

Thesis of doctoral (PhD) dissertation

**GIS EVALUATION OF THE DEVELOPMENT OF
WATER RESOURCE MANAGEMENT AT THE
HAJDÚSÁG LOESS RIDGE**

Ildikó Gombosné Nagy

Supervisor: Prof. Dr. habil János Tamás
doctor of Hungarian Academy of Sciences



**UNIVERSITY OF DEBRECEN
Kerpely Kálmán Doctoral School**

Debrecen, 2009

1. INTRODUCTION

Climate is not only condition system and resource of agricultural production, but risk factor as well; variability of climate within and between years affects significantly for agricultural production. Unfavorable environmental conditions primarily are low or high temperature, and lack of water or abundance of water, between the continental climatic relations of Carpathian Basin. Extreme amount and distribution of moisture shows increasing tendency in Hungary, and its negative effect manifests in the yields of field plants.

GIS, and within remote sensing gives significant help for the performing of tasks related to agro-environmental protection. Utilization of remotely sensed data is one of the most modern and the most effective tool of the observation and understanding of the analysis of difficult phenomena, which continuously vary in space and time and that pass off in our direct environment, and in spheres (soil, water, air), which are affected by agriculture, furthermore the following and monitoring of the variation of the different environmental parameters. Environmental modeling helps in understanding of environmental problems. Environmental modeling, as an important part of agro-environmental protection, and GIS became a well prepared, accepted and applied area in research and practice for these days, so the connection of them is obvious.

Occurrence probability of extreme climatic phenomena (long-term drought periods, floods, gales) increased in space and time in Hungary. Different climatic models show divers results in respect of the repetition density of these phenomena in the future. Correction of the reliability of calculations needs such data source, which is able to supply input data on daily level not only for climatic models, but for other calculations (hydrology, water management, GIS etc.) as well.

Moisture is one of the most changeable environmental elements. Spatial and temporal distribution of moisture is exceptionally determinative in respect of agriculture. The main problem of the appropriate handling of rainfall data is the lack of groundbased rain gauge stations; that is why measured data give reliable values only for the tight environment of the extant weather station, but do not give consequence information about those areas, where there are no rain gauge stations.

Density of weather stations decreased 150 km from 50 km after system change in Hungary. Data, supplied by these stations are not sufficient for the measurement and forecast of regional climatic anomalies, which is caused by the microclimate of bigger cities or quickly variable landuse. Groundbased data collection (gravimetric, TDR, pF tensiometer) needs a lot

of time, cost, and the results will be pointwise, so not georeferenced data. Dynamic changes can be covered only by quickly freshened measurement database, which covers the whole examined area. Accordingly, examine of the upper atmosphere became necessary. Meteorological balloons, than satellite images became really appropriate for this task. The earlier data shortage can be complemented by data, origin from satellite images, since these became useful instruments in the daily average aerial moisture estimation.

MSG-1 (Meteosat Second Generation) weather-forecast satellite operated by EUMETSAT (European Organization for the Exploitation of Meteorological Satellites) supplies data since 28th August, 2002. This satellite is appropriate for data getting with better quality, than the universally prevalent NOAA AVHRR satellite images, because time of image creating is oftener (15 minutes), examines more channels (12), and its spatial resolution is better as well (1 and 3 km). The satellites sense cloud covering, air humidity, air movements, and ground temperature. The retrieved data characterize the actual state of the Earth; however these can be used for weather forecast as well.

Data of MSG meteorological forecaster satellite can supply as an input for researches related to agro-environmental protection. Thanks for the continuous developments, local rainstorms that threaten with disaster and other unexpected natural afflictions can be forecasted with some couple of hours. Inland water and flood endangered areas can be observed continuously. The more accurate exploration of the amount and spatial and temporal distribution of one of the environmental elements, - which is significant in every scale, in my opinion -, the moisture is indispensably important in the mirror of sustainable agricultural approach.

2. AIMS OF THE RESEARCH

For my assays, which are about the development of water resource management, area of Hajdúság loess ridge, which is dry, and has capricious moisture distribution, but good water management, was chosen. With my assays, regional water resource management coordination and local farm level intervention wanted to be based. The major scientific aims are the following:

- I. Creation of the regional complex water management conceptual model.
- II. Applicability assay of Digital Elevation Models based on different interpolation methods in the water management.
- III. Applicability assay of spatial interpolation methods based on rainfall data.

- IV. Applicability advantage assay of a water management model integration based on a GPS based location determination and remote sensing in precision farming.
- V. Assay of runoff relations by the use of Digital Elevation Model.
- VI. Applicability assay of METEOSAT satellite images in the daily average aerial moisture estimation:
 - a. Review of the processing method of METEOSAT satellite images by GIS softwares.
 - b. Performing statistical analysis on three channels of the remotely sensed images.
 - c. Determination of relative reflectance of METEOSAT images in the environment of groundbased rain gauge stations.
 - d. Applicability assay of METEOSAT images in the daily average aerial moisture estimation by the coherence assay of the data of groundbased rain gauge stations.

3. MATERIALS AND METHODS

3.1. General characterization of the examined area

The area of the assays was the Hajdúság loess ridge within Hajdúhát. Soil cover was generated on loess sediment on Hajdúság loess ridge. Predominant majority of these soils has very good agricultural properties and productivity, plain chernozem with lime deposit occurs in major aerial part. This area is dry with capricious moisture distribution; the annual amount of moisture is 530-570 mm. The climate is moderately warm and dry, the mean-annual temperature is 9,7-10,0 °C.

3.2. Planning of the regional complex water management conceptual model

The annual average moisture amount of Hungary is not enough for the secure production. High rate of drought years requires the necessity of irrigation in such field cultures, like sugar beet, potato, or sweet corn. Hajdúság loess ridge is poor with water; water demand of cropping on the excellent quality chernozem soils of this area have to be ensured by irrigation. Rise of the security of water supply requires the integrated strategy of water demand- and water resource-regulation in the future. The integrated water resource management is a good frame in the planning of the accommodation to climatic changes.

5 phase conceptual model of the complex water management system was created for the researched area of Hajdúság loess ridge, which is determined basically by the integration to uniform database of data realized during data collection and the well based decision support system, which is lean on models and necessary to the interventions.

3.3. Process of the configuration of hydro-geoinformation system

As a first step of the creation of the system, complex data recording was performed in the Kaba production sector of the sometime sugar factory, Eastern Sugar Plc. One of the milestones of the data recording was the assay of the general production level. Data of the altogether 15 farmers were integrated to a uniform database. Mapping of soil relations was also performed. After this, data were totalized by farmers, than by cities.

Kaba production sector was covered by 39 maps, which were georectified. In the maps that were fit to projection, fields of those farmers of the sugar factory were digitized, which concerned to the 4 sub-sectors that have the biggest aerial extension (Bamazújváros-, Ebes-, Hajdúszoboszló-, Nagyhegyes-sub-sectors). Areas that were next to each other and concerned to the same farmer were blocked. The extant cropping technological data together with data of weather stations compose the base of the database that rest on relief and cadastre data, and from which geoinformation system integrated in digital form was created in unique thematic vector and raster environment. The system was completed with the hydro-geodatabase in possession of hydrological data.

In hydro-geoinformation system, farmers, who serve appropriate data in quantity and quality, were selected in the knowledge of crop lands, than attribute tables of the concerned plots were refilled with the data of registration. The created geodatabase was analyzed in ESRI/ArcMap, and ArcView environment by modern GIS and statistical methods.

