LAND COVER MODELLING WITH SENTINEL 2 IN WATER BALANCE CALCULATIONS OF URBAN SITES

SENTINEL 2 MŰHOLDRA ALAPOZOTT FELSZÍNBORÍTÁSI TÉRKÉPEZÉSI MÓDSZERTAN ÉS A VÁROSI TERÜLETEK VÍZMÉRLEGÉNEK KISZÁMÍTÁSÁBAN TÖRTÉNŐ ÉRTÉKELÉSE

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Abstract

This study investigates how a land cover map is produced using Sentinel 2 satellite images and how the resulting map is integrated with the calculation of hydrological parameters. Due to its capacity to deliver high-resolution spatial data, satellite imagery is increasingly being used for land cover mapping (1). The process involves several stages, including pre-processing of the Sentinel 2 imagery, image classification using machine learning algorithms, and post-processing of the classified image to generate a land cover map. The resulting land cover map is then integrated with hydrological parameters such as precipitation, evapotranspiration, and soil characteristics to calculate various hydrological parameters. Debrecen, north-east Hungary is the study area. This study's method is suitable for usage in other cities. Understanding the relationship between land cover and water availability requires the integration of the land cover map with hydrological parameters (2). The study demonstrates the potential of using remote sensing data for hydrological studies and highlights the importance of integrating various data sources for accurate estimation of hydrological parameters. The results show that the land cover classes have a significant impact on the water balance of urban sites. This study outlines the key steps involved in creating a land cover map using Sentinel 2 satellite imagery and integrating it with hydrological parameters calculation. The application of this strategy supports sustainable water management techniques and offers insightful information about a region's hydrological processes.
Keywords: *Urban hydrology, Sentinel 2, Machine learning algorithm, Evapotranspiration, Runoff and Infiltration*
JEL code: *Q1, Q24, Q25, Q56*

Összefoglalás

Ez a tanulmány arra keresi a választ, hogy a Sentinel 2 műholdfelvételek felhasználásával hogyan készíthető felszínborítási térkép, és ez hogyan integrálható egyes hidrológiai paraméterek kiszámításába. Mivel a műholdképek megfelelő felbontású térbeli adatokat képesek szolgáltatni, egyre gyakrabban használják őket a felszín feltérképezésére (1). A kutatás során végzett osztályozási folyamat a Sentinel 2 kép előfeldolgozásával indult, majd, a kép gépi tanulási algoritmusok segítségével történő osztályozását, valamint az osztályozott felszínborítottsági kép utófeldolgozását végeztük el. Az így kapott felszínborítottsági térképet ezután integráltuk az olyan hidrológiai paraméterekkel, mint a csapadék, a párolgás és a talaj

jellemzői, a különböző hidrológiai paraméterek kiszámításához. A vizsgált terület az Magyarország észak-keleti térségében elhelyezkedő Debrecen városa volt, reprezentálva egy közepes nagyságú város példáját, amely alapján a kidolgozott módszertan más hasionló városokra is kiterjeszthetővé válhat. A felszínborítottság és a vízkészletek közötti kapcsolat megértéséhez a felszínborítottsági térkép és a hidrológiai paraméterek integrálása szükséges (2). A tanulmány bemutatja a távérzékelési adatok hidrológiai vizsgálatokban való felhasználásának lehetőségeit, és rávilágít a különböző adatforrások integrálásának fontosságára a hidrológiai paraméterek pontos becslése érdekében. Az eredmények azt mutatják, hogy a felszínborítottság jelentős hatással van a városi területek vízháztartására. Ez a tanulmány felvázolja a Sentinel 2 műholdképek felhasználásával készült felszínborítottsági térkép kialakításának és a hidrológiai paraméterek számításával való integrálásának legfontosabb lépéseit. A kidolgozott módszertan tanulságos információkat nyújt egy városi régió hidrológiai folyamatairól és hozzájárul a fenntartható vízgazdálkodási tevékenységekhez.
Kulcsszavak: *városi hidrológia, sentinel 2, gépi tanulási algoritmus, evapotranspiráció, lefolyás és beszivárgás*
JEL kód: *Q1, Q24, Q25, Q56*

