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Research Article

Estimation of the water regime under different climate scenarios and the importance of the thoroughness of the soil as input layer in a small watershed in Central-Hungary

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Abstract: The indicators of climate change in Central Europe, Hungary is showing a trend of decrease in rainfall, increase in temperature and especially extreme weather that is becoming more usual and unpredictable. The current study presents the application of the MIKE SHE model to examine the role of unsaturated soil settings and the effects of climate change on various hydrological parameters and water balance components. The input data has been provided by Lower-Tisza District Water Directorate. The one-at-a-time method utilized in this study allows for the investigation of the impact of various input parameter combinations on the estimated values of different hydrological parameters and water balance components. The findings demonstrated that the level of detailedness of the soil as an input parameter significantly influences the results of the modelled groundwater circulation and therefore the dynamics of the water regime. According to the simulation results of the temperature increase, the water table can be regarded as the primary water supply that replenishes the streams. The simulation results show that the groundwater table and evapotranspiration are the two main driving forces in the Dong-ér catchment's water regime. These findings will be used as a reference for water resource management and irrigation infrastructure planning in the context of complex climate change contexts.

Keywords: Climate change; Dong-ér catchment; Water balance; MIKE-SHE.

1. Introduction

According to the most recent report of the United Nation's Intergovernmental Panel on Climate Change (IPCC – Sixth Assessment Report), climate change is having a significant impact on the hydrological cycle and leading to an increase in extreme weather events worldwide. The period from 2011 to 2020 has shown a warming of 1.09°C compared to before the first industrial revolution and the 5 years from 2016 to 2020 is the hottest period from 1850 to the present [1]. In general, the 1.5°C temperature limit *"will be exceeded in the 21st century"* under medium or higher emissions scenarios. The report also introduced the term equilibrium climate sensitivity (ECS) to allow more reliable predictions of future warming. Global warming will exacerbate droughts, increase evapotranspiration, and thus increase the frequency of extreme rains and floods.

The temperature increase in Hungary is in line with the general trend in the world, but the data from the Meteorological Service of Hungary (OMSZ) indicates, that the temperature in Hungary has increased by +1.2^{o}C over the last 4 decades, compared to the period before the first industrial revolution [2]. This is the level approach to the minimum allowed under the Paris Climate Agreement. 2019 is the hottest year on record since 1901 in Hungary [3]. Analysis of measurements from the Water Scarcity Management Observationary Network operated by the National Directorate of Water Management of Hungary (OVF) shows, that the impacts of climate change are making droughts more frequent, more intense, and longer. Rising mean temperatures are associated with rising urban temperatures [4–6], which increases energy demands in summer. The spread of various invasive pests [7–8], the significant increase in forest water use [9], and the general increase in water demand are also foreseeable.

According to the National Directorate of Water Management of Hungary (OVF), extreme weather events are becoming more common in Hungary as a result of climate change, and an increase in the frequency of high-intensity precipitation events should be expected soon, potentially increasing the magnitude of local water damages [10]. As a result, changing climatic effects have a direct impact on agriculture, causing greater damages primarily due to droughts and directly affecting agricultural sustainability as well as food security [11–12]. Water management is becoming increasingly important in mitigating the effects of extreme weather conditions. The importance of more effective and sustainable water resource management, planning, and consumption has never been greater [13-14].

According to [15], only local water balance models are reliable for making efficient and economically sustainable water use decisions in the dry season and water retention in the rainy season. Understanding the state of the water regime is becoming increasingly important. In the presence of both inland excess water and drought conditions, an integrated approach is required to evaluate the complex interrelationships of hydrological processes and changes in water balance from various perspectives, thereby providing effective solutions to the complex modelling challenges. The Tisza River Basin Management Plan provides an excellent introduction to the subject [14].

The geographical information system (GIS) can now be used thanks to recent advances in information technology. In addition, various mathematical and physical-based hydrological modelling software has made related research possible [16]. Among the various models, the MIKE SHE model stands out as a tool for implementing integrated water resource management. The model is capable of simulating the interaction of surface water and groundwater [17]. [18] published a model based on MIKE SHE where they simulated the excess water accumulation processes, and water regime, and generated excess water maps for the Dong-ér watershed. The findings indicate that the integrated MIKE SHE model is relatively calibrated and can be used to compute and analyse several other elements of climate change in the connection between hydrological parameters and water balance.

Among the benefits of the MIKE SHE model is that it offers a complete, integrated water balance calculation capability for calculating the entire regional and catchment-level water balance for any temporal and spatial scale. Areal fluxes, storage fluctuations, and water balance changes are the typical elements of the results regarding the water balance [19]. These results can further be used to integrate, map, and visualize hydrological processes between different hydrological parameters [17]. The overall water balance fluctuation estimate for the entire model catchment area is computed. Furthermore, each hydrologic component's water balance changes. The value of these characteristics is crucial because it serves as the basis for evaluating the water balance in the Dong-ér catchment. Temperature and rain are the two principal factors that impact a catchment's water balance, either directly or indirectly. These are the two primary forces at work in the hydrologic cycle. The issue is how climate change affects the model estimates of the hydrological parameters and the results of the water balance components. research. Permutation of the input dataset has an effect on model findings, and it is required to examine the sensitivity of the model on the input dataset and enables to discover which inputs have the largest influence on the model results [20]. Setting up sensitivity analysis is required to increase accuracy and optimize the calibration process [21]. Sensitivity analysis is an effective method for identifying influential model parameters and thereby making the model structure more robust [22]. Furthermore, the sensitivity analysis is capable for parameter estimations and explains the model's responses to changes in the input dataset. The one-at-a-time method, in which sensitivity measures are derived by adjusting each parameter separately while leaving all other parameters intact, is the easiest approach to conceive among the several approaches of sensitivity analysis that have been utilized in the literature. The method's shortcoming is that it can only do local sensitivity analysis at a single location in the parameter distribution rather than the complete distribution [20]. However, using the MIKE SHE model's flexible simulation framework on both the geographical and temporal scales, this disadvantage may be overcome, providing us with a more integrated and complete perspective.

The aim of the current study is to simulate different climatic conditions and to evaluate the influence of input parameters on hydrological parameters and water balance components using sensitivity analysis. However, in order, to be able to carry out these integration analyses, the hydrological models usually require various representative and reliable hydrological and meteorological datasets [23]. In the current framework, this is particularly complicated, given the limited data availability in the Dong-ér catchment at the chosen modelling scale. However, the variable parameters and the water calculation module were developed and used by the authors to simulate and assess with an integrated approach, which climate change manifestation has a more significant impact on the results of the hydrological parameters and water balance components. This can be achieved by applying the one-at-a-time method. To achieve the goals, it is required to 1) verify the suitability to determine the advantages and disadvantages of the MIKE SHE environment in the case of the area under study; 2) to simulate the hydrological system and the complete water regime under different combinations of input variables; 3) to compare the simulation results and determine the most affected factors thus mostly sensitive to the permutations of the input dataset. These results may make it possible to predict and assess the impacts of the ongoing climate change on water balance components and different hydrological parameters.

