Hydrogeological Conditions of Košice City

Monograph

Ladislav Tometz
Diana Dirnerová
Dana Tometzová

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INTRODUCTION

The settlement network of Slovakia is broken down into smaller settlements nationwide, which is also applied to the city Košice. The position of this city is defined by the coordinates 48° 43' north latitude and 21° 15' east longitude. The area studied covers the whole city of Košice, the largest distance is in the N-S direction (25 km) and the smallest in the E-W direction (3.5 km). The altitude ranges from 184 to 851 m above sea level but the centre of the city is at 208 m.

On July 24th in 1996, the National Council of the Slovak Republic adopted the Act No. 221/1996 Coll. on Territorial and Administrative Organisation of the Slovak Republic. Based on this act, the city of Košice was divided into 4 districts *(Table 1)* and in the lower level into 22 wards, which were in 2001 further divided into 126 urban zones. At its administrative borders the city has an area of 242.3 km^2. Košice has 239,095 inhabitants (2017) and its population densityis 987.2 inhabitants per km^2 (2016 data).

One of the most important needs of Košice is the supply of drinking water in sufficient quantity and quality. The main water sources – the water reservoir Starina (district of Snina) and the water reservoir Bukovec (Košice-okolie district) – are situated outside of the city limits. Long-distance water pipelines supply drinking water from them. Within the water system of Košice, the groundwater sources of the Slovak Karst (grouped water pipelines of Turňa–Drienovec–Košice) and some other sources located directly in the city are used as well.

At the turn of the 19th and 20th centuries, the oldest water supply system of the city employed the captured springs of the Čermeľ Valley and later also the wells situated in the valley of that Hornád (Hernád) River. Because of the industrial development of Košice, the demand for local use of groundwater has increased. Therefore, especially in the 1960s and 1970s numerous water sources were sought for, explored and built within the territory of the city.

This monograph describes the hydrogeological conditions in the territory of the city of Košice. It also provides a review of the distribution of groundwater sources in the city as well as an evaluation of their technical parameters, yield, water quality and quantity.

1. TERRITORIAL AND ADMINISTRATIVE ORGANISATION OF KOŠICE

Košice, as the metropolis of eastern Slovakia, is the second largest city in Slovakia, with more than 230,000 inhabitants. The city is a part of Košice and Košice–Prešov agglomeration, which, with 555,800 inhabitants, is one of the largest urbanised areas in Slovakia. As is documented in *Table 1*, Košice is divided into 4 districts and 22 wards.

Table 1. Districts and wards of Košice and basic information about them (as of 31 December 2017)

Ward	District	Area [km^2]	Population
Staré mesto	Košice I	4,34	20 751
Ťahanove		7,28	2 529
Sídlisko Ťahanovce		8,56	22 340
Sever		54,58	20 281
Kavečany		10,05	1 310
Džungľa		0,47	697
Západ	Košice II	5,53	39 978
Šaca		41,21	5 890
Sídlisko KVP		1,78	23 864
Poľov		12,96	1 198
Pereš		1,33	1 939
Myslava		7,01	2 257
Luník IX		1,07	6 411
Lorinčík		2,97	718
Košická Nová Ves	Košice III	5,77	2 691
Dargovských hrdinov		11,09	26 169
Vyšné Opátske	Košice IV	4,19	2 480
Šebastovce		5,1	732
Nad jazerom		3,66	24 803
Krásna		20,05	5 401
Juh		9,77	23 030
Barca		18,13	3 626

Košice is an important centre of political, economic, cultural and clerical life as well as the seat of the Constitutional Court of the Slovak Republic. It is also an important university and scientific centre: it is the seat of four universities as well as faculties and detached departments of other Slovak universities and is the seat of eight institutes of the Slovak Academy of Sciences.

1.1. District Košice I

The first district is divided into 6 wards and represents the central part of the city. 67,908 inhabitants live within its area of 85.46 km^2.