3.4. Assay of applicability possibilities of Digital Elevation Models in water management based on different interpolation methods

Digital Elevation Model of the 19 ha sample plot on Hajdúság loess ridge was created by digitizing of the elevation points of two pieces of 1:10 000 topographic maps. TIN-model was the base of the creation of slope-, aspect-, and hillshading maps.

By smoothing the contour lines drawn from TIN-model, estimation was performed by spatial interpolation method in those points of the region, which had no elevation values. From the interpolation methods, Kriging, Inverse Distance Weighted, and Spline methods were applied.

For interpolation surfaces realized by kriging and IDW techniques, slope-, aspect-, and hillshading maps were created. After this, geostatistic analysis was performed for the best resulted interpolation technique.

3.5. Assay of spatial interpolation processes based on rainfall data

Analyses were performed for the data of three different rainfall amount days (03.31.2006. – 12,3 mm; 11.04.2006. – 53,7 mm; 05.17.2006. – 106,0 mm).

This assay oriented for the evaluation of spatial interpolation techniques, where different spatial interpolation methods, based on the data of 13 rain gauge stations, were compared. Estimations, generated from the data of rain gauge stations, were performed with 30 meters output cellsize. Interpolation methods, used in the assay are the following: Inverse Distance Weighted – IDW (variable searching radius); spline interpolation (regulized and tension option); kriging (ordinary: spherical, circular, exponential, Gauss, linear).

3.6. Remote sensing based on field size precision water management

Water management system of a 19 hectare sugar beet field on Hajdúság loess ridge was analyzed. Agro-technological data was prepared in ArcGIS environment. Plant evaporation surface was calculated by ADC AM100 type leaf area scanner in different phenological phases, and parallel sampled and measured the actual soil water content by TDR method in every 0.2 m layers till 1.5 m depth. Locations of sampling were registered by GPS.

Sample points were selected by geostatistical evaluation, which was based on 1:10 000 scale digital elevation TIN model and digital soil maps. Time-series were calculated from nine different Landsat images that cover the sample plot and the full phenological period. NDVI (Normalized Difference Vegetation Index) was calculated from the Landsat images.

Basic input of farm level irrigation models is the crop coefficient (K_c), which can be defined by the leaf area. In the knowledge of leaf area, magnitude of transpiration can be determined depending on phenological changes. FAO CROPWAT irrigation planning and managing program uses the climatic, soil characteristics and water management attributes and data of the given field as input parameters, and estimates K_c by three points, but this estimation is accused comparatively with big fault. With the help of the software and the utilisation of Penman-Monteith equation, reference crop evapotranspiration (ET_o) can be calculated. Crop evapotranspiration (ET_c), is calculated by multiplying the reference crop evapotranspiration (ET_o), by the crop coefficient (K_c).

The value of the crop coefficient is between 0,3-1,2 depending on crop varieties, so its average estimation error can reach the 200-300 %. Since the value of the actual crop water requirement based on model sensitivity analyses depends on the actual value of K_c significantly, the error propagation influences the reliability of the whole model. One of the aims of my searches is the rise of the accuracy of these parameters using remote sensing data sources.

Considering runoff direction, the amount of effective rain was calculated by D8 runoff algorithm from the digital elevation model. Statistical and image analyses were performed by different software packages. Principal components analysis was performed by SPSS 12 statistical program, and spatial statistic evaluation by clustering was fulfilled by IDRISI Andes and ENVI 4.2 softwares.

3.7. Assay of runoff relations by the use of Digital Elevation Model

Knowledge of the directions of runoff is necessary for the selection of drainless areas and assignment of accumulation points. Start-up database of these tasks is the detailed digital elevation model of the examined area. Digital Elevation Model of Hajdúság loess ridge covered by 2 pieces of 1:10 000 topographic maps was created by digitizing of the contour lines and elevation points of the maps. Shape files, created in ESRI/ArcView 3.3 GIS software were transformed to XYZ form, than interpolation was performed with kriging, by SURFER 8.0 software.

Slope- and aspect map of the sample plot was created by the program. By derivation of the surface, accumulation map of the sample plot was made, from which location of convergent and divergent areas can be determined. Calculation based on the rate of the terrain aspect-variation measured in horizontal level. By the selection of those areas from the accumulation map, where the water keeps gradually to the natural pits in the surface, such map was created that contains the inland-water sensitive areas. Water balance map, which is based on the difference between inflow and outflow, was fulfilled by the interpolation of those values, which were calculated for all cells of the continuous surface.

3.8. Daily average aerial moisture estimation from remote sensing images

Visible (VIS, 2. channel), infrared (IR, 3. channel) and water vapour (WV, 6. channel) channels of 2 hourly images were used for the daily average aerial moisture estimation analyses from METEOSAT satellite images. For the validation of estimation method of daily average moisture values origins from remotely sensed images, daily rainfall data of six

weather stations located on the Great Hungarian Plain (Balmazújváros, Derecske, Hajdúszoboszló, Kaba, Orosháza, Szarvas) were applied. The analysis was performed for the 21st August, 2006 and 08th September, 2006 period, where rainfall estimations, origins from groundbased rain gauge stations, were brought to synch with the rastered satellite remotely sensed data. Georeferencing of satellite images was performed, then the further processing of rectified images by IDRISI Andes GIS software.

For the comparison of average relative reflectance values to rainfall data, pixel values around the points that sign the six rain gauge stations were averaged on the satellite image by channels. Average was also calculated from rainfall data of the six groundbased rain gauge stations and the values were used for the comparison to average pixel values on behalf of further process. Diagrams were created from the appropriate value pairs and the acquired results were evaluated. Images of the different channels were analyzed, principal components analysis and regression-calculation were performed.

4. MAIN RESULTS OF THE THESIS

4.1. Conceptual model of regional water management system

Regional complex water management conceptual model was processed for the 23450 ha research area located at Hajdúság loess ridge, which was dissociated to 5 phases.

Phase 1: Planning of start-up state

After surveying of necessity, aims and tasks are determined. Preliminary model conception is performed considering model barriers.

Phase 2: Data collection, creation of database and data integration

This phase can be dissociated to the following parts: groundbased data collection (measuring of soil, plant, climate, cropping technologies parameters); dynamic data realizing with remote sensing (task is the performing of reliability parameters); collection of other information (relating laws, regulation, organization data); water balance creation (dynamism (moisture distribution, - fluctuation, groundwater flow, variability of evapotranspiration, periodic runoff)); surveying of the possibilities of irrigation; assay of irrigation strategies (for water resource, time and cost); irrigation-modeling (CROPWAT).

Phase 3. Decision support system, processing of alternatives, running of model parameters

Decision-maker is helped by an established, computer based system, which uses data- and analysis models as a resource, for the water management interventions, to be able to come to the best decision from the direct intervention possibilities. The three major elements of decision support are information technology, evaluation technology and decision-makers. Processing of alternatives is followed by running of model parameters. Keep in touch with professionals have huge significance during planning. An assay is necessary, whether decision making group is pleased with the prepared alternatives. The given answer for this question shepherds the process of planning to two ways. If the contact persons find the prepared alternatives not appropriate, process of water management planning have to be trace back to the stadium of processing of new alternatives, and determination of the project have to be rethink, performing optimization and different analyses, and maintaining continuous contribution by contact persons. Process of planning steps to fourth phase, in case of complacency with the processed alternatives.

