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ASSESSMENT OF RUNOFF AND DRAINAGE CONDITIONS IN A NORTH BANAT SUB-CATCHMENT, NORTH-EASTERN SERBIA

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Abstract

The lowland area of the southeastern part of the Carpathian Basin is exposed to extreme hydrological conditions. The monitoring and analysis of the excess inland water are necessary in order to understand the scope and direction of the development of this type of flooding. When solving the problem of the drainage of an area and dimensioning drainage systems, one of the most important steps is to calculate the rate of runoff. Before calculating the rate of runoff, it is necessary to perform various analysis such as: hydrological, hydrogeological, pedological and land use analysis. The use of empirical formulas by different authors is one of the methods for determining the rate of runoff. These formulas can be of regional character, while some are applicable in different parts of the world. In this paper, the runoff coefficient and rate of runoff were calculated as indicators of the efficiency of the area drainage, employing the formulas by Nemet and Turazzo. The emphasis was put on the usage of modern tools and databases of soil characteristics while using a "traditional" method to determine rate of runoff. The obtained results demonstrate that the rate of runoff which reflects the current state of the drainage basin is very similar to the rate of runoff used for dimensioning of drainage system. The problem of retaining smaller amounts of water that remains even after the anticipated drainage deadlines can be solved with the regular maintenance of amelioration canals and additional ameliorative measures.

Keywords: Galacka sub-catchment, drainage, runoff coefficient, GIS

INTRODUCTION

The lowland area of the southeastern part of the Carpathian Basin is exposed to extreme hydrological conditions, therefore the monitoring of the water regime is of great importance on the catchments of this region (Právetz et al., 2015). When it comes to excess water, the two most common forms of occurrence are the vertical type, which occurs as a result of the increase in the groundwater level and horizontal type, which is created by the accumulation of water in the lowest areas. Horizontal type occurs due to difficulty in infiltration and onflow and often is the result of an inadequate application of agrotechnical measures, which lead to degradation of the soil structure, i.e. its compaction (Barta, 2003). Monitoring and analysis of such phenomena are necessary in order to understand the volume and direction of the spreading of this type of flooding and mitigate the consequences for agricultural production (van Leeuwen et al., 2017).

The Vojvodina province, the northern part of the Republic of Serbia, was a wetland area in the past, where after extensive hydro-meliorative works, conditions were created for the development of agricultural production. Construction of riverbanks along large rivers, as a form of protection from high waters and construction of drainage canals as a form of protection from inland waters, water regime regulation is achieved. By the construction of the Danube-Tisza-Danube hydro system, drainage of about one million hectares of land in Vojvodina has been enabled. Thus Vojvodina became the main production region in the Republic of Serbia (Kolaković and Trajković, 2006).

From the Roman era, the drainage of lowland areas was done by the construction of open canals or different forms of subsurface drainage, which would provide an adequate water regime for the needs of agriculture. However, mechanization of agriculture, abandonment or change the purpose and land use leads to the dysfunctionality of drainage systems (Calsamiglia et al., 2018). In addition, the inadequate function of the system can be the result of climate and hydrological changes that are present in a particular area. Therefore, it is justifiable to periodically analyze the efficiency of drainage systems, which could determine the possible causes of their difficulty in functioning.

During the solving of the problem of drainage of some area and dimensioning drainage systems, one of the most important steps is calculating the rate of runoff. Previously, it is necessary to carry out various analysis, such as hydrological, hydrogeological, pedological and land use analysis. Rate of runoff by its size defines the need for the drainage of some area, and it is directly related to the investments necessary for the construction of such systems (Avakumović, 2005; Kolaković and Trajković, 2006). The use of empirical formulas of different authors is one of the methods for determining the rate of runoff. These formulas can be of a regional character, while some are applicable in different parts of the world. However, the final choice of the method depends on the availability of input data (Kang et al., 2013). In this paper, using a series of empirical formulas, which were given in the 1965 Main Project of the drainage of the Kikinda Canal catchment (Galacka sub-catchment), the calculation of the runoff coefficient and the rate of runoff was performed as an indicator of the drainage efficiency of the area. The focus is on combining modern tools and databases on soil characteristics and land use with a "traditional" method for determining the rate of runoff. The obtained results should indicate whether this drainage system adequately performs its function in the current hydrological and agroecological conditions.

