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INLAND EXCESS WATER PROJECTION BASED ON METEOROLOGICAL AND PEDOLOGICAL MONITORING DATA ON A STUDY AREA LOCATED IN THE SOUTHERN PART OF THE GREAT HUNGARIAN PLAIN

Károly Barta*

Department of Physical Geography and Geoinformatics, University of Szeged, Egyetem u. 2-6, H-6722 Szeged, Hungary
*Corresponding author, e-mail: barta@geo.u-szeged.hu

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Abstract

The research investigated the process of excess water formation. Complex measurement stations were developed in order to determine the most important hydro-meteorological and soil factors contributing to the formation of excess water. The stations measure the amount of precipitation, evapotranspiration, evaporation from water surface, soil moisture in 3 different depths; soil temperature in 5 different depths; furthermore, soil water level. The study area is located in the southeastern part of Hungary, near Szeged, in the flood plain of Tisza and Maros with extremely clayey soils. The former soil data were completed by new soil survey to determine several soil parameters (e.g. bulk density, porosity, field capacity, saturated hydraulic conductivity). Infiltration was calculated from the measured parameters and water budget elements of bigger rainfall event were analyzed between March 2010 and August 2011. Genetic types of excess water can be separated based on the data.

Keywords: excess water, infiltration, water budget, soil

INTRODUCTION

The two most frequent type of inland excess water formation are the upwelling (or vertical) type (due to the increasing groundwater table) and the accumulative (or horizontal) type (the water accumulates under gravity in the lowest areas due to limited infiltration and/or runoff, independent from the groundwater table or communicating by capillary system). This type of inland excess water is often caused by inadequate agrotechnic methods which can lead to soil structure degradation, e.g. soil compaction. These degradation processes can be noticeable all over the world where you can find any agricultural activities. Based on data of JRC IES (Joint Research Centre Institute for Environment and Sustainability, Ispra) the soil compaction affects 94 million ha only in Europe, almost 10% of the continent. Several studies deal with this problem (Hamza and Anderson, 2005; Ndiaye et al., 2007) mentioned both the effects of agricultural machines and overgrazing as well. Clayey soils are particularly sensitive to compaction that can step up the probability of inland excess water (Birkás, 2011; Birkás et al., 2009).

In the last years a lot of methods were developed to determine the spatial extent of inland excess water hazard, as a result of which maps with small spatial resolution were born (Thyll and Bíró, 1999; Körösparti et al., 2009). There is an increased need in humid years for a detailed projection of the extent and location of inland excess water formation in a better resolution. The projection and the monitoring require an elevation model of high resolution and the exact data of groundwater level. Furthermore, the projection of accumulative inland excess water needs the monitoring of water budget parameters (precipitation, infiltration, evapotranspiration, soil moisture etc.) in a high spatial resolution apart from the knowledge about the basic soil parameters.

A complex monitoring system was developed firstly to get detailed knowledge about the formation of the phenomenon, furthermore, to project the future inundations based on the measured data series. A further question was if the method is able to distinguish the upwelling and accumulative types, and to determine the weight of the affecting factors in the formation of groundwater and the rise of the groundwater table (the role of local infiltration, vertical groundwater flow, soil frost etc.). The method was tested on study areas in the Marosszög microregion. The paper focuses on the technical and methodological development of the monitoring system and the results of the monitoring.

TECHNICAL PARAMETERS OF THE MEASUREMENT STATIONS

The complex measuring unit was set up using 1 precipitation measuring unit, 2 lysimeters, 1 soil temperature measuring unit, 3 soil moisture measuring unit and 1 groundwater-table measuring unit.

