Impact of Green Infrastructure on Flood Prevention in Urban Area

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Abstract

Intensities of short-term rainfalls are the basic design parameters for the dimensioning and design of urban sewerage systems. However, in connection with climate change, there is a change in rainfall characteristics, which are represented i. a. also by increase of the short-term rainfall intensity. This means an increased hydraulic load on urban sewerage systems, which can be resolved by increase of the sewerage system capacity or by reducing the of rainwater inflow into the sewerage system. Currently, within the framework of adaptation measures for climate change mainly the second option is preferred, i.e. reduction of the inflow into the sewerage system. This has to be realized prioritizing the green adaptation measures (green infrastructure). The paper deals with impact of the of green infrastructure implementation in urban sewerage system on the operational safety of the urban sewerage system from the point of view of the floods occurrence in the urbanized area. As shown by the results of the model study, the biggest effectiveness of green infrastructure in terms of preventing the occurrence of flooding is shown in case of short-term rainfalls with a lower return period (1-2 years). With increase of the return period (up to 10 years), the effectiveness of green infrastructure in terms of the occurrence of flooding decreases.

Keywords: *climate change, urban drainage, adaptation measures, green infrastructure, surface flooding*

1. Introduction

The large-scale development of sewerage network construction nowadays raises a number of conceptual questions to which there is not always a simple or unambiguous answer. In particular, there are the basic conceptual questions of the strategy for the sewerage of agglomerations. When observing the development in some cities in the Slovak Republic, the trend and the overall concept of the development of sewerage networks is to maintain a combined sewerage system in the wider city centres, but in all development areas outside the city centres there is pressure for the separation of water, i.e. separated sewerage system.

However, as we already mentioned, surface water runoff is a particular problem for new development sites. In most cases, the sewerage system operators resist the connection of storm water to the existing combined sewerage network, as the hydraulic capacity of the main collectors is in most cases exhausted. Connecting stormwater from large development areas would increase the risk of flooding.

Another problem represents the ongoing climate change, causing the increased rainfall intensity (Bara et al., 2013). This fact makes the situation even worse, causing large urban flooding cases, as well as increased transport to the receiving waters.

The two strategies for urban flood prevention are 1. Reduction of the rainwater runoff into the urban sewerage infrastructure or 2. hydraulic capacity enlargement of the sewerage system. The first strategy of dealing with surface water runoff assumes disposal at the point of runoff generation (infiltration, evaporation), or accumulation and subsequent regulated discharge to receiving waters or to the sewerage network.

The second strategy requires high investment costs and this approach can exacerbate water pollution issues, as the increased capacity accelerates and concentrates runoff prior to its inflow to the wastewater treatment plant (WWTP). Currently, due to the limited hydraulic capacity of WWTPs, managing these large flows often necessitates discharging untreated wastewater into receiving water bodies through combined sewer overflows (CSOs), thereby polluting the watercourses.

At present, this regulation type is mainly understood as the implementation of green infrastructure (GI). The green infrastructure is defined as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters".(US EPA, 2024b).

The definition of the GI in the document of European Commission (European Commission, 2024) is "strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity. Such services include water purification, improving air quality, providing space for recreation and contributing to climate change mitigation and adaptation."

From a hydrological perspective, GI plays a crucial role in reduction and retention of stormwater runoff. This involves slowing the flow and decreasing the volume of stormwater entering the urban sewerage system, which should result in fewer floods and pollution reduction transported to receiving waters. Beyond its hydrological benefits, GI also positively influences the urban environment by cooling cities (mitigating heat island effects), enhancing habitat diversity and providing recreational areas, among other benefits.

