Journal of Environmental Geography 14 (3–4), 1–13.

DOI: 10.2478/jengeo-2021-0007
ISSN 2060-467X

SENSITIVITY ANALYSIS FOR EFFECT OF CHANGES IN INPUT DATA ON HYDROLOGICAL PARAMETERS AND WATER BALANCE COMPONENTS IN THE CATCHMENT AREA OF HUNGARIAN LOWLAND

Hop Quang Tran[1*,2]

[1]Department of Geoinformatics, Physical and Environmental Geography, University of Szeged,
Egyetem u. 2-6, 6722 Szeged, Hungary
[2]Hanoi University of Natural Resources and Environment, Faculty of Water Resources, Hanoi, Vietnam
*Corresponding author, email: hoptran@geo.u-szeged.hu, Tel.: +36 30 179 9296

Research article, received 1 April 2021, accepted 7 September 2021

Abstract

Extreme weather and climate changes are emerging more frequently in Central Europe, Hungary, and in the near future the increase in prolonged droughts, high-intensity precipitation events and the temporal variations of precipitation are expected, which may increase the magnitude of local water damages (OVF, 2016). As a result of climate change, these extreme weather events will be more frequent, however it is difficult to predict them, as until now insufficient amount of observations are available on smaller watercourses and on refined territorial water balances. For the future assessment of the environmental and economic impacts of climate change, it is essential to explore the integrated relationship of evapotranspiration, runoff, infiltration, surface and subsurface waters, and other hydrological processes, which can fundamentally describe regionally the water management conditions.

In this research, an earlier study (DHI Hungary 2019) on the catchment area of the main canal of the Dong-ér Brook is pursued to continue the development of the MIKE SHE model in a more complex manner. Within the frame of the present study, the relationship between the individual hydrological parameters, the water balance components and extreme precipitation events (drought, heavy rainfall events) for the entire drainage basin have been examined, besides, the expected effects of the predicted temperature rise on the water balance is evaluated. Using data from 2018 as reference, the sensitivity of the changes in daily precipitation and daily mean temperature has been assessed to estimate the effects of the future climate change on hydrological parameters and water balance components.

Keywords: Dong-ér Brook, MIKE SHE, sensitivity analysis, water balance

INTRODUCTION

Water management is playing an increasingly important role in mitigating the effects of the extreme climate changes. Based on Lower Tisza District Water Directorate (ATIVIZIG) data in Hungary nearly 1100 settlements over about 42000 km^2 area occasionally struggle with severe inland water problems (ATIVIZIG, 2016). General Directorate of Water management (OVF) emphasizes that as result of climate change, extreme weather events are becoming more frequent in Hungary, and soon an increase in the regularity of high-intensity precipitation events should be expected, which may increase the magnitude of local water damages (OVF, 2016).

Extreme climatic events are also reflected in the phenomenon of drought, with a longer degree, intensity and duration. According to the survey results in South Hungary by Ladányi et al. (2014) water shortage was more damaging than inland water. Consequently, the changing climatic effects have a direct impact on agriculture, causing greater damages mainly due to the droughts and directly affect the sustainable development of agriculture and food security (Singh, 2014, Ladányi, 2010). Due to climate change, precipitation has decreased by at least 12% in recent decades in Hungary, with perhaps the most significant consequences on the Danube–Tisza Interfluve (Ladányi, 2009), where the study area is located. According to the experiences, harmful water scarcity occurs in an average of 4 years per decade in Hungary. At the same time varying amounts of excess water occurs in most years, while it is not even uncommon for the two extremes to occur in the same year, such as between the Danube and the Tisza in 2000 (Rakonczai et al., 2014). An integrated approach is necessary to evaluate the complex interrelationships of hydrological processes and changes in water balance from many aspects, thus provide effective solutions for the complex modelling challenges in the presence of both inland excess water and drought. The topic is well introduced by the Tisza River Basin Management Plan (KÖTIVIZIG, 2015).

As a result of the developments in the information technology, the application of the geographical information system (GIS) and various mathematical- and physical-based hydrological modelling software has also become feasible for related research. Among the many models, the MIKE SHE model emerges as a tool capable of implementing integrated water resources management. The model tends to effectively simulate the interaction between surface water and groundwater (Graham and

Butts, 2005). The research group of Lu et al. (2006) also had positive comments about the effectiveness of the model in simulating temporal flow dynamics in the whole basin. MIKE SHE is widely used in studies such as calculating the effect of land use changes on components of water balance in the unsaturated zone (UZ) and saturated zone (SZ) (Asadusjjaman and Farnaz, 2014). Some studies apply MIKE SHE and GIS to simulate hydrological processes for several basins (Paparrizos and Maris, 2015; Právetz et al., 2015) and assessing the effects of land change and climate change on groundwater and ecosystem by Keilholz et al. (2015). Among the hydrological models that have been verified on the catchment area of the Fehértó-majsa Canal, which is located next to the Dong-er catchment to the south by Benyhe et al. (2015) include BUDYKO, HEC-RAS and MIKE SHE and concluded that the MIKE SHE model was more efficient than the other two. The process of modelling inland excess water with MIKE SHE and using satellite imagery for validation by van Leeuwen et al. (2016) is another example showing the effectiveness of the MIKE SHE model to predict the extent, location and duration of inland excess water. The research team of Nagy et al. (2019) built a MIKE SHE model to simulate the accumulation processes of excess water, water storage, and excess water maps for Dong-ér catchment and have very remarkable results. However, the above studies also have shown a disadvantage of this model is that it requires many good quality input data. In Dong-ér catchment, the data is not continuously measured, there is no data for water level and discharge in the open channels, and many parameters are not validated (e.g. LAI, root depth. hydraulic conductivity). Nagy et al. (2019) has calibrated the model focused on the groundwater levels for 2015 and 2018-years' springtime. The comparison between the modelled and measured groundwater level is 45 cm, which is very relevant considering the lack of input parameters and the uncertainties. This result shows that the integrated MIKE SHE model built for the Dong-ér catchment has been relatively calibrated and can be inherited to calculate and analyse many other aspects of hydrology in the relationship between surface water and groundwater.

In such areas where inland excess water and drought are both affects the landscape heavily, understanding the state of the water balance becomes even more imperative. Importance of management, planning and optimal consumption of water resources more effectively and sustainably is even more crucial (EU Water Framework Directive, 2000; OVF, 2009). Sipos and Právecz (2014) stated that only the local water balance models can be considered reliable in order to make efficient and economically sustainable water use options in the dry season and water retention in the rainy season.

One of the advantages of MIKE SHE is that it includes a comprehensive, integrated water balance tool for the complete local and entire catchment water balance for any time interval. Water balance output can include area flows, storage changes and water balance changes (DHI, 2017). The total water balance change value is calculated for the entire model catchment. In addition, there are water balance changes for each hydrologic component. However, within the scope of this study, only the variation of total water balance change under different climatic conditions are considered, analyzed and evaluated. The value of these parameters plays an important role as the foundation for assessing the water balance in the Dong-ér catchment. It is useful for integrating, mapping and plotting water flow processes between water balance components (Graham and Butts, 2005). There are many factors that affect directly and indirectly on the water balance of a basin, the first of which is precipitation and temperature. They are the two main forces that operate the hydrologic cycle and have a major impact on water balance. The question is how changes in inputs due to climate change affect the outputs of hydrological parameters and water balance components. According to the studies of Hamby (1994) and Lenhart et al. (2002) the variation in the input data causes effects on the model results and it is necessary to consider the sensitivity of the input data and apply the sensitivity analysis method to determine which inputs have the greatest influence on the outputs. Ibarra et al. (2016) confirmed that setting up sensitivity analysis is necessary to improve the accuracy and optimize the calibration process. Besides, the sensitivity analysis enables the estimation of the parameters and explains the response of the model for the variation of the input data.

