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Assessment of Groundwater Recharge, Evaporation, and Runoff in the Drava Basin in Hungary with the WetSpass Model

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Received: 7 January 2019; Accepted: 13 March 2019; Published: 16 March 2019

Abstract: The assessment of spatial and temporal distribution of groundwater recharge is required as an input to develop the regional groundwater model in the Drava flood plain for more accurate simulations of different management scenarios. WetSpass-M, a GIS-based spatially-distributed water balance model, was implemented to assess monthly, seasonal, and the annual averages of groundwater recharge, surface runoff and actual evapotranspiration in the Drava basin, Hungary for the period between 2000–2018. The basic relevant input-data for the Wetspass-M model is prepared in grid-maps using the tool ARCGIS tool. It comprises monthly climatological recordings (e.g., rainfall, temperature, wind speed), distributed land cover, soil map, groundwater depth, topography, and slope. The long-term temporal and spatial average monthly precipitation (58 mm) is distributed as 29% (17 mm) surface runoff, 27% (16 mm) actual evapotranspiration, and 44% (25 mm) groundwater recharge. The mean annual groundwater recharge, actual evapotranspiration, and surface runoff were 307, 190, and 199 mm, respectively. The findings of the WetSpass-M model are intended to support integrated groundwater modeling. The analysis of simulation results shows that WetSpass-M model works properly to simulate hydrological water budget components in the Drava basin. Moreover, a better understanding of the simulated long-term average spatial distribution about water balance components is useful for managing and planning the available water resources in the Drava basin.

Keywords: Groundwater Recharge; WetSpass-M Model; Water Balance; Drava Basin; Hungary

1. Introduction

Two billion people worldwide rely on groundwater for their water supply, irrigation for agriculture, and more. But a growing global population combined with climate change, pollution, and insufficient groundwater recharge leads to declining groundwater levels. Understanding the spatial extent and variation of groundwater levels is essential to protect available water resources, especially as a primary source for drinking water [1]. Protecting groundwater resources in the Drava basin is especially important for the provision of ecosystem services, landscape management, natural conservation, and economic development in improving agricultural productivity.

The Hungarian Drava floodplain is characterized by alternations of drought and floods periods. On the lower sections of the Drava River, the Drava river incision and entrenchment of the river resulted in decreasing groundwater levels in the adjacent floodplain by 1.5 to 2.5 m and increasing drought hazard [2,3]. Moreover, human interventions, such as (regulator constructions, extraction gravel from the river bed, improved water retention in the reservoir of hydroelectric dams.) led to dropping water stages in the river [4]. The water budget of Drava flood plain is unbalanced; the available water resources are not sufficient and efficient for ecosystem services, agricultural productivity, or natural conservation [5]. Consequently, to develop a groundwater model for the Drava flood plain requires accurate estimation of groundwater recharge as an input data and boundary condition. An integrated groundwater model of the flood plain is crucial to assessing the exchanges between surface water and groundwater at a critical part of this system under different hydrological conditions, and to quantify the water budget and water retention, under different management scenarios in the lower parts of the flood plain, in order to protect the wetland habitat and agricultural production.

Several techniques are used to assess the groundwater recharge quantities, including experimental methods, hydrological budget (HB), empirical methods, distributed hydrological budget (DHB), and water table fluctuation (WTF). Wang et al. [6] used experimental methods through isotope tracers, to evaluate groundwater recharge. Moon et al. [7] estimated groundwater recharge by applying a modified WTF and groundwater hydrographs for the basin of a river in South Korea. Manghi et al. [8] utilized (HB) method to estimate the groundwater recharge in Hemet subbasin, United States. According to the reported results, the annual long term average recharge was 12.5 million cubic meters, for the period between 1997 and 2005. Martin [9] applied WTF to quantify the annual average groundwater recharge in Atankwidi, West Africa. He found that the recharge varies from 13 mm to 143 mm. El-Rawy et al. [10] used DHB approach to estimate the distribution of recharge rate over Zarqa River Basin, Jordan. Salem et al. [11] used empirical methods based on WTF and precipitation depths to assess the groundwater recharge in Cún-Szaporca oxbow of Drava floodplain, Hungary.