The certain units are determined by the following parameters:

- Precipitation measuring unit: the precipitation is measured with 0.1 mm precision by Reed switch and buckets.
- Lysimeters: the equipments work as weighting lysimeters; PVC trays of 20 cm diameter and 5 cm depth are connected to the scales. In one of the equipment, undisturbed soil monolith with vegetation is placed, the other is filled by water. The former one measures the evaporation of the vegetation of the sampled area (usually crops or meadows), the latter is able to simulate the evaporation of opened water surfaces (and excess water inundations). The weight loss on the scales refers to the evaporation that is counted by the measured data in mass unit compared to the surface of the trays.
- Soil temperature measuring unit: a tube of 50 cm that measures the temperature of the soil in 5 different depths. This unit measures the temperature profile of the soil. Its importance increases in winter and early spring time when the formation or the termination of a soil frost can be monitored.
- Soil moisture measuring unit: TDR soil moisture meters are used that are able to measure over not only the field capacity, but around saturation with a reliable precision. With this method the depth of infiltration can be monitored, the capacity of water intake can be calculated from the unsaturation of the soil, furthermore, the detection of a soil layer, where soil moisture is below the moisture of the capillary zone around the groundwater table and the soil moisture of the (almost-saturated) near-surface layers. The latter has a crucial role in the formation of the accumulative type of inland excess water. The changes in the soil moisture make the estimation of the infiltrated water in mm possible.
- Groundwater-table measuring unit: DATAQUA measuring sensors are implemented to control the level of the groundwater. The exact groundwater data levels control the independence of inland excess water formation from the groundwater.

The sensors measure in an hour interval, and the measured data are transferred to a central server by GPRS connection. The data of the measurement stations are managed online and delivered to PC-s in .xls format.

STUDY AREA AND METHODS

Two measurement stations were set up in the inundated areas between the Tisza and Maros in Maroslele settlement. Measurement station 1 was installed in a meadow called Tápai-rét, Measurement station 2 is located westwards from Batida to monitor an area determined by accumulative inland excess water (*Fig. 1-2*). The investigated areas are located at the boundary of the micro-regions South-Tisza-valley and Marosszög. It is a lowly elevated backswamp area around 78-85 m a. s. l. with an extremely variable precipitation around 530-570 mm/year (Dövényi, 2010). The subsoil horizons are the recent sediments of Maros and Tisza, determined by clay, sandy or silty clay, only the ancient point bars are determined by coarser fractions. The mechanical composition of the upper 50-90 cm of the soils became more extreme due to the soil formation, as a result of which a low permeability layer formed, promoting the formation of inland excess waters. The characteristic soil types are humic Fluvisols and Gleysols, in some places Vertisols, on highly elevated areas Solonetz soils occur (AGROTOPO, 1985-86). The relief of the area is small; due to the fluvial origin remnants, point bars occur in the mostly plain area. In the backswamp areas many close depressions of high extent occur that contribute to the formation of accumulative inland excess water. These factors are further strengthened by anthropogenic facilities: roads covered by asphalt, dirt roads and the levees along the channels (Kozák, 2011).

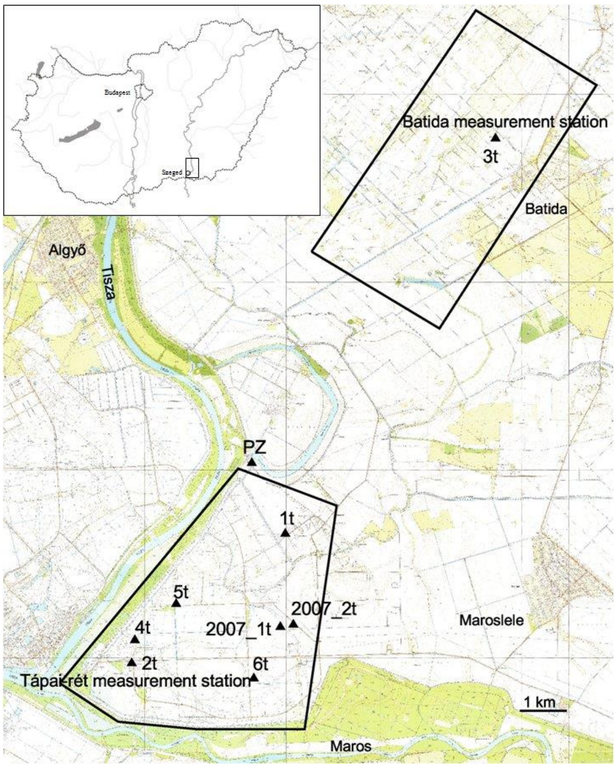

Fig. 1 Measurement stations in Marosszög (2t: Tápai-rét, 3t: Batida). Other marks show the other soil sampling points