The objective of the study is to simulate different climate conditions and use sensitivity analysis to evaluate the influence of input parameters on hydrological parameters and water balance components. However, to perform these integration tasks, MIKE SHE needs a lot of hydrological and meteorological data input (van Leeuwen et al., 2016) and especially difficult for areas with few data such as Dong-ér catchment. Deterministic models have uncertainties, these include reasons such as measurement errors, variation of parameters on the sub-grid scale and incorrect initial, boundary conditions (Graham and Butts, 2005). Bahremnad and De Smedt (2007) also highlighted sensitivity analysis as a valuable tool to identify influential model parameters and thereby make the model structure more stable. There are many methods of sensitivity analysis that have been used in the international literature, most of them are very complex and the simplest approach to conceptualize is the one-at-a-time method where sensitivity measures are determined by varying each parameter independently while keeping all other parameters do not change. The disadvantage that it can only do local sensitivity analysis at a certain selected point and not for the entire parameter distribution (Hamby, 1994). However, with the flexible simulation framework on spatial and temporal scale of the MIKE SHE model, this disadvantage can be improved and gives us an integrated view and more comprehensive. To understand the hydrological phenomena that will occur in the future, this study inherits the MIKE SHE data tree built by Nagy et al. (2019). However, to apply the one-at-a-time method, the variable parameters and the water calculation module has been developed and used by author to simulate and evaluate with an integrated approach which manifestation of climate change has the greater impact to the outputs of the hydrological parameters and water balance components. To achieve these objectives, it is necessary to 1) review the suitability, determining the advantages and disadvantages of the MIKE SHE model for Dong-ér catchment, 2) simulate hydrological and complex water balance processes under different input variable conditions, 3) simulation results are compared to see which factors are most affected and most sensitive to variations in input data. Based on this result, evaluate the effects of climate change on hydrological parameters and water balance components in the future.

STUDY AREA

The inland water system of the Dong-ér brook is in the middle part of the sand ridge region of the Danube-Tisza Interfluve, about 50 km from the southern border of Hungary (Fig. 1). The total area of the catchment is 2127 km^2, and it is characterized by a small relative relief (<2m/km^2).

In the initial section of the Dong-ér Brook the surface water transport is minimal, the occasionally drying riverbed is revealed only by the vegetation of wetlands. Therefore, water resources of this area are not suitable for utilization, rather the use of groundwater resources comes to the fore (Kozák, 2020). The system of small brooks collects and carries excess water into the main Dong-ér Brook and then flows into the Tisza River near the settlement of Baks. The gravitational flow terminates only in the case of the formation of an extreme Tisza flood wave. The discharge of the Dong-ér Brook is 2-3 m^3/s during the normal period, meanwhile in times of spring inland excess water it can excess 20-30 m^3/s. However, in extremely dry summer days, the brooks dry out completely (K&K Mérnöki Iroda Kft, 2013). Prevailing wind direction NW, average wind speed about 2-3 m/s. The surface-forming activity of the wind shaped the topography. The topography of the area basically defines the water networks. The flow direction of the Dong-ér is SW-NE, while the flow direction of the tributaries is NW-SE, typically follows natural deflationary depressions. In rainy years, groundwater can appear in the deflation hollows, forming temporarily inundated areas (Sipos and Právecz, 2014).

Based on studies conducted by the Hungarian Meteorological Service (2018) with two regional climate models and two scenarios, the average temperature in Hungary may increase by 3-4˚C by the end of the century and the 2˚C threshold is expected to reach earlier. Dong-ér catchment is one of the warmest and driest areas. Therefore, the drought hazard is high in the area (Sipos and Právecz, 2014). The area under investigation is dry continental temperate climate. According to the data from Hungarian Meteorological Service (OMSZ) and from 25 available meteorological stations between 2010 and 2018, the average annual rainfall in the area over the period is 611 mm, but in extreme cases it can reach as high values as 842 mm (in 2014) or as low as 203 mm (2000). During the period between 2000 and 2018, the lowest monthly mean temperature was -5.2°C measured in February 2012 and January 2017, the highest was +24.5°C measured in August 2018. The average thickness of the snow cover in winter is about 18-22 cm. The most frequently mentioned feature of climate change is rising temperatures. According to the climate models adopted by the Intergovernmental Panel on Climate Change (IPCC, 2018), the average temperature of the Earth could reach an increase of 1.5˚C in 2030-2052.

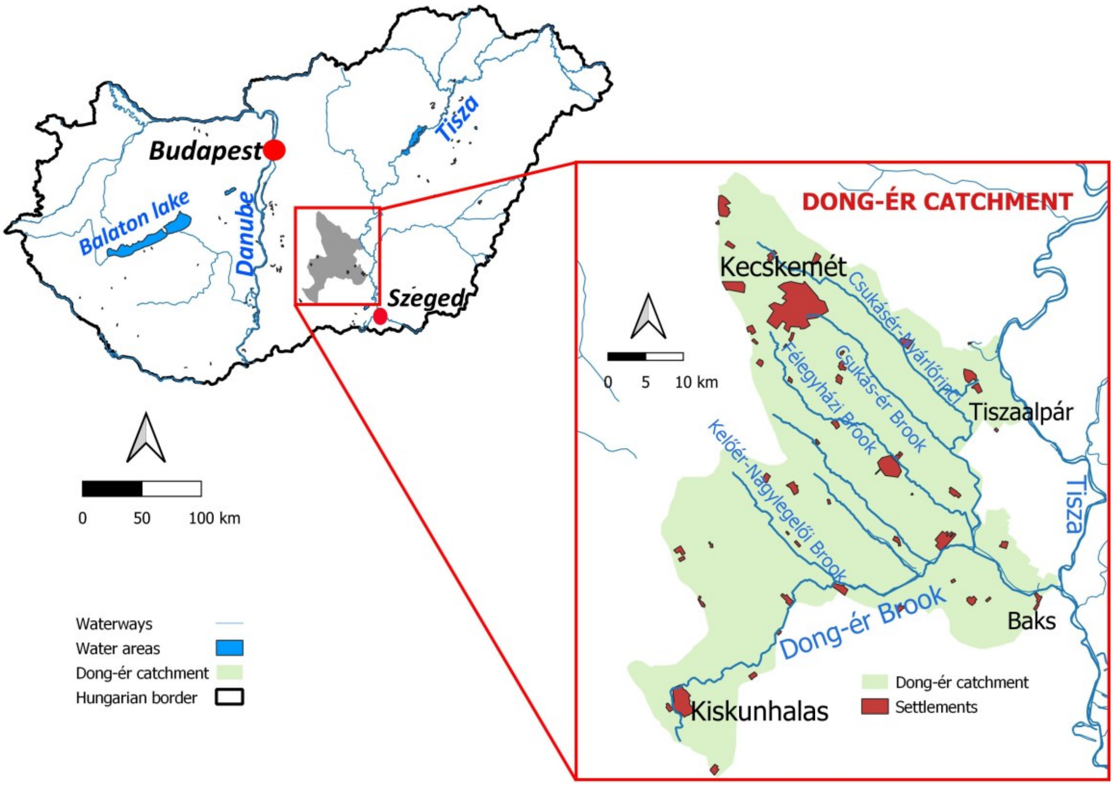

Fig. 1 The study area

Non-irrigated arable land dominates the area by ~41%, followed by pastures ~13%, by broad-leaved forest ~10% of the total study site, the rest are various small land uses, like transitional woodland-shrub, complex cultivation patterns, discontinuous urban fabric. Based on the available agrotopographic map, the soils in the area are extremely heterogeneous. The most typical soil types are blown sand, humid sand, sandy soils, chernozem and saline soils. These soils have the potential to infiltrate. Since the late 1970s, the decreasing trend of the precipitation induced significant decrease of the groundwater level in the Danube–Tisza Interfluve, which exceeds 2 meters on average (Fehér, 2019). Afterwards, in the periods of persistent precipitation, water shortages in the lower parts of the sand ridge have been restored; in fact, sometimes the groundwater level has risen to harmful level, causing surface overflows (Szatmári and van Leeuwen, 2013).

DATA AND METHODS

Input data used in the model

Meteorological data

The most important meteorological data in a hydrological cycle are precipitation, temperature and evapotranspiration. For the observed precipitation in study area, the daily data of 25 meteorological stations was available in the period 2010-2018 from ATIVIZIG. According to this, the average monthly precipitation of the study area varies around 46 mm. According to the OMSZ (2018a) database, in the drought year of 2000, about half of the average monthly precipitation (29 mm) was measurable in Szeged, but some extreme years, such as the 2014 rainy year, also occurred in 89 mm in the study area. Snow storage is a physical state of precipitation and differs from the rainfall form in the time of accumulation, so participate more slowly in the water cycle. Temperature is a factor that can accelerate water accumulation through melting. Temperature also affects directly (e.g., pond water evaporation, soil evaporation) and indirectly (transpiration by vegetation) on evapotranspiration. As a result of temperature fluctuations, several important climatic elements change, and these greatly affect the water balance of the area. Temperature data for 2014 and 2018 are taken from the European Climate Assessment and Dataset (ECAD) database for the period 2010-2018 by Nagy et al. (2019). Daily average temperature data for the year 2000 are obtained from the OMSZ (2018a) database by author.