Recently, energy and water transfer among plants, soil, and the atmosphere under a quasi-steady state (WetSpass) model [12], has been used widely for groundwater recharge assessment. Abdollahi et al. [13] developed a WetSpass-M model by downscaling the seasonal resolution to monthly scale. AbuSaleem [14] developed a modified WetSpass model WetSpass-Jor, for watersheds by adjusting the parameters for Jordanian conditions. WetSpass model has been shown to help better characterize recharge, including its variety over geographical areas in the world. It has been successfully used in Belgium [12] and different environments like Hasa and Jafr basin, Jordan [15,16], Birki watershed, Werii watershed, and Geba basin, Ethiopia [17–19], Mashhad basin, Iran [20], Takelsa multilayer aquifer in northeastern Tunisia [21], Gaza Strip, Palestine [22], and it works well in the Nile Delta aquifer, Egypt [23]. A better understanding of the temporal and spatial variations of water balance components, especially actual evapotranspiration, surface runoff, and recharge, is crucial for a sustainable, and efficient management of water resources in the Drava basin. The main contribution of this paper were in assessing long-term spatial distribution of monthly, seasonal, and annual components of water budget, which will be used as an input for developing the groundwater model in the Drava Basin, Hungary.

2. Materials and Methods

2.1. Study Area

The Drava basin is located in south-western Hungary along the lower section of the Drava River. It lies between longitudes 17°26′13.05″ and 18°21′38.71″ East and latitudes 46°3′20.05″ and 45°45′50.8″ North (Figure 1). This section of the river coincides with the Hungarian/Croatian border in an area of 1587 km^2. There are twenty major channels, eighteen major oxbow lakes, of 150 hectares, and thirteen tributary streams on the Hungarian side [24]. Ground Penetration Radar (GPR) and borehole samples show extreme spatial heterogeneity in the hydraulic properties of sediments in the Drava basin [25].

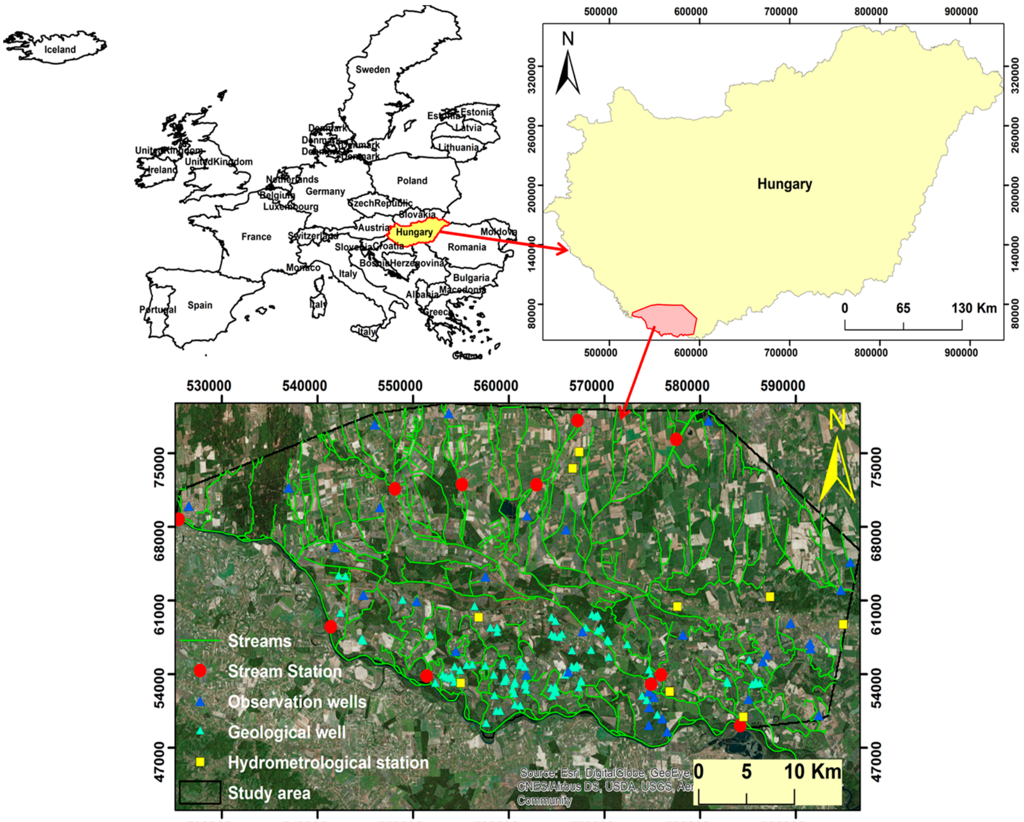


Figure 1. Location of Drava basin, Hungary; Location of stream station; Location of observation wells; Location of geological wells and Location of hydrometrological station.