STUDY AREA

The North Banat once represented the flooding area of the unregulated Tisza river and the delta of Moriš river. After regulating the mentioned rivers and their tributaries, as well as the construction of riverbanks along river streams, there was a need for inland waters drainage. The Kikinda Canal is the northernmost canal of the Danube-Tisza-Danube hydro-system, and its catchment is divided into 24 subsystems. Drainage is carried out by gravity in 20 subsystems, at total area of 418.52 km^2, while in combination with gravity and pumping stations, excess water is discharged from 4 subsystems, at total area of 432.40 km^2 (Pantelić, 1965). The land reclamation works in the subject area start from the moment of regulation of the river Tisza and its tributaries till the present day.

The Galacka sub-catchment covers an area of 32.74 km^2. The total length of the canal network is 67.8 km. The water from this system is drained by gravity or by pumping station, depending on the water level in the recipient the Kikinda Canal. This sub-catchment also includes an area of 4.42 km^2 of lowland along the Kikinda Canal, northern from the recipient. This area is drained by a peripheral canal, which is 10.5 km long. The position of the Galacka sub-catchment is shown in Figure 1.

From the pedological point of view, the types of soil occurring on the Kikinda Canal catchment can be divided into three groups: zonal soils formed under the dominant influence of the climate, intrazonal soils formed predominantly under the influence of relief and basic rock mass, as well as genetically undeveloped and poorly developed soils (Pantelić, 1965). The first group includes chernozem with all its varieties. The second group includes marsh soil and its varieties, while the third group includes alluvial soils and sands. The geological base of these soils are the loess and the hydrological formations of the Tisza and Moriš rivers, which occur on the fractions of sand, gravel and clay. The loess is mainly wetland origin, made under the influence of winds and sedimentation in the water. Its characteristic is that it has a low permeability power and contains a higher percentage of clay particles, which is the main difference from the typical loess.

At the territory of northern Banat, there is a series of wells in which the groundwater level ranges from 1.5 to 4.0 m below the terrain. Therefore, it can be concluded that the influence of groundwater on the rate of runoff is insignificant (Pantelić, 1965). The climate of this area is