Introduction

Urbanization is a worldwide phenomenon that has led to rapid changes in land use and cover, which have had a substantial impact on the hydrological cycle (MCLEMAN et al., 2022). As cities grow, impermeable surfaces like highways, buildings, and paved areas replace natural land surfaces, which limiting infiltration and enhancing surface runoff. The management of water supplies, urban design, and environmental sustainability may be significantly impacted by these developments. (QINGYAN et al., 2021).
Remote sensing technology have been essential in providing accurate and timely information about land cover changes in recent years. The Sentinel-2 mission, launched by the European Space Agency (ESA), has distinguished itself as useful instrument for mapping and monitoring land cover among the numerous satellite sensors. Sentinel-2 is the perfect tool for monitoring metropolitan areas because it contains a multispectral imaging equipment that produces high-resolution imagery with a revisit period of 5 days (QIN et al., 2021).
Calculations of water balance are an essential part of hydrological research and are crucial for comprehending the availability and distribution of water resources in urban settings. The equation for the water balance takes into consideration a number of factors, including as precipitation, evapotranspiration, infiltration, and runoff (THORNDAHL et al., 2019 ; YANG et al., 2022). For the management of urban water resources, flood prediction, and drought assessment, accurate estimation of these components is essential (MANANDHAR et al., 2023).
Hydrological modeling in metropolitan settings can be made more accurate and reliable by integrating land cover data from Sentinel-2 imagery into water balance calculations. It is feasible to estimate the spatial distribution of evapotranspiration, infiltration rates, and surface runoff by mapping different land cover types and measuring their features, such as imperviousness and vegetation cover (CHEMAK et al., 2022).
This article investigates the use of Sentinel-2 imagery in land cover modeling for calculating water balance in urban areas. We will investigate how land cover classification works with Sentinel-2 data and evaluate how well it describes various land cover types in the city. In order to calculate evapotranspiration, infiltration, and runoff at the urban scale, we will also investigate the incorporation of land cover data into hydrological models.
The overall goal of this publication is to use Sentinel-2 imagery to close the gap between remote sensing, land cover modeling, and estimations of the water balance in cities. We want to

improve our understanding of urban hydrological processes and contribute to the sustainable management of water resources in urban areas by investigating the potential of this integrated approach.

Material and methods

To investigate the relationship between land cover and water balance, we utilized Sentinel-2 satellite imagery in combination with hydrological models. The study area selected for this research is an urban site characterized by mixed land cover types, including impervious surfaces, vegetation, and water bodies.

First, we obtained multispectral data from Sentinel-2, which provides imagery with a spatial resolution of 10 meters, allowing for detailed land cover classification. The data comprised several spectral bands, such as the red, green, blue, near-infrared, and shortwave infrared, which offer valuable information about the land surface characteristics (NAGY et al., 2007; NAGY - TAMÁS, 2009).

Next, we employed image processing techniques to preprocess the satellite imagery, including atmospheric correction and geometric correction. These steps ensured accurate and reliable data for land cover classification and subsequent analysis.

For land cover classification, we utilized a Support Vector Machine (SVM) approach, training a classifier with ground truth data collected through field surveys and high-resolution aerial imagery (DHRITI - MANSI, 2015). We considered various land cover classes, such as built dense areas, planted/cultivated areas, surface water bodies, forest and bare soil.

A crucial part of every classification process is carrying out an accuracy assessment. In this procedure, the classified raster image is compared to a well-known, trustworthy source of ground truth data, including Google Earth and Corine Land Cover images (YONABA et al., 2021).

Ground truth data from the Google Earth engine was used to generate 500 randomly selected points. A comparison between these sampling sites and the classified data within a confusion matrix was used to evaluate the accuracy of the newly classified land cover map.

Once the land cover classification was completed, we integrated the results with a hydrological model. This model considered factors such as evapotranspiration, infiltration, runoff, and water storage, enabling us to estimate the water balance components for the urban site under different land cover scenarios.

Study area

The research region is Debrecen, which is located in the Great Hungarian Plain in eastern Hungary. The city is surrounded by flat terrain, productive agricultural regions, and low hills, which makes it an excellent research location for the science of managing water and land cover. The area has a continental climate with four distinct seasons that are distinguished by warm summers and cold winters (NAGY et al., 2018). The research area includes a variety of hydrological systems, such as lakes, wetlands, rivers, and groundwater reservoirs. The Tisza River, one of Hungary's biggest rivers, flows nearby Debrecen, having an impact on the hydrological dynamics of the city. The river supports a variety of ecosystems and is a significant supply of water. Smaller rivers, streams, and oxbow lakes are also present in the area, which adds to the region's overall hydrological network (NAGY et al., 2021).