Phase 4: Processing of the detailed determination of the project

During processing of the final phase, detailed determination of the project is processing, which is followed by the build and analysis of the model. After analysis, conformation parameters are planning. Parallel with model building and analysis, cost-, yield- and risk-analysis is performing. Certainly, survey of functioning rules and models is performing before model-building. After performing all these tasks, selection of project plans is fulfilled, which point means the end of feasibility assay.

Phase 5: Planning

Phase 5 is for planning, in which implementation can start after resolving, than, action, next to continuous monitoring.

4.2. Analysis and coherence assay of factors integrated to hydro-geodatabase

Extent of fields of Kaba production sector in distribution of sub-sectors are the following: Balmazújváros sub-sector: 1904,4 ha; Ebes sub-sector: 351,9 ha; Hajdúszoboszló sub-sector: 3991,5 ha; Nagyhegyes sub-sector: 834,4 ha.

After processing of the possessed cropping technologies data, evaluation of yield averages of the similar production sub-sectors was performed and compared to nationwide yield averages of year 2004. Yield averages of the eight major cropping plants (sweet corn, fodder corn,

corns, sugar beet, potato, sunflower, rape, pulses) were processed. Results of farmers in this sector passes the nationwide yield averages significantly in case of sugar beet and potato, and lower rate in case of sunflower, corns and pulses, but remained under in case of sweet corn, fodder corn and rape. Sugar beet yield average of the examined farmers was 51,9 t/ha, standard deviation was 6,71.

Survey was performed concerning to the extent of irrigable fields of farmers (Figure 1). In case of two farmers from the 15 in Kaba sector, 100% of the whole are is irrigable. Also in case of two farmers is the opposite, namely conditions that necessary for irrigation, are missing. In case of the further farmers, more than 50% of the whole area is irrigable by 7 farmers. Less, than 50% rate occurs only at four farmers.

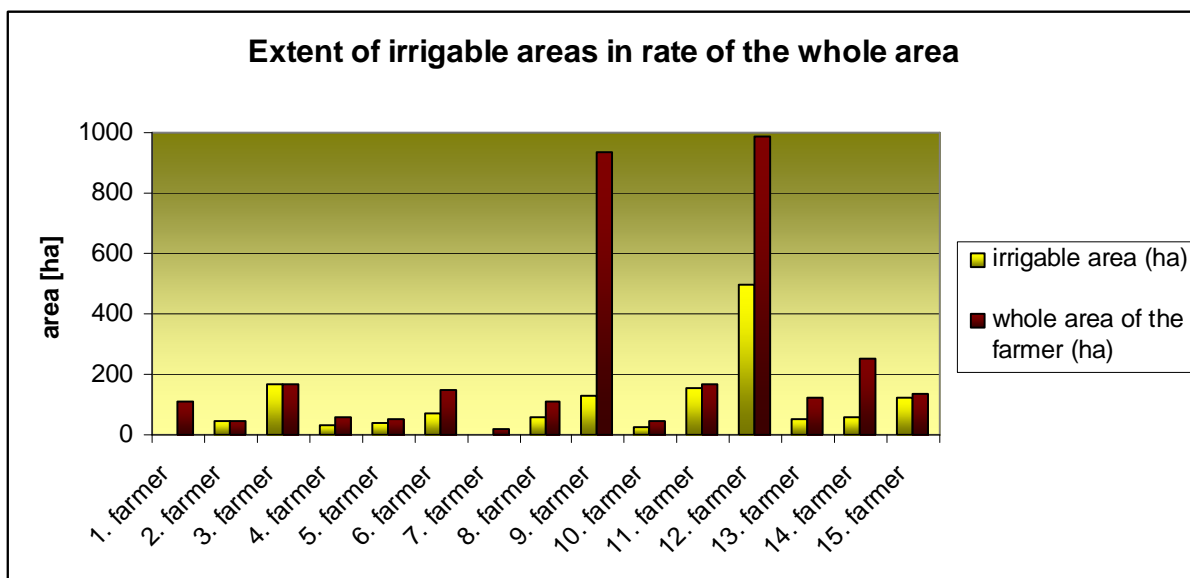


Figure 1. Extent of irrigable areas in rate of the whole area in case of farmers in Kaba production sector of Eastern Sugar Plc.

Pearson-correlation analysis was performed for the major cropping technologies parameters. The considered factors were the following: yield average (t/ha); nutrient supply (N (kg/ha), P (kg/ha), K (kg/ha)); soil disinfection (name of the chemical: Counter, dose: l/kg/ha); leaf fertilization (Boron: name of the chemical: Solubor, dose: l/kg/ha; MgSO₄: name of the chemical: bitter salt, dose: l/kg/ha); irrigation (dose: mm/ha).

As a result of correlation calculations by factor pairs, irrigation shows tight ($r = 0,824$, $P = 5\%$) relation with the conformation of yield average. Significant coherence between yield average and other factors could not be established. Result of correlation analysis support the huge significance of irrigation on behalf of access of bigger yields.

4.3. Creating of Digital Elevation Model based on digitizing of elevation points

Digital Elevation Model was prepared for the examined 19 ha sample plot in Hajdúság loess ridge by Triangulated Irregular Network (TIN) method, which is based on the point-type shapefile, which was created by digitizing of the elevation points of 2 pieces of 1:10 000 topographic maps. Slope-, aspect- and hillshading maps were created for the TIN-model.

Elevation values can be considered to continuous data type; hereby they are appropriate for value estimation for those areas, which are not coinciding with the sampling point set. These unknown values can be calculated by the ambient values with the help of spatial interpolation. As a comparison, Kriging (Figure 2.a), Inverse Distance Weighted (Figure 2.b), and Spline interpolation methods were applied.

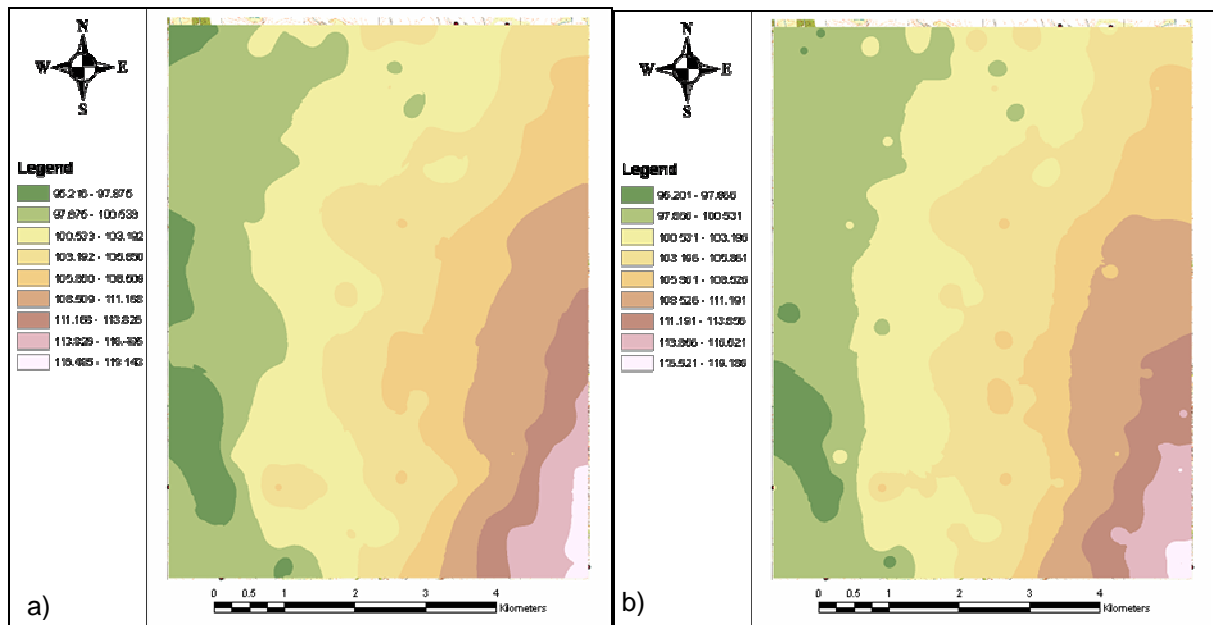


Figure 2. a) Result of Kriging interpolation for the sample plot in Hajdúság loess ridge; b) Result of Inverse Distance Weighted interpolation