Ward Staré Mesto

The dominant of this part of the city is its historical center with numerous monuments of Gothic, Baroque, Classical and Historical architecture. It represents the largest area of historical importance in any city in Slovakia (85.4 ha). The most prominent is the largest religious structure in Slovakia – the Gothic Cathedral of St. Elisabeth. Hlavná Street, lined with palaces and burgher houses housing restaurants, boutiques and cafés, provides a nice promenade of the city.

In the past, this ward was supplied from sources located in the Čermeľ Valley. Today, combined sources Bukovec Dam, springs in the area of Medzev, Starina Dam and springs in the area of Turňa – Drienovec – Hatiny are used.

Up to 40 groundwater sources have been documented within this study, although most of them are not used. One of the most important is the groundwater source supplying the Singing Fountain between the State Theatre and St. Urban Tower.

Ward Ťahanovce

Until 1969 Ťahanovce was a separate village and the first written mention of it dates back to 1263. At present, about 2,000 (mostly older) inhabitants stay here. It is closely interconnected with the neighbouring ward Settlement Ťahanovce. Approximately half of the central part of the area is represented by build-up area of older age with individual houses, which often include dug wells. The population is supplied with drinking water through sources located in the Hornád River valley. In the cadastral area Ťahanovce itself there are neither numerous nor significant groundwater sources. In the mapping base compilation for this study, the recreational zone Anička (belonging to the ward Sever) was also affiliated to this ward. Anička is an area where not only important sources of drinking water but also wells capturing natural mineral water have been identified. In total, 45 hydrogeological wells are documented here.

Ward Settlement Ťahanovce

The centre of the ward is characterised by a panel housing estate built between 1984 and 1997 on the left-bank river terrace of the Hornád above the village Ťahanovce, where the sanitation works relating to the expansion of the housing estate were planned in the past. The ward Settlement Ťahanovce is the youngest in the city and currently has about 23,000 inhabitants. The drinking water supply is from the central system (Starina–Košice water supply system). Groundwater sources are not found here. On *Map 1*, this ward is affiliated with the ward Ťahanovce.

Ward Sever

This ward covers the largest area in the city. It contains a magnesite mine in the Bankov area, Hradová Hill with ruins of the castle and the View Tower, Clinic Sever, Komenského and Angelinum parks, stadiums of the Lokomotíva area, and the recreational zones Anička, Alpinka, Čermeľ, Bankov and Jahodná. This part of the city is supplied by drinking water from Čermeľ sources as well as groundwater sources situated in the vicinity of the Hornád River. In total, 15 hydrogeological wells are documented in this area, some of which are locally used.

Ward Kavečany

According to the oldest written document dated from 1423, the original Slovak name of this ward was Kavečany. It is a name found in all regions of Slovakia. The village Kavečany was merged with Košice City in 1969. At present, people visit this area mainly for relaxation activities since a ski resort, relaxation zone and zoo are located here, and the southern part is intensively used for neighbourhoods of individual houses. Because of there are some local groundwater sources, Kavečany has its own water supply network. One hydrogeological well (CH-7) supplying the water to the zoo was identified here.

Ward Džungľa

This is the smallest ward of Košice, founded in the 1930s. In the 1970s it was designated for sanitation works, which were not finally realised. The location of the ward Džungľa between the centre of the city and newly built residential areas brought dynamic shopping development to this area. In addition, construction of a traffic and railway junction, Terminal Sever, is planned. The existence of Džungľa as an autonomous city unit with only about 450 inhabitants is an often discussed political question. In discussion of the reduction of Košice wards, its affiliation to the ward Sever has been proposed. The water supply in this area is similar to the ward Staré Mesto. In addition, 5 groundwater sources and some dug wells related to the housing estate are situated here.

1.2. District Košice II

The second district is located in the western part of the city and consists of 8 wards. Totally, 82,255 inhabitants reside in the district, whose area is 73.87 km^2.