In this work, the term 'Study area' was used to denote the boundaries and administrative region of the city of Debrecen, Hungary. It is essential to emphasize that our research focuses on the administrative area of Debrecen and does not pertain to the analysis of a natural geographical watershed. This distinction is crucial for a precise understanding of the scope of our investigation.

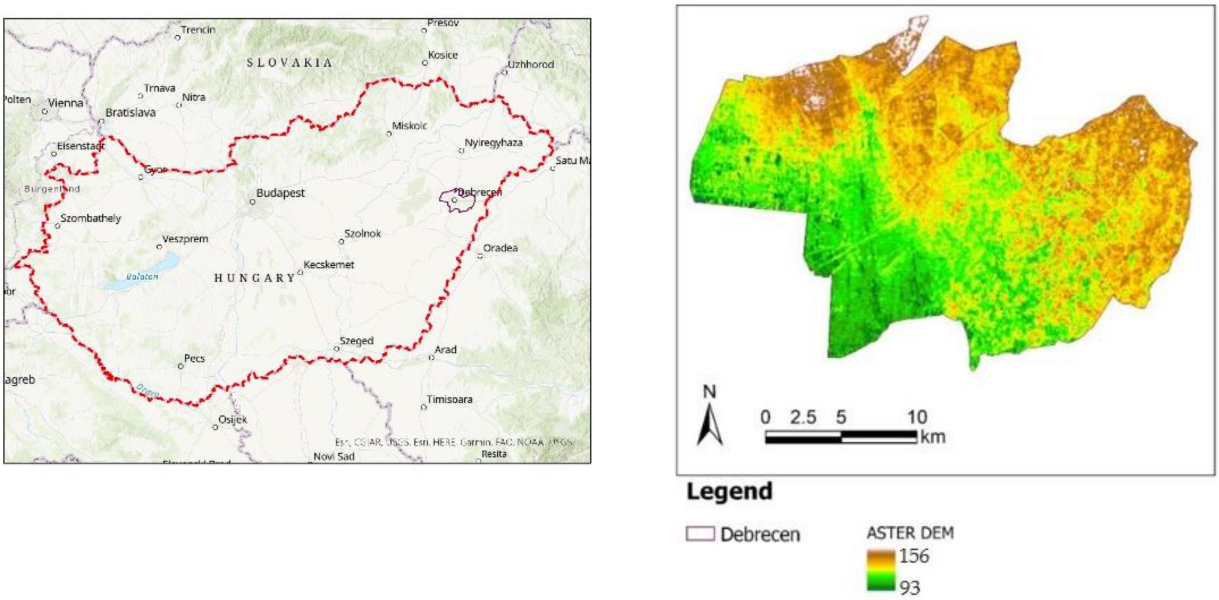

Figure 1. Study area, Digital Elevation Model (DEM) of Debrecen / 1. táblázat: Vizsgálati terület, Debrecen Digitális Terep Modellje (DEM)

Source: Own construction / Forrás: Saját szerkesztés

Land use classification

Classification method

A uniform supervised classification was used during the classification stage. In order to perform supervised classification, training samples for various land use classes were collected. For each of the classes, training areas were precisely generated using polygons, and classification was carried out using Support Vector Machine (SVM) method.

Support vector machines (SVM) are among the most widely used machine learning techniques for classification or prediction analysis (BARAKAT - BRADLEY, 2010).

Six basic categories: built-up area, forest, surface water body, lawns, bare ground and planted / cultivated area were the classes taken into account while classifying the area (Table 1).

Table 1. Lists and description of the primary classes / 1. táblázat: Az elsődleges osztályok felsorolása és leírása

built-up	**Land covered by buildings and other man-made structures.**	
forest	Trees cover more than 60% of the land and reach heights of more than two meters	
lawns	Lands with less than 2-meter woody vegetation hight.	
surface water body	Lakes, stream, reservoirs, rivers, swamps.	
bare soil	Lands with exposed soil, rocks or sand, and never has more than 10% vegetated cover during any time of the year.	
planted/ cultivated area	Temporary crops on the land, followed by a harvest period.	

