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Assessment of selected combined sewer system in the city of Trnava

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ORIGINAL RESEARCH PAPER

ABSTRACT

The goal of this work is the hydraulic capacity assessment of selected combined sewer systems in the city of Trnava. The selected sewer system constitutes from 160 sections 3.3 km long. Hydraulic capacity assessment will test sewer system, created in SeWaCAD program with design rainfall events with varied frequencies. The result of assessment showed that hydraulic capacity of combined sewer system did not meet requirements to properly work. Malfunctioning sewer pipelines must be changed. Design rain with frequency at least one in two years will be used as restoration model.

KEYWORDS

combined sewer system, design rain, rain, restoration of sewer system

1. INTRODUCTION

The public sewer system must be designed and built in accord with knowledge of technological advance without negative impact on environment. Sewer system must have sufficient working capacity for continuous discharge and wastewater treatment for standard climatic conditions and for abnormal seasonal climatic conditions [1].

Sewer system assessment is process of controlling correct function and localization malfunctioning sections of sewer system. Overloaded sections lead to restoration or reconstruction plan of sewer system. Mathematical models can be used for assessments. Static models are used for determining amount of overload in sections and hydraulic mathematical models are used for detailed analysis of flow in sewer system and all its objects [2].

Nowadays rainwater is causing problems in the cities and towns. In combined sewer rainwater is mixing with sewage. This mixture is either treated in Waste Water Treatment Plant (WWTP), which is increasing the amount of treated water. Thus, increase in treatment costs. The mixture can be also reduced in combined sewer overflow chamber and part of combined sewage water is discharged into watercourse. Most of combined sewer systems and objects on them were built in previous millennium. Standard and abnormal climate conditions drastically changed during previous years and hydraulic capacity of old sewer systems is insufficient. Another part of the problem is increased amount of impermeable surfaces in urbanized areas [3]. The topics like restoration of sewer systems or effective rainwater management are essential to solve problems that rainwater is causing in cities or towns. There is no general answer for towns and cities how to adapt to climate change because each of them has its own specifics. It is essential to propose solutions separately for each city to find optimal way to solve problem with rainwater [4].

The goal of this work is point out the rainwater problem with insufficient capacity of existing combined sewer systems. In the past combined sewer network was preferred in Slovakia. This is dated type of rainwater harvest system. Initially the goal in cities and towns was to remove rainwater as soon as possible with combined sewer systems [1]. Assessed sewer system is in the city of Trnava. It is located in the urban center of the city and it is dated with insufficient hydraulic capacity [5].

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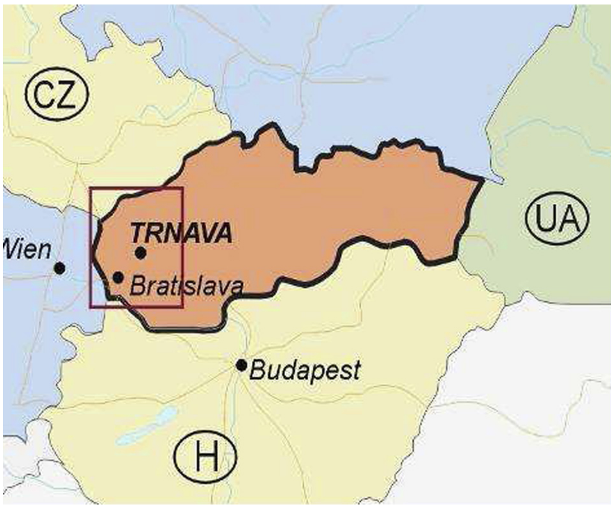

Fig. 1. Location of Trnava city (based on [6])

2. CASE STUDY AREA

City of Trnava is main city in Trnava region, which is in Western Slovakia. Total population in city is 65,033 inhabitants (31.12. 2019) [6]. Combined public sewer system is built in city with 20 combined sewer overflow chambers. Wastewater is treated in WWTP located south of the city in Zeleneč. Owner of public system is Trnavas Waterworks Company. The sewer network was built in year 1997 and is divided into main sections A, B, C, D, G, I, II, III and V together 111,236 km long [5]. Assessment focus on sewer system section G, which is in two parts of city: Trnava west and Trnava south. Selected sewer system consists of 160 sections around 3,297 km long. Figure 1 shows the location of Trnava city and Fig. 2 shows the area of interest in the presented case study.