2.2. WetSpass Model

Spatial distributed water balance quasi-steady state WetSpass model [12,26] stands for water and energy transfer among plants, soil, and atmosphere. A physically-based WetSpass model is usually applied to assess long-term mean spatial patterns of actual evapotranspiration, surface runoff, and groundwater recharge. In this paper, a WetSpass-M model is utilized to estimate the spatial groundwater recharge on monthly, seasonal, and annual scales. The total components of water balance of the vegetated, bare soil, open-water, and impervious fraction per raster cell are calculated using the following equations [12]:

$$\mathrm{ET_{raster}} = \mathrm{a_vET_v} + \mathrm{a_sE_s} + \mathrm{a_oE_o} + \mathrm{a_iE_i}, \tag{1}$$

$$\mathrm{S_{raster}} = \mathrm{a_vS_v} + \mathrm{a_sS_s} + \mathrm{a_oS_o} + \mathrm{a_iS_i}, \tag{2}$$

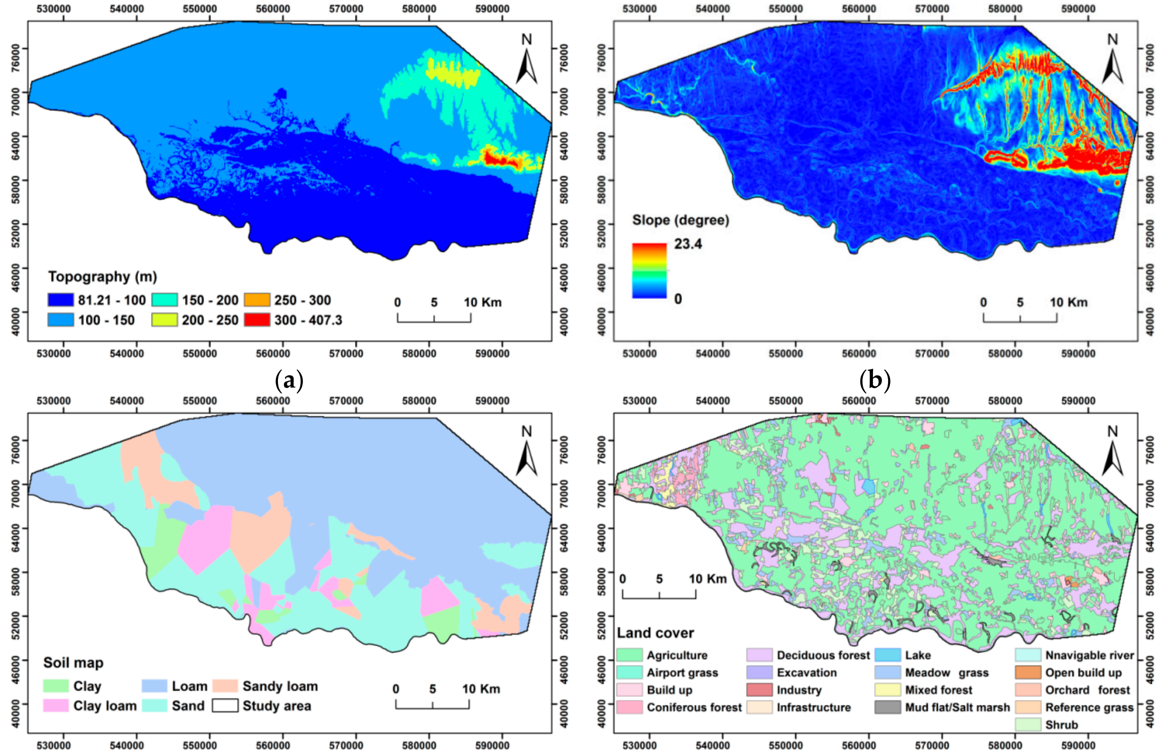
$$\mathrm{R_{raster}} = \mathrm{a_vR_v} + \mathrm{a_sR_s} + \mathrm{a_oR_o} + \mathrm{a_iR_i}, \tag{3}$$

where ETraster, Sraster and Rraster are total evapotranspiration, surface runoff, and groundwater recharge of a grid cell, respectively, each having a (v) vegetated, (s) bare-soil, (o) open-water, and (i) impervious area, respectively. The terms av, as, ao, and ai are the fraction area of vegetated, bare-soil, open-water, and impervious area, respectively. The equations of WetSpass-M model, that are used to compute monthly water balance components, are presented in Appendix A.

2.3. Input Data

The WetSpass–M model requires a set of basic input data, including meteorological data (precipitation, air temperature, wind speed, and potential evapotranspiration), distributed groundwater depth, LAI, soil types, topography (DEM and slope), and land use/land cover of the investigated area [13,26,27].