Source: Own construction / Forrás: Saját szerkesztés

Validation

The process of evaluating the accuracy of the results from the classification stages is part of the image classification process's final stage. This procedure assists in evaluating the classification algorithm and can estimate the amount of inaccuracy that the image contributes (SOPHIA - NDAMBUKI, 2017).

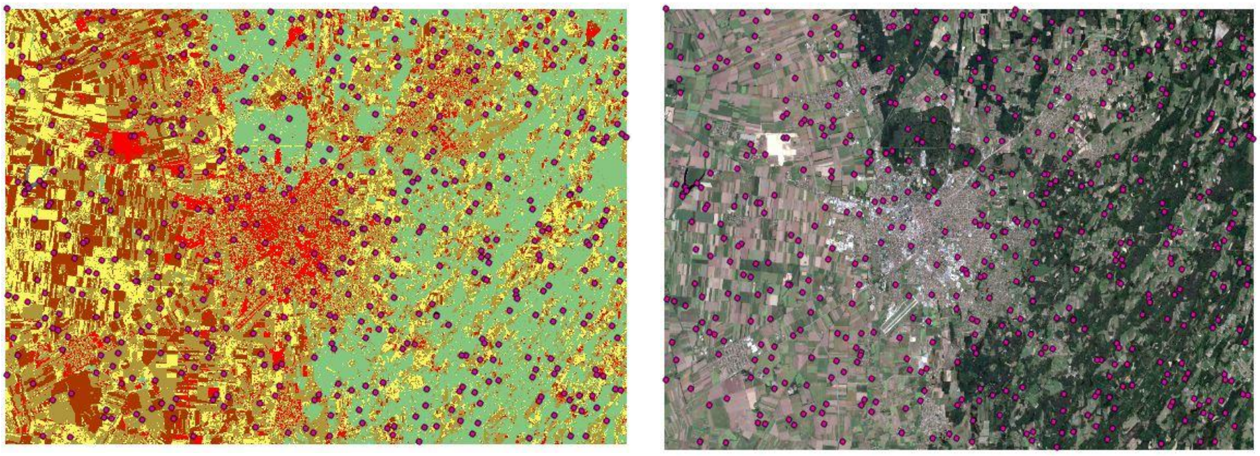

Figure 2. Randomly sampled points for classified and ground truth maps / 2. ábra: Véletlenszerű mintavételezés az osztályozáshoz

Source: Own construction / Forrás: Saját szerkesztés

Using additional satellite imagery and aerial photographs with high spatial resolution, up to 10 m, the results were verified by 500 ground truth samples. Confusion matrices are used to express or display the classification accuracy of each algorithm. The accuracy measures for this study investigated the kappa index, user and producer accuracy, and overall accuracy. The number of pixels correctly identified into a category divided by the total number of pixels classified into that category represents the user's accuracy. The producer's accuracy is the number of the accuratly classified pixels of a category divided by the number of reference pixels collected from the training data. Combining these two measurements generates the overall accuracy. The consistency between the model prediction results and the actual classification results can be assessed using the kappa index. High consistency is indicated by a high kappa coefficient value (CONGALTON, 1991; FOODY, 2002).

Hydrological coefficients

Evapotranspiration coefficient

The average annual temperature and precipitation for the years 2016 through 2019 were determined in order to determine the evapotranspiration coefficient by land cover class in the watershed. The average yearly evapotranspiration is calculated using the Turc formula (TURC, 1961).

$$ET0 = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}}$$

With: L=200+25t+0.05t^3

ET0: Reference evapotranspiration (mm/ year)

P: Annual precipitation (mm)

t: mean annual temperature (°C)

Using the above formula we campute the minimum and maximum values of the average annual reference evapotranspiration of the Basin:

$$ET0min = \frac{P}{\sqrt{0.9 + \frac{P^2}{Lmin^2}}}$$

$Lmin = 200 + 25\ tmin + 0.05tmin^3$

$$ET0max = \frac{P}{\sqrt{0.9 + \frac{P^2}{Lmax^2}}}$$

$Lmax = 200 + 25\ tmin + 0.05tmax^3$

Evaluation of evapotranspiration for land use classes

According to the formula below, crop evapotranspiration (ETc.) is determined (QINGHUA TET al., 2022):

$\mathrm{ETcn} = \mathrm{kcn} * \mathrm{ET0}$

For the purposes of this study, we evaluate the ETcn values for each of the land cover classes, For each land use class (Kcn), we identify a crop coefficient.

n: land use classes (n= 1,2… 6)

ETcn: annual evapotranspiration by class (imm).

