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Characterising the basic water balance parameters of Debrecen

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SUMMARY

This work aims to develop a hydrological modelling tool to help managers make the right decisions for Debrecen, in the face of water scarcity and the increase in agricultural and domestic needs over time. The methodology was based on the creation of a climatic database, at monthly time steps, from 2016 to 2019, and cartographic (land use, digital elevation model, and hydrological network). As a next step, the watershed was delimitated into sub-basins to determine the shape and the physiographic characteristics of sub-watersheds. Finally, a hydrological study was prepared by calculating the time of concentration to build a database of water resources in the study area. This water resource will be used as an input parameter for urban farming.

Keywords: *urban hydrology; watershed; GIS; water cycle; hydrographic network*

INTRODUCTION

Water is an essential natural resource for life. The existing planetary freshwater stock is very low when compared to the mass of salt water that covers 70% of the earth's surface (Goude, 2011). This precious fresh water is not only inequitably distributed but is becoming scarce. In the last 60 years, its consumption has multiplied by six times. Globally, 71% of this available water (rain, soil reserve) is used for crop irrigation. The scarcity, coupled with the increase in the population, creates a challenge to be overcome to double food production by 2030, while consuming less water due to the constraints imposed by the extension of urbanization, the industrialization or even climate change as indicated by Shinde (2005).

Water resources are an integral part of the socio-economic and environmental system, which is a complex artificial sub-ecosystem dominated by humans (Zhang et al., 2007) therefore its allocation must respect a balance between these three dimensions. As a result, to make an informed decision, a greater understanding of the factors that influence the supply and demand of water resources is required (Zhang et al., 2007).

Reliable estimates of runoff generated from watersheds are required that help watershed managers and stakeholders to make information-based decisions on water planning and management. Good management of water resources depends on its ability to balance the natural availability of water with the pressures exerted by users (Rees et al., 2005).

This research aims are:

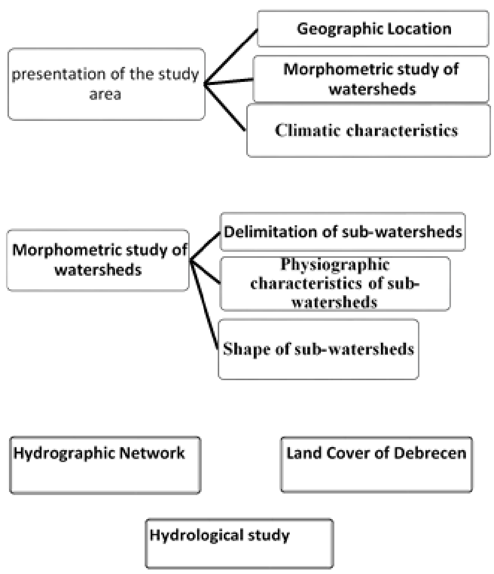
- Prepare a morphometric study of watersheds and physiographic characteristics of sub-watersheds,
- Study the water resources in the basin,
- and a hydrological study by calculating the Concentration time (hours).

MATERIALS AND METHODS

The methodology adopted was based primarily on the construction of a cartographic, climatic, and physical database covering the study area. The simulation period covers the years between 2016 and 2019. The maps of this study are created using ArcGIS and Global-Mapper software's. The second stage was determining the watershed properties by the sub-watershed's delimitation.

Finally, extraction of different physical and geometric characteristics of each sub-watershed to be able to calculate the flow rates and know the water resources in the study area (*Figure 1*).

Figure 1: **Methodology chart**



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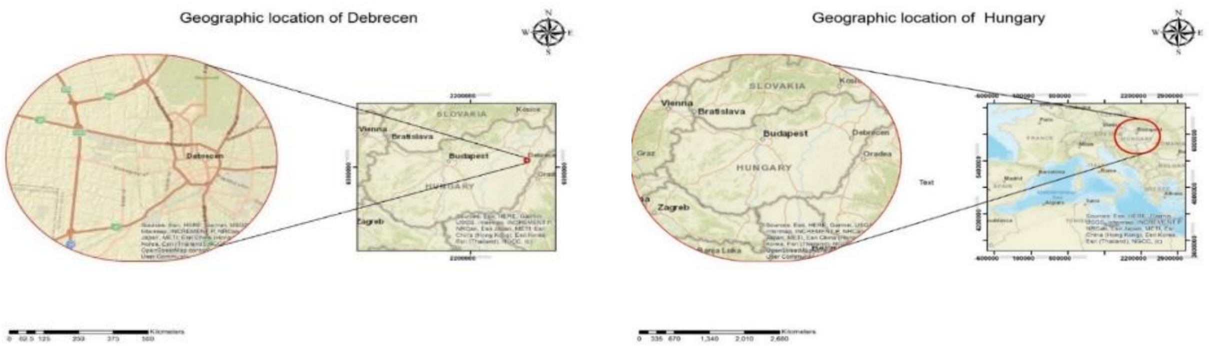
Description of the study area