2. Materials and methods

2.1. Study area

The 2127 km^2 Dong-ér inland excess water protection management system is located in the central-southern part of the Danube–Tisza Interfluve Sand Ridge, about 50 km from the Serbian border (Figure 1). The western part of the watershed belongs to the eastern part of the Bugaci Sand Ridge, where the slightly undulating plain and the series of ridges stretching in the northwest-southeast direction, the wind furrows, is an area covered with wet bogs and peat. The average relative relief is 3.5 m/km^2. In the sediment near the surface of the area, shifting sand shows dominance; its thickness can vary from a few meters to 50-60 m. Most of its waters flow into the Dong-ér Brook. Incidentally, the initial stages of the Dong-ér stream belong to this landscape [24]. The western, higher area consists mainly of highly permeable sandy sediments. The eastern part is mainly covered by river sediments with minimal gradient and lower hydraulic conductivity.

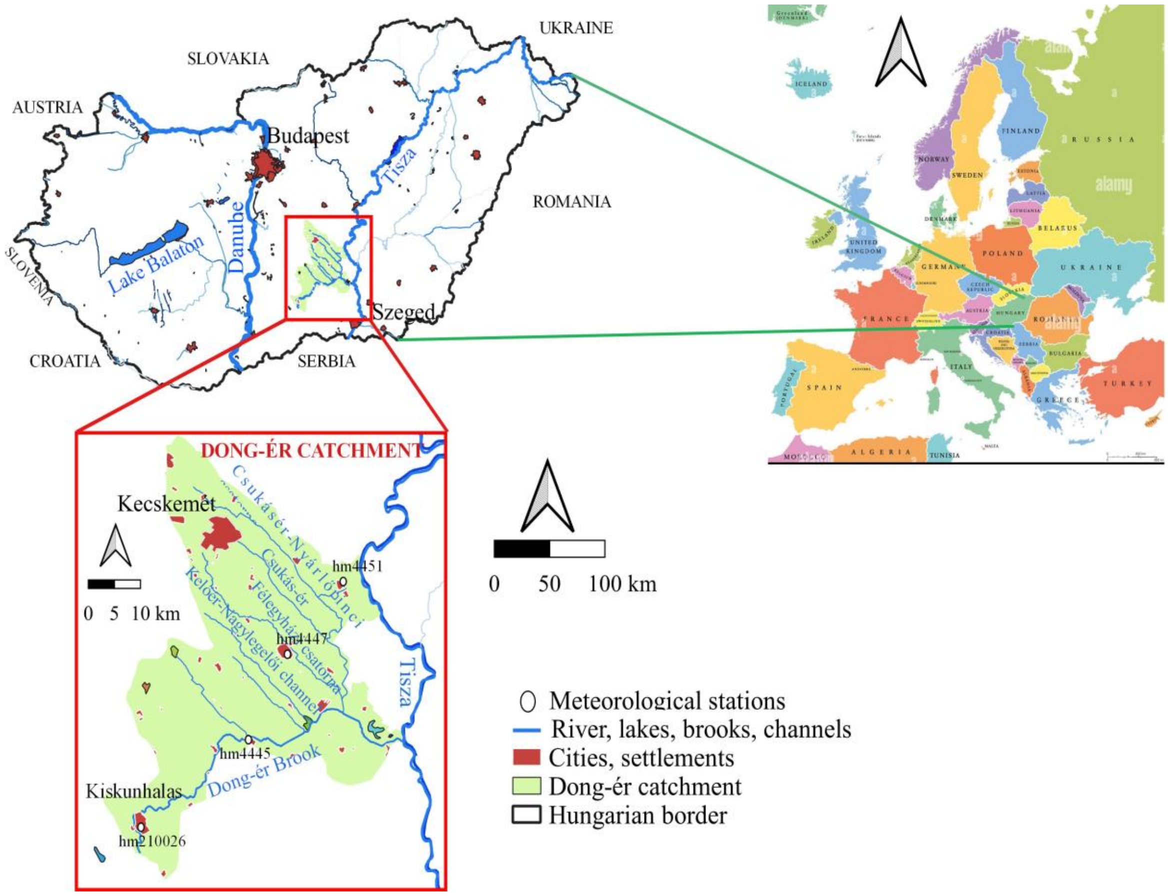

Figure 1. The Dong-ér stream watershed.

In the initial section of the Dong-ér stream, the surface water transport is minimal, the occasionally drying-up river bed is revealed only through wetland vegetation. Consequently, the area's water resources cannot be exploited; therefore, groundwater mostly plays the only source for irrigation purposes [25]. 50 years ago, the water table of the Bugaci sand ridge was available at a depth of 2-4 m, but later, significant discharge was observed [24]. The southern part of the Dong-ér catchment, more specifically the area on the right side of the Dong-ér stream, belongs to the Dorozsma-Majsai-Sand Ridge. Most of the Dong-ér catchment belongs to the Kiskunság Loess Ridge, which is an alluvial cone plain covered with loess and sand. The value of the relative relief here is 5 m/km^2. In the northwest-southeast direction between Kiskunfélegyháza and Kecskemét, a 1.5 m thick loess covers the sand dunes [24]. In the catchment area, the almost parallel canal system collects and transports the excess water to the Dong-ér stream, and then flows on into the Tisza. Only when an extreme Tisza flood wave forms does the gravitational flow end. The Dong-ér stream's flow rate during the normal period is around 2-3 m^3/s; however, in years, when inland excess water is formulated in spring, the runoff can exceed 20-30 m^3/s, and in extreme drought summer periods, the stream is often dries up completely [26]. The speed of the prevailing north-west wind is about 2-3 m/s, thus the surface forms are predominantly shaped by aeolian effects and the area's topography has fundamentally shaped the water networks. The Dong-ér stream's dominant flow direction is SW-NE, while the tributaries are flowing perpendicularly, following the characteristic natural deflationary depressions. In years, when the rainfall exceeds the average, the water table usually rises above the surface in deflationary depressions, forming temporarily flooded regions [27].

The climate projections released by the United Nation's Intergovernmental Panel on Climate Change (IPCC) forecasts, that the average temperature increase of our planet may exceed 1.5^{o}C in 2052 [28]. Two regional climate models and two climate scenarios from the Meteorological Service of Hungary (OMSZ) indicate, that the average temperature in Hungary could increase by 3-4ºC by the end of the 21st century, hence the 2˚C threshold will be exceeded in the near future. The Dong-ér watershed is particularly exposed to temperature rise, and is one of the driest areas in Hungary, hence, the risk of drought will increase in the future [27]. The mean annual precipitation total in the catchment over the past two decades is 611 mm, meanwhile in extreme cases, it can exceed 800 mm (1999, 2010, 2014) or can represent desert conditions with the extremely minimal 203 mm (2000, 2011, 2021, 2022). Between 2000 and 2018, the lowest monthly mean temperature was -5.2ºC (February 2012 and January 2017), the highest was +24.5ºC (August 2018). Snow cover has disappeared over the past decade, although the long-term average snow cover is 20 cm thick.