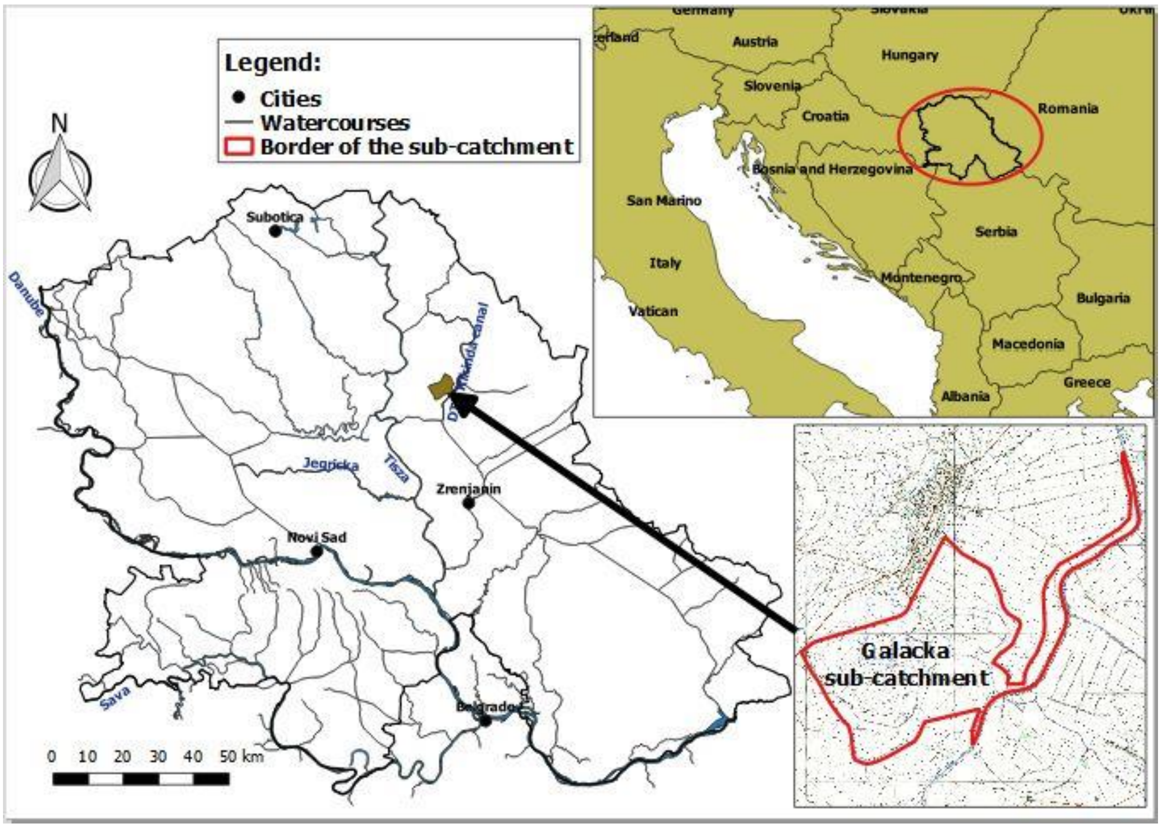

Fig. 1 The position of the Galacka sub-catchment

moderately continental, with a mean annual precipitation of about 560 mm for the observed period 1971-2010. The area is of a very rural nature, where almost 70% of the area is represented by agricultural production.

MATERIAL AND METHODS

The vegetation period rainfall analysis showed that the precipitation in terms of its duration, intensity and uniformity was most conspicuous in May. In April and September, precipitations are by its intensity and duration insignificant. In June, July and August they are higher than the precipitations in May, but also short and uneven (characteristic rainstorms). For these reasons, the rainfalls in May are taken as the most appropriate for estimating the rate of runoff (Pantelić, 1965).

By using the empirical formulas of various authors, obtained from studies carried out in different parts of the world, it is possible to calculate the rate of runoff. In this paper, empirical formulas which were applied in the main project of the drainage of the Kikinda Canal catchment (Galacka sub-catchment) from 1965, were used. In order to determine the efficiency of the drainage of the subject area, the runoff coefficient and rate of runoff are calculated. During the calculation, contemporary databases on pedological soil characteristics (Benka and Salvai, 2006) and type of soil cover (CORINE Land Cover, 2012) were used. Different types of land cover are an important factor in modeling surface runoff (Právetz et al., 2015). The subject of this paper is the functional check of this drainage system in current conditions, taking into account that it was built more than half a century ago.

Water from the Galacka sub-catchment is drained by gravity or pumping station, depending on the water level in the recipient, the Kikinda Canal. Drainage is done by gravity when the water level in the Kikinda Canal is below 75.36 m. At water levels in the Kikinda Canal lower than mentioned, drainage is done through the gravity discharges, and they are 2.0 m^3 s^{-1} capacity. When the water level is higher than mentioned level, drainage is carried out by the pumping station "Galacka", using centrifugal pumps with a capacity of 2.0 m^3 s^{-1} (two pumping units, capacity 1.0 m^3 s^{-1}). The pump station is located at km 9+516 on the right bank of Kikinda Canal.
For the calculation of the runoff coefficient and the rate of runoff in the Main drainage project (Pantelić, 1965), the formulas given by the authors Nemet and Turazzo were used. This method was used in the middle of the last century, mainly for drainage system designing in the area of Vojvodina (northern part of Serbia) and Hungary. The following are the steps used in analysis of this drainage system.