Databases and detailed soil measurements were used for the allocation of the measurement stations. The characteristic soil/sediment layers were sampled in a 2 m depth. The main soil parameters (pH, soil plasticity according to Arany, carbonate-, salt- and humus content) and the particle size distribution were measured. In case of the compacted layers (B horizon or plough pan layer) bulk density, porosity, field capacity, actual soil moisture and saturated hydraulic conductivity were determined from undisturbed samples. Based on the particle size distribution, the bulk density and the humus content the characteristic pF values (pF 0; 2.5; 4.2; 6.2) and saturated hydraulic conductivity were determined using pedotransfer functions.

Fig. 2 Installation of the measurement stations

The water surplus on the soil surface can be calculated from the measured and calculated parameters using the following water regime function:

R = P – ET – I

where:
R: water surplus (mm)
P: measured precipitation (mm)
ET: evapotranspiration (mm)
I: infiltration (mm) (generally calculated from the saturated hydraulic conductivity of the soil horizon with the lowest water infiltration capacity, however, the changes in the soil moisture give more exact estimations from the infiltrating precipitation)

These point measurements can be extended only until the soil patch of the measurement stations, further values of *I* have to be estimated by using available soil maps. In spring and summer of 2010 a more detailed pattern of precipitation measurements would have been needed due to the spatial distribution of weather events (rainstorms, thunderstorms etc.), thus, the measured data of the dike-reeve’s houses were implemented in the estimation of the spatial pattern of precipitation.

The calculated water surplus map using the data series of the measurement stations and the digital elevation model of the area allows the projection of the occurrence and extent of the inundations. Although, measurements are made in every hour, due to the temporal dynamics of the process, the method can be used only in the autumn and winter period with low evapotranspiration, and only in areas where almost impermeable (clayey) soil horizons can be found near the surface. In other cases, the spatial projection of the accumulation process will have significant errors.

Data series between March 2010 and August 2011 were used. Due to technical problems, evapotranspiration data are available for short intervals, thus, the water regime calculations are made only for low-temperature-periods.

RESULTS

Analysis of the soil parameters

The most relevant soil parameters effecting the formation of inland excess water were analysed. Using former results of soil measurement, 9 soil profile were investigated altogether. The number of the analysed points was not enough to compile a detailed soil map, however it allowed to outline the overall description of the area. Heavy, non-calcic clay and clay loam soil are characteristic. Salt content of these soils are not signifi-

Table 1 Characteristic soil parameters of the study area (Perneki, 2010; Galbács, 2011)
A: soil sample, K_A: plasticity index according to Arany, TFT: bulk density, P: porosity, vk_{sz}: field capacity, F: saturated hydraulic conductivity

A	B	C (g/cm^3)	D (v/v%)	E (v/v%)	F (m/s)
2007_1t/50-70 cm	51	1.67	37.2	17.1	1.20E-08
PZ/0-30 cm	60	1.55	40.4	17.0	1.60E-06
1t/50-70 cm	51	1.67	37.2	34.8	1.20E-08
2t/50-55 cm	63	1.61	28.4	21.5	8.00E-10
3t/0-40 cm	50	1.65	37.9	33.9	6.00E-09
4t/50-55 cm	81	1.46	31.8	24.3	9.00E-10
5t/55-60 cm	61	1.65	32.4	24.3	9.00E-10
6t/50-55 cm	95	1.32	31.2	22.8	9.00E-10

cant, only in the deeper layers was detected more than 0.05% salt content. The humus content of the top-soil varied between 1 and 2% in the samples. The soil forming alluvial sediments are characterised by high clay content and low carbonate content in the analysed profile. The only exception is the Batida area, where loess also occurs under the young sediments.