Non-irrigated cropland dominates the area with about 40%, followed by pasture with 13%, and deciduous forest with 10% of the total study area. The rest are various small land uses, such as transitional forest-shrub, discontinuous urban structures, and complex cultivation patterns. The agrotopographic map indicates an extremely heterogeneous soil distribution pattern, predominantly chernozem, humid sand, blown sand, sandy, and saline soils. Each soil type found in the area typically has a high infiltration potential. Since the 1970s, there has been a decreasing trend in precipitation, which has led to a significant lowering of the water table, which today averages more than 2 meters [29]. Recently, in periods of sustained rainfall, water scarcity can be restored in the lower parts of the Sand Ridge. In the recent 20 years, the water table has occasionally risen to harmful levels and caused surface flooding [30].

2.2. Basic concepts of the water regime model in the catchment area

The unsaturated soil settings and temperature sensitivity analysis focused on the impact of changes in the modelled hydrological parameters and water balance component outcomes. Based on data from the Hungarian National Geological Institute (MÁFI), the unsaturated data were uniformly and spatially adjusted. Taking into account the results of the long-term climate forecast models IPCC [28] and OMSZ [31] for the temperature increase for 2050, the temperature data series of the reference model for 2018 (BS scenario) was increased by +0.3ºC, +0.5ºC, +0.7ºC and +1.5ºC. All other parameters were left unchanged and the differences between the three hydrological models were compared (Figure 2).

2.3. Data requirements of the current model

In the MIKE SHE model, the input data depends entirely on the purpose of the hydrological process simulation and the problem that the model is intended to solve. Obviously, there are essential input data, such as the catchment area, the topography and the water network of the investigated area. This includes data that changes little or remains unaffected over the long term, such as the watershed topography, water networks (rivers and lakes), soils and geological features. In addition, there are data that change within a relatively short period of time, like precipitation, temperature, evapotranspiration, and vegetation (leaf area index and root depth). Mitigating these factors is critical to modelling a variety of processes, including water management. Table 1 presents the basic input data requirements of the MIKE SHE modelling environment.

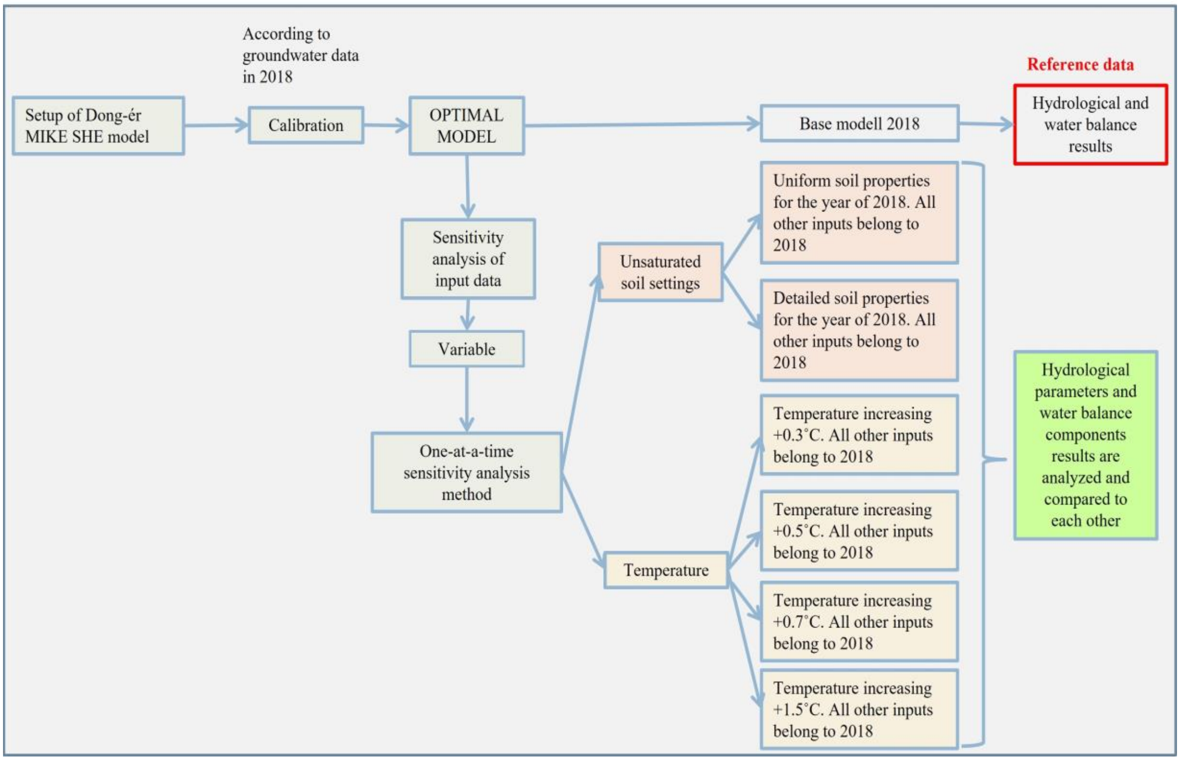

Figure 2. Schematic structure of the research workflow.

Table 1. Input features and included data sources of the MIKE SHE model.

Data	Format	Notes
Catchment area	Shape	
Water networks	Shape	
Geometry data of water networks	Shape and Excel table	It can be divided into two main classes. The first group includes streams from the previous era, that provide routings and survey cross-sections and process them into 3D point features. ATIVIZIG manages the stream attributes in a different way, where the path lines are provided as polylines, and the cross-section data is defined by longitudinal profile and various cross-section data.
Digital Elevation Modell (DEM)	Tiff	10×10m spatial resolution, spatial reference: Hungarian Datum 1972/ EOV. In order to run the MIKE SHE model, the DEM data must be converted to a spatial distribution grid point file (dfs2). The point file was created with ArcGIS Desktop and could be converted to a dfs2 file using MIKE Zero Toolbox [19]. The resulting spatial distribution grid can be imported into the model.
Precipitation	Excel table	Daily mean temperature dataset provided by the Hungarian Meteorological Office (OMSZ).
Temperatures	Excel table	Daily precipitation totals at individual gauges provided by the Hungarian Meteorological Office (OMSZ).
The potential evapotranspiration (ET_P)		Potential evapotranspiration (ET_P) can be estimated in a simplified way based on the correlation with the temperature (T). The following function describes a good relationship between the two phenomena [32]: $ET_P = ET_{ref} = e^{0.07T}$
Surface water level	Excel table	Surface water level dataset for the Dong-ér catchment provided by ATIVIZIG.