Ward Západ

A significant part of this ward territory is characterised by the residential area known as Nové Mesto – Terasa. Moreover, other parts are also characterised by residential or built-up areas: in the southern part the residential area Železníky, on the eastern edge a built-up area originally of family-houses, and on the western edge of the ward an area of new houses can be found. Západ is the third most urbanised ward of Slovakia. Higher populations are found only in the Petržalka and Ružinov wards belonging to Bratislava.

Groundwater sources supplying this area are located mainly in the Slovak Karst (the Turňa–Drienovec water supply network), but water is also supplied from the Bukovec Dam. In general, 14 groundwater sources were documented, some of which are used as irrigation sources or as sources of non-drinking water.

Ward Šaca

This district consists of two former villages, Šaca and Buzinka, as well as the largest industrial section of Košice (U.S. Steel Corporation). In this area a major medical facility is situated, a private hospital belonging to the AGEL Group. Drinking water is obtained from the Turňa–Drienovec water supply network here and the hospital is sourced by wells of the Malá Ida cadastral area. 32 hydrogeological wells were documented and most of them were realised for groundwater protection purposes in the industrial section (US Steel).

Ward Settlement KVP

This ward is characterised by a complex of panel apartment blocks built mainly in the 1980s. In addition, shops, a convent, sport facilities, tennis hall etc. are situated here. Water supply is resolved in the same way as in the ward Západ. No groundwater sources are available here due to the unfavourable local hydrogeological conditions.

Ward Poľov

Formerly this ward was a historically independent village. Even today, it has preserved by its rural character and a few kilometres of green areas separate it from the panel flats in the built-up area of the city. The cadastral area of Poľov is around 1217 ha, of which the built-up area is over 165 ha. Drinking water is supplied to the population through dug wells as well as through the Turňa–Drienovec water supply network. For use in farmyards, 5 hydrogeological wells were dug in the territory of this ward but all of them were identified as being of little value both quantitatively and qualitatively.

Ward Pereš

Pereš is one of the youngest parts of Košice city and is characterised exclusively by built-up areas of individual houses. Between 1997 and 2000 more than 90 building permits were issued here. The ward is also known for the fact that it is rather difficult to establish a groundwater source. Therefore, the area is supplied from the Turňa–Drienovec water supply network. Information about the realisation of hydrogeological wells is absent in the archives.

Ward Myslava

The village is located in the Myslava Creek valley. At present, however, the built-up area of individual houses is expanding also to the surrounding slopes. Myslavská Maša, the part of Myslava Village known for its metallurgical history, belongs to this ward as well. Its cadastral area also includes a closed-down dump. Drinking water is supplied from the Bukovec Dam reservoir, but some houses have their own dug wells.

Ward Luník IX

This is the housing estate with the highest density of the Roma population in Slovakia. Although the capacity of the housing estate is around 2,400 inhabitants, around 6,411 inhabitants are registered in Luník IX, of whom approximately 2,200 are children. As a result, one flat is occupied by 14 to 16 people on average. A difficult problem for Košice City is the inadequate social and hygienic condition of the people staying here. The ity district uses the Bukovec Dam reservoir and the Turňa–Drienovec water supply network as a source of water. Six hydrogeological wells are situated within the territory of this ward and ward Myslava. Most of them are located in the area of the dump, in order to monitor the groundwater quality.

Ward Lorinčík

This was an autonomous village in the past. The territory of this ward is located on the north-western edge of the District Košice II. The building expansion typical of this area is related to its location as well as the fact that it is the one of the best places for relaxation and peaceful life in Košice. The water is supplied from the Bukovec Dam reservoir. In addition, inhabitants use also individual dug wells, especially as sources of irrigation water. However, official information about the utilisation of groundwater sources is missing in this territory. In the northern part of Lorinčík, a new built-up area for individual houses has been developed during the past decades, but related hydrogeological works did not meet with success.

1.3. District Košice III

The third district is the smallest district of Košice City. It consists of only two wards.