$ET_{\circ}$:Average annual reference evapotranspiration (mm)

Kcn: crop coefficient for land use class.

To calculate the crop coefficient we went through the following process to estimate the crop coefficients (Kc) of the Debrecen city classes (Table 2): To recreate the classes in the city of Debrecen, the computation was first performed on homogenous classes that were described in the literature.

Table 2. Cropping coefficients (Kc) for the major vegetation types and for the different classes of Debrecen land cover / 2. táblázat: Termesztési együtthatók (Kc) a főbb növényzettípusokra és a debreceni földhasználat különböző osztályaira

Land use class Debrecen	Crop coefficients (kc)
Forest	1
Built-Up	0.001
Bare Ground	0.001
Water	1.2
Planted/cultivated	0.783
Lawns	0.833

Sources: ALLEN et al., 1998; TALLIS et al., 2013 / Forrás: ALLEN et al., 1998; TALLIS et al., 2013

Results

Sentinel 2 land cover map of Debrecen

To assess the quality of our Land use map, we first evaluated the accuracy of our classification. The results show an overall accuracy of 84 % with a Kappa value of 0.79. The model also works well since, according to PONTIUS et al. (2000), a classification model can be used if its Kappa index is greater then 0.50. The classified land cover map using SVM approach is presented in the following Figure 4.