Such input data are prepared as grid maps using Geographic Information Systems (ARCGIS) collected for the period from 2000 to 2018. The cell size of the raster is 100 m × 100 m with total number of (761,350) raster cells. A Digital Elevation Model (DEM) (Figure 2a) with 10 m resolution is obtained from the south-trans Danubian water management directorate, the highest point of the study area, was 407m, in the eastern part of the area at Villany hills, and the lowest point was 81m in the southwest of the case study. The mean elevation of the Drava basin is found to be 114 m. The slope map is derived from the DEM in ArcGIS, using the slope analysis tool. The slope varies from 0% to 23% with an average value of 0.7% (Figure 2b).



(**a**) (**b**)

(**c**) (**d**)

Figure 2. Input data for the model (**a**) topography; (**b**) slope; (**c**) soil texture map; and (**d**) land-cover map of Drava Basin.

The spatial soil map (Figure 2c) is constructed using the Thiessen polygon method for 89 geological bore holes (Figure 1). The missing part of the study area is obtained from AGROTOPE base [28]. The dominant soil textures of the case study are loam, sand, sandy loam, clay loam, and clay, which cover 53%, 27%, 9%, 7%, and 4 % of the study area, respectively. Land use and land cover patterns of the Drava basin are obtained from the CORINE database for Land Cover (CLC 2012) with a scale of 1: 50,000, this is online available in the website: https://land.copernicus.eu/pan-european/corine-land-cover.

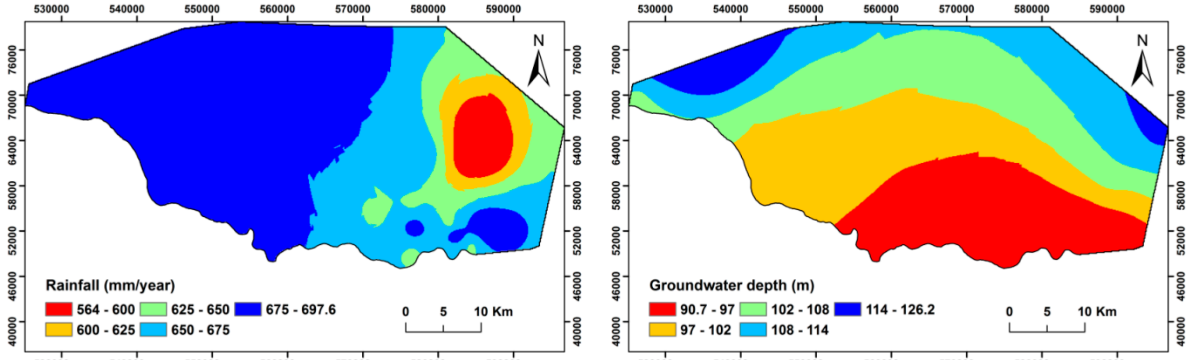
The investigated area is characterized by 17 land cover forms as depicted in (Figure 2d). It is dominated by agricultural area of (69%), forestland area of (25%), artificial surface area of (4%), and a total area of wetlands and water bodies of (2%). Monthly dataset of meteorological parameters for the period 2000–2018 is obtained from south-trans Danubian water management directorate through 9 meteorological stations (Figure 1). The long-term spatial distribution of average annual rainfall for the period from 2000 to 2018 is shown in (Figure 3a). The average annual precipitation shows a large variation between 398 mm/year and 1072 mm/, with a mean value of 696 mm/year and a standard deviation of 161 mm/year. The Drava flood plain receives about 60% of the annual precipitation in rainy season (summer and spring), with the remaining 40% in the dry season (winter and autumn). The potential evapotranspiration (PET) is calculated by Thornthwaite formula from meteorological data [29,30]. Thornthwaite take into consideration the average monthly temperature and the thermal index:

$$\mathrm{PET} = 1.6\,\mathrm{K}\left(\frac{10\mathrm{T}}{\mathrm{I}}\right)^{\mathrm{a}}, \tag{4}$$

where PET is the monthly potential evapotranspiration in cm, T is the monthly mean air temperature in Celsius, a = $0.000000675\mathrm{I}^3 - 0.0000771\mathrm{I}^2 + 0.01792\mathrm{I} + 0.49239$, and I is the annual thermal index given by:

$$\mathrm{I} = \sum_{m=1}^{12} i_m \quad i_m = \left(\frac{t_m}{5}\right)^{1.514}, \tag{5}$$

where, i_m is the monthly thermal index, and T_m is the mean air temperature in Celsius for the month m, where m takes any value between 1 and 12.



(**a**) (**b**)

Figure 3. (**a**) The spatial average annual rainfall distribution; (**b**) Spatial distribution of groundwater level.