Ward Košická Nová Ves

Košická Nová Ves was a village that became affiliated to Košice City in 1968. The original family houses make up 99% of the building area of this ward. Only 3 structures are prefabricated. However, according to the land-use plan, settlement expansion is planned, during which around 2,000 new houses will supplement the currently existing 700 houses. The Košice–Starina water system supply is used as a source of drinking water for the population of Košická Nová Ves. Three relatively deep (25 to 95 m) hydrogeological wells are documented in this area. In addition, a well-known spring used as source of refreshing water for the local population is located in the centre.

Ward Dargovských hrdinov

This ward is located on the hill known as Furča, which is also the popular name of this district. At present, approximately 30,000 inhabitants live here, predominantly in housing estate buildings. In this territory, there is essentially no industry. Drinking water is supplied through the Starina–Košice water system. As is evident from *Table 9*, the area contains 9 hydrogeological wells. They are situated mainly on the western edge of the area, closer to the Hornád River. As a result, their hydrogeological value is higher (efficiencies even higher than 10 ls^{-1}).

Numerous geological surveys related to its development were carried out in the housing estate area itself. However, engineering geological wells did not confirm the possibility of obtaining a significant amount of groundwater. Despite this, the groundwater, although it is only in a small amount, affects the stability of the territory. As a result, some of the more permeable layers in the marginal parts of the area are drained by more than 130 horizontal wells and water is taken to a local canal.

1.4. District Košice IV

The fourth district of Košice is located in the south-eastern part of Košice City and consists of 6 wards. It covers an area of 60.89 km^2 and has a population of 60,072.

Ward Vyšné Opátske

Ward Vyšné Opátske was established on 23–24 November 1990 by Acts of the National Council No. 369/1990 Coll. of Municipalities and No. 401/1990 Coll. on Košice City. It was formed by affiliation of the cadastral areas Vyšné Opátske and Košice-Východ. Today it consists of two cadastral territories, Vyšné Opátske and Nižná Úvrať. Predominantly a built-up area of individual houses has evolved here, with some industrial structures. The drinking water supply is provided from the sources of the supra-regional Starina–Košice water system and from the Turňa–Drienovec water supply network. From the hydrogeological point of view, only three wells of minor importance were realised here. Since the ward is characterised mainly by built-up areas, the occurrence of dug wells is relatively frequent here.

Ward Barca

Barca was a separate village in the past, which was affiliated to Košice in the second half of the 20th century because of the expansion of the city. Most of the village is made up of an area of industrial plants, an airport, a municipal waste incinerator and the sewage plant, and only a minority of its area consists of residential neighbourhoods. Ward Barca is supplied with drinking water in the same way as ward Vyšné Opátske. Regarding the archive documentation, up to 42 hydrogeological wells were realised here. Most of them are related to the planned food industry section in the eastern part of the territory. After the development of this complex and its restructuring in 1989, some groundwater sources are still used today. In the area of the airport, besides the water sources for utility and drinking purposes, hydrogeological works related to the protection of groundwater have been carried out. In addition, dug wells are relatively frequent in the built-up area.

Ward Šebastovce

This part of the Košice city has a rural character, characterised by family houses with no blocks of flats. Until 1976, Šebastovce was an autonomous village. Generally, 8 hydrogeological wells are documented in this area. Deeper wells (31 to 163 m) pass also through artesian beds and as a result, their efficiencies are higher than 10 Ls^{-1}. Shallower wells (maximally of 18 m) are used as water sources for the local nursery school and the restaurant. Besides these wells, drinking water supply is provided from the same water supply systems as in wards Barca and Vyšné Opátske. Individual wells dug by the inhabitants are used mainly as sources of irrigation and non-drinking water.

Ward Nad Jazerom

The name of this ward comes from the lake (in Slovak "jazero") belonging to this territory that was formed due to gravel mining along the Hornád River in the past. The ward consists of estate housing and a bit larger area is represented by industrial and business area located on the southwest. All of the 23 documented hydrogeological wells are situated in the fluvial gravels of the Hornád River valley and some of them are still in use today. The district's population as well as industrial (mainly food) facilities use drinking water mainly from the supra-regional Starina–Košice water system but also from the Turňa–Drienovec water supply network.