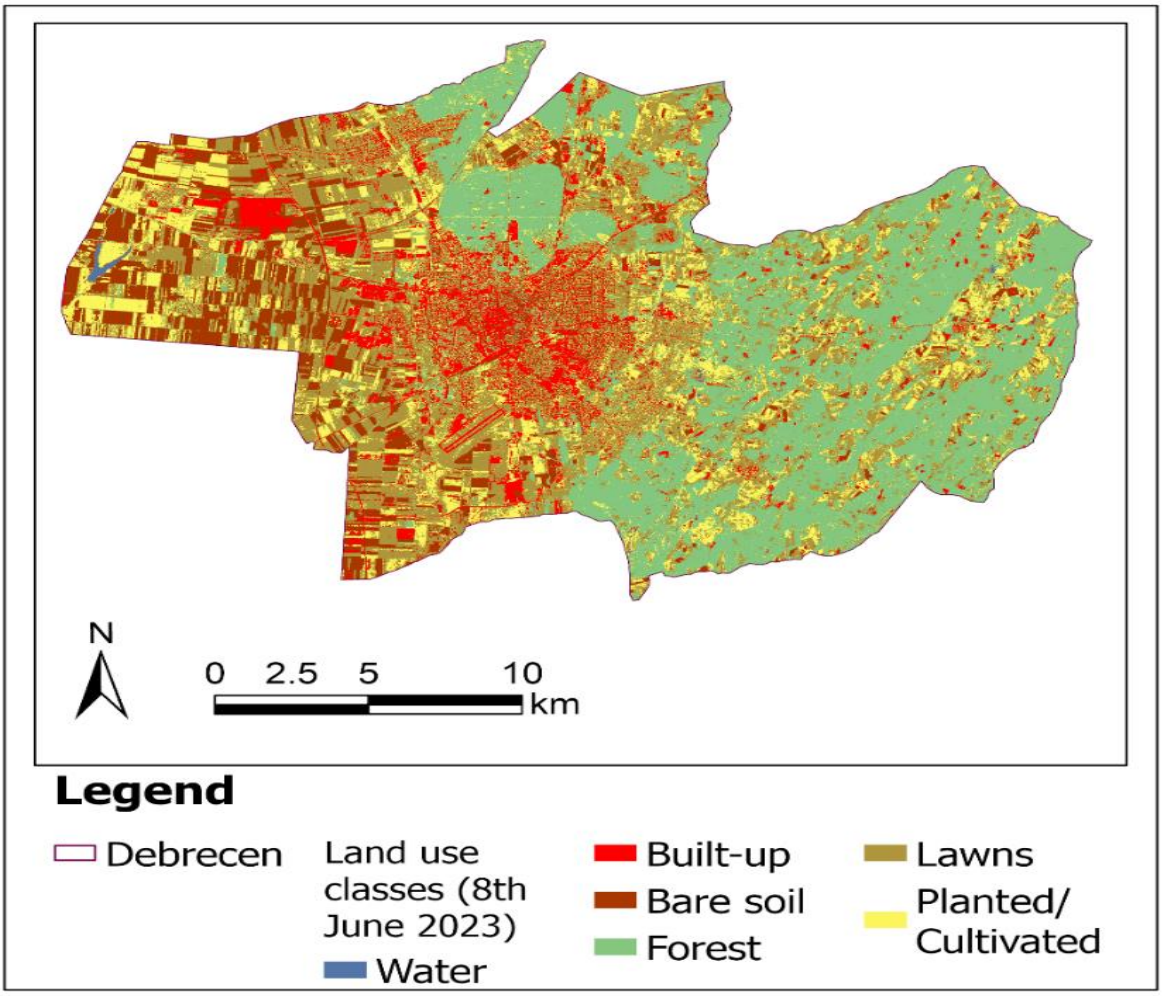

Figure 4. Classified land cover map using SVM algorithm / 4. ábra: SVM algoritmussal osztályozott talajborítási térkép

Source: Own construction / Forrás: Saját szerkesztés

Each class's area was computed using its entire area (the study area) and pixel count. Figure 5 shows the percentage distribution for each classed area. About 31.11 % of the entire study area is classed as being used for agriculture, making it the dominating category of land use, followed by forest areas while the least classified category was surface water bodies which accounts for 0.4%.

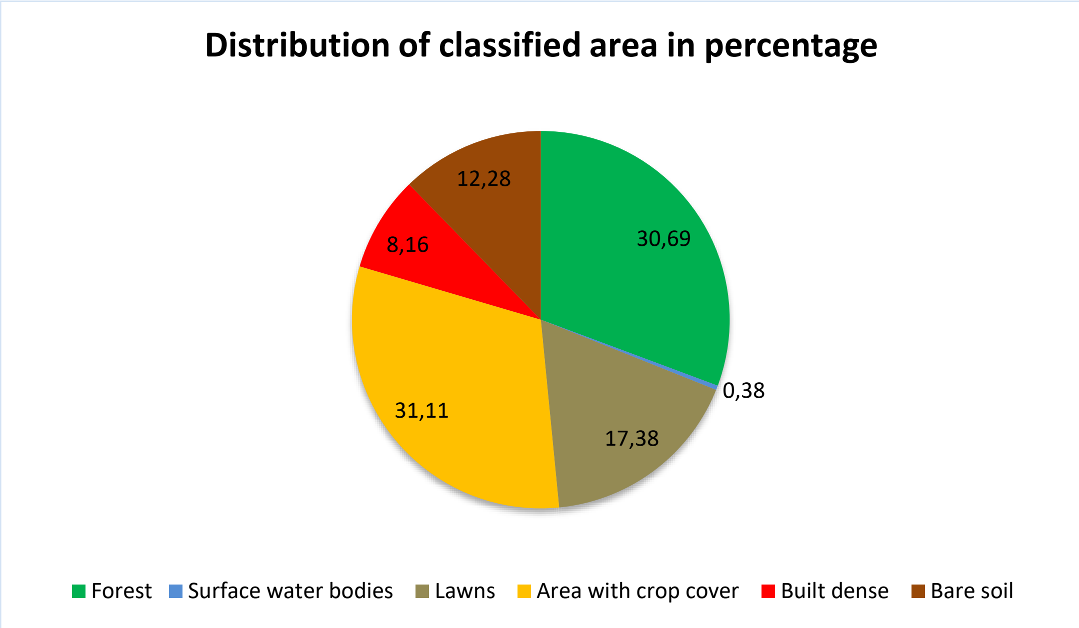

Figure 5. Pie chart showing distribution of classified area in percentage / 5. ábra: A kördiagram a besorolt terület százalékos megoszlását mutatja

Source: Own construction / Forrás: Saját szerkesztés

Land cover map validation

According to the accuracy assessment results, an overall accuracy of 84.7% was attained for the image through the random sampling technique. User accuracy varied between 63.2% and 92.4%, whereas producer accuracy varied between 53.3% and 96.4%.