Evapotranspiration is the most difficult parameter to determine and there are no data in the study area. To calculate the amount of evapotranspiration the Food and Agriculture Organization of the United Nations (FAO) recommends a combination of the FAO-56 Penman-Monteith equations (Allen et al., 1998). Due to the lack of input data, the use of the FAO-56 Penman-Monteith equation is limited. The potential evapotranspiration (ETP) can still be estimated more easily and simply by the function for different temperature (T) values, to which the following exponential function describes the relationship well (Fiala et al., 2018):

$$ET_P = ET_{ref} = e^{0.07T} \tag{1}$$

Land cover data

The current modelling framework identified 23 different land use classes. Each class has different characteristics of canopy interception, transpiration, soil evaporation, flow formation, and different water retention ability by roots. The research is based on the Corine Land Cover (EEA, 2018), the de facto standard for land use and land cover monitoring at the pan-European level (Feranec, 2016; Aune-Lundberg and Geir-Harald, 2020). The Leaf Area Index (LAI) is determined by the combination of MODIS images (Myneni et al., 2015) and root depth values are referenced from the results of scientific studies for CORINE categories (Nagy et al., 2019).

Soil data

Exact determination of subsurface conditions (water content of unsaturated and saturated soils) is crucial in our model building scenario, since both Rakonczai et al. (2011) and Farsang (2014) indicated significant interrelationship between the soil and the water balance of the site. The current model is based on the 250 m resolution 3D Soil Hydraulic Database of Europe (Tóth et al., 2017). Since there is no reliable data source available deeper than 2 meters for the study site (nor even Hungary), the current research is based on the 2 m depth soil layer of the database. The author has updated the following parameters of the original model: saturated water content, saturated hydraulic conductivity, and moisture retention curve. The parameters of deeper geological layers were spatially estimated based on 13 borehole records provided by ATIVZIG.

Topography

Since topographical conditions determine overland and underground flows significantly, an accurate digital elevation model is crucial for a successful modelling scenario. The present study is based on a 10 x 10 m resolution DEM. To run the MIKE SHE model, it is necessary to convert the DEM data into a spatial distribution grid point file (.dfs2). Point file was created using ArcGIS and could be converted to a .dfs2 file using the MIKE Zero Toolbox (DHI, 2017). The resulted spatial distribution grid can be used as input data.

Water flows

Surface channels provide unobstructed gravitational flow paths for the water into its recipient reservoir, thus proper knowledge of the geometry of the channels and surface depressions can significantly improve the model reliability. In the current framework, the water network geometry is provided by ATIVIZIG, and it can be classified into two main groups. The first class includes brooks from the previous epoch, whereby paths are provided, cross-sectional data are measured, and data is set up as 3D GIS points. Other types of brooks are managed by ATIVIZIG. In this case the pathlines are provided as a polyline shapefile, the cross-section data is defined by longitudinal profile and different cross-section data. These data are set up in the specialized MIKE Hydro hydraulic module. The module enables complex dynamic river network modelling and can be linked to MIKE SHE to comprehensively simulate hydrologic modelling of the catchment under investigation.

Groundwater data

Groundwater has more stable water level and is less affected by external factors than the unsaturated zone or the channels. The groundwater series provided by ATIVIZIG includes 33 groundwater measurement stations with specific coordinates from 2010 to 2018. The groundwater level changes according to topography and all flows into the Tisza River and seasonal variation greatly affects groundwater change. Based on the measured data in the period 2010-2018, the highest groundwater level in the study area usually occurs in April-May, the lowest in October-December. However, there are different rainfall and temperature conditions at some measurement points, so the difference is up to 2-3 months of the year.

Computational layers

To simulate the flow processes occurring in the saturated zone it is necessary to define computational layers. In the MIKE SHE model the numerical vertical discretization is defined by explicitly defining the lower level of each calculation layer. The spatial distribution of lower level is uniform, the value of aquifer lower level is -75 m. To make corrections to the elevations layers, the minimum layer thickness is applied with a value of 2 m, this is to prevent zero-thickness or very thin layers. To define outer boundary conditions this model applies a fixed head type, based on a spatially distributed and time-varying dfs2 file, extracted from the specified groundwater table. Specified groundwater table is established based on daily groundwater elevation data from 2010 to 2018. Specified groundwater table is divided into 200 m x 200 m grid cells. MIKE SHE then interpolates in both time and space from the .dfs2 file to the local head boundary at each local time step (DHI, 2017).

Calibration data

The MIKE SHE model built for Dong-ér catchment lacks a lot of data such as brook water-level and discharges to be fully calibrated and validated. The current model has only been calibrated focused on groundwater data for 2018-years' springtime by Nagy et al. (2019). Comparing simulation results and measured data, the variance is about 45 cm, which is very suitable considering the lack of input parameters and uncertainties (such as topographic maps, vegetation features and soil characteristics). There are many parameters that need calibration to make the model more complete, for example a saturated hydraulic conductivity for unsaturated flow calibration and hydraulic conductivity, specific yield, specific storage for groundwater flow calibration. However, due to the lack of data and not the objective of the study, it was not mentioned.

MIKE SHE output results

The output results obtained from the MIKE SHE simulation depend on the selected modelling sequence. According to the MIKE SHE User guide (2017), the model saves the results in three groups of files, these are 1) ASCII files, which is a catalogue of all output files (.sheres) of the simulation; 2) a binary output file containing all the static information of the simulation (.frf); 3) the simpler, timeseries-generated dfs0, 2-dimensionally defined dfs2, and 3-dimensional dfs3 files (.dfs).

In this study only the results in .sheres format and the time series results (dfs0, dfs2, and dfs3) for the water balance are examined (Table 2). The water balance simulation can be performed with a separate module, Water balance calculation, which delivers results of a post-processing of the data stored in the .sheres file.

The common understanding which states that all water flows into system are positive and all outflows or loss of water is negative. The storages of water system are positive in case of storage increase. Positive water balance change means that the change in storage plus the total outflows is less than the total inflows (ΔStorage + Outflow < Inflow).

Among several hydrological parameters and water balance components, the following were examined in Table 1-2.

Modelling

In the first stage of the sensitivity analysis, the input data can be divided into two groups, according to their temporal variability. The first type is constant in long timespan, including the topography, water networks (rivers and lakes), soil properties, geological features. This phenomenon has negligible changes or remains unchanged in the long run without human activities. The other group consists of data that change rapidly, whether minute by minute, hour/day, or seasonally. Such features are daily precipitation, daily mean temperature, reference evapotranspiration, and land cover (including vegetation).

Thereafter the one at a time type sensitivity analysis was elaborated by five MIKE SHE simulation scenarios, including base simulation (BS), SIM1, SIM2, SIM3 and SIM4 simulations (Fig. 2). Base simulation (BS) is used to simulate integrated hydrological processes and water balance in Dong-ér catchment in 2018. The following factors supported the reason 2018 was chosen to run the base model: 1) The model has been calibrated by Nagy et al. (2019) according to the groundwater level measured in 2018. 2) The land cover data of the year 2018 used from Corine Land Cover. 3) The latest van Genuchten parameters of the moisture retention and hydraulic conductivity have just been updated by the author from the 3D Soil Hydraulic Database in the previous year (Tóth et al., 2017). 4) The precipitation measured in 2018

Table 1 Output hydrological parameters used for research (Source: DHI, 2017)

Parameters	Units	Notes
Actual evapotranspiration (ActualET)	mm/d	Actual evapotranspiration is depending on water availability at root depth and Leaf area index (LAI)
Actual transpiration (T_{act})	mm/d	Evaporation of water is mostly through the pores of the leaves.
Actual soil evaporation	mm/d	Actual soil evaporation is depending on factors such as soil characteristics, land use, vegetation.
Depth of overland water	m	It is the amount of water at the surface.
Overland flow in x- and y-direction	m^3/s	Flow on the horizontal and vertical axis
Infiltration to unsaturated zone (UZ)	mm/d	Just like overland flow in y-direction, the vertical downward flows will be positive.
Unsaturated zone (UZ) deficit	mm	Unsaturated zone deficit is the amount of air in the unsaturated zone. Thus, a decreasing deficit means that the more air has been pushed out by the water, the soil gradually becomes wetter.
Average water content in the root zone	-	It is depending on precipitation, soil features, groundwater flow and vegetation features.
Water content in unsaturated zone (UZ)	-	Contrast to unsaturated zone (UZ) deficit
Groundwater flow in x- and y-direction	m^3/s	Groundwater flow is in the horizontal and vertical axis.