Data	Format	Notes
Subsurface water level	Excel table	The water table shows longer temporal autocorrelation as it is less influenced by the dynamics of external environmental phenomena than the unsaturated zone or the water level of the streams. The water table time series provided by ATIVIZIG consists of 33 groundwater gauges and their geospatial locations between 2010 and 2018.
Landcover	Shape	In our model, we distinguished 23 classes of land use [33], based on the CORINE dataset [34-35].
Rivers and lakes	mhydro	Hydrodynamic module built with MIKE Hydro River model
Root depth	Text	Mean root depth values estimated using CORINE classes [18].
Leaf Area Index (LAI)	Tiff	Estimation of average LAI values by CORINE category using MODIS remotely sensed images [36].
Geological layers	Shape and Excel table	The hydraulic parameters of the upper 10 m layer of the soil with the RETC software built by [37], the ratio of soil layers for each soil type according to the data of MÁFI, the data of bulk density by [38] were determined. Deeper geologic parameters were spatially estimated from 13 drill hole logs provided by ATIVZIG.
Computational layers	Shape and Excel table	The MIKE SHE model discretizes the numerical vertical calculation grid by explicitly defining the bottom level of each computational layer. The spatial distribution of the lower level is even; The value of the bottom aquifer limit is set to -75 m. To correct the relief layers, the minimum layer thickness is set at a value of 2 m. The outer boundary conditions are defined based on a fixed head type based on a spatially distributed and time-varying dfs2 file, which is extracted from the specified water table. A fixed water table is determined based on the daily groundwater level data from 2010 to 2018. The specified groundwater level is divided into 200 m × 200 m grid cells. MIKE SHE then interpolates both temporally and spatially from the dfs2 file to the local head boundary at each local time step [19].

2.4. Output features of the MIKE SHE model

The output results obtained from the simulation depend on the selected modelling workflow. According to the User guide (2017), the MIKE SHE model saves the results in three groups of files. The ASCII files store the catalogue of the simulation output files (.sheres). Every constant information of the simulation is stored in binary files (.frf). The dynamic results of the simulation are stored as, 1-d time-series (dfs0), 2-d spatial datasets (dfs2), and 3-d datasets (dfs3).

Basically, MIKE SHE considers all water inflows into the hydrological system to be positive, while all outflows or water losses are negative. As storage increases, the amount of water stored in the watershed increases. A positive change in the water balance is when the sum of the change in storage and the total outflows is less than the total inflows (Storage + Outflow Inflow).

The following tables summarize the hydrological parameters and water balance components considered in the current study Table 2 and Table 3.

Table 2. Output hydrological parameters used for the current study [19].

Hydrological parameters	Data type	Unit	Notes
Actual evapotranspiration	Evapotranspiration rate	mm/day	Evapotranspiration occurring under actual soil moisture conditions in the period under study for the given climate [39]
Actual transpiration	Evapotranspiration rate	mm/day	Evaporation of water occurs mainly through the pores of the leaves.
Actual soil evaporation	Evapotranspiration rate	mm/day	Actual soil evaporation depends on factors such as soil properties, land use, and vegetation.
Depth of overland water	Water depth	m	Represents the actual amount of water on the surface.
Overland flow in the x-direction	Discharge	m^3/sec	Runoff on a slope has a positive x-direction
Overland flow in y-direction	Discharge	m^3/sec	Downward water movement is positive
Infiltration to unsaturated zone (UZ)	Infiltration	mm/day	Water movement toward the system is positive
Unsaturated zone deficit	Deficit	mm	The deficit of the unsaturated zone represents the amount of air in the soil pores. A decreasing deficit indicates wetter soil, while an increasing deficit indicates drier soil.
Average water content in the root zone	Water content	-	
Groundwater flux in the x-direction	Discharge	m^3/sec	Positive for water flow from south to north
Groundwater flux in the y-direction	Discharge	m^3/sec	Positive for water flow from west to east
Groundwater flux in the z-direction	Discharge	m^3/sec	Positive when the water flow is directed downwards

Table 3. Output water balance components used for the current study [19].

Water balance component		Units
Precipitation		mm
Evapotranspiration	Evapotranspiration (ET) Infiltration include ET Exfiltration include ET	mm
Flows	Overland boundary inflow (OL Bou.Inflow) Overland flow to river (OL->River/MOUSE) 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 changes		mm

2.5. Calibration and validation of the hydrodynamic model

The preliminary hydrodynamic model for the catchment described earlier in this study, lacks several data (e.g. channel water levels and discharge) to perform proper calibration and validation. The model built by [18] was calibrated based on the 2018 spring water table conditions. The cross-validation of these simulation results with the measured water table depths resulted in a non-negligible RMS error of 45 cm. This high value can be considered reasonable given the lack of input parameters and the limited information content of the input datasets (e.g. topographic maps, vegetation conditions, soil properties). The results of some measuring points show a slightly larger difference and a different trend than reality. This is because many parameters are necessary for calibration to make the model more complete. The additional data sets include saturated hydraulic conductivity to calibrate unsaturated flow, specific yield and specific storage to calibrate groundwater flow. Due to data limitations, these parameters were not examined.

As it was previously described, the unsaturated zone has been completely upgraded from the original model. Figure 3 and Figure 4 compares the simulation results with the actual groundwater data measured at each monitoring gauge.