Debrecen is located on the Great Hungarian Plain, 220 km east of Budapest. Debrecen is Hungary's second largest city after Budapest. It covers a total area of 461.25 km^2. It is the centre of the Northern Great Plain region and belongs to Hajdú-Bihar county (*Figure 2*).

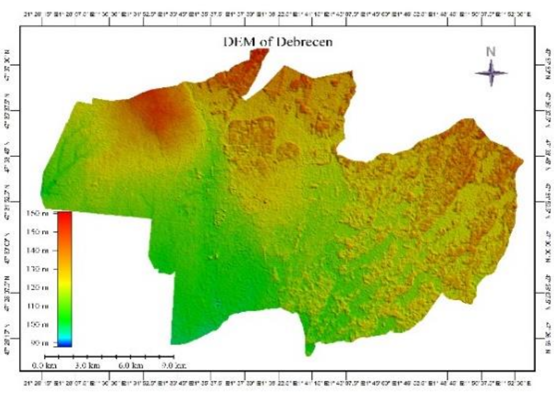
Figure 2: **Geographic location of Debrecen**



Geomorphological characteristics: topography of the region

Topography is used to determine the local flow directions that make it possible to determine the position of the hydrographic network and the boundaries of basins as well as sub-watersheds. The Digital Elevation Model (DEM) has a spatial resolution of 10 m (*Figure 3*) (Refsgaard et al., 1997).

Figure 3: **Digital Elevation Model of Debrecen**

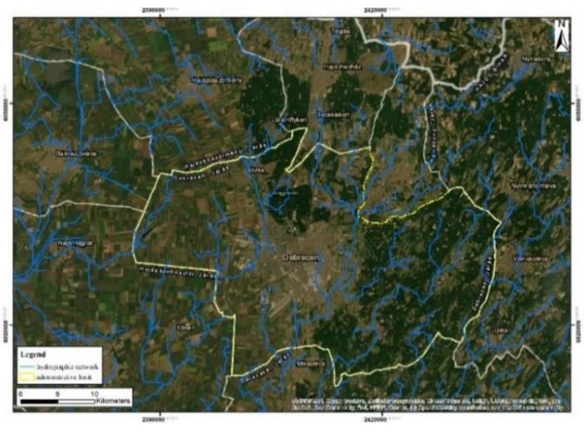


The DEM of Debrecen was created by using ArcGIS, as it is presented in the above figure; the highest level of elevation in Debrecen is between 150 and 161 m, while the lowest elevation level is around 97 m.

Hydrographic network

After layering the Shape file layers of the digital elevation model and the hydrographic network using ArcMap, a map was obtained, which represents the hydrographic network of Debrecen. The hydrographic network represents all the watercourses (rivers, lakes, etc.) that drain toward a reference point from a specific region. The primary stream of water is tributary by multiple secondary water streams (WOHL, 2009). In fact, this drainage network, is built on the primary stream of water combined with all the secondary stream channels of water (*Figure 4*).

Figure 4: **Hydrographic network of Debrecen**



Determination of the concentration time of sub-watersheds

For hydrologists, time of concentration (tc) is one of the most important parameters to be able to predict the response of a watershed to a given rain event and plays a key role in rainfall-runoff simulation. The hydrological reaction of a watershed to a particular solicitation is characterized by its speed and intensity. These two characteristics are a function of the type and intensity of the precipitation and of a variable characterizing the state of the watershed: the time of water concentration in the basin. (Muzy, 2003).