The following formula is used for the calculation of the mean rate of runoff:

$$q_s = 0.1157 \cdot \frac{\alpha \cdot h}{t + \tau} \quad \text{(Eq. 1)}$$

where are: q_s - mean rate of runoff (l s^{-1} ha^{-1}), α - runoff coefficient, h - relevant rainfall (mm), t - duration of the relevant rainfall (days), τ - time of concentration (days).

If the previous relation is multiplied by the coefficient that represents the ratio of the maximum and intermediate flows, and which for the Hungarian conditions is 1.7 (applicable for the territory of Vojvodina), the maximum rate of runoff is obtained - q_{max} (l s^{-1} ha^{-1}):

$$q_{max} = 0.1157 \cdot \frac{\alpha \cdot h}{t + \tau} \cdot 1.7 \quad \text{(Eq. 2)}$$

When determining the runoff coefficient, it is necessary to take into consideration the drainage characteristics of the soil, the terrain slope, the way of soil cultivating, as well as soil cover type. In the Main drainage project (Pantelić 1965), it is stated that in the study "Amounts of inland waters" by Dr J. Bogardi, the change in the runoff coefficient by months was given in function of:
(1) terrain slope (α_1);
(2) soil permeability (α_2);
(3) vegetation cover (α_3).

The values of these partial runoff coefficients are given in Tables 1, 2 and 3. The total runoff coefficient is obtained by summing of these three factors:

$$\alpha = \alpha_1 + \alpha_2 + \alpha_3 \quad \text{(Eq. 3)}$$

Table 1 Partial runoff coefficient in the function of terrain slope (α_1)

Terrain slope	Coefficient α_1
>35 %	0.22 – 0.25 – 0.30
11 – 35 %	0.12 – 0.18 – 0.20
3.5 – 11 %	0.06 – 0.08 – 0.10
<3.5 %	0.01 – 0.03 – 0.05

Table 2 Partial runoff coefficient in the function of soil permeability (α_2)

Soil permeability	Coefficient α_2
Very impermeable soil	0.22 – 0.26 – 0.30
Moderate impermeable soil	0.12 – 0.16 – 0.20
Permeable soil	0.06 – 0.08 – 0.10
Very permeable soil	0.03 – 0.04 – 0.05

Table 3 Partial runoff coefficient in the function of vegetation cover (α_3)

Land cover	Coefficient α_3
Non-covered soil	0.22 – 0.26 – 0.30
Marshes and pastures	0.17 – 0.21 – 0.25
Cultivated soil	0.07 – 0.11 – 0.15
Forests and soils of weak structure (sands)	0.03 – 0.04 – 0.05

For the purpose of determining the partial coefficient α_2, GIS pedological map of Vojvodina was used (Benka and Salvai, 2006). Coefficient α_2 is obtained by calculating the percentage of different soil types at the subject area and classification according to their drainage characteristics. The soils are classified into five drainage classes based on the average limit values of their water constants and the main chemical parameters (Miljković, 2005):

(1) Drainage class I - soil that is naturally very poorly drained, indicating a high risk of excess inland water;
(2) Drainage class II - soil that is naturally poorly drained, indicating a medium risk of excess inland water;
(3) Drainage class III - soil that is naturally somewhat poorly drained, indicating a moderate risk of excess inland water;
(4) Drainage class IV - soils of lighter texture which are naturally moderately well drained, indicating a low risk of excess inland water;
(5) Drainage class V - soils of light texture which are naturally well drained, indicating no risk of excess inland water as well as no necessity for drainage.

The values of coefficient α_3 have been determined using the CORINE Land Cover 2012 (EEA, 2012) map, which contains data on land cover and attributed areas. GIS tools have been implemented in the analysis of the representation of different types of soil and their land cover, as well as the creation of maps presented in this paper.

Determining the height of relevant rainfall, which is especially used in the prediction of floods with deterministic methods, must be based on the duration of high-intensity rainfall (storm precipitation) or the time of concentration, both for a specific location and a wide area (Gericke and Plessis, 2011). The time of concentration (τ) is a key temporal parameter of basin response, necessary for the prediction of the maximum volume of runoff (Perdikaris et al., 2018). Time of concentration (τ) is the time required for runoff traveling from the hydraulically most distant point in the drainage basin to the outlet, and in the Project (Pantelić, 1965) it is determined with the Venturi formula, where it is expressed in the function of the catchment area:

$$\tau = 0.315 \cdot \sqrt{F} \quad \text{(Eq. 4)}$$

where F is catchment area in km^2.