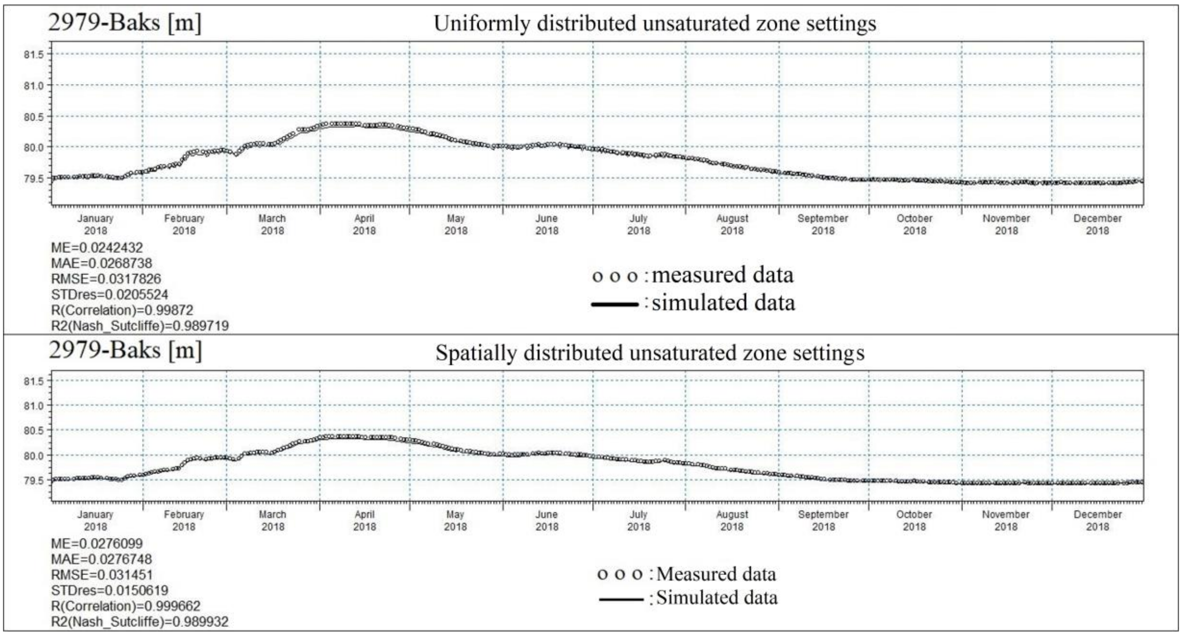

Figure 3. Example of calibration results for the Dong-ér basin for 2018 for groundwater well No. 2979 in Baks village.

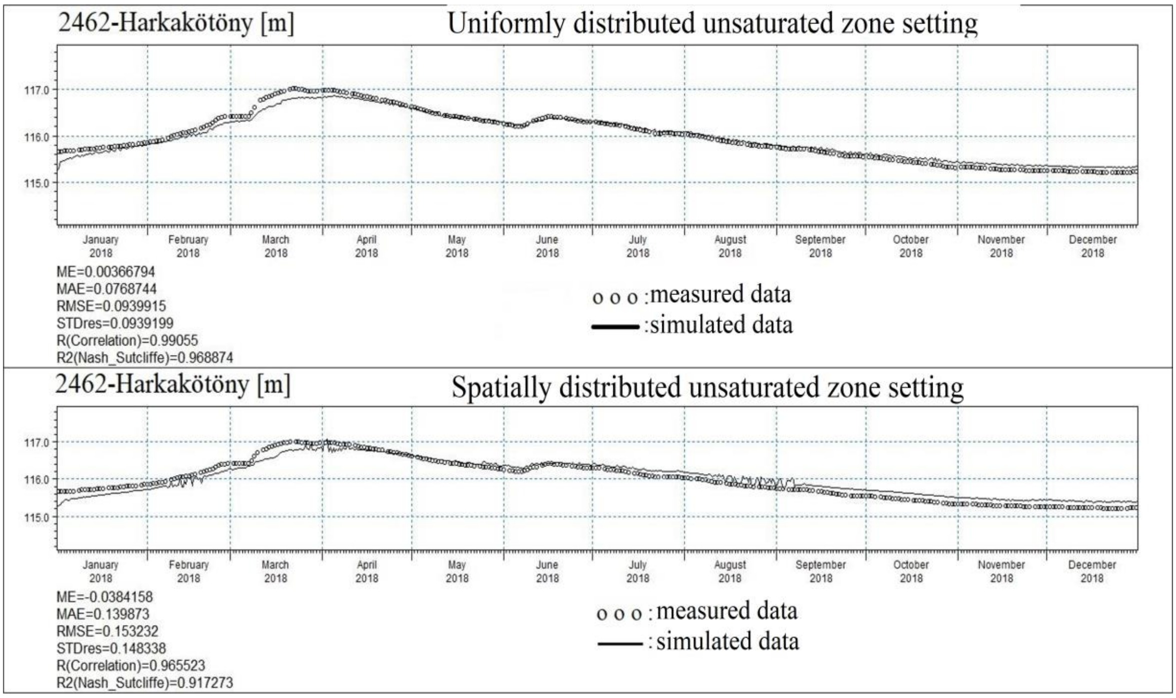

Figure 4. Example of calibration results for the Dong-ér basin for 2018 for groundwater well No. 2462 in Harkakötöny village.

The results show that the spatially more detailed structure of the input data for the unsaturated zone gives similar results for groundwater. In both results, the simulated data “fit” the measured data and the observed trends also represent reality. However, the simulation results for the processes in the unsaturated zone and those occurring in the spatially distributed model are certainly different from the results of the uniformly distributed model. The disadvantage of defining the unsaturated zone with a more detailed spatial distribution is that the simulation shows a large difference in time. The uniform distribution model version takes about 20 hours to run, while the model I developed took more than 72 hours of calculation time. There is also a significant difference in the amount of disk space required, with the results of the simulation of the model built with the uniformly distributed unsaturated zone taking up about 330 GB, while the one with the more detailed spatial distribution took up 497 GB of disk space.

3. Results

3.1. 2018 base model

The year 2018 was chosen as the baseline year for the simulation of the integrated hydrological process and the hydrological regime of the Dong-ér basin, for the following reasons:

1) The preliminary model by [18] is based on water table depth measurements from 2018; 2) the 2018 baseline model with spatially distributed unsaturated zone was calibrated and validated by consideration of surface water level, water yield and groundwater data; 3) 2018 Corine surface cover data was applied; 4) Data for 2018 vegetation characteristics (leaf area index, root depth) were determined by [18]; 5) Overall, the year 2018 had an average amount of precipitation (573 mm) compared to the extreme years 2000 and 2014. Thus, the baseline simulation for the year 2018 is suitable for carrying out sensitivity analyses and the simulated results can be used as references for comparison with the simulation results of other scenarios. Figures 5 and 6 compare the models using either the uniform or the spatially distributed unsaturated zone in terms of hydrological parameters (for the whole of 2018 and the whole catchment) and hydrographic components.

Figure 5 shows that there are significant differences between the results of the simulation with uniform and more detailed spatially distributed soil properties in the following parameters: actual evapotranspiration, actual evapotranspiration, and actual soil evaporation. Thus, for soil types built with horizontal distribution, the values of evapotranspiration processes are smaller than for soils with uniform distribution. Because of the detailed horizontal and vertical distribution of the surface soil types, a decrease in infiltration and consequently an increase in the deficit of the unsaturated zone can be observed in the case of spatially distributed soil properties in the simulation. The average water content in the root zone is slightly higher for the uniformly distributed soil properties due to higher infiltration than for the spatially distributed case. For the unsaturated zone water content parameter, the values are equal in both cases, but no specific conclusion can be drawn, since several parameters have an influence on the water content in the unsaturated zone, such as infiltration, groundwater elevation, and evaporation. The surface runoff and groundwater flow in the x- and y-directions parameters are so small that the numbers are equal to zero due to rounding. In addition, difference in the z-direction groundwater flow can also be observed, yet the simulation result of the model built with spatially distributed soil properties shows that the groundwater rises 70 mm higher than in the case of the uniformly distributed model.