Thirty-five observation wells (Figure 1) for daily groundwater depth data are obtained from the south-trans Danubian water management directorate for the period from 2000 to 2018. The distributed map of monthly groundwater depth is produced using Kriging interpolation as shown in (Figure 3b). The monthly average leaf area index (LAI) is obtained from commission (EU) open data portal [31], which can be downloaded from: http://data.europa.eu/89h/jrc-mappe-europe-setup-d-18-lai.

3. Results and Discussion

The main outputs of the WetSpass-M model are raster maps of monthly groundwater recharge, surface runoff, actual evapotranspiration, and interception for the period 2000 to 2018 (223 time steps). In these maps, every pixel represents the magnitude of the water budget component (in mm). A WetSpass-M model calculates the total actual evapotranspiration per pixel as a sum of evaporations from open water, impervious surface area, bare soil, interception of vegetated area, and the transpiration of the vegetative cover [13,32]. This research is the first study to assess spatial and temporal distribution of groundwater recharge in the Drava flood plain. The WetSpass results for water balance components will be used as an integrated groundwater modeling inputs and boundary conditions in the Drava basin.

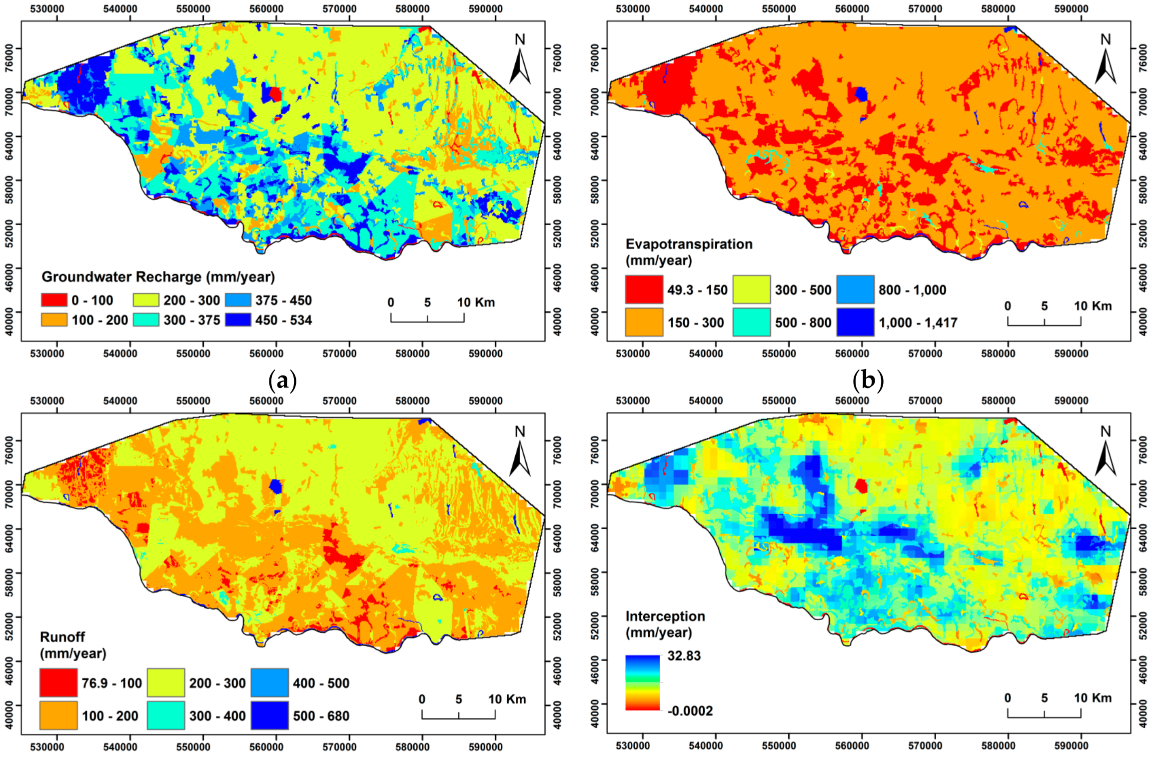
The spatial monthly, seasonal and annual actual evapotranspiration, simulated by the WetSpass model, are presented in (Table 1). Assessment of water balance components on the annual scale are required to evaluate the total water budget of the Drava flood plain, also for monthly and seasonal scale to determine the agriculture water requirements. The simulated monthly long-term actual evapotranspiration of the Drava flood plain ranges from 0 mm/month to 67 mm/month as the lowest and highest values. The mean and standard deviation are 16 mm and 14 mm. The total annual actual evapotranspiration is determined by accumulating the simulated monthly of actual evapotranspiration in the Drava basin. The annual average of evapotranspiration varies from 127 mm/year to 263 mm/year as the minimum and maximum values, with an average value of 190 mm/year and a standard deviation of 39 mm/year (Table 1). The average actual evapotranspiration represents 27% of the annual average rainfall (Figure 4b), of which an average of 158 mm (83 %) takes place during the wet seasons (spring and summer), while the remaining 32 mm (17 %) occurs in the dry seasons (winter and autumn) (Table 1). This variation is a result of the rainfall differences within the two seasons. High annual and seasonal actual evapotranspiration are observed in northern west of the Drava basin because of the higher rainfall, while the north-east part, which receive less precipitation, has a lower evapotranspiration as depicted in (Figure 4b).