3. RAINFALL

3.1. Design rainfalls

Rainwater is important for calculations of characteristic outflow from roads, sidewalks, roofs, and courts in urban area. In design rainfall calculation is used statistically determined periodicity p or period of occurrence T.

As design rains can be used historical rainfall events or model rainfalls. Model rainfalls can be block rainfalls, reduced block rainfalls or synthetic rainfalls. Calculation of design rainfalls is inevitable for design, or assessment of rain sewers and combined sewers [7].

Synthetic rainfalls belong to the group of model rains, which are close to the course of a natural rain event.

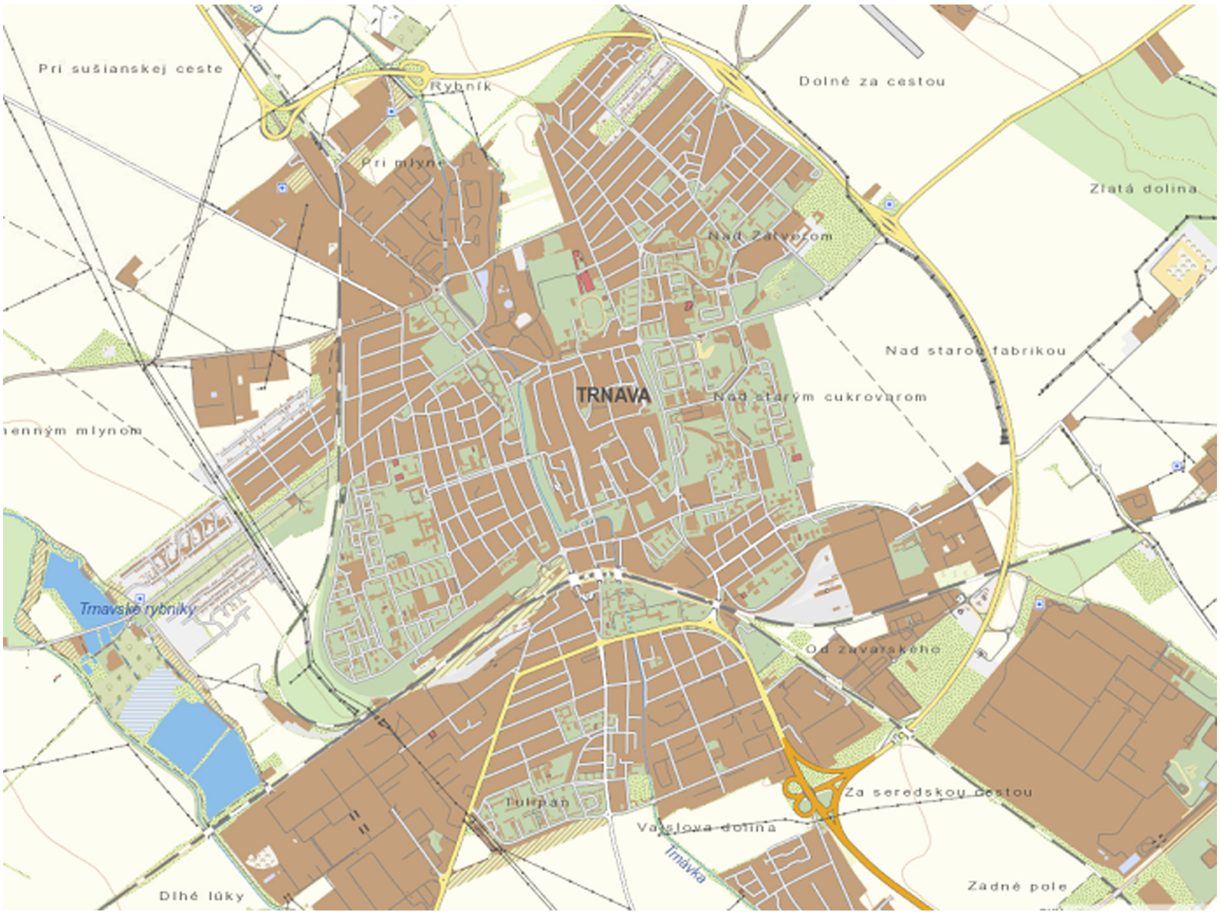

Fig. 2. Area of interest - City of Trnava (ZBGIS.sk)

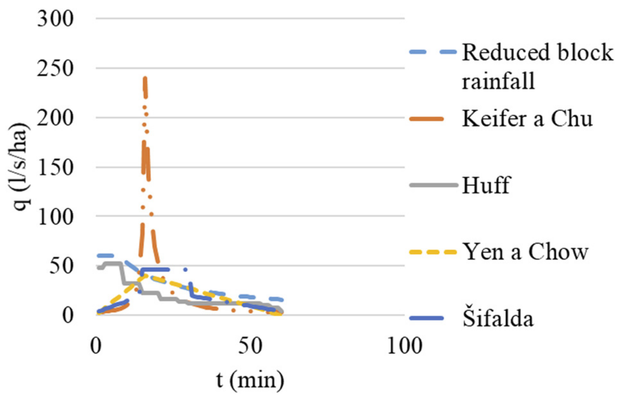

Fig. 3. Model rainfalls

Synthetic rains have a variable intensity due to their time distribution. They are more suitable for more detailed calculations, which do not neglect the formation of surface runoff and simulate non-stationary flow in sewers. Since they must be as close as possible to the natural precipitation, the intensity profile has an ascending part, where the intensity increases, a central part with maximum intensity, and a descending part, representing the gradual end of the rainfall event [8].

The oldest and best-known design rains derived from Intesity, Duration, Frequency (IDF) curves include the "Chicago Design Storm" or the Keifer and Chu model [9], the block rainfall [10], or the "Alternative Blocks Method" [11]. The design rain designed by Šifald [12] also has a simple course, the time course of which is divided into three parts. The middle part is rectangular, and the outer parts taper linearly towards the ends [12]. The design rains Yena and Chowa [13] and Desbordesa [14] have a triangular course of the hyetogram. They are suitable for the design of sewer networks for small urban river basins [14].