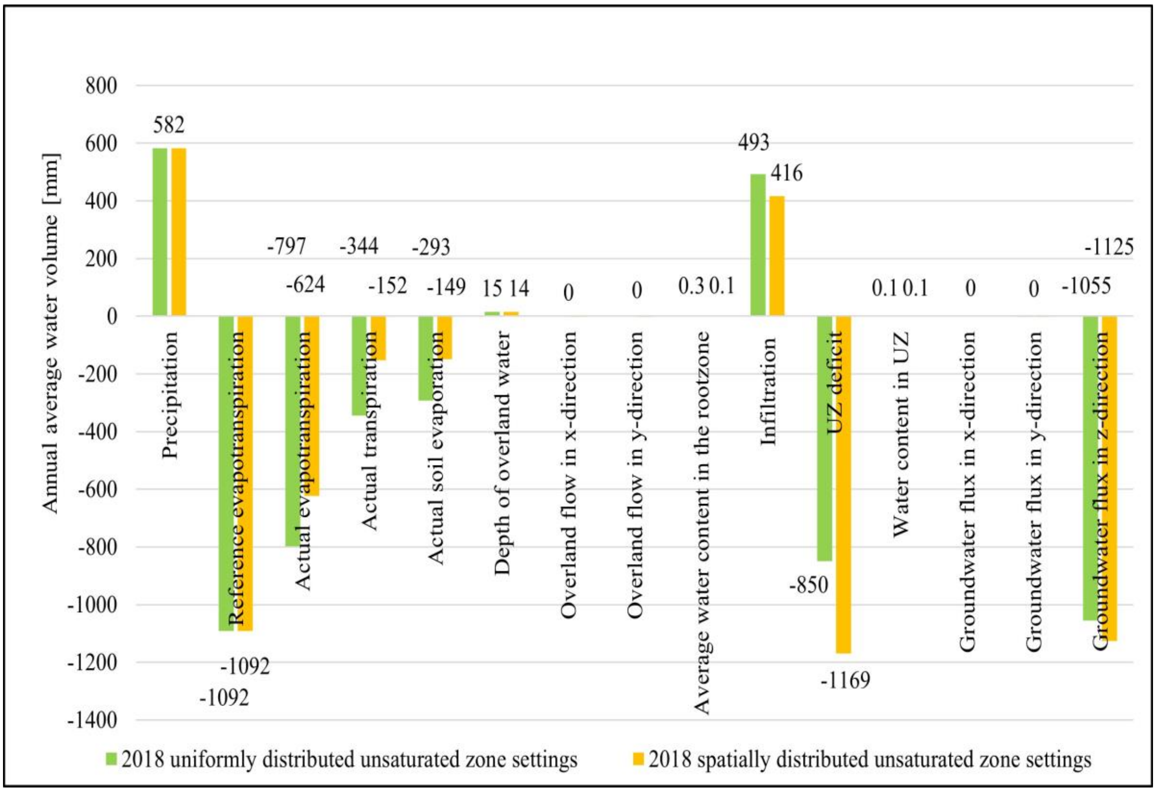

Figure 5. Hydrological results of the simulation of the Dong-er catchment with uniform and detailed soil properties for the year of 2018.

The water balance comparison (Figure 6.), suggests a significant difference in the groundwater (unsaturated and saturated zone). For the uniformly defined soil properties, the simulation estimated a 129 mm lower groundwater table compared to the model run with detailed soil properties. Multiplying this difference by the catchment area (2,127 km^2), there is a difference of more than 270 million m^3 of water between the two model estimates. This is a substantial amount of water that greatly affects the accuracy of the water balance calculation. The result suggests that the soil composition of the study area plays an important role in the estimation of groundwater resources and thus the water balance. For the simulation with detailed soil properties, the values of surface runoff, subsurface runoff and near-surface runoff are larger than those of the steady-state version. The vertical distribution of the soil results in more groundwater inflow from the outer catchment (1269 mm) than the uniformly defined soil profile (1132 mm). Overall, the difference in water balance between the two settings is 277 mm, corresponding to about 580 million m^3 of water. This can be considered a large difference, so We consider it necessary to adjust the unsaturated zone soil as detailed as possible.

Based on the above results, the Dong-ér small catchment was modelled with the unsaturated zone based on the more detailed spatially distributed soil properties. The hydrological parameters were investigated using the annual average runoff of the entire catchment and the water volume accumulated over the entire catchment and the study year for the hydrometeorological components.