Table 1. Long-term monthly, annual, and seasonal Wetspass simulated components of the Drava basin during 2000-2018.

Period	Value	Precipitation (mm)	Recharge (mm)	Evapotranspiration (mm)	Runoff (mm)
Monthly	**Range**	0–229	0–58	0–67	0–114
	Average	58	25	16	17
	Std. dev.	28	10	14	13
Annual	**Range**	398–1072	175–412	127–263	77–418
	Average	696	307	190	199
	Std. dev.	161	55	39	81
Winter	**Range**	44–202	30–121	6–16	9–71
	Average	129	81	11	37
	Std. dev.	47	28	3	18
Spring	**Range**	93–414	48–102	41–138	10–187
	Average	215	72	83	59
	Std. dev.	67	14	23	39
Summer	**Range**	94–334	50–104	40–152	9–123
	Average	200	76	76	46
	Std. dev.	62	14	24	32
Autumn	**Range**	82–228	49–110	13–31	22–96
	Average	153	77	21	57
	Std. dev.	38	17	4	23

The spatial distribution of annual average interception is given in (Figure 4d). Such annual average interception ranges from 10 mm/year to 15 mm/year, with an average interception rate of 13 mm/year. The southern part of the Drava basin has the highest interception, due to presence of a dense vegetation cover (Figure 4d). About 91% of the simulated interception occurs in wet seasons (spring and summer), while the remaining 9% takes place in dry seasons (winter and autumn).

The used WetSpass-M model calculates monthly surface runoff in (mm/month) using a rationale method through an actual surface runoff and soil moisture coefficient [13]. The monthly, seasonal, and annual WetSpass simulated runoffs in the basin are presented in (Table 1). The estimated monthly surface runoff varies from 0 mm/month to a maximum of 114 mm/month, with an average value of 17 mm/month and a standard deviation of 13 mm/month. Annual surface runoff is calculated by accumulating the simulated monthly values during the whole period. The annual actual surface runoff shows large spatial variation, with values between 77 mm and 418 mm. The average and standard deviation of this distribution are 199 mm/y, and 81 mm/y, respectively (Table 1). The mean surface runoff in the basin constitutes about 29% of the annual mean rainfall. The mean surface runoff in summer and spring seasons are 105 mm, while the average runoff in winter and autumn seasons are approximately 94 mm. As presented in (Figure 1c), the northeastern hill has a high seasonal and annual surface runoff rate attributed to steep slope. The highest mean seasonal and annual surface runoff of the Drava flood plain are observed in northern part attributed to presence of clay, clay loam and loam soils those have low permeability, which increases the surface runoff. On the other hand, the lowest runoff occurs in southwestern and central area due to the presence of sand and sandy loam soils. This clearly reveals that the soil map is strongly affected on the spatial distribution of surface runoff.