Spline method considered less appropriate for surface estimation from elevation data. Major reason of rejection of this method is the high absolute fluctuation of elevation values within the examined area, namely the variety of the values of input points within a little horizontal distance, so the value of curvature is high as well. At those assayed surfaces, where variability of elevation values is high slope of the surface between the points is less moderate, Spline interpolation method does not give appropriate value. While the method minimizing the whole curvature of the surface, two extremes of elevation values are under-, and over estimated.

By kriging, spatial variety of elevation values is statistically homogeneous everywhere in the surface (the same pattern variation can be observed on every part of the surface). Variograms, origins from the original measurement data, can be considered completely stable, since literature consider variogram stable in case of at least 50-100 data points, and our inquiry based on 167 measurement points.

IDW method determines output cell values by linear weighted combination by the pattern of input points. The weight is a function of inverse distance; the surface is an interpolated of a variable depends on a location.

On the whole it is determined that kriging and IDW interpolation is more detailed, than Spline interpolation. Nevertheless, kriging weights are more sophisticated for the ambient measured points, than IDW weights.

As a result of the inquiries it is established that point type shape file created by digitizing of elevation points of a given area is exceedingly suitable for the preparation of digital elevation model by Triangulated Irregular Network (TIN) method, furthermore value estimation by spatial interpolation methods for those points, which have no measured data. As a result of three examined interpolation technique it is established that spline interpolation method is less suitable for the estimation of elevation values of a given region because of the excessive smoothing. In contrast to this, both kriging and IDW interpolation techniques can be applied for estimation accordingly, with good results. Slope- and aspect maps created from these interpolated surfaces give detailed information about slope and aspect relations of the region.

4.4. Evaluation of spatial interpolation methods based on rainfall data

Data of the rain gauge stations of year 2006, three days with different moisture amounts were selected and estimation was performed for these dates with 8 different interpolation methods. Dates, selected for the analyses, were the following: 31.13.2006., 11.04.2006., 17.05.2006. Date March was a low moisture event day (12,3 mm), date April was a middle (53,7 mm), and date May was a higher moisture event day (106,0 mm).

From the moisture interpolation assay based on 13 measurement points it is established that for estimation of the moisture amount and distribution of a region with a low density rain gauge network, the best approach can be reached by ordinary kriging with exponential semivariogram and variable searching radius (Figure 3). Method of kriging ensures loyal value rendition in the given points. It is weighting from the ambient measured data on behalf of getting data for those areas, where there were no measurement in fact, therefore contour lines follow trend more appropriately and there is no such under- or over-estimation, than by

in case of the other methods. Inverse Distance Weighted interpolation with variable searching radius gives less sophisticated, but approximately good result.

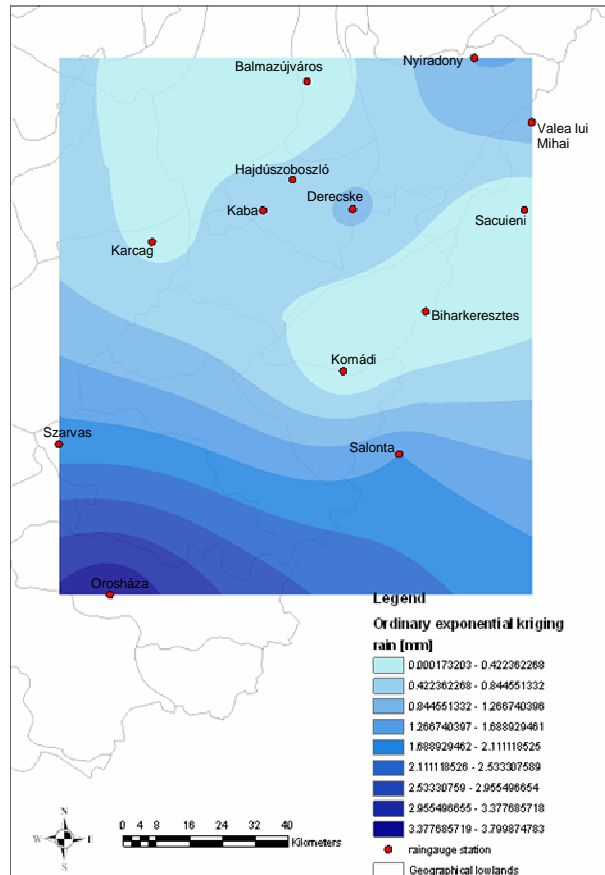


Figure 3. Result of ordinary exponential kriging based on moisture data concerning to 31.03.2006.

Geostatistical analysis was performed for the best resulted exponential kriging and IDW technique. During both kriging and IDW interpolation, the least estimation error was experienced by in case of the lowest moisture amount day (Table 1 and 2).

Table 1. Cross validation results of moisture data on 31.03.2006. concerning to kriging interpolation

Location of rain gauge station	Calculated value	Estimated value	Standard error	Error	Standardized error	Normal value
Szarvas	1,9	1,9249	1,0001	0,0249	0,0249	0,0000
Orosháza	3,8	1,4003	1,0613	-2,3997	-2,2611	-1,7688
Karcag	0,3	0,9900	0,9323	0,6900	0,7401	0,6151
Kaba	0,7	0,4797	0,6349	-0,2203	-0,3470	-0,1940
Hajdúszoboszló	0,5	0,6644	0,5905	0,1644	0,2784	0,1940
Balmazújváros	0,0	0,7331	0,8852	0,7331	0,8282	0,8694
Komádi	0,0	1,0602	0,7988	1,0602	1,3272	1,7688
Derecske	1,0	0,3368	0,7274	-0,6632	-0,9117	-0,8694
Salonta	1,7	0,6061	0,9129	-1,0939	-1,1982	-1,1984
Biharkeresztes	0,0	0,5352	0,8063	0,5352	0,6638	0,3957
Nyíradony	1,3	0,7044	0,8488	-0,5956	-0,7017	-0,6151
Sacuieni	0,0	0,8136	0,8242	0,8136	0,9871	1,1984
Valea lui Mihai	1,1	0,6729	0,7639	-0,4271	-0,5591	-0,3957

Table 2. Cross validation results of moisture data on 31.03.2006. concerning to IDW interpolation

Location of rain gauge station	Calculated value	Estimated value	Error
Szarvas	1,9	1,5693	-0,3307
Orosháza	3,8	1,1182	-2,6818
Karcag	0,3	0,8069	0,5069
Kaba	0,7	0,5203	-0,1797
Hajdúszoboszló	0,5	0,6604	0,1604
Balmazújváros	0,0	0,6815	0,6815
Komádi	0,0	0,7796	0,7796
Derecske	1,0	0,4699	-0,5301
Salonta	1,7	0,4027	-1,2973
Biharkeresztes	0,0	0,5943	0,5943
Nyíradony	1,3	0,6750	-0,6250
Sacuieni	0,0	0,8009	0,8009
Valea lui Mihai	1,1	0,6065	-0,4935

Accuracy of interpolation was defined statistically, difference between the original and values origins from interpolation were determined in the test set. Deviation of estimated and measured data was analyzed by every interpolation. Calculated errors by the selected test sample showed that kriging and IDW methods gave almost the same values. Goodness of kriging values was determined on the similar days: $RMSE_{kriging31.03.2006.} = 0,9238$; $RMSE_{kriging11.04.2006.} = 2,262$; $RMSE_{kriging17.05.2006.} = 2,935$. Values are the following in case of IDW method: $RMSE_{IDW31.03.2006.} = 0,972$; $RMSE_{IDW11.04.2006.} = 2,184$; $RMSE_{IDW17.05.2006.} = 3,234$.