However, for storage and regulated discharge into sewer system or local streams, developers are often facing requirements from the local stream authority or sewerage network operator to regulate runoff to a certain peak flow. The regulation is usually limited to the unit runoff from the paved area, or even to the general requirement that the amount of stormwater discharged must not be higher than the natural runoff from the catchment area. The solution to such a situation is stormwater flow attenuation to the maximum extent possible, i.e. exclusion of all slightly polluted or unpolluted stormwater (e.g. from roofs, pedestrian roads). Such water can be infiltrated into the subsoil indirectly (with adequate filtration through the soil layer) or directly (drainage wells). In case of polluted stormwater (e.g. from car parks, roads) it is first necessary to remove harmful substances, e.g. to remove oil with use of oil separators. (442/2002 Coll., 2002), (269/2010 Col., 2010)

From a hydrological standpoint, GI serves to reduce and delay stormwater runoff, thereby decelerating flow and decreasing the volume of stormwater entering the urban sewerage system. This process is anticipated to diminish the frequency of floods and the amount of pollution transported to receiving waters. Beyond its hydrological functions, GI confers additional benefits to the urban environment, including cooling urban areas (mitigating heat islands), enhancing habitat diversity and creating recreational spaces.

The legislative framework also endorses the use of GI. The updated EC Directive 271/91/EEC (Council of the European Union, 1991), specifically Article 5, mandates a preference for GI solutions to achieve the directive objectives.

In this study, we evaluate the influence of green infrastructure (GI) on the hydrological characteristics of an urban sewerage system. We examine the efficacy of GI as an adaptation measure from a safety perspective, particularly in relation to the incidence of flooding caused by inadequate sewerage capacity. Our research encompasses a case study of the urbanized watershed of Trebišov, wherein we modelled various scenarios of adaptation measures predicated on the implementation of green infrastructure.

2. Material and Methods

The town of Trebišov lies in the east Slovakia and is the administrative centre of the south-east Slovak region, called Zemplín region (see Figure 1). The city and the surrounding area is flat, which is typical for the East-Slovak lowland. In the city, there is a small stream (Trnávka stream, see Figure 2). The town of Trebišov has approximately 24 500 inhabitants, the area of the urbanized part of the city, which was used for this study was 382.6 ha. Detailed information about the case study area are in Table 1.

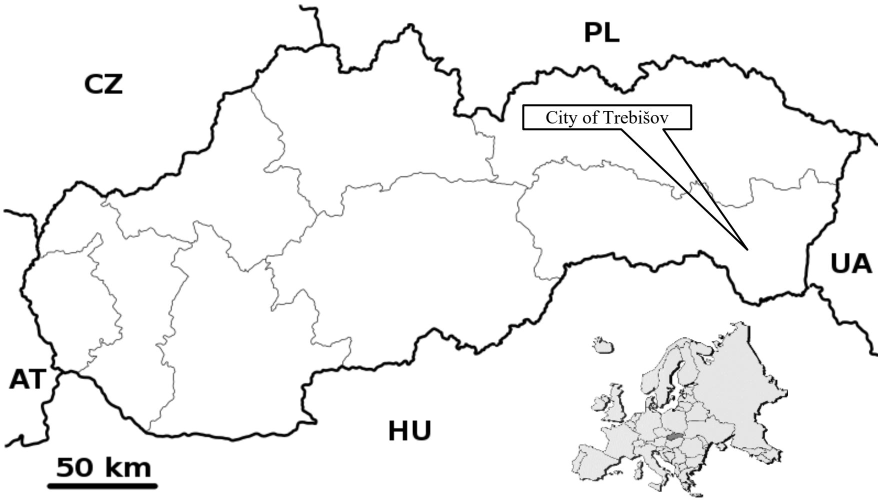

Fig. 1. The location of the case study area – town of Trebišov (Wikipedia, 2024)

In the city, there is a combined sewer system, which collects both dry weather wastewater and stormwater. The system has in total two pump stations: one pump station in the city and one at the inflow at the wastewater treatment plant (WWTP). Because the sewerage system is of the combined type, it contains also two combined sewer overflows (CSO's). The WWTP lies in the southeast part of the city (see Figure 2).