Ward Krásna

Until 1990, this was an autonomous village named Krásna nad Hornádom. It is located in the south-eastern part of the Košice city, on both banks of the Hornád River. The territory of this ward extends also to the Torysa River valley. A built-up area of houses prevails in this area and on the western edge the is some industrial production. The drinking water supply is provided similarly to the ward Nad Jazerom. Although 9 hydrogeological wells were realised here, none of them are used at present.

Ward Juh

The southern part of the city was established in the period of business development as a continuation of the historic centre of Košice. In the Middle Ages some colonies near the city existed here, such as Bednárska, Špitálska and Ludmanova Ves. Today, the ward Juh has a multifunctional character due to residential as well as industrial zones being present here. In this territory, 24 groundwater sources are situated. In addition, the well with one of the highest yields in the city is in this area: it is labelled K-1N, has a yield of 41 ls^{-1}, and is located in – the area of University Hospital of L. Pasteur on Rastislavova Street. Currently it represents the source of the drinking water for this hospital. However, as whole, the ward Juh is supplied with the drinking water from the supra-regional Starina–Košice water system and Turňa–Drienovec water supply network.

2. NATURAL CONDITIONS OF KOŠICE

The natural conditions of Košice City are characterised in the following text only in the context of the evaluation of its hydrogeological conditions.

2.1. Geomorphological conditions

Košice city is located on the territory of two geomorphological areas *(Figure 1)*:

a) The Slovenské Rudohorie Mts. including The Čierna hora Mts. (with Hornád foothills) and Volovec Mts. (with Kojšov Hill and Holička Hill).
b) The Lučenec–Košice Depression including the Southern Slovak Basin (with the Košice Basin).

Figure 1. Geomorphological units of eastern Slovakia with the highlighted territory of Košice city (Mazúr and Lukniš, 1986)

The relief of the area studied is relatively varied. In the central part of the Košice Basin, it has a plain character with the lowest point 204 m above sea level at its southern edge in the ward Šaca (District Košice II) near Bočiar. This kind of relief represents a substantial part of the District Košice I and District Košice IV.

The highest point, 809 m above sea level, is located on the northern edge of the city territory, in the Kavečany district. From the Hornád Valley towards the east, the character of the relief changing from the plain to hilly (ward Ťahanovce – District Košice I, Košická Nová Ves – District Košice III, and Vyšné Opátske – District Košice IV). The mountain character of the relief occurs in the area of Čierna hora Mts. as well as the Volovec Mts. (Mazúr and Lukniš 1986).

2.2. Climatic conditions

Climatic conditions of the area studied depend on the altitude and the relief of the terrain.

The Košice Basin is characterised by a warm slightly humid climate with the maximum long-term average annual temperature of 25 °C and cold winters. Monthly average air temperatures of the years 2015 to 2018 are summarised in *Table 2*.

The hilly area of the eastern part of the Volovec Mts. and the southeast part of the Čierna hora Mts. is represented by a slightly warm and slightly humid climate with the maximum long-term average annual temperature of 16 °C.

Table 2. Average monthly air temperatures in Košice, °C (2015–2018)

Station	Year	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Košice – the airport	2015	0.1	1.0	5.8	9.9	14.9	19.6	22.1	23.4	16.9	9.6	4.8	2.1
	2016	–2.9	4.4	6.0	11.6	15.7	20.7	21.2	19.6	17.4	8.7	4.1	–2.3
	2017	–6.6	0.9	7.4	9.8	16.3	20.9	20.4	22.0	17.3	9.9	4.7	0.9
	2018	1.4	–1.1	2.3	14.9	18.9	20.1	21.8	23.0	17.0	12.0	6.0	–0.4

Source: SHMÚ

According to the measurements at the climate station Košice – the airport, the long-term average annual rainfall is 630 mm (1975–2005, *Table 3*).

Table 3. Average monthly and annual rainfall, mm (1975–2005)

Station	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Košice – the airport	30	34	29	36	78	85	82	73	44	46	54	39	630

Source: SHMÚ

Potential vapour ranges from about 650 mm in the north to more than 730 mm at the southern edge of the area. The evaporation rate from the soil surfaces is about 480–530 mm.