In cross validation, the prominently bad error value was origin from the estimation of the data of Orosháza rain gauge station, which can be explained with the location of this station, because this rain gauge site lies at the most south within the research area, namely slim is the measured data within a given cell distance, - since ambient measured data are the most far from this point – so the estimation is accused with higher error.

4.5. Analysis results of the development of remote sensing based field size precision water management

Applicability advantages of a water management model integration based on a GPS based location determination and remote sensing in precision farming was examined. Principal components analysis was carried out from Landsat time-series. Clustering was made from the first principal components image, and 5 parts of the plot that considered homogeneous were selected by this. NDVI was calculated from Landsat time-series images, from which K_c crop coefficient value was calculated (Figure 4). The results of the analysis showed that crop coefficient values, calculated from remotely sensed images, are far reliable, than K_c values,

estimated by CROPWAT irrigation planning model. Consideration of K_c values, calculated from NDVI are suggested during planning of irrigation, since 200-300% average estimation error can be eliminated by the adaption of this, which origins from the wide interval of the value of crop coefficient by the usage of CROPWAT model.

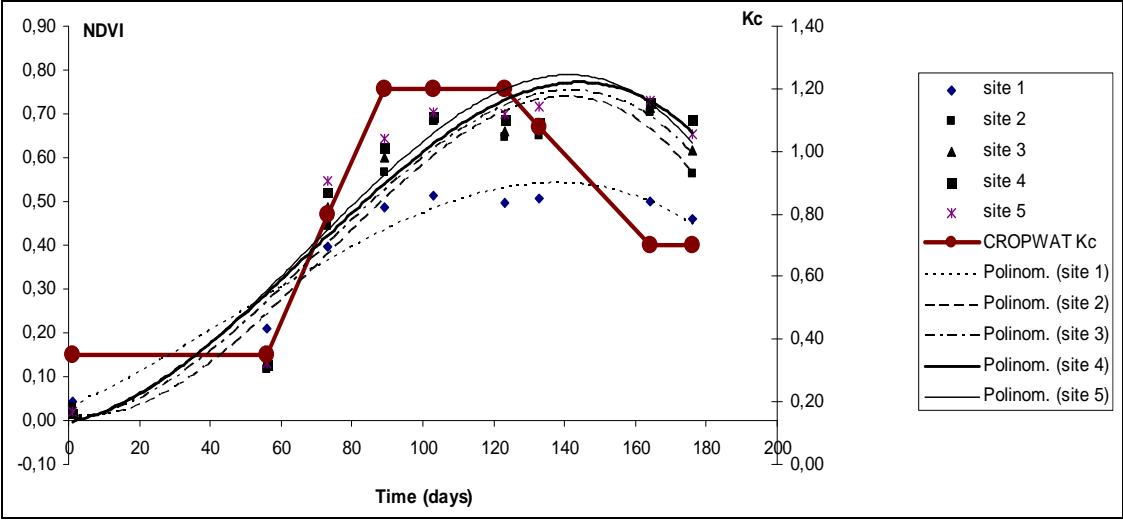


Figure 4. Relationship between crop coefficient (K_c) and normalized difference vegetation index (NDVI) values and tertiary equations for the 5 selected sites

Reference evapotranspiration measurement results were multiplying by a c constant factor (the average value of this factor is 0,76), and multiplying the modified reference crop evapotranspiration (ET_o) by the crop coefficient (K_c), crop evapotranspiration (ET_c) was calculated for the 5 selected sites (Figure 5).

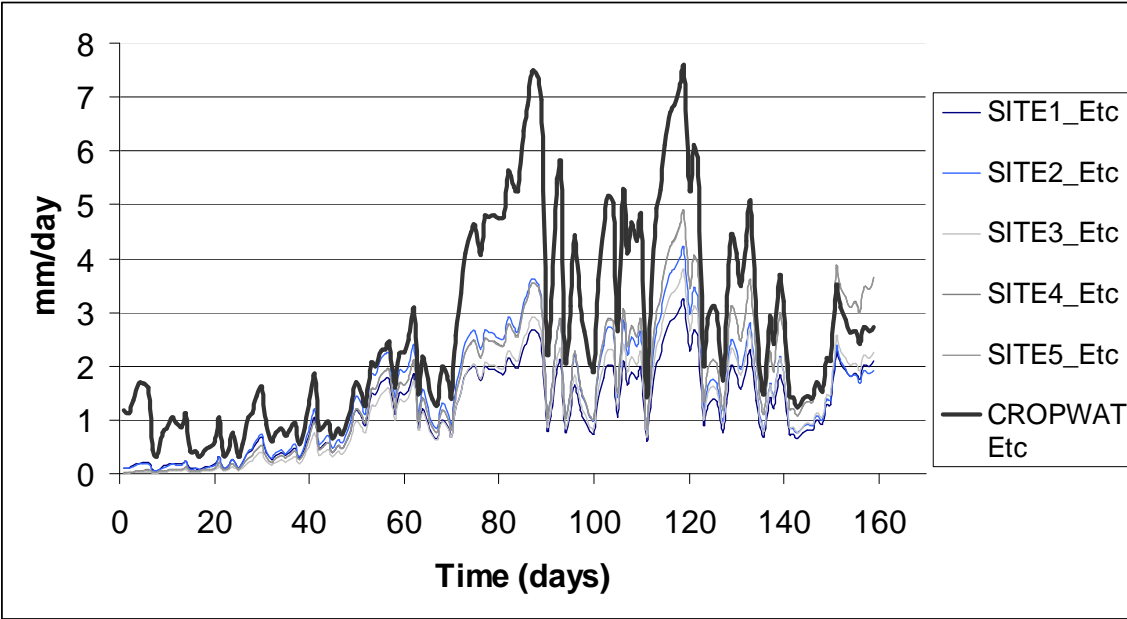


Figure 5. Curves of calculated crop evapotranspiration (ET_c) for the 5 sites and estimated ET_c by CROPWAT

Correlation analyses between NDVI and LAI, and between LAI and K_c proved to be close. Analyses, origins from satellite images, were found appropriate for the calculation of reference crop evapotranspiration (ET_o). ET_o and crop water requirement values estimated by CROPWAT model have exceeded the calculated values, which based on measured data. By the results, usage of the measured data is suggested in practice. The model is suitable for not only the development of water management strategies based on natural moisture, but also for different irrigation variants, such as irrigation time period and technical optimization of water distribution.

