A magyarban nem jól van a zárójel

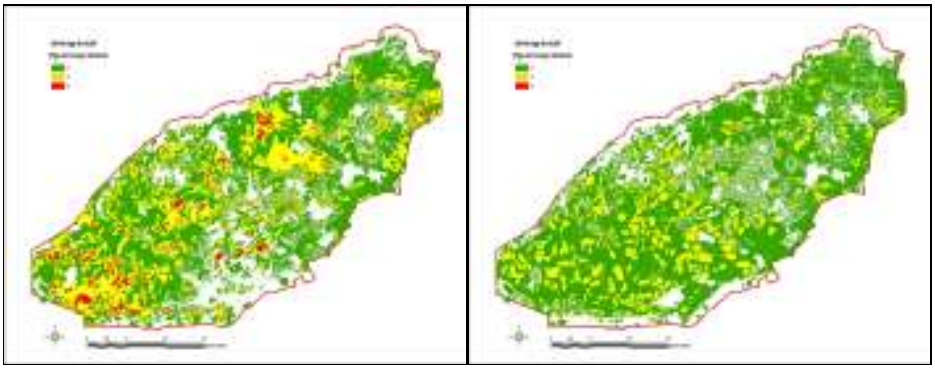

Figure 5 A comparison of the results of methods estimating the inland water phenomenon for the summer and winter inland water risks

Table 1

Megjegyzés [Z4]: Cím?

	Summer half-year		Winter half-year	
	Area (ha)	Ratio of the total area (%)	Area (ha)	Ratio of the total area (%)
1	43,325	50.0	53,957	62.3
2	20,895	24.1	14,265	16.5
3	3,049	3.5	60	0.1
In total	6,269	77.6	68,283	78.9

A given spatial segment was classified to be actually vulnerable, when the high likelihood of the occurrence of inland water was revealed by at least two research methods. Based on this, it can be concluded that in the winter half-year, 16.6% of the research area whereas in the summer half-year, 27.6% of the research area can be considered to be vulnerable to inland water.

The three analysis methods have also been evaluated by their applicability and practical feasibility. This evaluation took place according to the following aspects:

- The quantity of specific data used for the analysis (applicable-necessary)
- The quality of specific data used for the analysis (applicable)
- The time and cost demands of data-processing
- The amount of time spent on analysis
- The reliability of the results detected
- Other unclassifiable aspects

The evaluation has been carried out in a subjective scale of 1 to 5 where the higher values indicated the optimal direction. It can be concluded in the case of all three methods, that the framework required to their accomplishment compounds (regarding hardware, software, network, skill, and environment). During the evaluation of the results obtained, in the case of all three methods, the geometrical accuracy of the resultant layers were considered to be conformable.

Summarising the ranks given to the evaluation points listed above, 73% of the maximum of 30 points was reached by the method of risk-assessment based on the frequency of inundations, 63% by the method of the empirical theoretical risk-assessment whereas 77% by the risk-assessment based on volume calculations.

Results of the land-use stability study

Based on the spatial statistical values obtained by the assessment of historical maps, the following conclusions can be drawn:

- Following the water regulation works, the forest coverage of the area decreased to less than its half that is explained by the plough-land cultivation of these areas; the value has, by today, recovered to the state as 200 years ago.
- Areas intermittently or permanently inundated (marshlands) have significantly increased compared to the conditions prior to the water regulations, for which an unequivocal explanation has not yet been given. The most likely assumption is that the period of data recording was that of higher precipitation thus resulting in a greater water inundation. Today, this category occupies only a low area.
- The intense increase of plough-land is extremely outstanding; the increment taken place for areas permanently or intermittently inundated is determinant.
- The research area from the point of view of vine-growing has not played a relevant role even in the historic times.
- The continuous increase of built-up areas has been construed as a phenomenon in the history of settlements concurrent to the growth of population.
- For the grasslands, no changes of scale took place between the periods prior to and following the water regulation works. By today, a significant spatial

regression has been defined, considered to be an unequivocal impact of the intensive agriculture.

- The perpetual increase of continuous water surfaces can be explained by the establishment of artificial reservoirs and the network of inland water channels.

From the point of view of land-use, areas of the same land-use category at all three times of data-collection were considered to be absolute stable. Figure 6 shows spatial segments considered to be stable from the point of view of land-use as well as plough-lands developed on areas of former permanent or intermittent inundations.