The User's accuracy reflects the reliability of the classification to the user. User's accuracy is the more relevant measure of the classification's actual utility in the field. Forest was found to be more reliable with 92.1% of user accuracy. In this study an overall Kappa coefficient of 0.798 was obtained which is rated as substantial.various accuracy evaluating parameters were computed and tabulated in Table 4.

Table 4. Accuracy evaluation of the classes / 4. táblázat: Az osztályok pontossági értékelése

OBJECT-ID	Class Value	Water	Built dense	Bare soil	Forest	Lawns	Cropped area	Total	U-Accuracy	Kappa
1	water	8	0	0	0	0	2	10	0.8	0
2	Built dense	1	32	2	0	3	1	39	0.820513	0
3	Bare soil	0	4	50	0	4	1	59	0.847456	0
4	Forest	6	4	0	134	1	0	145	0.924136	0
5	Lawns	0	6	6	0	152	1	169	0.899406	0
6	Cropped area	0	1	5	5	21	55	87	0.632184	0
7	Total	15	47	63	139	181	60	509	0	0
8	P-Accuracy	0.53333	0.680851	0.793651	0.964029	0.839779	0.916667	0	0.846756	0
9	Kappa	0	0	0	0	0	0	0	0	0.798893

Source: Own construction / Forrás: Saját szerkesztés

Hydrological parameters of land cover categories

As delineated in the methodology section, a thorough examination of the climate conditions is necessary to determine the evapotranspiration coefficient by land cover class within the study area. An essential component of this procedure is the average annual temperature and precipitation data for the years 2016 through 2019, which offer a representative view of the current weather patterns. The Turc formula, which was first presented by Turc in 1961, was applied to calculate the evapotranspiration coefficient. Utilising the crucial variables of temperature and precipitation, this formula functions as a tool for calculating the average annual evapotranspiration. Using this approach guarantees that the dynamics of evapotranspiration are well understood for various land cover classes, which is important information for hydrological evaluations and plans for managing water resources in the study area.

The Kenessay equation, as outlined in the methodology, offers a thorough way for determining runoff coefficients that are appropriate for different types of land cover. This equation provides an understanding of hydrological processes by taking into account important variables including the area's slope, the types of land cover, and the types of soil. The Kenessay equation makes it possible to determine the runoff coefficients particular to each type of land cover by summation the three factors. Land cover is included in the equation to take into account the impact of plant and surface features, while soil types are taken into account to account for differences in water penetration capability. Slope evaluation also acknowledges the influence of steep terrain on runoff formation.

Determining the infiltration coefficient after calculating the runoff and evapotranspiration coefficients is an important step in the hydrological assessment of various land cover classes. The infiltration coefficient can be calculated for each land cover class once the runoff coefficient, which shows the ratio of precipitation that results in surface runoff, and the evapotranspiration coefficient, which shows the ratio of actual evapotranspiration to potential evapotranspiration, are calculated. The infiltration coefficient describes the rate at which a particular land cover class's soil can absorb precipitation. The infiltration coefficient is calculated as the remaining percentage of precipitation that is not accounted for by evapotranspiration and runoff by using a water balance calculation and taking into consideration the interaction between precipitation, evapotranspiration and runoff.

This method offers new perspectives on the interactions between various land cover types and water, which is essential for managing water resources sustainably and preserving ecosystems.

Based on metereological data, calculated evapotranspiration, runoff and infiltration, the results of the hydrological parameters per land use category is presented in the following Figure 6. for Debrecen study area.