Table 2 Output water balance components used for research (Source: DHI, 2017)

Name of components and in parentheses are abbreviations		Units
Precipitation		mm
Evapotranspiration	Evapotranspiration (Evapotrans), Infiltration includes evapotranspiration (Infilt.incl.ET). Exfiltration includes evapotranspiration (Exfilt.incl.ET)	mm
Flows	Overland boundary outflow (OL Bou.Outflow). Overland boundary inflow (OL Bou.Inflow). Overland flow to river (OL->River/MOUSE). Subsurface boundary inflow (SubSurf.Bou.Inflow). Subsurface boundary outflow (SubSurf.Bou.Outflow). Baseflow to river. Baseflow from river	mm
Storages	Canopy storage change (CanopyStor.Change). Snow storage change (SnowStor.Change). Overland storage change (OL Stor.Change). Subsurface storage change (SubSurfStor.Change) includes both unsaturated (UZ Stor.change)- and saturated zone storage changes (SZ Stor.change),	mm
Water balance change		mm

is much closer to the multi-annual average compared to the other years under investigation. Thereafter the base simulation running for 2018 has been considered suitable to perform one-at-a-time sensitivity analysis and the outcomes were used as reference values to compare with the other simulation scenarios.

The precipitation sensitivity analysis focused on the years with extreme precipitation (drought, rainy) and the

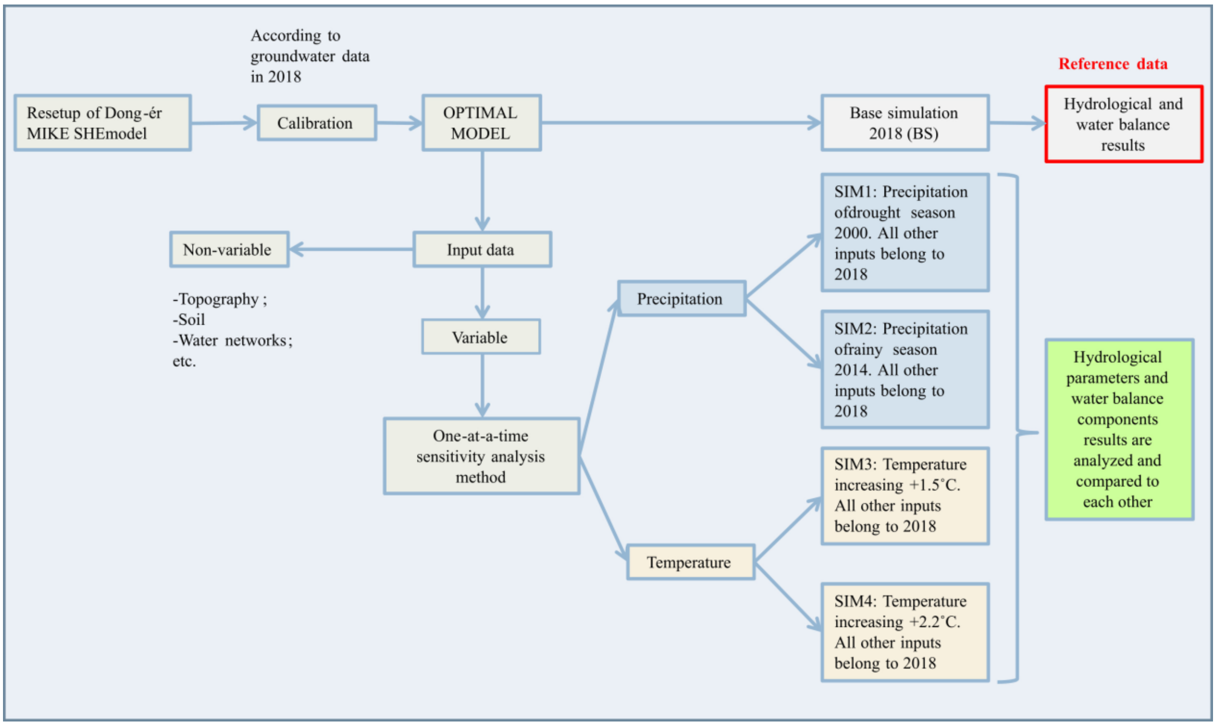

Fig. 2 Research workflow

year with average precipitation. In this part of the research, the precipitation data of the (BS) model was replaced by the drought season 2000 (SIM1), rainy season 2014 (SIM2), while keeping the other parameters of 2018 fixed. Thereafter the differences of the three models have been compared to each other.

The temperature sensitivity analysis focused on the effect of temperature increases on changes in results of hydrological parameters and water balance components. Based on the results of the IPCC (2018) and OMSZ (2018b) climate models, the temperature data of 2018 (BS) reference model was increased by +1.5˚C (SIM3) and +2.2˚C (SIM4), while the other parameters left unchanged. Thereafter the differences of the three models have been evaluated.

RESULTS

Due to time and hardware constraints, hydrological results were only extracted from cells near the settlement of Tiszaalpár, rather than from whole catchments.

The area near the settlement of Tiszaalpár has a low elevation, so it is more susceptible to groundwater level rises by extreme precipitation events or flood wave of Tisza. However, the simulation results in Figure 3 show the opposite, specifically on September 13, 2014, with 49.8 mm of precipitation, but the depth of overland water component gave a low value from 0.74 mm-0.77 mm, so there is no significant change for heavy rain events. There is a direct correlation between the precipitation events and infiltration because the top surface soil has a high permeability, most of the precipitation when reaching the surface is mostly absorbed into the soil.

The amount of infiltration into the soil is 20.6 mm, the unsaturated zone deficit is 14.8 mm. The water leaving the system through evapotranspiration, whose rate is from 1.1 mm/day to 4.1 mm/day on the 13 September of analysis years. However, the water content (~16.5 mm) infiltrates to unsaturated zone does not appear yet in the unsaturated zone (water content in unsaturated zone is 0.5 mm) and in the root zone (0.4 mm). This can be explained as a quantity of infiltrated water which is clinging to the dry soil particles, thus temporarily stored in the upper soil layer and infiltrates very slowly to the unsaturated zone because the leakage coefficient of sand is very small, about 10^{-5} m/s. Thus, it can be affirmed that even in years with high precipitation conditions like 2014, the rainfall shows no significant correlation with surface water and groundwater. Among the hydrological parameters related to the precipitation events, the unsaturated zone deficit and infiltration are found to be the most sensitive.

To explore the relationship and correlation between water balance components for the entire catchment can be performed with a *Water balance calculation* module of the MIKE modelling environment (Figs. 4-5).

Based on the values of the accumulated water balance components in the whole test years, it can be concluded that the components of subsurface boundary inflow, overland boundary outflow, evapotranspiration and precipitation have a high impact on the entire catchment water balance. The precipitation will supplement the overland storage change (12 mm and 19 mm) in some deflationary depressions and low permeable topsoil, the overland flow (-5 mm and -10 mm) direct addition to brooks (Fig. 4). However, these amounts are not much compared to the amount of precipitation and of overland boundary outflow.

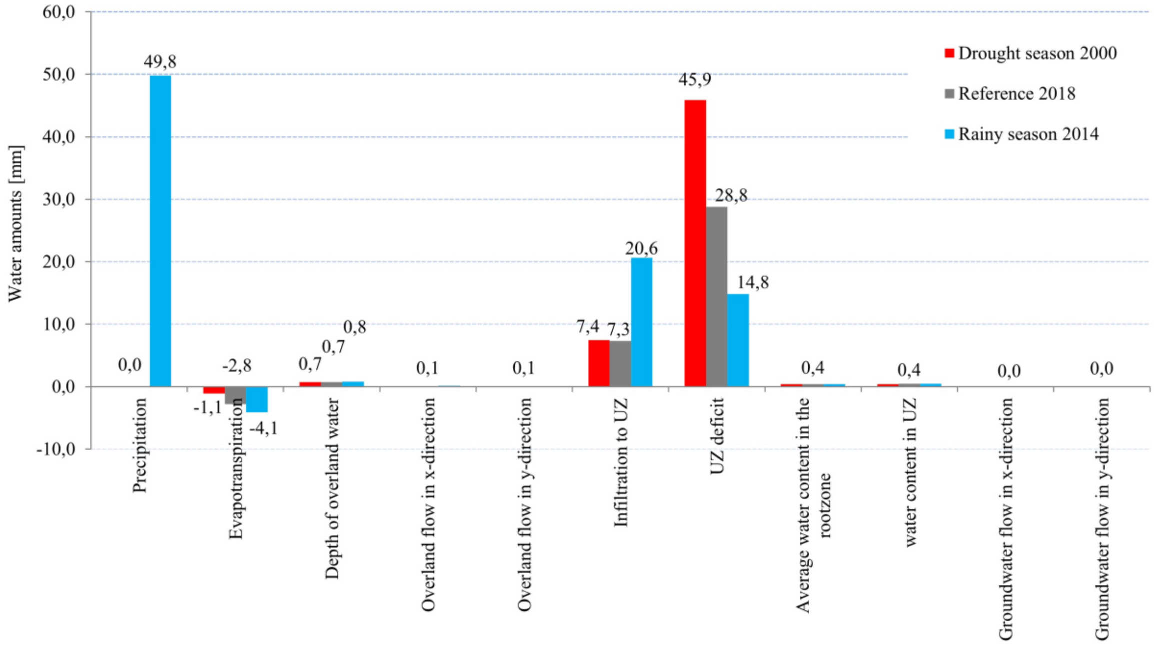

Fig. 3 Temporal changes simulated up to 13 September as a result of precipitation events in the reference year 2018, drought events of 2000 and the rainy year of 2014