Tab. 1. Parameters of the case study catchment (city of Trebišov)

Parameter	Value
Catchment area	386.62 ha
Impermeable surfaces area	153.46 ha
Effective catchment area (reduced area)	148.32 ha
Runoff coefficient	0.384
Nr. of inhabitants (population)	24 546 inh.
Number of manholes	969
Nr. of subcatchments	645
Sewer network length	48 864 m
Sewer network volume	18 320 m^3
Specific sewer length (per inh.)	1.99 $m.inh^{-1}$
Specific sewer volume (per inh.)	0.746 $m^3.inh^{-1}$
Specific sewer length (per hectare)	126.38 $m.ha^{-1}$
Specific sewer volume (per hectare)	47.38 $m^3.ha^{-1}$
Population density	3.50 $inh.ha^{-1}$

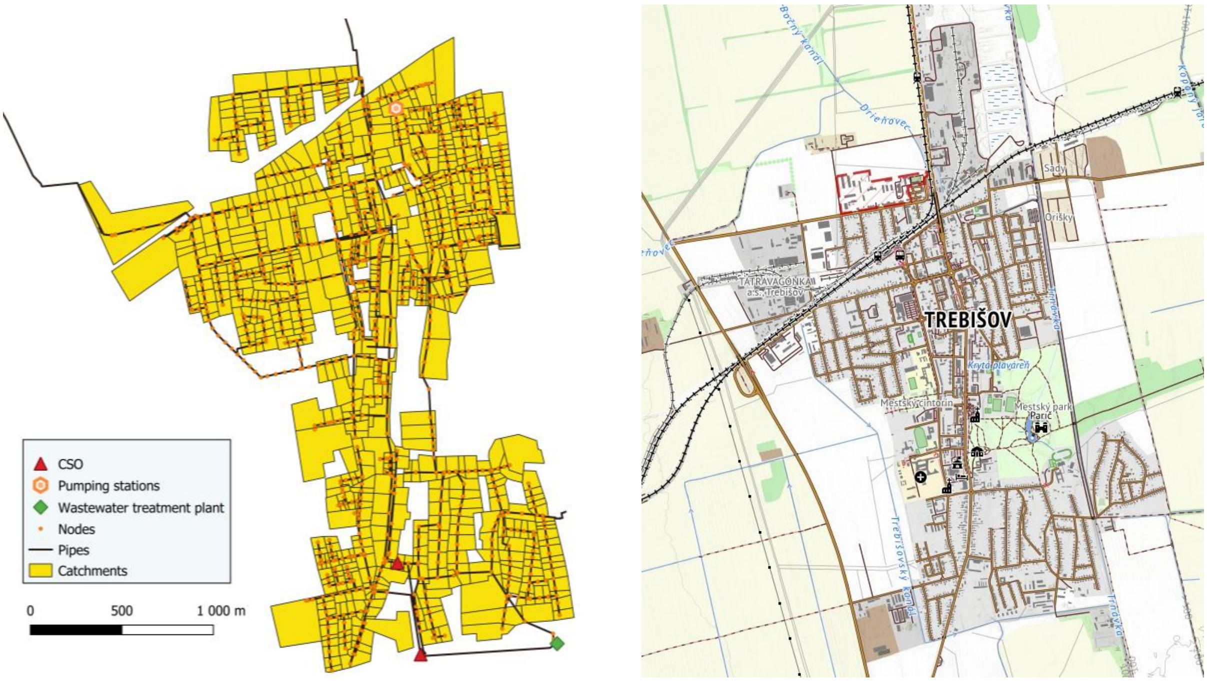

Fig. 2. Catchments layout and sewerage system (left), physical map (right) of the case study area – town of Trebišov (physical map – freemap.sk, 2024)

For this study, short-term block rainfall intensities were utilized as per (Urcikán & Imriška, 1986), which are based on the previous works of (Šamaj, Valovič, 1973). These block rainfalls are also incorporated into the current Slovak technical standard (UNMS SR, 2016). The values for these rainfall intensities, corresponding to various return periods and durations of block rains are presented in Table 1. In connection with climate change, it is expected, that rainfall intensities of short rainfalls (up to 180 min.) will increase in range 5-20 % (Onderka, 2024). Work published up today confirms this increase (Onderka et al., 2023; Onderka & Pecho, 2022, 2023).