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Concentration time is the time between the onset of precipitation and reaching maximum flow at the outlet of the watershed. It is the time required for water to flow from the most remote point of the watershed to the outlet. (Welle and Woodward, 1986). Several methods have been developed to calculate the concentration time of a watershed. In this study, Kirpich's formula had been used (Edris et al., 2016).

$$c = 0.945 \times \left(\frac{L^{1.155}}{H^{0.385}} \right) \qquad (1)$$

where,
tc: concentration time (hours),
L: length of the main thalweg (km),
H: difference in elevation between the ends of the thalweg (m)

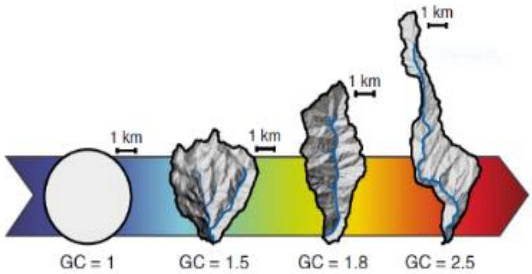
Shape of sub-watersheds

The shape of a watershed is characterized by its compactness index. This index is established by comparing the perimeter of the catchment area (P) to a circle, which has the same area (S). Kc can be calculated by the following formula (Timothée et al., 2018):

$$Kc = 0.282 \times \text{P}/\sqrt{S} \qquad (2)$$

Where S and P are the compactness indices of the area and the perimeter of the watershed, respectively. Thus, the watersheds can be classified according to the value of KC as shown in the following figure (Timothée et al., 2018).

Figure 5: **Gravelius compactness index Scale**



Climatic characteristics

The climatic data provided for the study area come from the meteorological sites (I1), (I2) and (I3), as indicated in the subsequent sections. The highest and lowest temperatures are indicated in *Figure 6.*

As demonstrated in this figure, it can be seen that the average maximum temperature is 0.7 °C in January. The warmest month (with the highest average maximum temperature) is July (27.1 °C). The month with the lowest average maximum temperature is January (0.7 °C). And the average minimum temperature in January is -5.7 °C. The month with the highest average minimum temperature is July (14.3 °C). The coldest month (with the lowest average minimum temperature) is January (-5.7 °C). The wettest month (with the highest rainfall) is June (72.9 mm). The driest months (with the lowest rainfall) are February and March (31.6 mm). *Figure 7* summarizes the precipitation values for Debrecen in 2019.

Figure 6: **Max and min monthly temperatures (Tamás et al., 2019)**

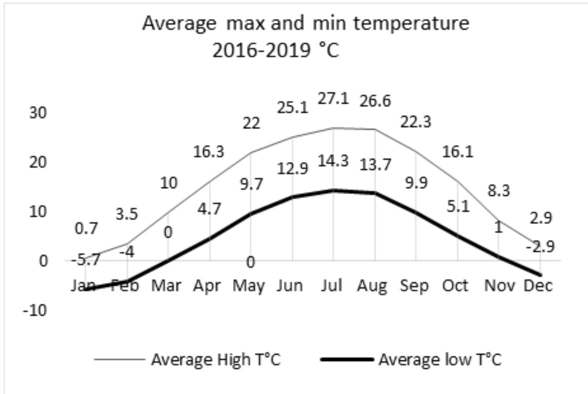
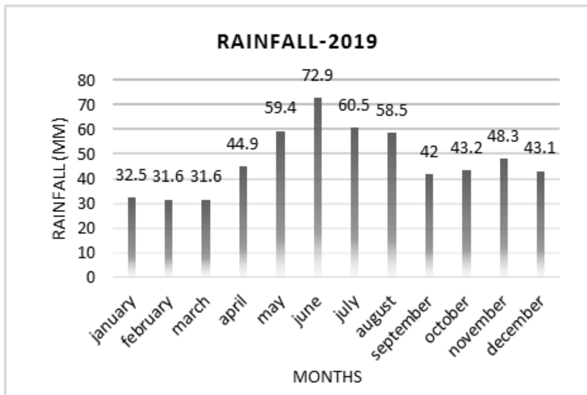
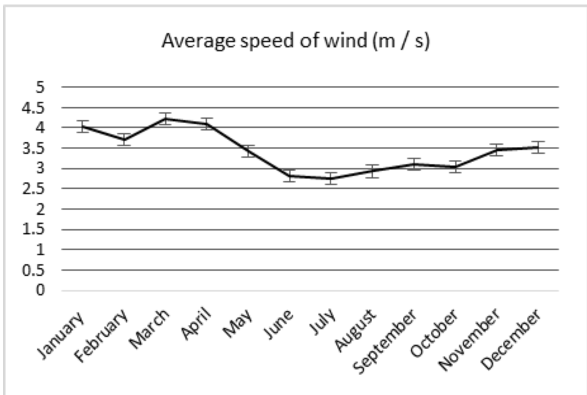