According to the results shown in Figure 5 can see that as precipitation increases, the infiltration also increases from 32 mm in 2000 to 138 mm in 2014 (increased rate is 331%). In all three years, the amount of water lost through evapotranspiration was more than precipitation, with the rate of 154% more in 2000, 7.7% more in 2014 and 35% more in 2018. The year 2000 has the largest difference rate, this further aggravates the dehydration of the topsoil. Thus, it can be confirmed that evapotranspiration includes direct evaporation and indirect transpiration through vegetation which has caused a large amount of water loss from surface- and groundwater. The change in unsaturated water storage (from 2000 to 2014 increased by 166 mm) is much larger than that in saturated (increased by 35 mm), which again shows that most of the water infiltration into the soil is stored in the topsoil layer. Overland boundary outflow values were higher for precipitation and evapotranspiration in all three study years. Based on these results, the above statement is confirmed that the source of overland flow in the Dong-ér catchment is not primarily the precipitation or the overland boundary inflow. The question is where does overland boundary outflow (surface water of brooks) get its water? The watercourse nature of Dong-ér can rather be observed close to the inner area of Kiskunhalas. From this point, the water supply of the brook is gained from three sources. First, the subsurface boundary inflow source from high elevation

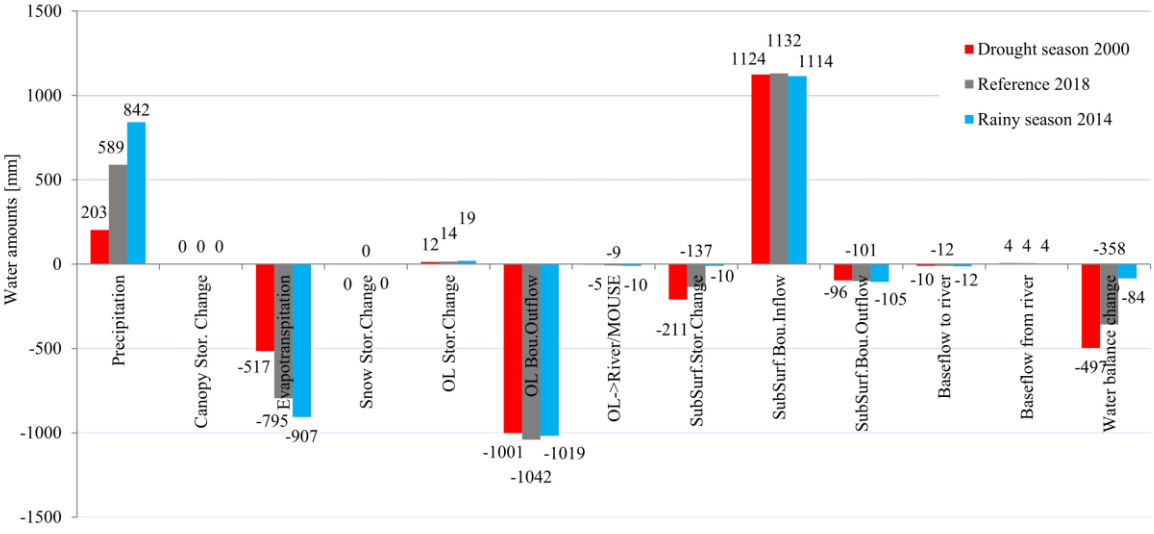

Fig. 4 Water balance values accumulated from the beginning to the end of the study years

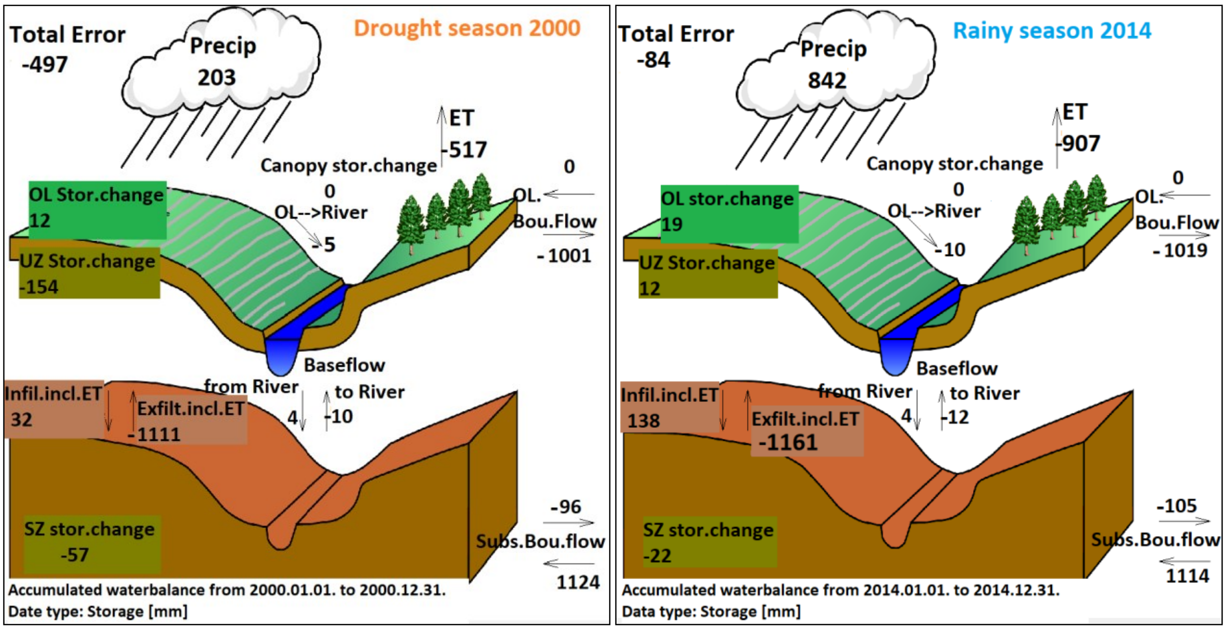

Fig. 5 Water balances for the 2000 drought and 2014 rainy years (Modified after DHI, 2017)

areas flows to the surface water in the lower area under the influence of gravity. Figure 6 shows the elevation of the groundwater level measurement stations and the elevation of the terrain.

According to Figure 6 and to the principle of communicating vessels, subsurface boundary inflow will continuously supply the surface waters from the NW, SW and W directions. On this basis, it can be concluded that the surface and groundwater dividing lines are unlikely to fall into one. In the process of water moving underground, an amount of water from 10 mm and 211 mm is stored at the subsurface storage and shows an increasing trend for