For the runoff modelling of the urbanized area of Trebišov, the MIKE+ model was utilized. MIKE+ is a simulation software package designed for modelling stormwater and wastewater systems, including surface runoff and pipe flows. The collection system modelling relies on the US EPA SWMM (US EPA, 2024a) engine, augmented by DHI's multi-core MIKE 1 engine. The current version of MIKE+ supports the simulation of super- and subcritical flow conditions in partial, full and pressurized pipe networks. Calculations employed a combination of the time-area unit hydrograph and kinematic wave methods, with the latter applied to GI analysis in MIKE+. The platform facilitates the modelling of various GI practices at both hydrological screening and detailed hydraulic levels to evaluate their impact. An advantage of MIKE+ is its universal database platform, which enables the integration of different models (e.g., urban collection systems and river models) for both hydraulic and water quality modelling (DHI, 2024).

The MIKE+ platform incorporates a GI implementation mechanism that allows specification of GI hydrologic parameters, the extent the GI element, its linking to particular subcatchment. The parameters include hydraulic conductivity, sewerage mat thickness, water permeability, initial water level, clogging factor, sewerage outlet, and others. The aforementioned parameters were determined through the utilisation of manuals and building codes originating from both Slovakia and the Czech Republic (Balko et al., 2017; Hudeková et al., 2018; JV PROJEKT VH s.r.o, 2018).

The data required for the modelling of runoff from the urbanised area of Trebišov were provided by Východoslovenská vodárenská spoločnosť, a.s. (VVS, a.s., East Slovak Water Utility, JSCo.) and DHI Slovakia, Ltd. This data set constitutes a comprehensive hydrological model, which was calibrated during the hydraulic assessment of the wastewater system based on measurements taken at seven locations throughout the city. The resulting model was subsequently refined in consultation with experts from DHI Slovakia, Ltd., with the objective of correcting errors and incorporating more detailed sub-catchment modelling for potential GI development. This refinement included the addition of information on surface slope and surface permeability parameters, which are essential in MIKE+ for the application of kinematic wave equations.

Tab. 2. Short-term rainfalls intensity with different periodicity (return periods) in the town of Trebišov (in $l.s^{-1}.ha^{-1}$)

Periodicity / return period in years	**Duration of rainfall partitions in minutes**				
	15	30	60	90	120
0.5 / 2	178	118	72	52	41
0.2 / 5	224	157	100	73	58
0.1 / 10	263	187	118	88	72

In developing the scenario with GI adaptation measures, it was considered that green roofs have been primarily designed and implemented on larger public or industrial buildings, rather than residential ones. Green roofs are notably absent from the architectural landscape of single-family residences. This is largely due to the fact that homeowners in this category of housing typically favour alternative forms of rainwater infrastructure, should the need arise. It should be noted that exceptions do exist, namely in the case of new constructed single-family houses and new residential projects, where green roofs or other water retention measures incorporating GI elements are frequently proposed.

The implementation of green roofs on older buildings is frequently constrained by concerns regarding the structural load capacity of the existing structure. Furthermore, the infiltration capacity and potential erosion on certain types of green roofs can be challenging (Danáčová et al., 2022). for older buildings green roofs with relatively low water retention capacity (extensive green roofs) are considered. For detached and semi-detached family houses, it was assumed that minimal runoff from roofs would occur, given that the current Water Supply and Sewerage Act (442/2002 Coll., 2002) mandates that the sewerage of rainwater runoff be paid for. This results in the majority of single-family houses disconnecting their roofs and paved areas from the urban sewerage system.

The second GI element, semi-permeable surfaces, also has its technical limitations. Such conflicts frequently arise from incompatibilities with other technical infrastructure, such as utility networks. Moreover, this type of surface should not be employed in parking lots with high traffic loads (e.g., shopping malls, shopping centres). In such instances, it is preferable to utilise paved areas, or alternatively, rainwater can be directed into surface retention basins or bioswales. However, it should be noted that these systems require more intensive maintenance.