Crop irrigation requirement, net scheme irrigation requirements in mm day^{-1} , $1 \text{ s}^{-1} \text{ ha}$ and 1 s^{-1} , irrigated area as percentage of total scheme area, and irrigation requirement in $1 \text{ s}^{-1} \text{ ha}^{-1}$ within the actually irrigated area were calculated. Crop water requirement was determined and applicability of the method for optimization of irrigation necessity was established.

Water management model integration based on a GPS based location determination and remote sensing proved to be appropriate for the analysis of effectiveness of environmental water management strategies, and also for development of effective utilization of water amount, origins from natural moisture and artificial water supply, furthermore it has a great significance in respect of cost reduction and water providence. With low inputs it is also suitable for testing of the water regime of different plant varieties and precision soil cultivation alternatives.

4.6. Relief analysis of water relations of Hajdúság loess ridge

Runoff-accumulation relations of Hajdúság loess ridge were assayed by the creation of Digital Elevation Model. Accumulation mapping was performed and runoff directions were illustrated on 3D elevation model of the sample plot. Convergence and divergence of runoff directions showed the rate of accumulation and the location of the possible inland water spots. Slope- and aspect-map of the area was created. Convexity values were determined accordingly to runoff directions fit to slope of the surface. Those parts of the sample plot, from where surface waters spread, and those areas, where the waters accumulate (convexity), were illustrated on map (Figure 6.a). By the impoundment of convergent areas, such map was created that shows those parts of the sample plot, which are liable to overmoisturing, inland water (Figure 6.b). Map, which illustrates these spots, was exported to shape file from Surfer 8.0 software, which can be processed in ESRI/ArcView 3.3 environment. In this software, area of these spots was calculated by the running of an ESRI script that serves the area

calculation. Summarizing the results, it was found that almost half (49,63%) of the whole 4570 ha area is liable to overmoisturing.

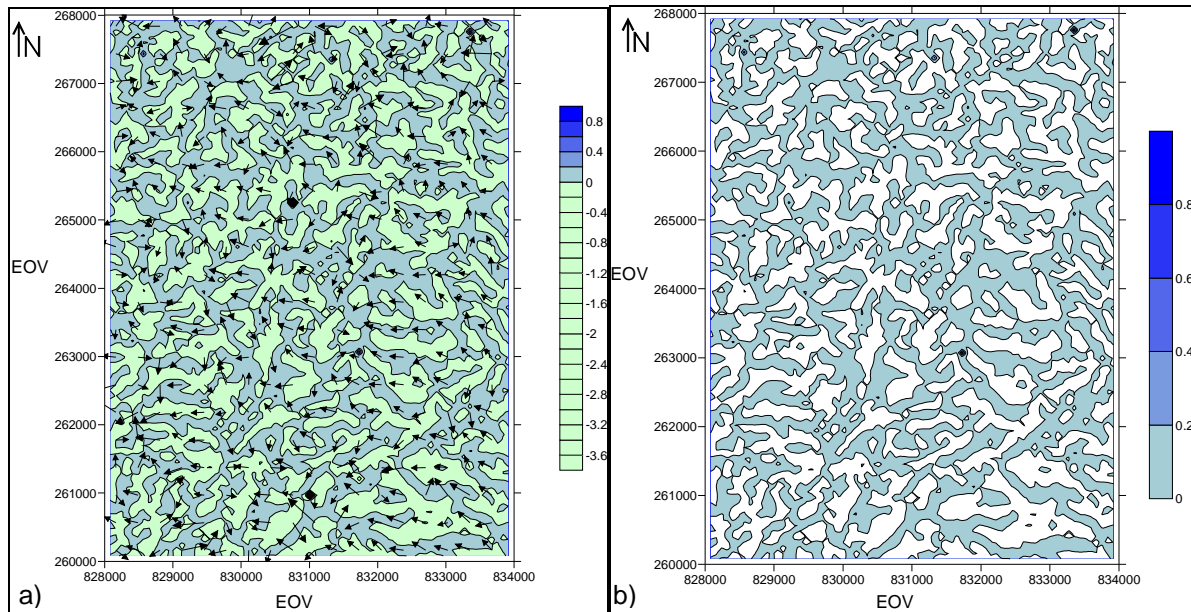


Figure 6. a) Values of convexity for the sample plot at Hajdúság loess ridge; b) Impoundment of selected convergent areas of the sample plot at Hajdúság loess ridge

Inflow and outflow can be observed equally on terrain field parts. Water balance map, which is based on the difference between inflow and outflow, was created by the interpolation of those values, which were calculated for all cells of the continuous surface (Figure 7).

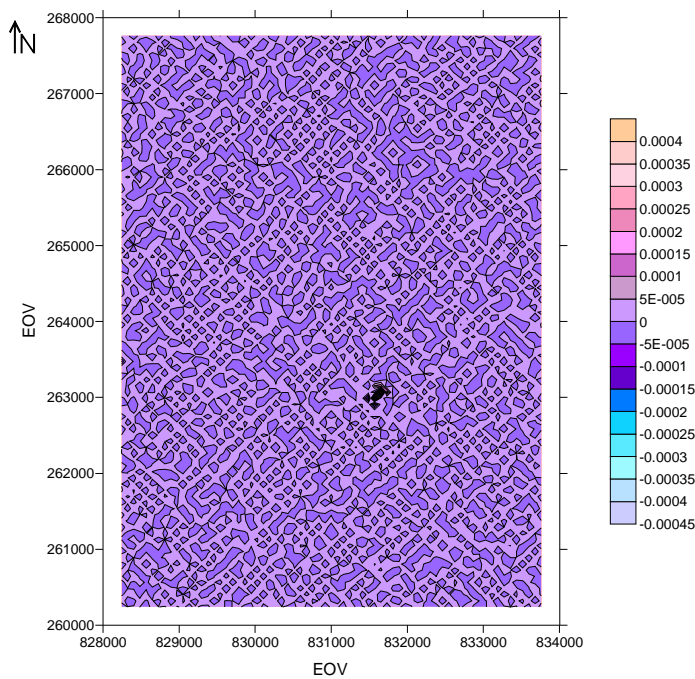


Figure 7. Map of water balance of inflow and outflow for the sample plot at Hajdúság loess ridge

The prepared digital data file contributes to the rational planning of water management interventions, realignment of cultivation sectors. In case of major coherent spots, which are liable to inland water, farmer units can get help for assignment of substrahend areas from production, and optimizing of cultivation.

4.7. Evaluation of the applicability of METEOSAT satellite images in daily average aerial moisture estimation

Remotely sensed images were submitted to a several level image processing method. In ENVI 4.3 software, cutting of Region of Interest and saving as a *.tiff* image was performed, than fitting to EOVS projection of the satellite image was fulfilled in ArcMap9.2 software by rectification to the vector layers of DTA 50 file. This significant time needed image processing procedure was performed altogether for the images of 6 dates of 19 days, and 3 channels by dates, concerning to the whole time series.

Processing of the numerous rectified images was continued in IDRISI Andes software further. Geotiff can be imported to this software, but software processing needs its conversion to raster. This transformation was performed on every images, so the barrier of determination of relative reflectance left off.

During this, shape file in ArcView 3.3 GIS software was created by the EOVS coordinates of the 6 groundbased rain gauge stations, which made possible the illustration on map of the geographical location of the measuring stations. This shape file was also needed to be “coded”, namely convert to vector.