According to Pantelić (1965) rainfall during the month of May was used in the calculation, and with the Montanari climatic formula which is individually performed for each analyzed area, relevant precipitation levels were obtained using the following formula:

$$h = a \cdot t^n \quad \text{(Eq. 5)}$$

where are: h – relevant rainfall levels (mm), a and n – variables that depend on the hydrological characteristics of the analyzed area, while t represents the duration of precipitation (days).

According to Nemet, the duration of relevant rainfall (t) can be determined on the basis of the Montanari formula and time of concentration (τ):

$$t = \frac{n}{1-n} \cdot \tau \quad \text{(Eq. 6)}$$

In the Main Project as stated by Pantelić (1965), the duration of relevant rainfall is adopted based on the analysis of the rainfall table in duration t and runoff in duration τ. Three cases are characteristic:

(1) Duration of rainfall is equal to the duration of runoff ($t=\tau$);
(2) Duration of rainfall is greater than the duration of runoff ($t>\tau$);
(3) Duration of rainfall is less than the duration of runoff ($t<\tau$).

In the event that the duration of runoff is less than three days, the duration of relevant rainfall is determined as three days. In the case that the duration of runoff is greater than three days, the duration of relevant rainfall is established to be the same as the duration of runoff. Pantelić (1965) maintains that after analysing consecutive daily precipitation levels, t=3 days was for economic reasons adopted as the duration of relevant rainfall. The value of relevant rainfall of 3 days was applied during the calculation of the rate of runoff.

RESULTS AND DISCUSSION

Calculation of the runoff coefficient

Employing the empirical formulas by Nemet and Turazzo, the runoff coefficient and rate of runoff have been determined based on current conditions of the drainage system. In order to reach the most precise runoff coefficient it is necessary to meticulously determine the partial runoff coefficients which are given in the function of terrain slope (α_1), soil permeability (α_2) and vegetation cover (α_3).

Since it is a markedly lowland area, in order to determine the runoff coefficient in the function of terrain slope (α_1), the slope of the Main Canal was used, which steers all water from the analyzed area to the "Galacka" pumping station and has an average slope of 0.005%. Based on the aforementioned, a minimal value of α_1=0.01 was adopted from Table 1.

Table 4 represents the estimation of the complex coefficient value α_2, which was obtained based on the soil type represented in the subject area, as well as their drainage characteristics. To calculate the coefficient in the function of soil permeability (α_2), the percentage share of different soil types was used and values from Table 2 were assigned. The coefficient value in the function of soil permeability which is applied to the entire drainage basin is α_2=0.21. The drainage classes of the soils in the subject area are represented in Figure 2.

From the analysis of the CORINE Land Cover 2012 database, which provides soil use and land cover characteristics, a partial coefficient in the function of vegetation cover (α_3) was obtained, with the results displayed in Table 5. Non-irrigated arable land was most represented in the subject area with 62.55%, while natural grasslands were the second most represented with 26.45%. According to the representation of soil types as well as data from Table 3, the value of the coefficient in the function of vegetation cover valid for the entire drainage basin was determined to be α_3=0.14. Figure 3 shows the proportion of soils of different land use and type of land cover.