In order to evaluate the hydraulic effectiveness of GI measures, we selected the number of flooded manholes and the number of surcharged manholes as criteria. Surcharged manholes are defined as those where the maximum water level is less than 1 metre below terrain level (see also UNMS SR, 2014). In the context of the aforementioned hydraulic conditions within the sewer network, there is a significant risk of property damage due to the flooding of basements, cellars and low-lying areas.

In the context of our case study, we have defined the extent of GI realistically, taking into account the current economic, legislative and technical constraints. From the available options, it was determined that the integration of green roofs and semi-permeable surfaces into the city's overall sewerage system was a feasible approach. Other elements of GI are uncommon in the Slovak Republic and could be further linked to these two types of structures (e.g., rainwater barrels).

3. Results and discussion

The results of the runoff simulations are presented in Table 3 and on Figure 3.

Tab. 3. Number of flooded and surcharged manholes for different rainfall return periods

Rain duration	**2 years**		**5 years**		**10 years**	
	Current conditions	**Combined**	**Current conditions**	**Combined**	**Current conditions**	**Combined**
15 min.	199	134	392	346	475	469
30 min.	320	262	415	408	554	529
60 min.	305	262	440	401	556	536
90 min.	250	212	355	338	513	485
120 min.	202	170	314	304	441	413

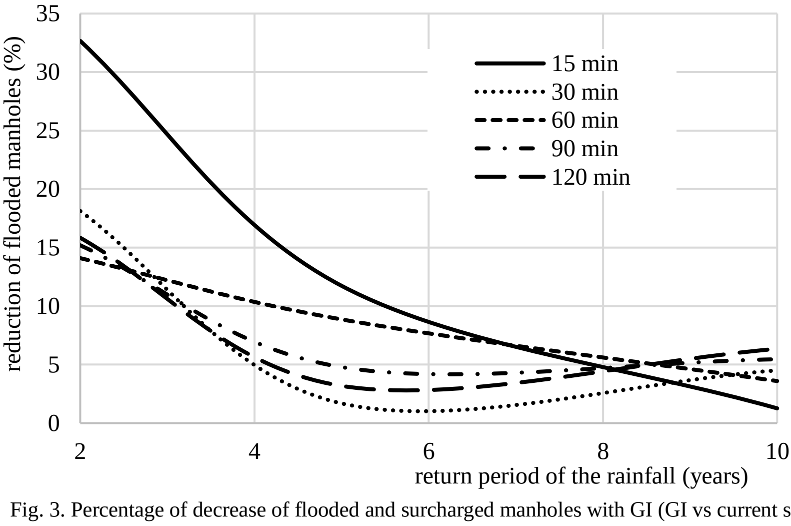

Fig. 3. Percentage of decrease of flooded and surcharged manholes with GI (GI vs current status)

Figure 4 presents the percentage reduction in flooded and surcharged network manholes in comparison to the current conditions. The data indicates that the most significant reduction occurs for rainfall events with a short return period (2 years), achieving approximately 15-30%. As the return period increases, the effectiveness of GI in mitigating flooding and surcharging in the urban sewerage system diminishes. For a 5-year return period event, the reduction is approximately 2-15%, while for a 10-year return period event, it is 2-6%.

We believe that the results obtained are fully in line with the results of a similar study that was each carried out on the natural catchment of the Kamp River (Austria) (European Environment Agency, 2012). One of the results of this study is presented on Figure 4.

As it can be seen on this figure (Figure 4), the GI adaptation measures are mainly effective in case of rainfalls with small return periods and only partially effective for rainfalls with bigger return periods. This is fully applicable also for results of this study (compare Figure 4 and Figure 3).