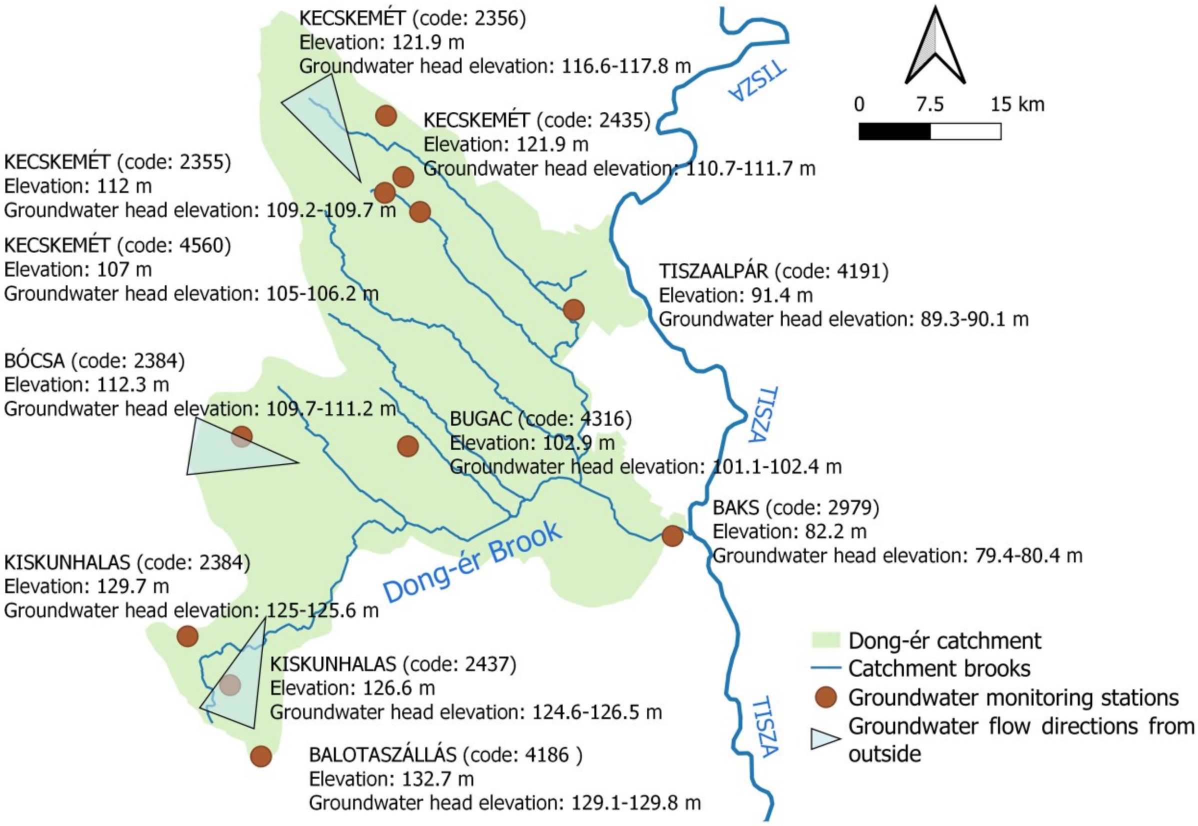

Fig. 6 The elevation of the groundwater measurement stations and the elevation of the terrain

rainy events. In high elevation areas, the height difference between the ground water level and the topography is not large, even considering the brooks bottom elevation, it is often lower than the groundwater level, so in the area near the settlements of Kecskemét, Kiskunhalas and Bócsa groundwater continuously replenishes the brooks and the deflation hollows. In low elevation areas such as Baks and Tiszaalpár settlements, where the groundwater level is also close to the terrain level, in the rainy season, when the groundwater level rises, the phenomenon of upwelling excess water inundation occurs and so on continuously adding water to the brooks. Only an amount of -96 mm to -105 mm of subsurface boundary outflow exits the catchment system to join the Tisza River flow (Fig. 5).

Subsurface water flowing from the outside into the Dong-ér catchment provides ~90% of the water for the brooks (overland outflows). It can be confirmed that for the entire water balance of the catchment, there is a close relationship between the subsurface inflows and overland outflow (surface water of brooks) components. In addition to the subsurface water inflow from the outside, the amount of rainwater that falls directly and infiltrates to replenish water into the brooks, and the source of wastewater from settlements, but according to actual observations, this amount is not significant.

A comparison of the water balance results of extreme precipitation events (2000 and 2014) shows that the sensitivity is in descending order of the following components: Infiltration include evapotranspiration (331.3%), overland flow to river (100%), subsurface storage change (-95.3%), evapotranspiration (75.4%) and overland storage change (58.3%) (Fig. 5). Water balance change from drought and rainy years are -497 mm and -84 mm, so in a rainy year the system can store 413 mm more, which is 877 million m^3 of water. Negative value of water balance change shows that the amount of loss is more than the amount that is in and flows into the system. Thus, the conclusion is that even in the year with a lot of precipitation, the water balance of Dong-ér catchment is still lacking water.

The next section is to analyse the sensitivity of the hydrological parameters shown in Figure 7 under the influence of temperature increase +1.5˚C and +2.2˚C. The actual evapotranspiration increased by 41% under the influence of +1.5˚C and increased by 67% when the daily temperature increased by +2.2˚C. The unsaturated zone deficit parameter also showed high sensitivity, namely an increase of 37% and 57%, respectively. A temperature increases of +1.5˚C causes actual transpiration to increase by 6% compared to soil evaporation. The largest inverse

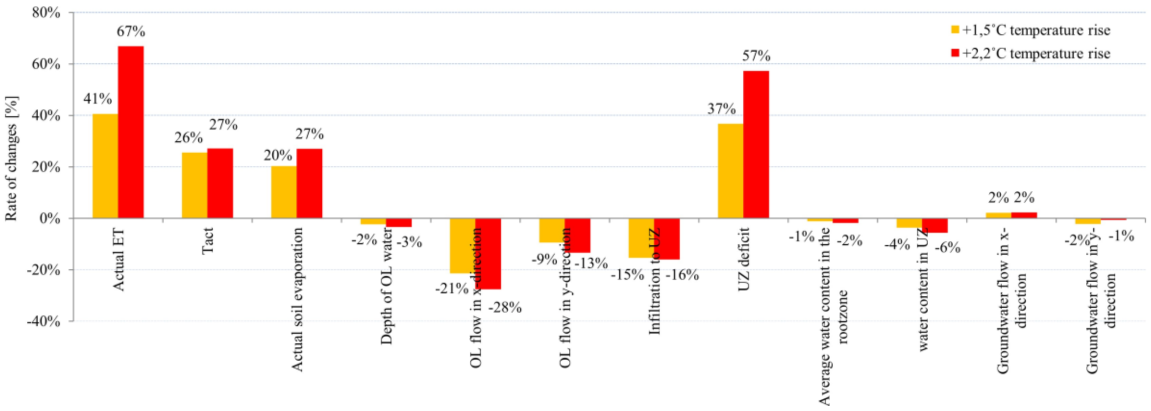

Fig. 7 Change in hydrological parameters due to temperature changes of +1.5 °C and +2.2 ° compared to the reference value on August 10, 2018 (Y = 0 horizontal axis)

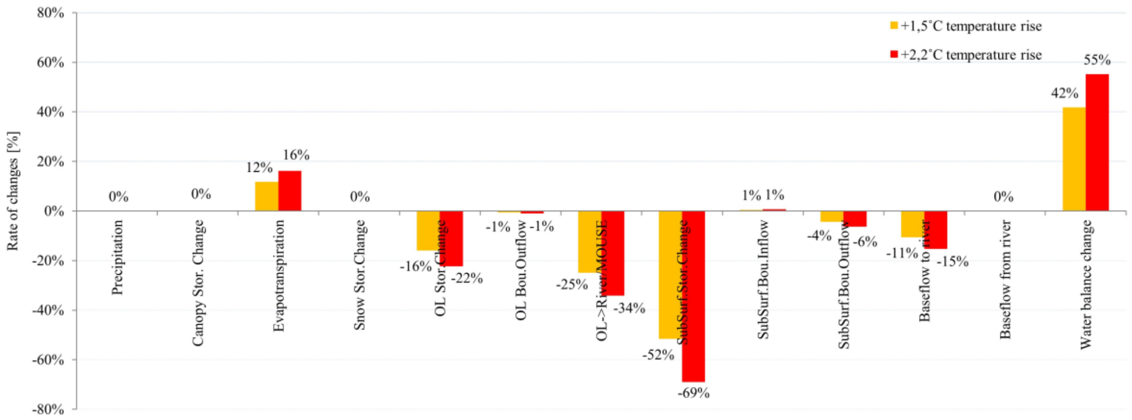

Fig. 8 Water balance values accumulated in the whole of 2018 due to temperature changes of +1.5 ˚C and +2.2 ˚C compared to the reference values (Y = 0 horizontal axis)

Table 3 Change in accumulated water balance in the whole of 2018 due to temperature changes of + 1.5 °C and + 2.2 °C and the differences compared to the reference value (DIFF1 and DIFF2)

Parameter	**Reference**	**(+)1.5 ˚C**	**(+)2.2 ˚C**	**Change (%)**	**Change (%)**
Precipitation	(+)589	(+)589	(+)589	0	%
Evapotranspiration	(-)795	(-)889	(-)924	12	16
OL boundary Inflow	0	0	0	0	0
OL boundary Outflow	(-)1042	(-)1036	(-)1032	-1	-1
Canopy Storage change	0	0	0	0	0
Snow Storage change	0	0	0	0	0
OL≥Brooks	(-)9	(-)7	(-)6	-22	-33
OL Storage change	14	12	11	-14	-21
UZ Storage change	-98	-153	-168	-56	-71
SZ Storage change	-39	-55	-63	-41	-62
Baseflow to brooks	(-)12	(-)11	(-)10	-8	-17
Baseflow from brooks	(+)4	(+)4	(+)4	0	0
Subsurface boundary inflow	(+)1132	(+)1137	(+)1140	0	1
Subsurface boundary outflow	(-)101	(-)97	(-)95	-4	-6
Infiltration include ET	(+)109	(+)64	(+)43	-41	-61
Exfiltration include ET	(-)1170	(-)1154	(-)1147	-1	-2
Water balance change	(-)357	(-)506	(-)554	42	55

Note: The sign in parentheses indicates the direction of the water flow. Not in parentheses is the value

proportionality change is the overland flow in x-direction parameter, even with a decrease of 21% for + 1.5˚C and 28% for a temperature rise of + 2.2˚C (Fig. 8). So, these hydrological parameters are the most sensitive to temperature rise.