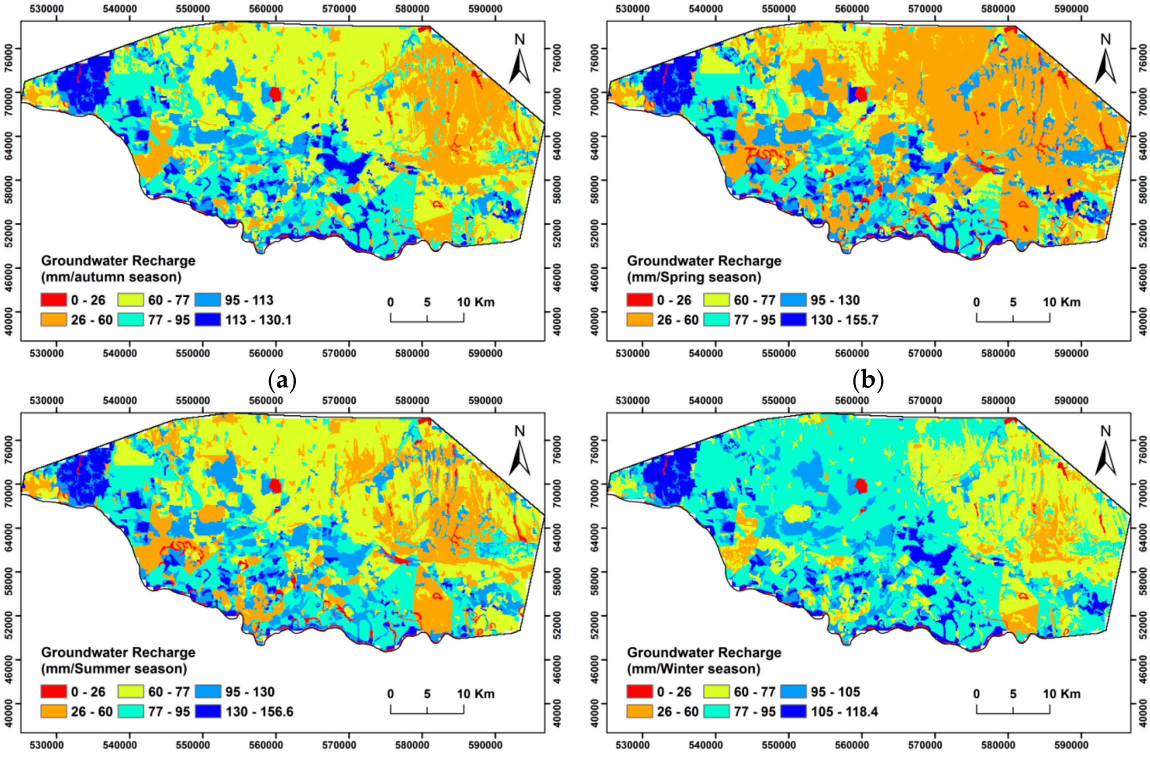


(**a**) (**b**) (**c**) (**d**)

Figure 4. Spatial distribution of simulated mean water balance component (**a**) groundwater recharge; (**b**) actual evapotranspiration; (**c**) surface runoff; and (**d**) interception.

Groundwater recharge is an essential factor to assess groundwater resources; however, it is difficult to evaluate groundwater recharge [33,34]. The WetSpass-M model evaluates long-term spatial distribution of monthly groundwater recharge for the Drava flood plain as a residual term of the water budget components, by subtracting the monthly surface runoff and actual evapotranspiration from the monthly rainfall. The spatial distribution of groundwater recharge relies on topography, slope, soil type, land cover/land-use, and climatological conditions [35]. Winter, spring, summer, and autumn groundwater recharge of the Drava basin changes spatially with the basin characteristics and topography (Figure 5a–d). The WetSpass-M model evaluates the monthly long-term groundwater recharge of the Drava floodplain to be 0 mm and 58 mm as minimum and maximum values, respectively, with a standard deviation of 10 mm/month and mean value of 25 mm/month (Table 1). The average annual groundwater recharge is determined based on monthly simulated data. The maximum, minimum, and mean values of annual groundwater recharge for the whole period are 412 mm, 175 mm, and 307 mm, respectively. The average recharge attributes to 44% of the total average annual rainfall (Figure 4a). The average long-term groundwater recharge in dry (winter and autumn) and wet (summer and spring) seasons are 158 mm, and 148 mm, respectively.

About 52% of the annual groundwater recharge takes place in the winter and autumn seasons (Figure 5a,d), while the remaining 48% occurs in the summer and spring seasons (Figure 5b,c). As shown in (Figure 4a), the central western part of the Drava basin that receives high value of precipitation has higher annual and seasonal groundwater recharge. Also, forests and agriculture areas, in the southern and central parts of the Drava basin, are characterized by high groundwater recharge due to presence of permeable (sand and sandy loam) soils with apparently flat topography. On the other hand, the northern part accounted for a lower rate of annual and seasonal groundwater recharge, attributed to presence of shrub and mudflat cover, with less permeable loam soil (Figure 5a–d). In general, the groundwater recharge analysis reveals that higher values are observed in agricultural land with permeable soils.



(**a**) (**b**)

(**c**) (**d**)

Figure 5. Simulated spatial distribution of average groundwater recharge in the Drava basin (**a**) Winter; (**b**) Spring; (**c**) Summer; and (**d**) Autumn.