The second group of design rains is those that are derived from actual rain events. A pioneer in this area was researcher Huff [15], who analyzed and processed up to 261 rain events in Illinois. It categorized rain into four groups based on which quarter of the most significant precipitation event occurs [12, 16].

The most used synthetic rainfalls in our condition are:

- Triangular synthetic rainfall;
- Šifald's synthetic rainfall;
- Chicago synthetic rainfall;
- Huff's synthetic rainfall [8].

The position of the maximum rain intensity and the time distribution of synthetic design rains are presented in Fig. 3.

3.2. Block design rainfalls

Block rainfalls has simplest and least real shape of all design rainfalls. They are created in form of block rainfall yield curves with concrete periodicity. This type of model rain has constant intensity thorough its duration, that is why it has rectangular block shape. Rainfalls are determined by periodicity p, rainfall duration t and constant yield q. They include the most intensive part of rainfall. With increasing rainfall duration its yield is decreasing. Periodicity represents occurrence of rainfalls with same or higher yield during one year. Several types of formulas were made to calculate block rainfalls. Based on data collected and processed by Šamaj and Valovič from year 1973, for Slovakia is used formula published by Ucrikán and Horváth from year 1979 [8]:

$$q = \frac{K}{(t^a + B)} \tag{1}$$

q is the yield of block rain (l. s^{-1}. ha^{-1}); t is the duration of block rain (min); K, a, B are parameters calculated for periodicity and location.