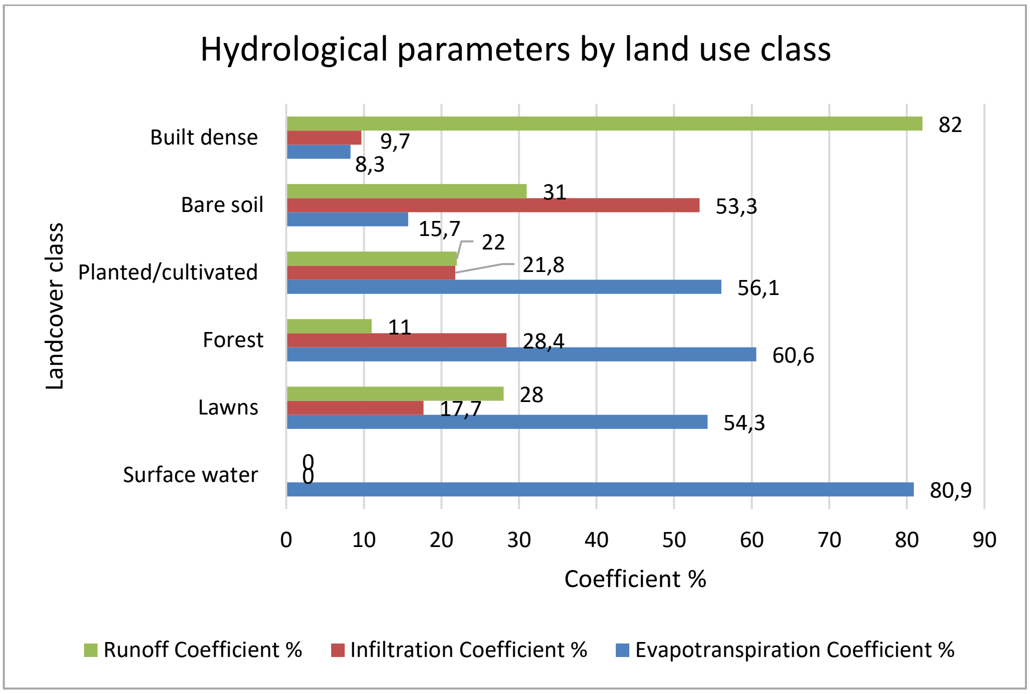

Figure 6: Hydrological parameters by land use class / 6. ábra: Hidrológiai paraméterek területhasználati osztályok szerint

Source: Own construction / Forrás: Saját szerkesztés

Due to its open water surface and direct exposure to solar radiation, which causes water evaporation, the class of surface water class has the highest evapotranspiration ratio.

In contrast to forests, which include vegetation that decreases water runoff, built dense, and bare soil have the highest runoff ratios. The limited runoff amounts in Planted/cultivated areas, Lawns highlight how crucial vegetation is to reducing water runoff. The surface water bodies and forest land use classes, respectively, had the greatest mean annual evapotranspiration percentage values of 80.9% and 60.6%. The built dense area and bare soil classes, on the other hand, showed the lowest evapotranspiration percentage values, 8.3% and 15.7%, respectively. We came to the conclusion that the low ET rates in urban areas were caused by the decreasing of green spaces, and this was corroborated by a number of research (HAO et al., 2018; CHEN et al., 2004).

Sentinel-2 imagery was used to classify the land cover, and the results gave precise information on the geographical distribution of land cover classes within the urban site.

Through the integration of land cover data into the hydrological model, this study opens up new avenues for future research on the implications of changing land cover on the water balance parameters. According to the findings, increasing impermeable surfaces increased surface runoff and decreased infiltration rates, increasing storm water runoff and raising the possibility of urban flooding.

On the other hand, regions with more vegetation showed lower runoff and higher rates of evapotranspiration, which increased water retention and decreased flood risk. Additionally, the presence of water bodies significantly influenced local climatic patterns and provided storage space, both of which helped to regulate the regional water balance.

Conclusions

This study demonstrates the effectiveness of using Sentinel-2 satellite imagery in land cover modelling for water balance calculations in urban areas. The integration of remote sensing data with hydrological models allows for a comprehensive assessment of the impact of land cover changes on water availability, runoff patterns, and flood risk. The findings highlight the importance of considering land cover dynamics in urban planning and water resource management. By understanding the relationship between land cover and water balance, policymakers can make informed decisions to promote sustainable urban development, implement effective storm water management strategies, and enhance water conservation efforts. Future research could focus on refining the land cover classification algorithm, incorporating additional data sources, and expanding the study to different urban sites. This would provide a more comprehensive understanding of the complex interactions between land cover, water balance, and urbanization, ultimately contributing to more resilient and sustainable cities.

Acknowledgement

This study was supported by the National Research, Development and Innovation Office of Hungary (under grant: National Laboratory of Water Science and Water Safety project RRF-2.3.1-21-2022-00008).

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The paper was presented at the 6th ISCW conference