Table 4 Estimating the partial runoff coefficient in the function of soil permeability (α_2)

Soil type	Percentage (%)	Drainage class	α_2	Complex coefficient value α_2
Alluvial waterlogged soil	8.76	II	0.16	0.01401
Carbonate marsh black soil	4.58	II	0.16	0.00734
Brackish carbonate marsh black soil	1.83	I	0.26	0.00476
Marsh black soil without carbonate	33.22	I	0.26	0.08636
Partly brackish marsh black soil without carbonate	1.38	I	0.26	0.00358
Chernozem on sandy loess	0.25	V	0.03	0.00001
Carbonate chernozem (micellar) on a loess terrace	16.38	V	0.03	0.00492
Solonetz	25.28	I	0.26	0.06573
Solonchak-Solonetz	8.32	I	0.26	0.02163
Σ=	100			0.20834

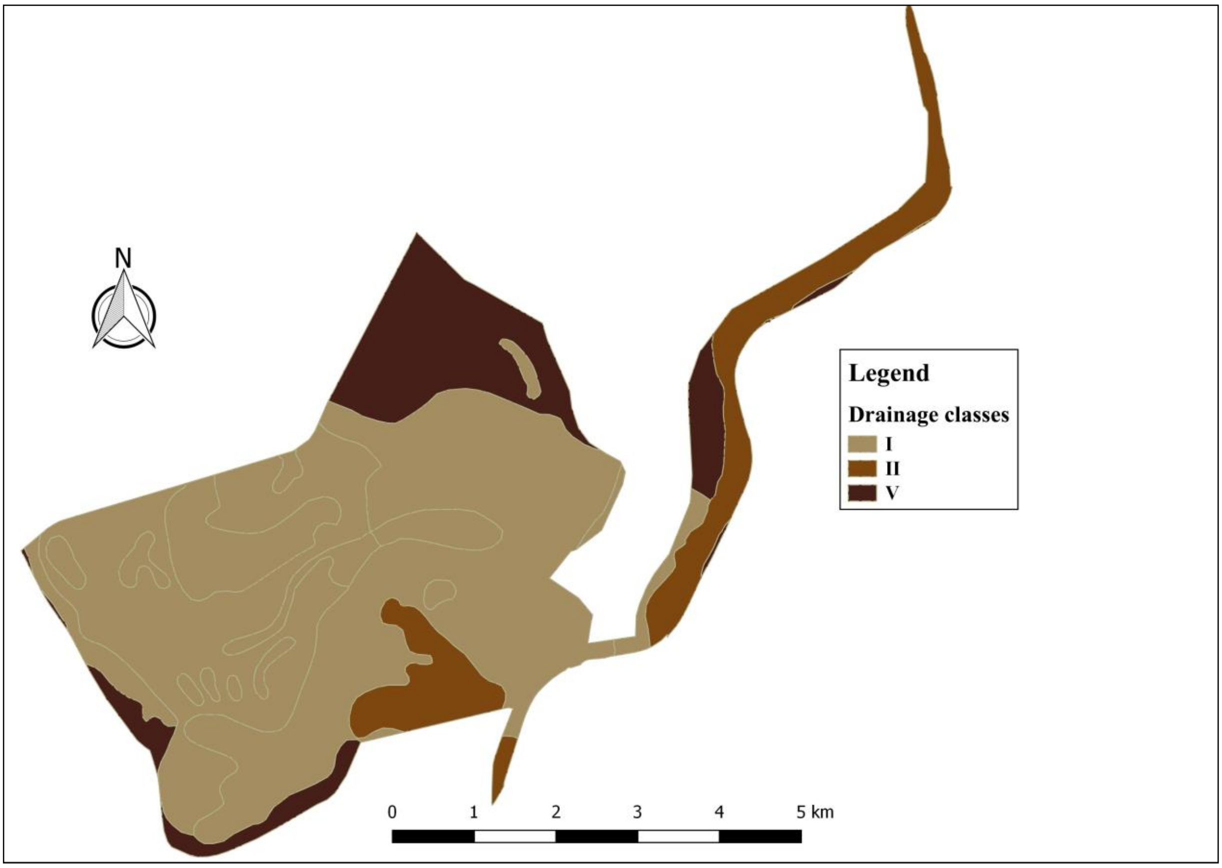

Fig.2 Drainage classes of soil of the Galacka sub-catchment

Table 5 Estimating the partial runoff coefficient in the function of vegetation cover (α_3)