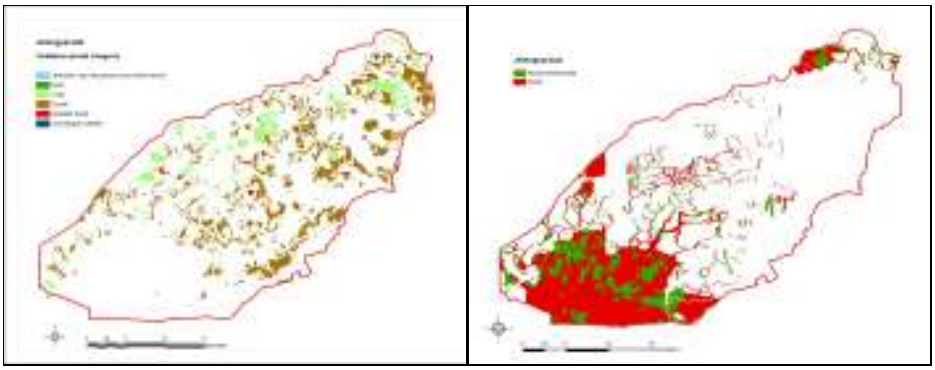

Figure 6 The distribution of areas considered to be stable from the point of view of land-use and plough-lands developed on areas of former inundations in the Bihari Plain

It is proved that land-use can be considered to be absolute stable at 17.7% of the study area. From the point of view of stability, the categories of plough-lands, grasslands and built-up areas are of outstanding value. The characteristics of forests and areas with intermittent or permanent inundation are, however, extremely low.

It has also been stated that, due to the water regulation works, the former marshes and bogs have been replaced mostly by plough-lands whereas also by grasslands and forests to a small degree. The ratio of land-use conversion is rather considerable, i.e. 27% of the total area.

Evolving a land-use model for the environmental transformation of the spatial structure

The present land-use structure induces several environmental problems, thus a function survey of the spatial elements from the point of view of ecology is extremely important. The most relevant environmental conflict of the research area was represented in the dissertation, of which triggering factors and impact area has been successfully localised. Based on the results of the analyses performed, a conception model of the spatial structure of the land-use has been determined. The model is based on the following parameters:

- Vulnerability to inland water
- Land-use stability
- Accentuated change of land-use functions (the conversion of inundated areas to plough-lands)

The following principles were taken into consideration in the spatial structure model:

- Functional changes of spatial units free of environmental conflicts are not recommended;
- Transformation of mono-functional (stable) areas in long-term are not recommended;
- The conversion of plough-lands replacing former inundated areas is recommended;
- Transformation of areas vulnerable to inland water is recommended.

The characteristics of the recommendations for spatial structure changes developed are shown in Figure 7, whereas its settlement-level values in Table 2.

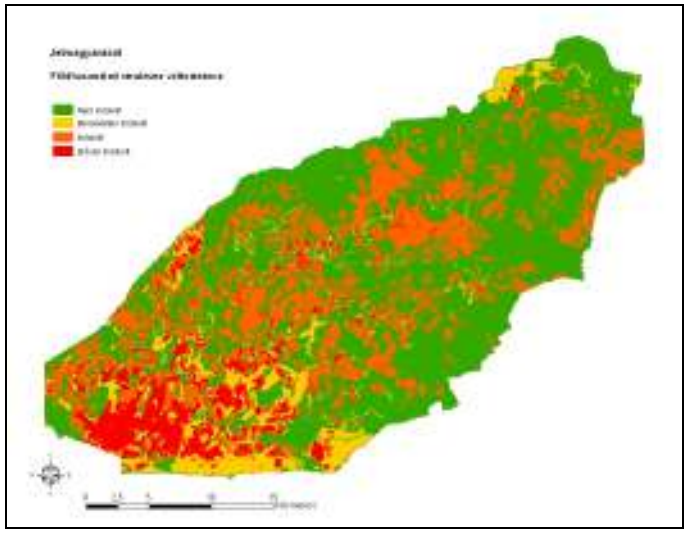

Figure 7 Spatial structural elements of the land-use conversion of the Bihari Plain

Megjegyzés [Z5]: Ez a magyarban 6. ábra volt!!!!