In most of the soil profiles there is a compacted layer, considering as impermeable, which affects the water management properties of the soil (*Table 1*).

There were only a few soil samples, which water permeability was better than 10^{-9} m/s. The evolution of this extreme low water permeability was caused by the extreme soil texture and also by the degrading effect (compaction, texture degradation) of the tillage and the inadequate cultivation technics. These soil properties have important effect on inland water formation, because only a small part of the area is suitable for infiltration. Thus probably the inland excess waters are accumulative type in this area and water can be infiltrated to the ground water on areas where the soils have the better water permeability, on the so-called "hydrological windows", and the water increase the level of the ground water table delayed. Beside these good water permeability soils, the ground water level is controlled by the adjacent Tisza River and the drainage channel network.

On the basis of the analysis, in the Batida area and in the Tápai-rét area the water permeability is very low, thus the *'I'* parameter in the water regime function can considered as 0, practically. Nevertheless, at intensive precipitation events few mm infiltrations can be detected, on the basis of the measurement dataset.

Analysis of data series of the complex measuring station

Soil moisture and groundwater table data are compared in three different depths in case of both measuring stations to analyse the relation of infiltration and groundwater – excess water. The measured data confirmed the previous experiences. In case of Tápai-rét study area, only excess water inundations of groundwater origin occurred in the investigated 1.5 year-period.

In case of Batida study area, accumulative inland excess water was found in spring 2010 (*Fig. 3*). Here, the groundwater table was below 2.5 m at the time of the installation, because the measuring station is located on a 40-50 cm higher elevation compared to its environment, where continuous inundations were observed from autumn 2009. The soil moisture decreased from up to down, thus the infiltrating water surplus hardly reached the 35 cm depth, confirming the presence of the accumulative inland excess water. During the spring 2010, the