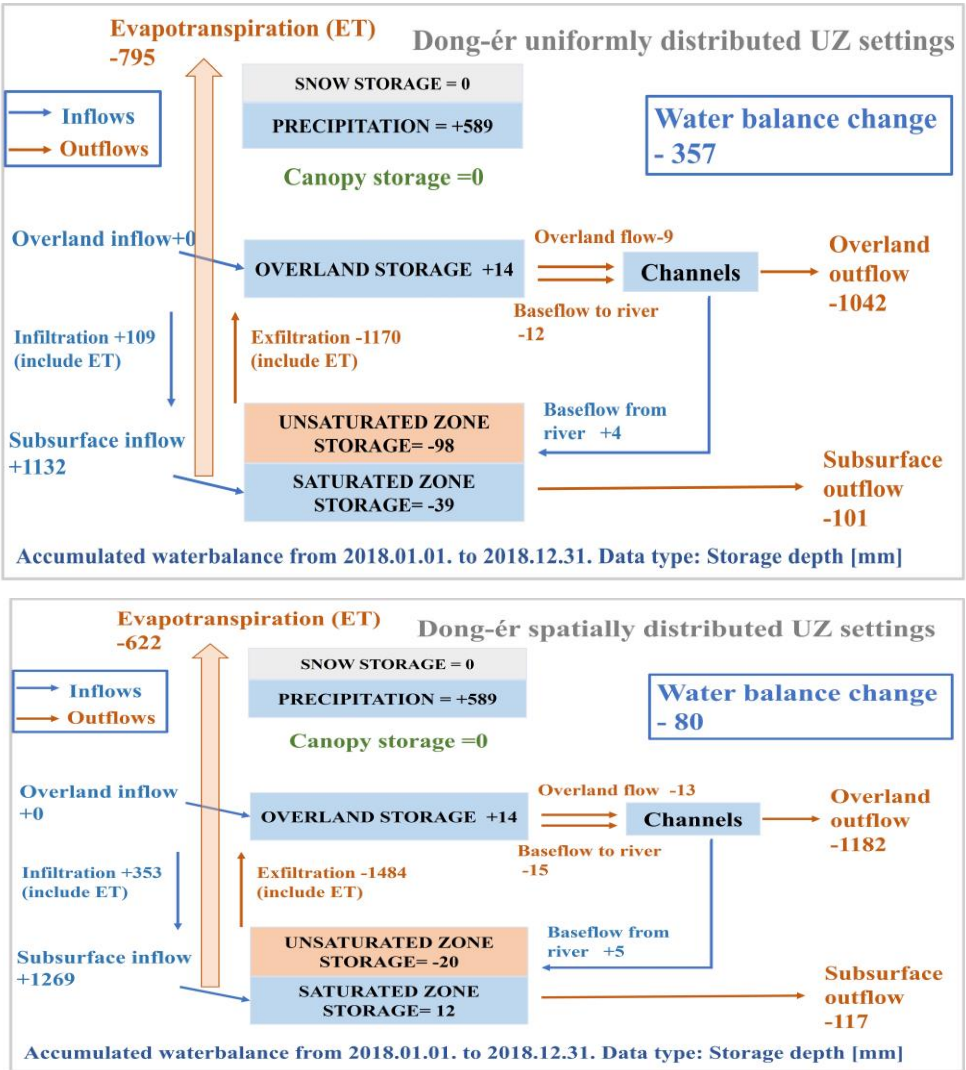

Figure 6. Hydrography results for Dong-er catchment with uniform and detailed soil properties simulation for the year of 2018.

3.2. Scenario-based simulation of the effects of temperature rise on the hydrological system

Several important climatic elements will change in the future, due to the increase in temperature, and these changes will have a major impact on the hydrological regime of the area. Therefore, sensitivity analyses were performed to determine the influence of temperature changes on hydrological parameters and water balance components. In addition to temperature data for 2018, the consequences of the daily temperature increases of +0.3°C, +0.5°C, +0.7°C and +1.5°C were analyzed, according to the IPCC [28] and OMSZ [31] climate forecast models. This was followed by a comparative evaluation of the results of the five scenarios (Figure 7). All other parameters, except temperature, were left unchanged in the model scenarios for 2018.

The model results show that the evapotranspiration (ET) parameters (reference ET, actual ET, actual transpiration, actual soil evaporation) increase gradually with the temperature. The surface runoff along the x- and y-coordinate axes is so small in each scenario that the values are rounded to zero. In the root zone, the water content decreases with temperature increase, here again rounding the values to equal 0.1 mm. This shows that the effect of a temperature rise of +0.3°C is reduced by 0.2 mm. The results of the four temperature rise scenarios hardly differ from each other. With respect to infiltration, it is obvious and natural that infiltration decreases with temperature rise, and even more so with a temperature rise of +0.3°C, infiltration decreases substantially and decreases gradually for temperature rises of +0.5°C, +0.7°C and +1.5°C. This phenomenon is also observed in the unsaturated zone deficit. No change is observed in the x- and y-directions for groundwater movements. In the z-direction (upward), groundwater movements differ by only 1-8 mm (Figure 7). The results of the simulation suggest that the most sensitive to temperature increases among the hydrological parameters are surface processes (evaporation, transpiration, surface water depth, infiltration, and the deficit of the unsaturated zone). Due to the nature of the Carpathian Basin and the direction of deep groundwater movement, it is not sensitive to temperature increases.

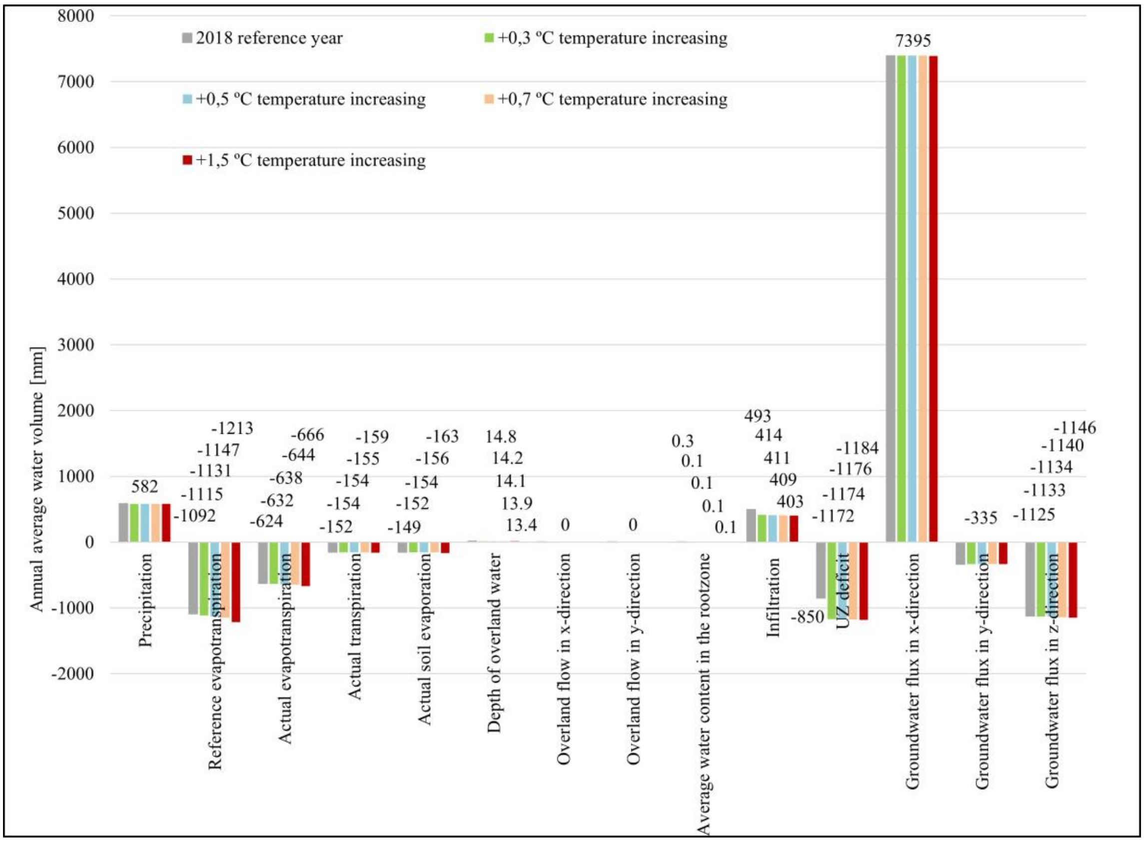

Figure 7. Effect of temperature increases of +0.3°C, +0.5°C, +0.7°C and +1.5°C on the simulated hydrological parameters.

The exploration of relationships between water balance components and temperature changes was investigated using water balance calculation. The results of the simulations indicate that evapotranspiration increases significantly (5 mm to 22 mm) with increasing temperature, thus substantially reducing the amount of infiltration into the open surface receiving basins in the form of springs. Intensive evaporation of water surfaces and evaporation from plants, and a reduction in near-surface flows feeding the channel, while the near-surface outflow component from the channel remains unchanged (5 mm), reduces the water content of the channel. The results in Table 4. show that the values of groundwater inflow, surface runoff and evapotranspiration are larger in relation to the amount of precipitation falling and the other indicators. Consequently, these components are of great importance in the water balance, as the study of precipitation events has shown. The groundwater inflow components show the highest significance. It can therefore be concluded that the water balance of the study catchment is highly dependent on groundwater inflow from the external catchment. The groundwater (unsaturated and saturated zone) shows a decreasing trend with increasing temperature. This result is also confirmed by the fact that the water scarcity problem in the Danube-Tisza basin shows an increasing trend [29].