Among the parameters in Figure 8, unsaturated deficit, actual evapotranspiration and infiltration to unsaturated emerged as the main factors, with higher values than other parameters. Temperature rise has the greatest effect on the value of the unsaturated deficit. In addition, increasing temperatures also increase actual evapotranspiration and naturally decrease the infiltration. The rest of the parameters have intraday values less than 1.0 mm. Meanwhile, the amount of precipitation on August 10, 2018 is zero. This again shows that the amount of water present and operating on this day is derived from the water that has been stored in the top layer from previous periods. Precipitation that reaches the ground surface, mostly infiltration into the deeper layers of the soil with delay and the rest will flow on the surface in the x direction (in the slope direction).

Based on the results in Table 3, the subsurface boundary inflow, overland boundary outflow and evapotranspiration components have a high weight on the studied water balance. The water balance of the Dong-ér catchment is highly dependent on the influence of subsurface boundary inflow from the external area. Evapotranspiration increases with increasing temperature greatly reduced subsurface (UZ and SZ) storage (from -48.5% to -66.5%). Overland storage change is reduced from -14% to -21%, so the baseflow to brooks and the sources to surface water are also reduced. Increasing temperature does not change the baseflow from minimum depths of brooks, where the water is always present, so the value does not change compared to 2018 (all equal to 4 mm). The conclusion is that increasing temperatures reduce the water retention of the brooks, especially in areas where its terrain level is higher than the groundwater level.

The overland boundary inflow in all three temperature conditions is zero, thus the surface watershed boundary has been correctly defined. Canopy and snow storage change in all three temperature conditions are zero, this is because the values are all very small, less than 0.03 mm so when rounding the number is zero.

The subsurface boundary inflow source is very stable and plays an important role in the water balance of the Dong-ér catchment. Subsurface boundary outflow parameters tend to decrease from -4% to -6%, partly due to additional seepage migration for groundwater and the rest being evaporated by vegetation. When considering the values of two parameters infiltration- and exfiltration including ET, it can be concluded that meanwhile temperature increases, infiltration decreases more strongly (-41% and -61%), while exfiltration decreases less.

The water balance change of 2018 show values around -357 mm, which practically more than

758 million m^3 of water is leaving the water system. The increase in temperature of +1.5˚C and +2.2˚C reduces the water balance of the Dong-ér catchment by 42% and 55%, i.e., more than 316 million m^3 and 418 million m^3 less water than in 2018. Increased temperatures directly and indirectly increase the amount of water lost through evapotranspiration and thus the water balance of the basin is significantly reduced. Based on these results, it can be concluded that subsurface storage change, infiltration include evapotranspiration, water balance change, overland flow into the brooks, overland storage components change to a greater extent than evapotranspiration changes, i.e., greater than 12% and 16%, so these parameters are sensitive to the increasing temperature of climate change.

CONCLUSION

The unsaturated zone deficit, infiltration to unsaturated zone, evapotranspiration and overland flows parameters seems to have a great weight in the daily hydrological circulation and have a highly sensitive to climate change conditions. The precipitation rapidly seeps the soil and temporarily stored in the upper soil layer and infiltrates into the deeper layers of the soil with delay and the rest will flow on the surface in the x direction (in the slope direction). During this time a large amount of water will leave the system through evapotranspiration.

Based on the relationship between manifestations of climate change and water balance components, probably the subsurface boundary inflow and evapotranspiration are the two main driving forces that constitute and regulate the water balance of the Dong-ér catchment. According to the models, the water balance in Dong-ér catchment is significantly determined by the subsurface boundary inflow since it continuously supplies about ~90% of the surface water. Subsurface boundary inflow does not show a close relationship with temperature change or extreme precipitation events. Meanwhile, evapotranspiration is highly dependent on the temperature. Due to the warming trend, the water retention of the Dong-ér Brook showed a decreasing trend, especially in areas where the groundwater level is deeper than the bed level of the brook. The components that play an important role in the water balance of the Dong-ér catchment in descending order are as follows: subsurface boundary inflow, overland boundary outflow, evapotranspiration and precipitation. However, among the components, subsurface storage change, infiltration include evapotranspiration, overland flow to brook, overland storage change and evapotranspiration components are the most sensitive to climate change.

Based on the water balance change of the model, the temperature increases of + 1.5˚C and +2.2˚C causes to lose more water than during the drought period in the Dong-ér catchment in 2000. Even such rainy years like 2014, the multi-annual water deficit can’t be replenished from the system. Ultimately, this causes the water balance of catchment to be in a state of water shortage. In the light of climate change, water shortage is probably getting worse in the Dong-ér catchment.

The results of the study have also shown the effectiveness of the MIKE SHE model and the water balance calculation module as useful tools to analyse and evaluate the effects of the changing climatic conditions on the hydrological parameters. However, the MIKE SHE model also has disadvantages such as MIKE SHE only calculating the permeability in the vertical direction, the calculation of the permeability value wrong in the area with high slope. Besides, the need for a lot of data with good quality, the difficulty of monitoring data, and changing environmental conditions in the future are issues that need to be improved, so the values of the calculated parameters cannot be absolutely accurate but gives an approximate value and trend.

The results of this study can be a reference for managers, landowners and other stakeholders in the planning, management and effective use of water resources are in a state of decline in the context of increasingly complex climate change.

ACKNOWLEDGEMENT

I am grateful to DHI Hungary Ltd. for the MIKE SHE student license. Thanks to the director of ATIVIZIG, Dr. Péter Kozák and his colleagues for their professional advices and supports. I am grateful to Professor emeritus János Rakonczai for his encouraging supports for writing this article.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration — guidelines for computing crop water requirements. *FAO Irrigation and drainage paper* 56. Food and Agriculture Organization, Rome. Online available at http://www.fao.org/3/x0490e/x0490e00.htm

Asadusjjaman, S., Farnaz, A. 2014. Investigation of Water Balance at Catchment Scale using MIKE-SHE. *International Journal of Engineering And Computer Science* 3(10), 8882–8887. Online available at https://www.ijecs.in/index.php/ijecs/article/download/1988/1838/

ATIVIZIG, 2016. River Basin Management Plan 2-20 Lower Tisza rightbank planning subunit (in Hungarian). Online available at http://www.vizugy.hu/vizstrategia/documents/C8F99A5D-2864-455E-85D6-7FB53AF0D179/VGT2__2_20_Also_Tisza_jobb_part_vegleges.pdf

Aune-Lundberg, L., Geir-Harald, S. 2020. The content and accuracy of the CORINE Land Cover dataset for Norway. *International Journal of Applied Earth Observation and Geoinformation* 96:102266. DOI: 10.1016/j.jag.2020.102266

Bahremnad, A., De Smedt, F. 2007. Distributed Hydrological Modeling and Sensitivity Analysis in Torysa Watershed, Slovakia. *Water Resources Management* 22, 393–408. DOI: 10.1007/s11269-007-9168-x

Benyhe, B., Právecz, T., Sipos, Gy. 2015. Assessment of different hydrological modelling software on a lowland minor catchment. In: Blanka, V., Ladányi, Zs. (eds.) Drought and Water Management in South Hungary and Vojvodina. University of Szeged, 320–323. (279–289.)