Area description	Percentage (%)	α_3	Complex value of coefficient α_3
Continuous urban fabric	0.01	0.30	0.00003
Non-irrigated arable land	62.55	0.11	0.06881
Pastures	6.11	0.21	0.01282
Complex cultivation patterns	0.89	0.11	0.00098
Predominantly agricultural land with larger areas of natural vegetation	3.43	0.11	0.00377
Natural grasslands	26.45	0.21	0.05554
Inland marshes	0.42	0	0.00000
Mineral extraction sites	0.14	0.3	0.00043
Σ=	100		0.14238

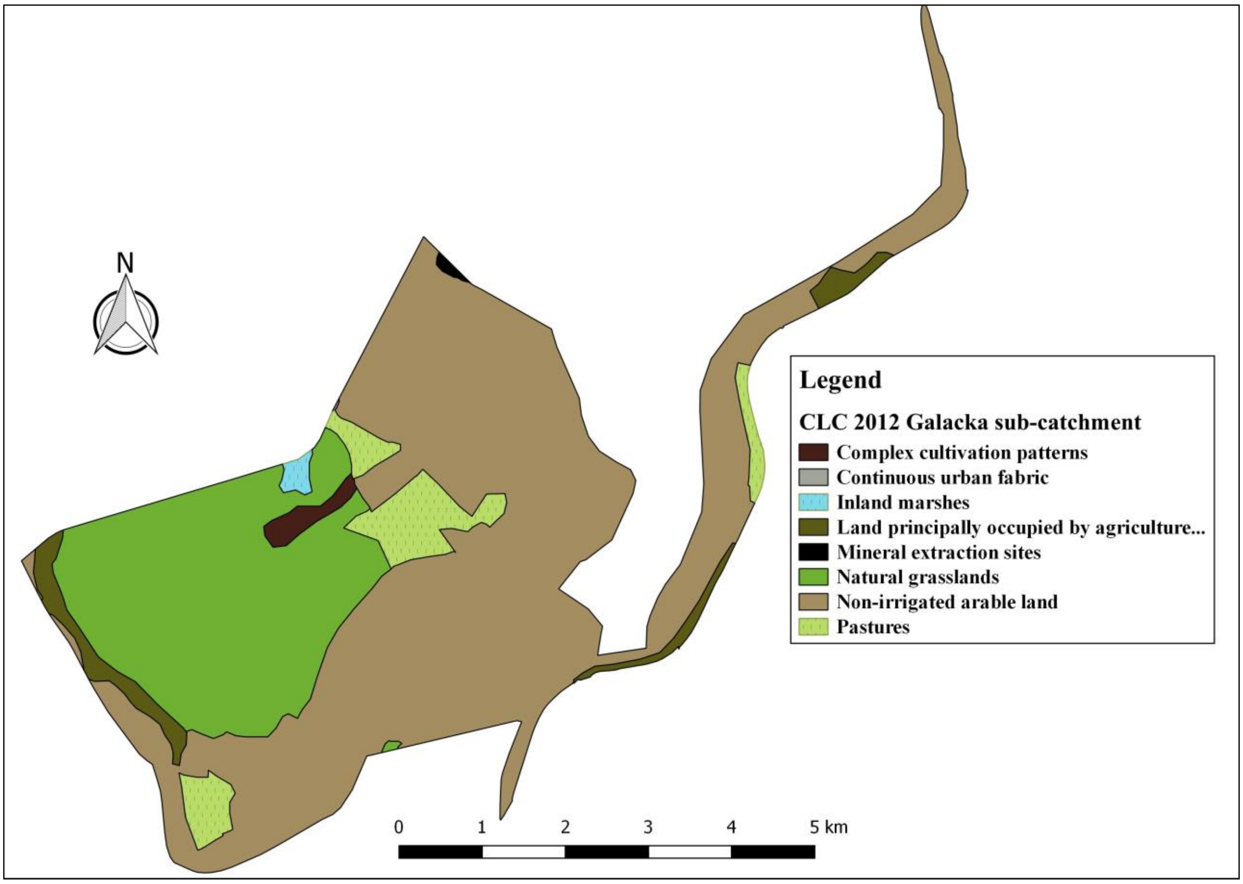

Fig. 3 CORINE Land Cover 2012 map - purpose and characteristics of land cover of Galacka sub-catchment

Implementing the formula (3), the total runoff coefficient of the subject area was assessed as α=0.36. The runoff coefficient value calculated for the recent period was slightly greater than the one calculated in the Main Project.