Principal components analysis of VIS, IR and WV channels was performed, which showed that 12, 14 and 16 hour is the most determinative in respect of moisture events. After preparation of NDVI image (Figure 8.a), mask was created by the selection of clouds (Figure 8.b), on behalf of the spatial narrowing of the assay. Threshold value was determined by 0,15. After this, tightness of coherence between the different channels was examined by cross-correlation calculation. During the calculation of cross-correlation, the resulted correlation values were similar to literary values (WV-IR: $r = 0,619$; VIS-IR: $r = 0,867$; VIS-WV: $r = 0,644$; where r is the cross-correlation coefficient).

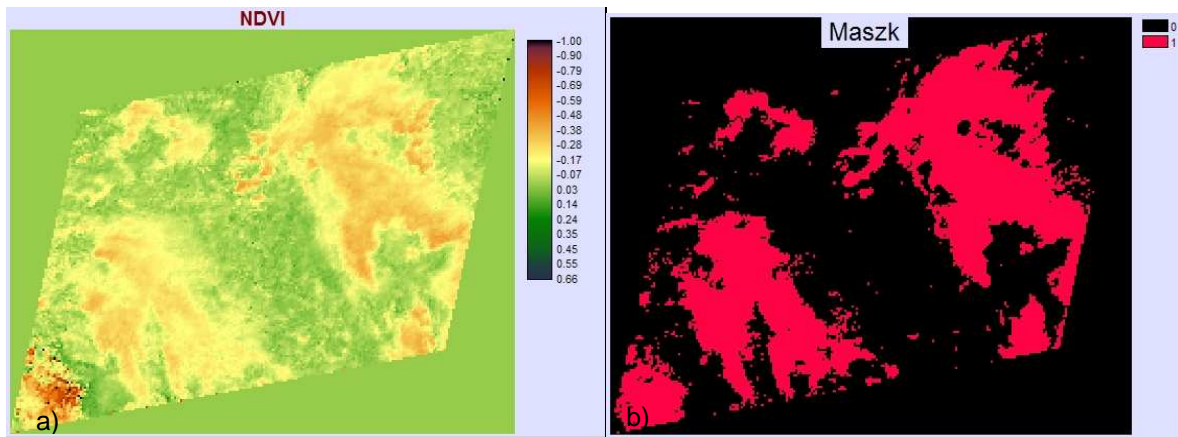


Figure 8. a) Normalized Difference Vegetation Index (NDVI); b) Mask, created from NDVI image

Vector layer, which contains the coordinates of weather stations, was fitted to the rastered satellite images. Thanks for the agreement of the projection system, value of relative reflectance of the 3x3 pixel area around the points, which sign the measuring stations, was readable. Values were recorded in Microsoft Excel program by measuring stations, dates and channels. At the end of data recording, relative reflectance values were averaged and compared to the daily average moisture data of the measuring stations and illustrated on a diagram (Figure 9).

Connection between VIS, IR and WV channels was expressed by regression-assay. Cross-correlation value is 0,61 between simulated and experienced values. By the results it is established that METEOSAT satellite images are appropriate for the conclusion of the average pointwise rainfall event of a region for a longer period. Performing regression assay for the average values of 1 day it is established that cross correlation value falls back to 0,34. Therefore, utilization of METEOSAT satellite images for the average moisture estimation is suggested only to a longer period (at least some weeks) on behalf of more reliable information.

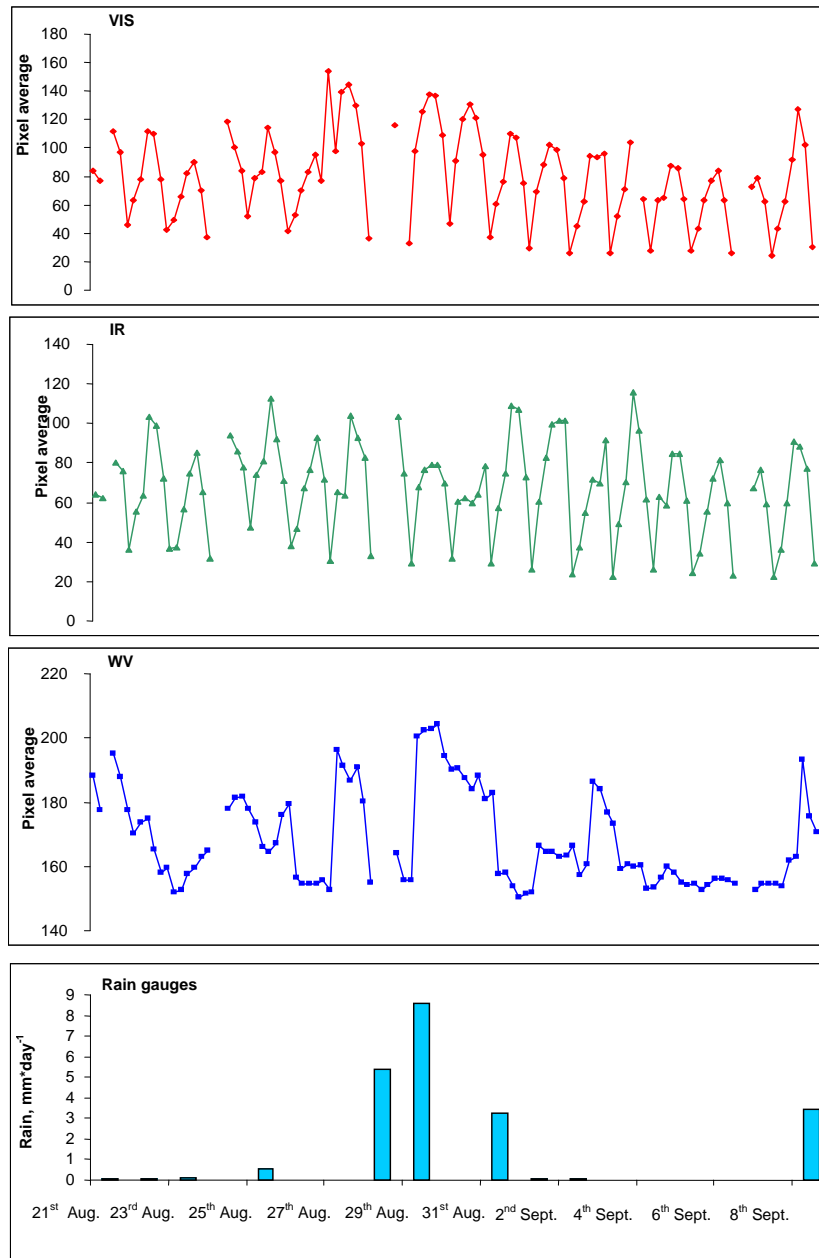


Figure 9. VIS, IR, WV and daily rainfall time series, as spatial averages in the environment of 6 rain gauge stations located at the Great Hungarian Plain

During the evaluation of the temporal variability of spatial averages it was established that the assay of the relative reflectance values of satellite images and comparison of their average values to the daily average moisture values of the groundbased rain gauge stations, give reliable information by the estimation of daily average moisture events of a given area (region).

By the result of regression assay of VIS, IR and WV channels, it was verified that information, origins from METEOSAT images, are useful for the conclusion of the average pointwise moisture event of a region, concerning to a longer period.

By the results, it is established that cross-correlation value falls back significantly in case of short time series, by the assay of the average moisture value of only one day, it decreases for its half.

On the whole, by the assays between the average pixel values of satellite images around the rain gauge stations and moisture values origins from the groundbased rain gauge stations it is determined that examination of a longer period gives better correlation value, that is why usage of satellite-based moisture estimation method is suggested primarily not for daily estimation, but for estimation of the moisture event of a longer period, on behalf of the more accurate data getting.