Most common calculation of design rainfalls use periodicities p = 5.0; 1.0; 0.5; 0.2 and parameters K, a, B are from 68 precipitation-gage stations in Slovakia listed in STN 75 6101 sewer systems and sewer connections [8]. Precipitation-gage stations are shown on map in Fig. 4 [9].

4. RESULTS AND DISCUSSION

4.1. Design rainfall

Yield of design block rain was calculated from Urcikán and Horváth formula (1). Parameters K, a, B are determined from precipitation-gage station 61 Trnava for periodicity p = 0.5, (Fig. 5).

Design rainfall calculations were created in SeWaCAD. Software SeWaCAD was developed for effective calculations combined and separated sewer systems. System SeWaCAD if defined by its desktop with user friendly view of sewer network what user can control or change [17]. Program SeWaCAD offers option to calculate block design rainfall for selected area. By choosing precipitation-gage station 61 Trnava and periodicity $p = 0.5$ was calculated yield of block rainfall $q15 = 169.23\,\mathrm{l\,s^{-1}\ ha^{-1}}$ and parameters $K = 2744.9$, $a = 0.93$ and $B = 3.81$. Calculated values are used for creation of design model of sewer system.

4.2. Sewer system assessment

Model of sewer system G of Trnava city, created in SeWaCAD software was assessed by design rainfall with periodicity $p = 0.5$. Assessment shows the locations and amount of overload on sewer system sections.

Modeling of sewer networks, including modeling of surface runoff and water quality, are very complex in terms of mathematical prediction of natural processes. The complexity of the models is diverse. Elementary ones predict only one process; conversely, complex models predict a set of interconnected processes.

Therefore, before selecting a simulation tool, it is necessary to determine the modeling objectives and the nature of the available input data. The choice of model also considers that the model is following current regulations and corresponds to the unit system.