DHI, 2017. MIKE SHE Volume 1: User guide. Online available at https://manuals.mikepoweredbydhi.help/2017/Water_Resources/MIKE_SHE_Printed_V1.pdf

EEA. 2018. Corine Land Cover 2018. European Environmental Agency. Online available at https://www.eea.europa.eu/data-and-maps/data/external/corine-land-cover-2018

EU Water Framework Directive, 2004. DOI: 10.2779/75229. Online available at https://ec.europa.eu/environment/pubs/pdf/factsheets/wfd/en.pdf

Farsang, A. 2014. The potential pedological effects of aridification due to climate change (A klímaváltozás okozta szárazodás potenciális talajtani hatásai). In: Blanka, V., Ladányi, Zs. (eds.) Drought and Water Management in South Hungary and Vojvodina. University of Szeged. 137–141. (117–126.)

Fehér, Z.Zs. 2019. Large scale geostatistical modelling of the shallow groundwater time series on the Southern Great Hungarian Plain. Two approaches for spatiotemporal stochastic simulation of a non-complete monitoring dataset. *PhD dissertation*. University of Szeged. DOI: https://doi.org/10.14232/phd.10122

Feranec, J., Soukup, T., Hazeu, G., Jaffrain, G. 2016 (Eds.), European landscape dynamics. Corine land cover data, *CRC-Press*, Boca Raton, 9-14.

Fiala, K., Barta, K., Benyhe, B., Fehérváry, I., Lábdy, J., Sipos, Gy., Győrffy L. 2018. Operational drought and water scarcity monitoring system (Operatív aszály- és vízhiánykezelő monitoring rendszer) (In Hungarian). *Hidrológiai Közlöny, 98 (3).* 14–24. *ISSN 0018-1323.* Online available at http://publicatio.bibl.u-szeged.hu/17598/1/Fiala_et_al2018HidrologiaiKozlony.pdf

Graham, D.N., Butts, M. 2005. Flexible, integrated watershed modelling with MIKE SHE. In Singh, V.P., Frevert D.K. (eds.) Watershed Models, CRC Press, 245–272., ISBN: 0849336090

Hamby, D.M. 1994. A review of techniques for parameter sensitivity analysis of environmental models. *Environmental Monitoring and Assessment* 32, 135–154. DOI: 10.1007/BF00547132

Ibarra, S., Romero, R., Poulin, A., Glaus, M., Cervantes, E., Bravo, J., Pérez, R., Castillo, E. 2016. Sensitivity analysis in hydrological modelling for the Gulf of México. *Procedia Engineering 154*, 1152–1162. DOI: 10.1016/j.proeng.2016.07.531

IPCC 2018. Global Warming of 1.5˚C. Thematic Reports. Online available at https://www.ipcc.ch/sr15

K&K Mérnöki Iroda Kft. 2013. Harmonized activities related to extreme water management events – especially flood, inland inundation and drought (Extrém vízgazdálkodási eseményekkel kapcsolatos területi érzékenység felmérése – különösen árvíz, belvíz és aszály esetén) (in Hungarian), HUSRB/1203/121/145/01, Ref. No.: T-51/2013

Keilholz, P., Disse, M., Halik Ü. 2015. Effects of Land Use and Climate Change on Groundwater and Ecosystems at the Middle Reaches of the Tarim River Using the MIKE SHE Integrated Hydrological Model. *Water* 7(6), 3040–3056. DOI: 10.3390/w7063040

Kozák, P. 2020. Changes in surface runoff on the south-eastern slope of the Danube-Tisza Interfluve Sand Ridge in the context of climate change (in Hungarian). In: Farsang, A., Ladányi, Zs., Mucsi, L. (eds.) Climate change challenges – From global to local. *GeoLitera*, 109–115.

KÖTIVIZIG 2015. Tisza River Basin Management Plan by Middle Tisza District Water Directorate. (in Hungarian). Online available at https://www.vizugy.hu/vizstrategia/documents/1DF34F16-04AC-48B6-AD62-C62146FA5913/Tisza_RVGT_aprilis.pdf

Ladányi, Zs. 2010. Climate change impact in a sample area of Danube-Tisza Interfluve. In: Kiss, T. (ed.) Natural geographical processes and forms. Natural Geography Studies of the 9th National Conference of Geographical Doctoral Students (in Hungarian), 93–98. Online available at http://acta.bibl.u-szeged.hu/68110/1/2009_termeszetfoldrajzi_folyamatok_es_formak.pdf

Ladányi, Zs., Blanka, V., Armenski, T., Stankov, U., Sipos, Gy. 2014. Interviewing agricultural stakeholders and landowners. In: Blanka, V., Ladányi, Zs. (eds.) Drought and Water Management in South Hungary and Vojvodina. University of Szeged. 363–372. (339–359.)

Lu, J., Sun, G., McNulty, G. S., Comerford, B.N. 2006. Evaluation and application of the MIKE SHE model for a cypresspine flatwoods watershed in North Central Florida. *Second Interagency Conference on Research in the Watersheds*, 63–74.

Myneni, R., Knyazikhin, Y., Park, T. 2015. MCD15A2H MODIS/Terra+Aqua Leaf Area Index/FPAR 8-day L4 Global 500m SIN Grid V006. NASA EOSDIS Land Processes DAAC. DOI: 10.5067/MODIS/MCD15A2H.006

Nagy, Zs., Pálfi, G., Priváczkiné Hajdu, Zs., Benyhe, B. 2019. Operation of canal systems and multi-purpose water management – Dong-ér catchment (in Hungarian) In: Ladányi, Zs., Blanka, V. (eds.) Monitoring, risks and management of drought and inland excess water in South Hungary and Vojvodina: University of Szeged. 262–275. (83–96.)

OMSZ 2018a. Observed changes in Hungary. (in Hungarian) Online available at https://www.met.hu/eghajlat/eghajlatvaltozas/megfigyelt_valtozasok/Magyarorszag/

OMSZ 2018b. To the margin of the IPCC Thematic Report assessing a 1.5 degree global temperature rise. (in Hungarian) Online available at https://www.met.hu/ismeret-tar/erdekessegektanulmanyok/index.php?id=2334&hir=Az_IPCC_1,5_fokos_globalis_homerseklet-emelkedest_ertekelo_Tematikus Jelentesenek_margojara

OVF 2016. Effects of climate change, hydrometeorological extremes. (in Hungarian) Online available at http://www.ovf.hu/hu/korabbi-hirek-2/a-klimavaltozas-hatasai-hidrometeorologiai-szelsosegek

Paparrizos, S., Maris, F. 2017. Hydrological simulation of Sperchios River basin in Central Greece using the MIKE SHE model and geographic information systems. *Applied Water Science* 7, 591–599. DOI: 10.1007/s13201-015-0271-5

Právetz, T., Sipos, G., Benyhe, B., Blanka, V. 2015. Modelling runoff on a small lowland catchment, Hungarian Great Plains. *Journal of Environmental Geography* 8 (1–2), 49–58. DOI: 10.1515/jengeo-2015-0006

Rakonczai, J., Farsang, A., Mezősi, G., Gál, N. 2011. Theoretical background of inland excess water formation (A belvízképződés elméleti háttere) (in Hungarian), *Hungarian Geographical Review* 135(4), 339–349.

Rakonczai, J., Fiala, K., Mesaros, M., Frank, A., Popov, S. 2014. Water management conflicts. In: Blanka, V., Ladányi, Zs. (eds.) Drought and Water Management in South Hungary and Vojvodina. University of Szeged, 78–80. (47–52.)

Singh, A. 2014. Conjunctive use of water resources for sustainable irrigated agriculture. *Journal of Hydrology.* 519, 1688–1697. DOI: 10.1016/j.jhydrol.2014.09.049

Sipos, Gy., Právecz T. 2014. Identification of water retention areas on the Dong-ér catchment using GIS. In: Blanka, V., Ladányi, Zs. (eds.) Drought and Water Management in South Hungary and Vojvodina. University of Szeged. 217–220. (157–167.)

Szatmári, J., van Leeuwen, B. (eds.) 2013. Inland Excess Water – Belvíz – Suvišne Unutrašnje Vode, Szeged: University of Szeged, Novi Sad: University of Novi Sad, 154 p.

Tóth, B., Weynants, M., Pásztor, L., Hengl, T. 2017. 3D Soil Hydraulic Database of Europe at 250 m resolution. *Hydrological Processes* 31(14), 2662–2666. DOI: 10.1002/hyp.11203. https://eusoilhydrogrids.rissac.hu/

van Leeuwen, B., Právetz, T., Liptay Z.Á., Tobak, Z. 2016. Physically based hydrological modelling of inland excess water. *Carpathian Journal of Earth and Environmental Sciences*, 11(2), 497–510