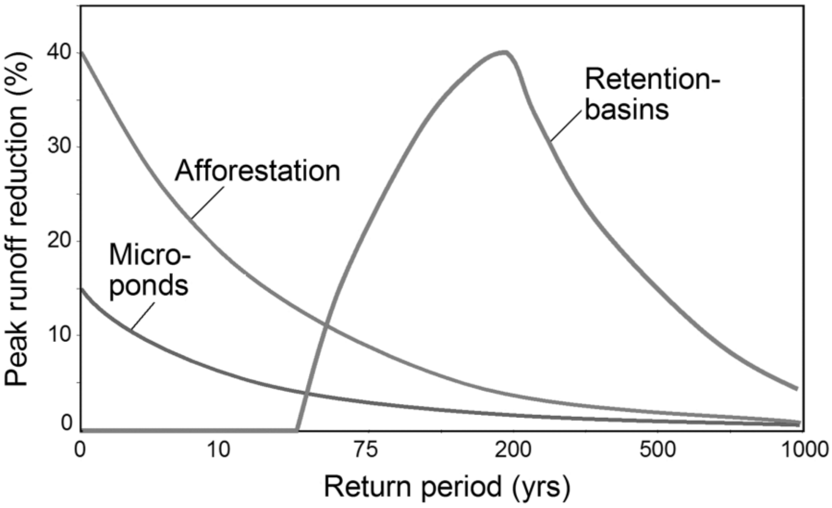

Fig. 4. The effect of particular adaptation measures on peak runoff reduction (European Environment Agency, 2012), (Blöschl, 2022).

4. Conclusions

The results of the case study for the city of Trebišov indicate that the GI implementation reduces by approximately 15-30% the number of flooded or surcharged manholes in case of rainfall events with a short return period (2 years). In case of increased return period, the effectiveness of GI in mitigating flooding and surcharging in the urban sewerage system diminishes. For a 5-year return period event, the reduction is approximately 2-15%, while for a 10-year return period event, it is 2-6%.

These findings indicate that GI is particularly effective in protecting urban areas from flooding during low-intensity rainfall events, but less so for high-intensity rainfall events (e.g., storms, torrential rain). Conversely, it is evident that the implementation of GI is beneficial in reducing the frequency of flooding events for low-return-period rainfall.

We can assume that the effectiveness of GI would be higher if it were implemented on a larger scale. Nevertheless, such a large-scale implementation would necessitate disproportionately high financial costs, thereby raising questions about the proportionality of the investment in relation to its benefits.

The study confirmed that the impact of GI on flood protection in urban areas is relatively limited during high-intensity rainfall events. Nevertheless, it is our contention that GI plays an important role in urban area due to its ecosystem functions. It is recommended that the implementation of GI shall be performed to an economically and technically reasonable extent, in conjunction with other measures such as grey infrastructure.

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References

1. 442/2002 Coll. (2002). The Public Water Supply and Sewerage Act (p. 49). Collection of laws of the Slovak Republic. Parliament of the Slovak Republic. https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2002/442/20240401
2. 269/2010 Col. (2010). Decree of the Government of the Slovak Republic laying down requirements for achieving good water status (Collection of laws of the Slovak Republic ed.). Bratislava: Parliament of Slovak Republic, https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2010/269/20221115
3. Balko, Z., Bihuňová, M., Gáborová, L., Lančarič, Š., Murínová, L., & Štrba, B. (2017). Budovanie prvkov zelenej infraštruktúry na Slovensku. (In Slovak: Construction of elements of green infrastructure in Slovakia). Slovenská agentúra životného prostredia. https://szkt.sk/wp-content/uploads/2021/02/Budovanie-prvkov-zelenej-infrastruktury-na-Slovensku.pdf
4. Bara, M., Velísková, Y., Dulovičová, R., & Takáčová, D. (2013). Hodnotenie bodových zdrojov znečistenia na hornom toku Hrona [Evaluation of point-source pollution hazard in the upper Hron river basin]. Acta Hydrologica Slovaca, 13(2), 416–422.
5. Blöschl, G.(2022): Three hypotheses on changing river flood hazards, Hydrol. Earth Syst. Sci., 26, 5015–5033, https://doi.org/10.5194/hess-26-5015-2022 , 2022.
6. Council of the European Union. (1991). Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31991L0271
7. Danáčová, M., Danko, M., Výleta, R., & Hlavčová, K. (2022). The generation of surface runoff in laboratory conditions using two portable rainfall simulators-an experimental study. Acta Hydrologica Slovaca, 23(2), 249–256. https://doi.org/10.31577/ahs-2022-0023.02.0028