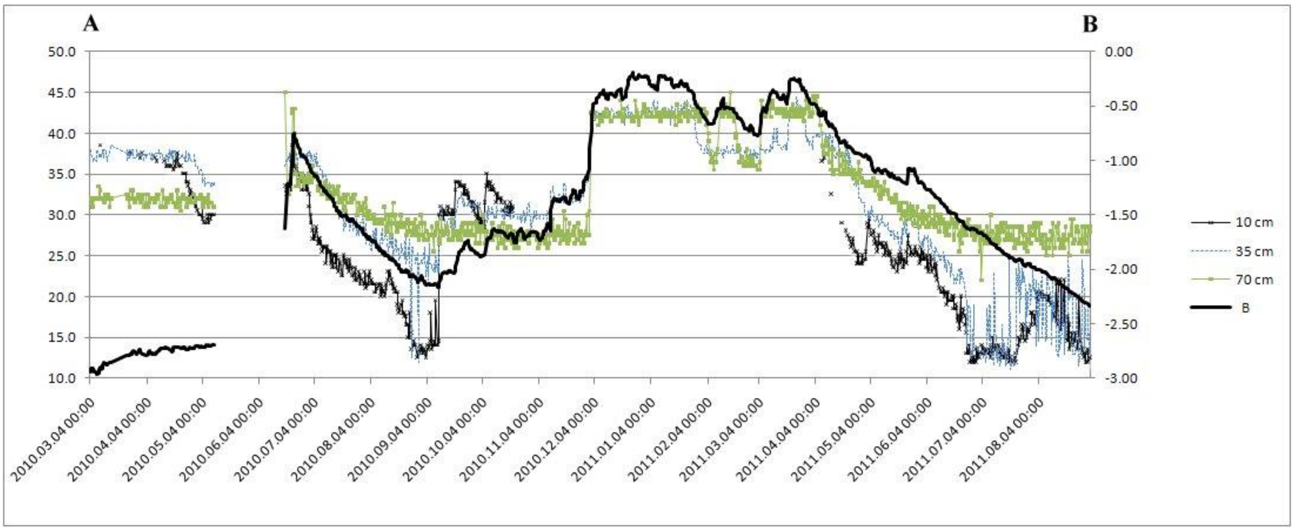

Fig. 3 1.5-year-long data series from Batida measurement station
A: soil moisture in depths 10, 35 and 70 cm (v/v%), B: soil water level below surface (m)

Table 2 The most important rainfall events in Batida
RQ: precipitation, T: temperature, ΔSM1, ΔSM2: soil moisture growth in depths 10 and 20 cm, I: infiltration rate
* the high value is caused by capillary lifting

Date	RQ (mm)	T (^{0}C)	ΔSM1 (v/v%)	ΔSM2 (v/v%)	I (mm)
11.03.2010	8.9	0.5	-	-	0
31.03.2010	7	8-9	-	-	0
05.04.2010	6.6	9.5	-	-	0
19.04.2010	15.4	10-11	-	-	0
10.09. 2010	37.6	17-18	15	5.5	36
16.09.2010	35.8	14-15	3.5	2	11
06.10.2010	41.6	11-12	5	-	10
16-20.10.2010	20.6	9-10	-	-	0
25-28.11.2010	17.1	3-5	2	1.5	7
01-02.12.2010	39.9	2-3	8.5	14.5	46 mm*

increase of the groundwater table was not due to the locally infiltrating water surplus, but the hydrological windows of higher water infiltration capacity in higher distances. Later, due to the humid spring of 2010, the groundwater level was increasing above 1 m below surface for summer, and helped the soil being saturated by the capillary rise. In autumn, the groundwater was decreasing again and the former situation occurred again. After the intensive precipitation of 1st December, the accumulative inland excess water and groundwater level has reached each other. Only the changes of soil moisture due to the precipitation was involved in the calculation of infiltration, thus, the March-April in 2010 and October-November in 2010 were taken into consideration, when groundwater-table was deep enough not to influence the soil moisture by the capillary rise (*Fig. 3*).

The more significant precipitation events, the temperature values influencing evapotranspiration and the increase of the soil moisture in the depths of 10 and 35 cm were selected (the effect of the precipitation events can not be detected in 70 cm depth). The moisture content of the soil is shown to be the most important influencing factor of infiltration among the affecting factors. The spring precipitation events were determined by lower precipitation, small evapotranspiration, but no infiltration occurred (*Table 2*). On the contrary, in case of early autumn precipitation events, infiltration was high in spite of the warmer weather conditions due to the low values of soil moisture (below 15-20 v/v%). Thus, due to the increased water infiltration capacity of the soil, accompanying by soil cracking due to the drying-out of the surface, rapid infiltration of water occurs.

When precipitation events are taken into consideration from March until November (191 mm), the infiltration of 64 mm occurred. If the precipitation, fallen below 10°C temperature, is regarded (40 mm), only 7 mm got into 10 cm depth, thus, by minimal evapotranspiration approx. 31 mm water surplus formed, meaning more than 300 m^3 potential inland excess water in every hectacres.

In case of the study area Tápai-rét, the inland excess water originated from groundwater in the whole investigation period. It is confirmed by the fact that inland excess water formation was not found when the groundwater-table decreased below 70 cm (2010 autumn, from May 2011). Therefore, infiltration can be concluded from soil moisture data series only in dry periods. Table 3 confirms that capillary rise plays an important role in the alteration of soil moisture, since the calculated data from soil moisture changes resulted in the same or higher estimated infiltration than the total precipitation amount. In case of Tápai-rét study area, a synergistic effect can also be observed. Due to the closeness of Tisza and Maros, the waters also influence the