Calculation of the rate of runoff

The time of concentration (τ) for a particular drainage basin from its most distant point to the outlet is determined with the Venturi formula (4) in which the duration of runoff is indicated in the function of the catchment area, with the calculated value being τ=1.8 days.

It is a fact that the duration of the return period takes on an economic character, therefore a return period of 10 years is used in hydromeliorative application during the dimensioning of drainage systems (Belić et al. 1995). Rainfall in a more recent period (1971-2010) was used to calculate the rate of runoff. For that purpose, maximal three-day rainfall in the month of May was used, which occurs once in ten years and amounts to h=54.7 mm. Using the formula (2) the maximum rate of runoff was determined to be q_{max}=0.8 l s^{-1} ha^{-1}.

Table 6 displays the comparative results obtained in the 1965 Main Project of the drainage of the Kikinda Canal, Galacka sub-catchment along with the results obtained for the recent period. Considering that the rate of runoff adopted in the Main Project amounts to q_{max}=0.60 l s^{-1} ha^{-1}, while the rate of runoff for the recent period is q_{max}=0.80 l s^{-1} ha^{-1}, we may conclude that they are quite similar.

Table 6 Comparative overview of values from the Project and new values obtained

Parameter	Values from the Project (Pantelić, 1965)	New values	Unit
α_1	0.01	0.01	-
α_2	0.18	0.21	-
α_3	0.11	0.14	-
α	0.30	0.36	-
t	3.00	3.00	days
h	55.4	54.7	mm
q_{max}	0.60	0.80	l s^{-1} ha^{-1}

CONCLUSION

With extensive construction carried out on the drainage canal in the middle of the previous century, the soil on the territory of Vojvodina has been transformed from a swamp and marsh area to a soil suitable for agricultural production. The construction of the Kikinda Canal has allowed the drainage of excess water from substantial surfaces of the analyzed area in Banat. The Galacka drainage sub-catchment analyzed in the paper belongs to the system of the Kikinda Canal and the efficacy of its performance has been reviewed.

The biggest differences between the values obtained in the Main Project and those of the analyzed period are in regard to the size of the runoff coefficient. Sufficient pedological research did not exist at the time of the Project, thus leading to different values of analyzed soil permeability in the more recent study. The coefficient value in the function of soil permeability amounts to 0.18 in the Main Project, while the analysis of more detailed surfaces resulted in a value of 0.21. The utilization of the CORINE Land Cover 2012 database resulted in a partial coefficient in the function of vegetation cover (α_3) for the recent period amounting to 0.14 while that value was 0.11 in the Main Project. The rate of runoff which reflects the current state of the drainage basin (q_{max}=0.80 l s^{-1} ha^{-1}) is slightly larger than the rate of runoff obtained in the Main Project (q_{max}=0.60 l s^{-1} ha^{-1}). We may conclude that the constructed system is of satisfactory capacity. The results obtained in this paper are in accordance with the research conducted by Bezdan et al. (2018) on a drainage basin of similar characteristics in another part of Vojvodina (Bačka). According to information received by experts in charge of system maintenance, in the previous period there were no major issues related to drainage of excess water. The problem of retaining smaller amounts of water that remains even after the anticipated drainage deadlines can be solved with the regular maintenance of amelioration canals and the employment of additional ameliorative measures. Onerous water drainage usually occurs on soil of "heavier" mechanical structure, and in such cases, it is recommended to use horizontal pipe drainage or biodrainage (Vranešević et al., 2017).

Based on the obtained results, we can expect adequate performance of the system in place and timely drainage of excess water. It is our recommendation to regularly maintain the system and utilize additional ameliorative measures in order to improve the conditions for agricultural production.

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