Figure 7: **Rainfall in Debrecen in 2019**



The recorded average monthly wind speed (I3) is 3.5 m s^{-1} (*Figure 8*).

Figure 8: **Wind speed rates recorded in 2019**



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As *Figure 8* shows, the months of March (4.2 m s^{-1}) and April (4.09 m s^{-1}) have the highest wind speed values recorded in 2019. It is well-known that wind speed is one of the natural factors that can have a significant effect on the water cycle.

RESULTS AND DISCUSSION

Land cover of the urban area of Debrecen

The following (*Figures 9* and *10*) provide an overview of the central and urban parts of Debrecen basin, along with the surface of every land cover type. This descriptive information was obtained via GIS statistical tool.

Figure 9: **Land cover of the urban area of Debrecen**

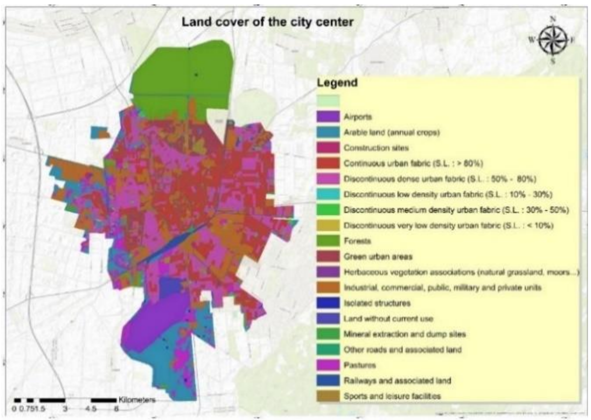
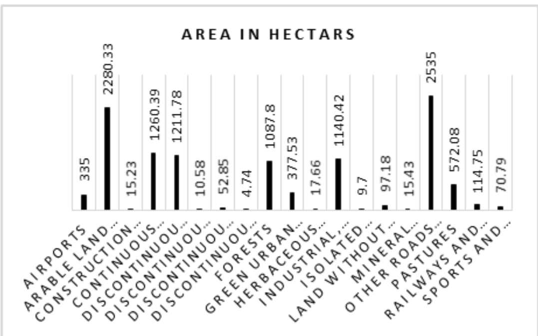


Figure 10: **Surface of each land cover class in the urban area of Debrecen**

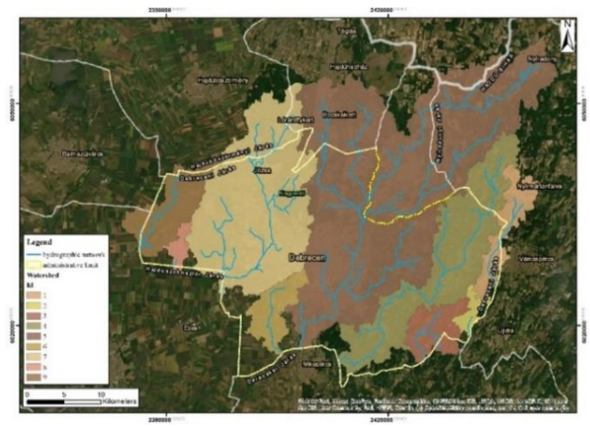


Airport, continuous urban fabric (S. L: > 80%), and industrial, commercial, public, military, and private units constitute 335, 1260 and 1140 hectares, respectively. Regarding green urban areas, sports and leisure facilities, land without current use, and pastures cover 70.79, 97.18 and 572.08 hectares, respectively. Railways and associated land, plus other roads and associated land extend over 114.75 as well as 2535 hectare, respectively. Furthermore, *Figure 9* indicates the surface of forests, extraction and dump sites, isolated structures, and arable lands, being of 1087.8, 15.43, 9.7, 2280.33 hectares, respectively.