Table 3 Calculated infiltration from soil moisture changes in Tápai-rét, 2010
RQ: precipitation, ΔSM1, ΔSM2: soil moisture growth in depths 10 and 20 cm, I: infiltration rate

Date	RQ (mm)	ΔSM1 (v/v%)	ΔSM2 (v/v%)	I (mm)
21-22.06.2010	12	6	5.5	11.5
03.07.2010	34.3	11	9	20
28.07.2010	17	5.5	6.5	12
06.08.2010	12	5	6.5	11.5
30-31.08.2010	15.1	8	16.5	24.5
10.09.2010	27.2	11	12	23
19.09.2010	20.4	12.5	11	23.5

groundwater-level. The previous correlation analyses confirm this additional effect only above a certain water level. However, further statistical analysis is required to determine the characteristic of the relation. In the investigated 1.5-year-long period, no soil frost was detected.

DISCUSSION

Differentiation of the upwelling (or vertical) type (due to the increasing groundwater table) and the accumulative (or horizontal) type (the water accumulates under gravity in the lowest areas due to limited infiltration and/or runoff, independent from the groundwater table or communicating by capillary system) of inland excess water important not only in scientific point of view, however because they demand different prevention and protection strategies. The accumulative (or horizontal) type of inland excess water is mainly topographic and agro technological problem, while upwelling (or vertical) type of inland excess water is more difficult problem and it can only be managed by ground water level decrease on large area, meaning large amount of water should be transported and/or stored (Kozák, 2003).

On the basis of the soil analysis the studied area is susceptible for the formation of accumulative) type inland excess water, but in very humid periods the ground water table can increase to the level of the surface. The dataset of the vertical and temporal changes of the soil moisture and the changes of ground water level, collected by the measurement station enables to clearly differentiate the two type of inland excess water.

On the Batida study area, the formation ‘pure’ accumulative type inland excess water could be analysed and the results show that the soil parameters had positive feedback on the inland excess water formation. At the time of the huge autumn precipitation and spring precipitation (snow melt) the soil become nearly impermeable, the gravitational pore volume is extremely decrease and exactly the same time when more infiltration capacity is needed due to the low evapotranspitation the soil retail the total surface water. However in summer periods, when the evapotranspiration is higher and decrease the potential of inland excess water formation, the dry soil has higher infiltration capacity. In this case the inland excess water formation can be delayed by better agrotechnics, which increasing the water holding and infiltration capacity of the soils (Birkás 2011), while the prediction of inland excess water occurrence can be achieved by continuous monitoring of the soil moisture in several depth. By the presented measurement stations, the amount of inland excess water on an exact location can be estimated. By the integration of these point measurements and a high resolution elevation model, the prediction of the real inland excess water inundation would be the next step in the research.

SUMMARY

The aim of the research was to investigate the formation of inland excess water in detail. A complex station for the monitoring of the hydro-meteorological and pedological factors influencing the formation of inland excess water was developed, which measures the precipitation, the evapotranspiration of the soil surface and opened water surfaces, the soil moisture in 3 different depths and the soil temperature in 5 depths. The study area was allocated the back-swamp area at high inland excess water hazard in the micro-regions of the South-Tisza-valley and Marosszög, northeast from Szeged. From the measured data, the estimation of infiltrating water was highlighted. Furthermore, soil samplings were repeated in the neighbouring areas, where pedological parameters (pH, soil plasticity according to Arany, carbonate-, salt- and humus content), and characteristic water regime parameters (bulk density, porosity, field capacity, hydraulic water conductivity) were determined.

The results described an area where due to the low elevation and the extreme particle size distribution, accumulative and upwelling-type inland excess water (of groundwater origin) both occur. The developed stations were able to differentiate the two types of inland excess water, furthermore in case of the accumulative type, the rate and temporal progress of infiltration, its extreme values in relation to soil saturation were estimated. The accumulation of potential inland excess water, the formation of the inundations can be determined by the detailed digital elevation and runoff models.

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