8. DHI. (2024). MIKE+ Collection Systems. MIKE+. Available at> https://www.mikepoweredbydhi.com/products/mikeplus/collection-systems/
9. European Commision. (2024). Green infrastructure. https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure_en
10. European Environment Agency. (2012). EEA Report No 11/2012 : Water resources in Europe in the context of vulnerability. Copenhagen: EEA. https://doi.org/10.2800/65298
11. Hudeková, Z., Mederly, P., & Tóth, A. (2018). Zelená infraštruktúra. Príručka nielen pre samosprávy. (In Slovak: Green infrastructure. A guide not only for municipalities.). Mestská časť Bratislava-Karlova Ves. https://www.karlovaves.sk/wp-content/uploads/Zelena-infrastruktura-prirucka-nielen-pre-samospravy.pdf
12. JV PROJEKT VH s.r.o. (2018). Hospodaření se srážkovými vodami-cesta k modrozelené infrastruktuře Olomoucké stavební standardy k integraci modrozelené infrastruktury. (in Czech. Rainwater management - the way to a blue-green infrastructure. Olomouc building standards for the integrati. City of Olomouc (Czechia). https://www.olomouc.eu/administrace/repository/gallery/articles/23_/23422/hdv_cesta_k_mzi.cs.pdf
13. Onderka, M., & Pecho, J. (2022). Observations from the Western Carpathians and Pannonian Plain show that rainfall return levels need to be adjusted to account for rising dew-point temperature. Acta Hydrologica Slovaca, 23(1), 89–98. https://doi.org/10.31577/ahs-2022-0023.01.0010
14. Onderka, M., & Pecho, J. (2023). Návrhové hodnoty intenzít krátkodobých dažďov na Slovensku. (Design values of short-term rainfall intensities in Slovakia.). Národný Klimatický Program Slovenskej Republiky (National Climate Program of the Slovak Republic), Vol. 17/22. https://www.researchgate.net/publication/369847422_Narodny_klimaticky_program_Slovenskej_republiky_Zvazok_1722_Navrhove_hodnoty_intenzit_kratkodobych_dazdov_na_Slovensku_ISBN_978-80-99929-40-2
15. Onderka, M., Sokáč, M., Pecho, J., & Mikulová, K. (2023). Digital atlas of rainfall design intensities in Slovakia. Meteorologický Časopis, 26, 27–38. https://www.researchgate.net/publication/372448219_Digital_atlas_of_rainfall_design_intensities_in_Slovakia
16. Šamaj, F., & Valovič, Š. (1973). Intenzity krátkodobých dažďov na Slovensku (in Slovak, Short-term rainfall intensities in Slovakia). SPN - Slovenské pedagogické nakladateľstvo. https://books.google.sk/books/about/Intenzity_krátkodobých_dažďov_na_Slo.html?id=kHv_XwAACAAJ&redir_esc=y
17. UNMS SR. (2014). STN EN 16323 Terminologický slovník pre techniku odpadových vôd (Glossary of the wastewater engineering terms). UNMS SR - Slovak Office of Standards, Metrology and Testing. https://normy.normoff.gov.sk/norma/132552/?csrt=9949739139078053723
18. UNMS SR. (2016). STN 75 6101 - Slovak technical standard: Gravity sewerage systems outside buildings (p. 64). UNMS SR - Slovak Office of Standards, Metrology and Testing.
19. Urcikán, P., & Imriška, L. (1986). Stokovanie a čistenie odpadových vôd. Tabuľky na výpočet stôk. (in Slovak. Sewerage and waste water treatment. Tables for sewer design.). SNTL Alfa.
20. US EPA. (2024a). Storm Water Management Model (SWMM). https://www.epa.gov/water-research/storm-water-management-model-swmm
21. US EPA. (2024b). What is Green Infrastructure? https://www.epa.gov/green-infrastructure/what-green-infrastructure
22. Wikipedia (2024): Slovakia - outline map, https://sk.m.wikipedia.org/wiki/S%C3%BAbor:Slovakia_-_outline_map.svg