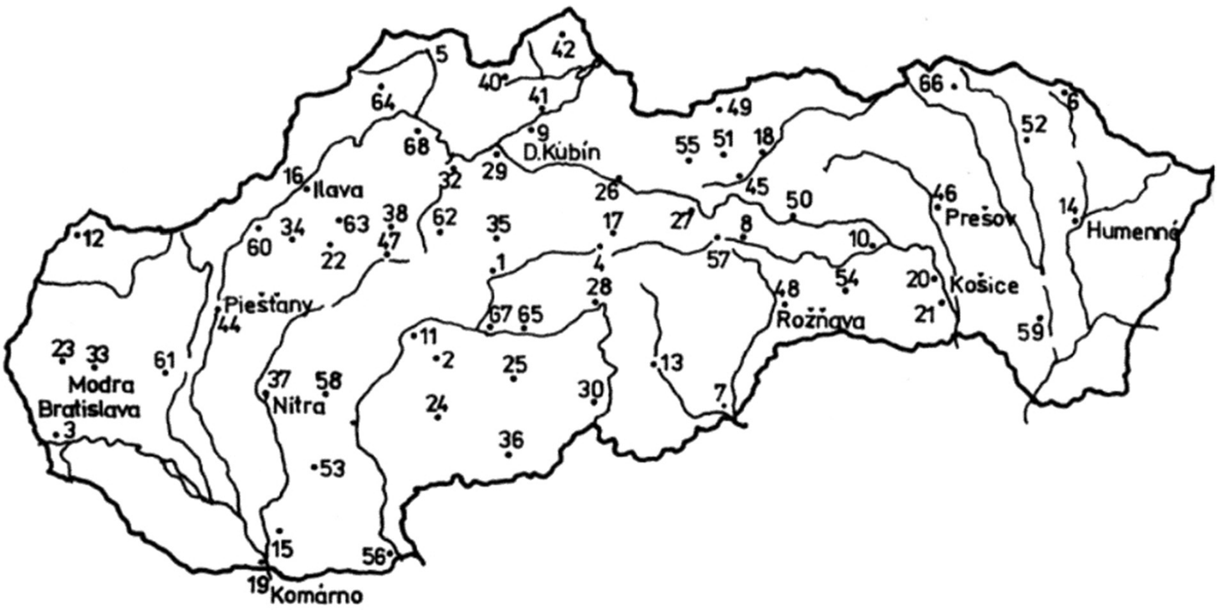

Fig. 4. Precipitation-gage stations in Slovakia

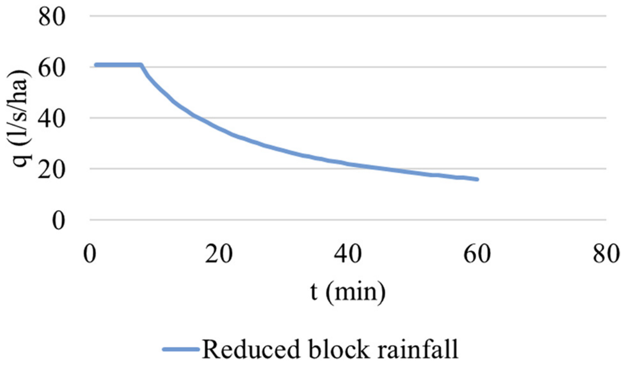

Fig. 5. Block rain yield curve $p = 0.5$, 61 Tranava

4.3. Periodicity $p = 0.5$

Model of sewage network was tested for block design rainfall with periodicity $p = 0.5$. This rainfall should occur at least once per two years. Results are shown in Table 1. Assessment showed that number of suitable sections was 86 from 160. Total length of suitable sections is 1745.75 m, which represent 52.94% of total length. Overloaded sections were on 47.06% what is 1,551.78 m from total length of assessed sewer system. In interval 100–150% is 15 sections with length 293.45 m, 8.90% from total length sewer system G. Most overloaded sections are in interval 150–250%, which represents 23 sections, total 566.27 m (17.17%). 22 sections, with sum length 440.7 m (13.36%) are included in overload interval 250–500%. Overload 500% and more is for 14 sections, 251.93 m, which represents 7.62% from total 3,297.53 m length of sewer system. Location of suitable and overloaded sections is shown in Fig. 6.

4.4. Restoration of sewer system

By restoration of sewer network is meant any type of measures to restore or to improve function of existing sewer sections or sewer system. Restoration can be repair, renovation or remediation, reconstruction, and replacement. Replacement is construction of new sewage system sections, which are improving function of old sewer system [18].

Sewer system from the point of rainfall flood protection must be designed with consideration of increased security. Design is using longer times of occurrence. Rainfall time of occurrence is based on previous cases and experiences. STN 75 6101 state that is needed to use periodicity $p = 0.5$ for combined sewer systems in cities with 5,000 and more population [8].

Table 2 shows design of sewer system restoration. DNj is overloaded section dimension and DNn represents design section dimension. According to sewer system assessment DNn must maintain its function during design rain with periodicity $p = 0.5$.

Table 1. Assessment results for $P = 0.5$

Length	Overloaded sections				Suitable sections	Sum
	100–150%	150–250%	250–500%	>500%		
(m)	293.42	566.27	440.70	251.39	1745.75	3297.53
(%)	8.90	17.17	13.36	7.62	52.94	100.00