4. Conclusions

The groundwater recharge in the Drava basin was evaluated by applying the WetSpass-M model, which is crucial for integrated groundwater modelling of the Drava basin and optimal long-term planning and management of the available water resources in the basin. The spatial variability of groundwater recharge relies on climate conditions, groundwater depth, distributed land-cover, soil texture, topography, and slope. Land cover and soil textures are dominated by agricultural area and loam in Drava basin. The WetSpass-M model estimates the annually actual evapotranspiration of the basin, for the period from 2000 to 2018, was 127 mm, and 263 mm as minimum, and maximum values respectively. This represents 27% of the annual average precipitation. While 83% of total evapotranspiration occurs in the wet season, the remaining 17% occurs during dry seasons. Around 29% (199 mm/year) of the average annually rainfall is accounted to surface runoff with a minimum and maximum average values 77 mm/ year, and 418 mm/ year, respectively. Annually simulated groundwater recharge ranges from 175 mm/ year to 412 mm/ year with an average of 307 mm/ year, which attributes for 44% of the mean annually rainfall. The outputs of the WetSpass-M model revealed a favorable structure of water balance in the Drava flood plain, with the dominance of groundwater recharge. Thus, using the groundwater recharge assessment is recommended in developing groundwater flow models for the Drava basin.

Author Contributions: Conceptualization, methodology, and investigation, A.S., D.J., and M.E.; building the model, formal analysis, and writing the paper, A.S.; review and editing the paper, and supervision, D.J. and M.E.

Funding: This research was funded by the project FEKUTSTRAT (No. 20765-3/2018) “Innovation for a Sustainable, Healthy Life and Environment” Grant.

Acknowledgments: The present scientific contribution is dedicated to the 650th anniversary of the foundation of the University of Pécs, Hungary. The first author would like to thank the Egyptian Ministry of Higher Education (MoHE) and tempus public foundation for providing him he Stipendium Hungaricum Scholarship. Also, the authors are grateful for financial support by FEKUTSTRAT (No. 20765-3/2018) Innovation for a

Sustainable, Healthy Life and Environment Grant and to the South-Transdanubian Water Management Directorate for providing access to the necessary data.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Assessment of monthly water balance components using WetSpass-M model

The monthly water balance per a grid cell can be represented by:

$$\mathrm{P_m} = \mathrm{SR_m} + \mathrm{ET_m} + \mathrm{R_m}, \tag{A1}$$

where $\mathrm{P_m}$ is the monthly precipitation, $\mathrm{SR_m}$ is the monthly surface runoff, $\mathrm{ET_m}$ is the monthly evapotranspiration, and $\mathrm{R_m}$ is monthly groundwater recharge. The surface runoff (SR) calculation is relied on the relationship between the land-use, soil, slope, precipitation intensity, interception, and soil infiltration capacity. $\mathrm{SR_m}$ is calculated on the monthly scale using:

$$\mathrm{SR_m} = \mathrm{C_{sr}}\ \mathrm{C_h}\ (\mathrm{P_m} - \mathrm{I_m}), \tag{A2}$$

where $\mathrm{I_m}$ is the monthly interception, $\mathrm{C_{sr}}$ is the actual surface runoff coefficient (-) that represents the monthly precipitation part, which contributes, directly, to runoff, and $\mathrm{C_h}$ is a coefficient that describes the moisture condition of soil [20]. Monthly interception ($\mathrm{I_m}$) is determined by:

$$\mathrm{I_m} = \mathrm{P_m}\ \mathrm{I_R}, \tag{A3}$$

where $\mathrm{I_m}$ is the interception [mm/month], $\mathrm{P_m}$ is monthly precipitation [mm/month] and $\mathrm{I_R}$ is interception ratio. In WetSpass-M, the total monthly evapotranspiration per grid cell (ETm; mm/month) is determined by:

$$\mathrm{ET_m} = \mathrm{a_v ET_v} + \mathrm{a_s ET_s} + \mathrm{a_o ET_o} + \mathrm{a_i ET_i}, \tag{A4}$$

where the area fraction and evapotranspiration for vegetated cover area, bare soil, open water and impervious surface are denoted by $\mathrm{a_v}$, $\mathrm{ET_v}$, $\mathrm{a_s}$, $\mathrm{ET_s}$, $\mathrm{a_o}$, $\mathrm{ET_o}$, $\mathrm{a_i}$, and $\mathrm{ET_i}$, respectively. Vegetated area Evapotranspiration ($\mathrm{ET_v}$) is a summation of actual transpiration and interception for the vegetated cover area [32]. Monthly groundwater recharge $\mathrm{R_m}$ (mm/month) in WetSpass-M is determined as a residual parameter of water balance:

$$\mathrm{R_m} = \mathrm{P_m} - \mathrm{SR_m} - \mathrm{ET_m}, \tag{A5}$$

where $\mathrm{P_m}$ is the monthly precipitation, $\mathrm{SR_m}$ is the monthly surface runoff, and $\mathrm{ET_m}$ is the monthly evapotranspiration [13].

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