In my dissertation, assay extended to a narrow part of agro-environmental tasks. However, by the delineated results, I think that invoke of GIS is indispensable for the effective water resource management development nowadays. Usage of remotely sensed data can help in better cognition of difficult processes that pass off spheres affected by agriculture, and monitoring of variability of the similar environmental parameters. My assay results point at such solutions that can be effective tools in not only the optimization of cropping, but in appropriate temporal and spatial completion of water management interventions as well.

5. NEW SCIENTIFIC RESULTS

- 1) A hydro-geoinformation database was created in uniform thematic vector and raster environment, based on cropping technologies, climatic, and relief cadastre data. Applicability possibilities of Digital Elevation Models in water management were optimized.
- 2) Comparative analysis was performed for 8 interpolation techniques concerning to the spatial estimation of the moisture amount and distribution of a region with low density moisture measurement network. It was verified that the best approach can be reached by ordinary kriging with exponential semivariogram and variable searching radius.
- 3) Applicability advantages of a GPS-RS based water management model in precision farming were verified.
- 4) K_c crop coefficient values calculated by physical spectral Landsat TM – NDVI time series were parametered.
- 5) By my establishments, literary ET_o values of CROPWAT model exceed the measured ET_o values calculated from spectral data with 7-12%.

- 6) During the evaluation of temporal variability of spatial averages, daily average aerial moisture estimation was calibrated using the visible, infrared, and water vapor channels of METEOSAT SG1 satellite. By the results of principal components analysis, performed for the channels, it is determined that 12, 14 and 16 hour was the most determinative in respect of moisture events.

6. PRACTICAL UTILIZATION OF THE RESULTS

1. Circle of value estimation processes based on Digital Elevation Models, which can be applied dependably in water management, was determined.
2. It was verified that exponential kriging method is the most appropriate for the assay of the distribution and intensity of moisture.
3. GPS-RS-WMM model integration can be applied effectively in the analysis of the effectiveness of environmental water management strategies, and also for development of effective utilization of water amount, origins from natural moisture and artificial water supply.
4. K_c values, calculated from NDVI that origins from satellite images can reduce 200-300% estimation error of empirical estimated K_c values order of magnitude.
5. ET_o and water requirement calculations by satellite images accused with significantly less error, than values estimated by CROPWAT model.
6. Near ground remotely sensed data sources supply data deficit origins from input model parameters that change dynamically, which can be experienced in case of the robust pointwise water management models. Usage of METEOSAT satellite images, in case of the assay of a longer period (at least some weeks) serves with reliable information concerning to the average moisture estimations.

7. PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

Reviewed scientific publications in Hungarian:

- Nagy I. – Tamás J.:* 2005. Regionális mezőgazdasági vízgazdálkodási rendszer koncepcionális modellje. Acta Agraria Debreceniensis. 16. 199-209.
- Nagy I. – Tamás J.:* 2005. Cukorrépa (*Beta vulgaris* L.) termelési kvóták denzitásának optimalizálása pontszerű geostatistikai módszerekkel. Acta Agraria Debreceniensis. 18. 46-50.

- Tamás J. – Buzás I. – Nagy I.:* 2005. A mintapontok folytonos GIS térbeli elemzése a cukorrépa (*Beta vulgaris* L.) termésének és minőségének vizsgálata során. *Acta Agraria Debreceniensis*. 18. Debreceni Egyetem. 56-61.
- Nagy I. – Takács P.:* 2006. Cukorgyári termeltetési rendszer térinformatikai értékelése. *Acta Agraria Kaposváriensis*. 10. 13-20.
- Nagy I. – Bíró T. – Tamás J.:* 2007. Lefolyási viszonyok vizsgálata Digitális Magassági Modell felhasználásával. *Acta Agraria Debreceniensis*. 26. 124-129.
- Tamás J. – Buzás I. – Nagy I.:* 2006. A mintapontok térinformatikai pontszerű elemzése a cukorrépa (*Beta vulgaris* L.) termésének és minőségének vizsgálata során. *Acta Agraria Debreceniensis*. 19. 32-37.

Reviewed scientific publications in foreign languages:

- J. Tamás – I. Nagy – P. Burai:* 2006. Dynamic data exchange in agricultural water management strategy. *Cereal Research Communications*. 34. 57-61. (IF: 1,037)
- J. Tamás – Cs. Lénárt – I. Nagy:* 2007. Evaluation of cropfield water supply by remote sensing method. *Cereal Research Communications*. 35. 1189-1192. (IF: 1,190)
- P. Burai – E. Kovács – Cs. Lénárt – A. Nagy – I. Nagy:* 2009. Quantification of vegetation stress based on hyperspectral image processing. *Cereal Research Communications*. 37. 581-584. (IF: 1,190)

Reviewed conference proceedings in foreign languages:

- I. Nagy – Cs. Lénárt – J. Tamás:* 2006. Advanced hydroinformatical technology: one solution for the creation of sustainable water management practice. [In: Maghiar T.T., Nagy J., Bara V., Kátai J., Csépi N. I., Jávora A., Tamás J. (eds.) *Natural resources and sustainable development*.] University of Oradea Publishing House, Oradea, 803-810.
- I. Nagy – P. Burai – P. Takács – J. Tamás:* 2006. Field size precision water management based on time series analysis of satellite images. [In: Suarez J., Márkus B. (eds.) *Shaping the Future of Geographic Information Science in Europe*.] College of Geoinformatics, University of West Hungary, Székesfehérvár, 151-160.

Non reviewed conference proceedings in Hungarian:

- Nagy I. – Burai P. – Tamás J.:* 2006. Távérzékelés alapú táblaszintű precíziós vízgazdálkodás. [In: XX. Országos Környezetvédelmi Konferencia és Szakkiállítás, Tanulmány kötet.] MTESZ, Balatonfüred, 135-143.

Tamás J. – Thyll Sz. – Juhász Cs. – Bíró T. – Lénárt Cs. – Kovács E. – Pregun Cs. – Burai P. – Kovács E. – Kovács N. – Takács P. – Nagy I. – Nagy A.: 2006. Integrált vízgazdálkodás a szántóföldi táblától a vízgyűjtőig. [In: Proc. Láng I., Jolánkai M., Csete L. (szerk.) A globális klímaváltozás: hazai hatások és válaszok, „VAHAVA” Project.] KvVM – MTA, Budapest, 1-4.

Publications in other topics

Reviewed scientific publications in foreign languages:

J. Zsembeli – G. Tuba – Cs. Juhász – I. Nagy: 2005. CO₂-measurements in a soil tillage experiment. Cereal Research Communications. 33. 137-140. (IF: 0,32)

Reviewed conference proceedings in Hungarian:

Zsembeli J. – Nagy I.: 2004. Talajművelési technológiák hatása a széndioxid emisszióra. [In: Kalmár I. (szerk.) IV. Alföldi Tudományos Tájgazdálkodási Napok.] Tessedik Sámuel Főiskola, Mezőgazdasági Főiskolai Kar, Mezőtúr, 130.

Nagy I.: 2005. Adatok a talajhasználat és a széndioxid emisszió összefüggéseinek feltárásához. [In: Kelemen É., Kobza R. (szerk.) XXVII. Országos Tudományos Diákköri Konferencia Agrártudományi Szekció előadásainak magyar nyelvű összefoglalója.] Tessedik Sámuel Főiskola, Mezőgazdasági Víz és Környezetgazdálkodási Főiskolai Kar, Szarvas, 201.