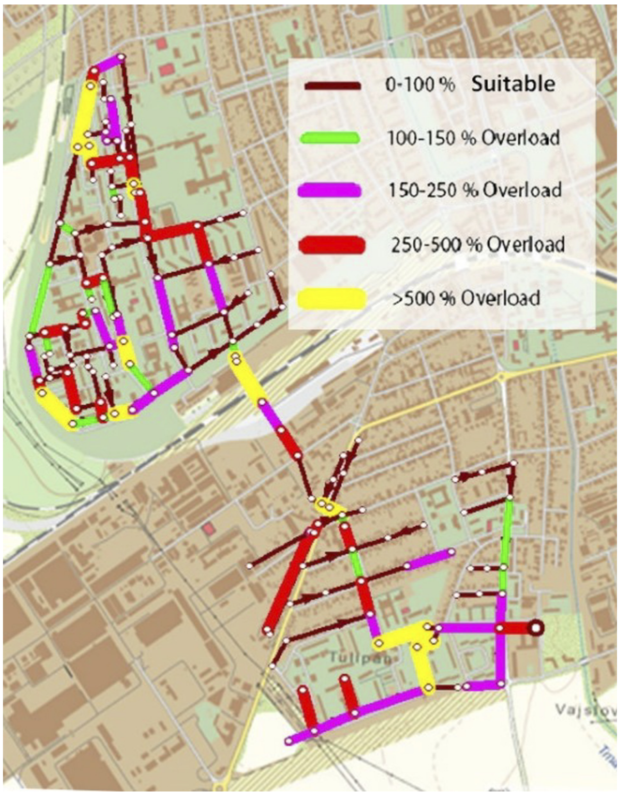

Fig. 6. Assessment of sewer system $p = 0.5$

Table 2. Restoration design of sewer system

DNj (mm)	DNn (mm)	Number of sections	Length (m)
300	400	7	135.44
300	500	9	140.28
300	600	5	79.79
300	800	6	228.10
300	1,000	2	19.73
400	500	3	76.36
400	600	1	32.15
400	800	8	121.52
400	1,000	1	19.24
400	1,200	2	30.02
500	600	1	32.15
500	800	1	52.25
500	1,000	1	10.38
600	800	3	66.37
600	1,000	2	21.91
600	1,200	4	48.39
600	1,400	8	129.65
1,000	1,200	2	64.96
1,000	1,400	2	59.14
1,000	1,600	1	20.74
1,000	1,800	2	44.90
1,000	2,000	3	81.77
1,100	2,000	1	10.60
1,200	2,800	1	3.54
1,200	3,000	1	32.19
1,200	3,200	1	23.27
1,600	3,200	3	58.42

(continued)

Table 2. Continued

DNj (mm)	DNn (mm)	Number of sections	Length (m)
1,600	3,400	2	15.80
1,600	3,600	1	7.36
1,800	3,600	2	38.49
1,800	3,800	4	85.76
2,200	3,800	2	66.26

Table 3. Restoration of combined sewer system G in the city of Trnava

	Restoration		
Length	Without change	Replacement	Sum
(m)	1,440.60	1,856.93	3,297.53
(%)	43.70	56.30	100

On places where section dimension DN value exceed 2000 mm is reasonable to double the pipe with smaller dimension or apply objects to collect rainwater on the area of assessed sewer system. For these changes, another calculations and assessments are needed to maintain proper rainwater harvesting system.

Restoration of assessed sewer system is needed for selected sections where overload was more than 100% and suitable sections, which were located after overloaded section where increase of dimension was needed. This is designed only for sections where DNj of suitable section was smaller than DNn of restoration section. By this change number of suitable sections dropped on 68 sections with total length 1.44 km and number of restored sections increased to 92 with length 1.85 km. From total 3.3 km length of assessed sewer system, 56.3% needs restoration (Table 3).

5. CONCLUSION

The goal of this work was assessment of selected combined sewer in city of Trnava. Assessment shows insufficient hydraulic capacity. According to STN 75 6101 was to assess used design rainfall with periodicity $p = 0.5$. On 14 sections capacity overload was more than 5 times bigger (250 m of sewer system). Restoration of sewer system is needed. From 160 sections were not suitable 92 during design rain. This represents 1.85 km of sewer system, what is more than half of total length (3.3 km) that need restoration or appropriate solution of rainwater collection and harvesting.

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