Table 2

Settlement	Not valid		Moderately valid		Valid		Extremely valid	
	Area (ha)	Ratio of the settlement's area (%)	Area (ha)	Ratio of the settlement's area (%)	Area (ha)	Ratio of the settlement's area (%)	Area (ha)	Ratio of the settlement's area (%)
Ártánd	1,610.5	81.9	0.0	0.0	355.3	18.1	0.0	0.0
Bakonszeg	488.6	92.5	1.7	0.3	38.2	7.2	0.0	0.0
Bedő	720.5	66.1	0.0	0.0	369.7	33.9	0.0	0.0
Berekböszörmény	3,610.4	84.4	76.1	1.8	566.5	13.2	22.3	0.5
Berettyóújfalu	3,659.2	61.4	110.0	1.8	2,121.2	35.6	70.3	1.2
Biharkeresztes	3,435.7	69.5	34.3	0.7	1,468.0	29.7	6.9	0.1
Bojt	2,229.2	82.3	0.0	0.0	481.0	17.7	0.0	0.0
Csökmő	1,926.0	24.9	762.9	9.9	2,243.9	29.0	2,800.9	36.2
Darvas	1,415.5	43.2	314.6	9.6	1,252.3	38.2	292.1	8.9
Esztár	436.8	97.9	9.1	2.0	0.0	0.0	0.0	0.0
Furta	1,709.3	36.4	221.8	4.7	2,492.4	53.1	271.9	5.8
Gáborján	622.5	95.8	0.0	0.0	27.5	4.2	0.0	0.0
Hencida	1,060.0	57.9	456.3	24.9	269.2	14.7	46.3	2.5
Kismarja	3,079.1	76.4	351.9	8.7	579.4	14.4	17.7	0.4
Komádi	3,208.2	25.9	4,111.2	33.2	1,744.2	14.1	3,310.9	26.8
Körösszakál	967.5	89.4	30.2	2.8	82.1	7.6	3.0	0.3
Körösszegapáti	2,976.4	59.8	113.7	2.3	1,790.6	36.0	97.0	1.9
Magyarhomorog	2,189.8	54.1	711.8	17.6	1,057.0	26.1	86.5	2.1
Mezőpeterd	720.4	39.4	42.3	2.3	997.2	54.5	70.4	3.8
Mezősas	1,787.5	64.1	128.2	4.6	773.6	27.7	99.8	3.6
Nagykereki	2,187.1	57.6	0.0	0.0	1,608.8	42.4	0.0	0.0
Pocsaj	102.1	99.4	0.6	0.6	0.0	0.0	0.0	0.0

Settlement	Not valid		Moderately valid		Valid		Extremely valid	
	Area (ha)	Ratio of the settlement's area (%)	Area (ha)	Ratio of the settlement's area (%)	Area (ha)	Ratio of the settlement's area (%)	Area (ha)	Ratio of the settlement's area (%)
Szeghalom	184.2	33.1	213.8	38.4	42.8	7.7	116.1	20.8
Szentpéterszeg	56.9	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Told	1,039.9	69.1	48.5	3.2	397.3	26.4	18.3	1.2
Újiráz	221.7	13.3	327.8	19.7	178.1	10.7	939.3	56.3
Váncsod	2,239.5	64.0	48.0	1.4	1,194.1	34.1	19.7	0.6
Vekerd	436.4	48.1	56.1	6.2	401.6	44.2	13.9	1.5
Zsáka	3,831.5	46.8	649.2	7.9	3,074.3	37.6	631.9	7.7

New and original results of the dissertation

1. The process of developing a high-resolution integrated geo-database of a significant geographical region, including a corrected relief model, from the point of view of hydrology and a large-scale soil information system with uniform data consistence, has been represented in the dissertation.

2. The data series land-cover database of the research area has been established and the index-values of land-use stability have been represented as well as areas that have undergone significant changes of the branches of cultivation during the last 230 years have also been delimited.

3. Settlement-level spatial statistics have been produced on the current and changing spatial factors of land-use.

4. By the three methods applied to define the risk of occurrence of inland water, risk values of inundation have been represented then settlement-level spatial statistics have been produced. A comparative analysis has been carried out among the three assessment methods applied according to a defined, practical system of criteria, based on which soil database used for the analyses were assessed.

5. A land-use model has been developed to advance the environmental reorganisation of the spatial structure, of which spatial elements were localised as well as expressed in settlement-level and in spatial values according to soil sub-types.

Practical use of the results

An integrated geoinformatic system, viable and capable of providing basic data has been developed by which environmental and natural disasters can be reduced.

Inland water inundation risks presented on the level of settlements are predestined to advance the preparation and the support of operative protection works.

Several basic information have been generated to transform the present structure of land-use by which the use of systems impelling changes and their sources can be localised.

The system developed can serve as an example of managing the process of estate reconstruction by an environment-focused approach.

PUBLICATIONS IN THE TOPIC OF THE DISSERTATION

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