Delimitation of sub-watersheds

Using Google Earth and ArcGIS software, the sub-watersheds of the study area were delimited and the various physical and geometric characteristics as well as the direction of the water flow were determined. Indeed, based on the digital elevation model with a spatial resolution of 30 m, ArcGIS makes it possible to analyse altitudes and determine the direction of water flow. The following map illustrates the different sub-watersheds in the study area as well as the hydrographic network and the administrative limit of Debrecen (*Figure 11*).

Figure 11: **Sub-watersheds and Hydrographic Network of Debrecen**



According to the above map, there are 9 sub-watersheds that are included in the study area with the total area of 1488 km^2. The physiographic characteristics of the sub-watershed were calculated using ArcGIS and summarized in the following table (*Table 1*).

Table 1: **Physiographic characteristics of the 9 sub-watersheds**

Id	Perimeter (Km)	Area (km^2)	Length (Km)
1	69.704	50.344	14.190
2	28.970	12.853	3.100
3	45.537	46.570	9.590
4	144.095	214.569	50.350
5	221.579	710.347	69.190
6	46.563	44.309	11.930
7	113.224	324.192	34.370
8	25.030	12.238	1.390
9	59.351	72.830	14.800

The table below shows the area, perimeter, and mainstream length for each sub-basin. The SB-5 is the biggest sub-basin covering 48% of the total study area

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with the mainstream length of 69.19 km, while SB-2 and SB-8 present the smallest sub-basins covering an area of 12.85 and 12.23 km^2, respectively. The shape of each sub-basin is determined by calculating the Gravelius compactness index (GC). After calculating Gravelius compactness index using the perimeter and the area of each sub-basin. The GC values had been compared with the scale values and presented in *Figure 5*. It was concluded that all the Gc values are greater than 1.8 which explain the rectangular and elongated shape of the 9 sub-basins (*Table 2*). The following table indicates the compactness index and the shape of each sub-watershed in the study area.

Table 2: **Gravelius compactness index and Basin Form**

Watershed	Compactness index (GC)	Basin Form
1	2.77	Elongated basin (Rectangular)
2	2.27	Elongated basin (Rectangular)
3	1.88	Elongated basin (Rectangular)
4	2.77	Elongated basin (Rectangular)
5	2.344	Elongated basin (Rectangular)
6	1.9	Elongated basin (Rectangular)
7	1.77	Elongated basin (Rectangular)
8	2	Elongated basin (Rectangular)
9	1.96	Elongated basin (Rectangular)

Time of concentration of the sub-watersheds (hours)

The time of concentration Tc for a watershed is a widely used time parameter to estimate peak discharges in hydrologic designs. In this study, Tc is estimated for 9 sub-watersheds using Kirpich's method. As it is shown in *Table 3*, sub-basins 4 and 5 have the concentration time of 15.13 and 28 hours, respectively which present the highest concentration times. These values are explained by the fact that these two sub-basins have the longest main streams, so it takes a longer time for water to reach the outlet. The results of the calculation of the concentration times of the sub-watersheds of the study area are given in *Table 3*.

Table 3: **Time of concentration of the sub-watersheds**

Id	Area (km^2)	Perimeter	H (m)	Concentration time (hours)
1	50.344	69.704	15.100	7.110
2	12.853	28.970	4.610	1.938
3	46.570	45.537	108.000	2.121
4	214.569	144.095	94.831	15.130
5	710.347	221.579	49.390	28.090
6	44.309	46.563	8.830	7.150
7	324.192	113.224	51.030	12.360
8	12.238	25.030	2.750	0.936
9	72.830	59.351	19.800	6.720

CONCLUSIONS

This study opens a new perspective based on the use of this tool for land use planning and integrated management of water resources at a watershed scale. This work also can lead to test different future scenarios related to the change in land cover and climatic change. The topography, land cover, sub-basins shapes and hydrographic network are necessary for the elaboration of a development scenario having as main objective the protection of the city against floods. Sustainable development of watersheds requires integration and coordination, including regarding land use issues, water conservation, and renewable energy sourcing. Achieving sustainable development will require making accurate decisions on future programs for watershed managers based on more precise information of watershed.

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