Table 4. Changes in water balance components due to temperature increase of +0.3°C, +0.5°C, +0.7°C and +1.5°C compared to the reference year.

Parameters [mm]	2018	(+) 0.3°C	(+) 0.5°C	(+) 0.7°C	(+) 1.5°C	%	%	%	%
Precipitation	589	589	589	589	589	0%	0%	0%	0%
Evapotranspiration (ET)	-622	-631	-637	-642	-664	1%	2%	3%	7%
Overland boundary inflow	0	0	0	0	0	0%	0%	0%	0%
Overland boundary outflow	-1195	-1192	-1185	-1182	-1172	0%	-1%	-1%	-2%
Canopy storage change	0	0	0	0	0	0%	0%	0%	0%
Snow storage change	0	0	0	0	0	0%	0%	0%	0%
Overland flow to river	-13	-12	-12	-12	-11	-8%	-8%	-8%	-15%
Overland storage change	14	14	14	13	13	0%	0%	-7%	-7%
Unsaturated storage change	-20	-22	-25	-24	-29	-10%	-25%	-20%	-45%
Saturated storage change	12	9	8	3	-5	-25%	-33%	-75%	-142%
Baseflow to river	-15	-15	-15	-14	-14	0%	0%	-7%	-7%
Baseflow from river	5	5	5	5	5	0%	0%	0%	0%
Subsurface boundary inflow	1269	1273	1273	1273	1269	0%	0%	0%	0%
Subsurface boundary outflow	-117	-116	-115	-115	-113	-1%	-2%	-2%	-3%
Infiltration includes evapotranspiration	353	348	343	336	316	-1%	-3%	-5%	-10%
Exfiltration includes evapotranspiration	-1484	-1485	-1482	-1481	-1469	0%	0%	0%	-1%
Water balance change	-93	-98	-100	-106	-132	-5%	-8%	-14%	-42%

The surface inflow component from the outer catchment is zero under both temperature conditions, and consequently, the surface watersheds are correctly determined. The canopy water and snowpack for each temperature increment have values less than 0.03 mm, thus they are equivalent to zero when rounded. Groundwater discharge components vary slightly (1%-3%). This suggests that, on the one hand, groundwater feeds deep riverbeds and cavities and, on the other hand, groundwater is subject to additional downward seepage. It is important for the water balance of the area that the groundwater influence from external catchments is stable. The results show groundwater inflows fluctuating between 1,269 mm and 1,273 mm, which can be considered stable. However, this amount is not able to compensate for the water losses (Table 4).

Simulated water balances for the whole of 2018 show a value of around -93 mm, which means, that practically 200 million m^3 of water leaving the water system. The temperature increases of +0.3°C, +0.5°C, +0.7°C and +1.5°C can result in 5% (5 mm), 8% (7 mm), 14% (13 mm) and 42% (39 mm) less water in the Dong-ér catchment, i.e. nearly 11 million m^3, 15 million m^3, 28 million m^3 and 83 million m^3 less water than the 2018 baseline, respectively. In other words, increased temperatures result in increased water loss through evapotranspiration, leading to a significant reduction in the water availability of the catchment. Consequently, groundwater resources (unsaturated zone and saturated zone water resources), hydrological regime, infiltration, and surface runoff to the channel components are more sensitive to changes in evapotranspiration (varying from 1% to 7%), making these components more sensitive to temperature increases due to climate change.

4. Conclusions

The unsaturated zone deficit, infiltration into the unsaturated zone, evapotranspiration and overland flow parameters appear to have a significant impact on the diurnal hydrological circulation and appear to be very sensitive to changing climatic conditions.

Based on the relationship between the manifestations of climate change and the components of the hydrological regime, the subsurface boundary inflow and evapotranspiration are likely to be the two main driving forces that form and regulate the hydrological regime of the Dong-ér catchment. According to the models, the water balance in the Dong-ér catchment is largely determined by the subsurface marginal inflow, as it continuously supplies about ~90% of the surface water. The subsurface marginal inflow shows no close relationship to temperature changes or extreme precipitation events. Therefore, this parameter is unlikely to be affected by the manifestations of climate change. Evapotranspiration, on the other hand, is strongly dependent on temperature. Due to the warming trend, the water retention of the Dong-ér Stream showed a decreasing trend, especially in areas where the water table is lower than the bottom of the stream. The components that play important roles in the water regime of the Dong-ér catchment are, in descending order: marginal surface inflow, marginal surface runoff, evapotranspiration, and precipitation. The components most sensitive to climate change include changes in subsurface storage, infiltration including evapotranspiration, overland flow to the stream, changes in overland storage, and evapotranspiration components.

In the model structure, the soil composition plays an important role in estimating both the groundwater balance and the water balance. When simulating with detailed soil properties, the results for surface runoff, subsurface runoff, near-surface runoff and near-surface flows exceed the values of the steady-state version. Therefore, it is strongly recommended to define the soil properties in the unsaturated zone in as much detail as possible.

Based on the modelled water balance changes, the temperature increases of +0.3°C, +0.5°C, +0.7°C and +1.5°C cause a larger volume of water loss than our measurements indicated during the drought year of 2018 in the Dong-ér catchment area. Ultimately, this leads to the water regime of the catchment area getting into a state of water scarcity. In the context of climate change, the rising temperature has a major impact on evapotranspiration, thereby greatly affecting the water balance of the Dong-r catchment. The limitation of the one-at-time method is that it does not take into account temperature-dependent parameters such as potential evapotranspiration, LAI [36], vegetation change. This causes certain errors in the output, but these errors are insignificant compared to the fluctuations in the system's water resources.

The results of the study have also demonstrated the effectiveness of the MIKE SHE model and its water balance calculation module as useful tools for the analysis and assessment of the impacts of climate change. In addition, the need for a large amount of high-quality data, the difficulty of monitoring environmental parameters, as well as changing environmental conditions and the uncertainty of their predictability for the future are the main challenges and therefore need to be improved by which values of the calculated parameters cannot be absolutely accurate but can provide a good approximation and highlight the ongoing trends more effectively.

Author contribution statement: Set up the input data of model; Analyzed and interpreted the data; Materials, analysis tools or data; Simulated the model; Analyzed and interpreted the results; Wrote the draft manuscript: H.Q.T.; Collected the data; analyzed and interpreted the data; Analyzed and interpreted the results; Materials, manuscript editing: Z.Z.F.

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