2.3. Hydrological conditions

The main flow draining the water from the surface in the area studied is the Hornád River flowing from the north to the south. Therefore, from the hydrological point of view, the territory of Košice City belongs to the watershed area of this river (Hydrological Order No. 1-4-32-03-068-01).

Regarding the flow regime of the flows, the area studied is represented by hilly lowland area with the rain-to-snow type of flow. It is an area typified by the accumulation of waters from December to January, high water flow from February to April, the highest discharge of the receiving streams during March (IV < II) and the lowest during September, and the significant secondary increase of water level at the end of autumn and beginning of the winter *(Table 4)*. The main flow of the Hornád River is widely influenced by the mid-mountainous area it flows through and also by the human interference in the area beneath the waterworks Ružín.

Table 4. Average monthly and extreme discharge of the river Hornád

8705	Station: Košice			River: Hornád			Stationing: 26,60				Area: 2 440,40		
Qm	34,77	20,75	23,89	43,87	73,27	129,80	44,23	44,55	50,58	21,67	29,88	46,28	47,00
Qmax 2010	520,5	day/month/ hour:			05/06/04	Qmin 2010		9,841	day/month:		02/11		
Qmax 1966-2009	320,5				24/07/20-2008	Qmin 1966-2009		3,580			23/01 - 1972		

Source: SHMÚ

3. GEOLOGICAL CONDITIONS

The territory of Košice City has relatively varied geological conditions *(Figure 2)*. A substantial part of it is located in the Košice Basin, where almost exclusively Neogenic and Quaternary deposits overlapping Paleozoic and Mesozoic rocks of Gemericum and Veporicum are preserved on the surface. The north-western part of the area studied, the area of the Čierna hora Mts. and Volovec Mts., is characterised by the emerging of the subjacent rocks on the surface. Neogene and Quaternary deposits are preserved here only rarely.

The whole area of the Čierna hora Mts. and Volovec Mts. is dissected by faults, predominantly of the northeast-southwest to north-south direction. However, regarding the geological structure the more important factor is the oldest tectonic activity of the northwest-southeast direction (the Lubenik–Margecany fault) representing the contact of the Veporicum and Gemericum. It is therefore possible to identify the following rock complexes from the northeast to the southwest (Bajaník et al. 1983; Polák et al. 1997):

a) Paleozoic rocks of the Veporic crystalline complex represented by biotitic granodiorites of the Bujanová Complex,
b) late Paleozoic rocks of the Veporicum represented by arkosis metagrey-wackes of the Brusno Formation and in the northernmost part also by sandstones and shales with fine-grained conglomerate intercalations of the Nižná Boca Formation (Choč Nappe),
c) Mesozoic cover of the Veporicum, in the area studied represented mainly by Triassic dolomites, also by Jurassic limestones at a lower rate, as well as by Triassic quartzites and clayey-sandy shales,
d) Paleozoic rocks of the Gemericum represented by:
   - phylites with intercalations of tuff and tuffite and amphibolites of the Rakovec Group,
   - chloritic-sericitic and graphitic phylites with metabasalt tuffs and tuffite intercalations of the Črmeľ Group,
   - polymict metaconglomerates and metasandstones with graphitic shale intercalations of the Dobšiná Group,
   - polymict metaconglomerates, sandstones, shales and metaryolites of the Krompachy Group,
e) Mesozoic cover of the Gemericum represented by Triassic rocks of the Stratená Group, i.e. variegated shales and sandstones with intercalations of shelly limestones.

Neogene sediments occur in the area studied as deposits of several formations. In the territory of the Moldava Basin variegated shales and siltstones with sand and gravel intercalations interpreted as a Sečovce Formation are preserved on the surface. Beneath, also kaolinised ryolite tuff and tuffite of the same formation are locally present.

The territory of the Prešov Basin is characterised by the transition of the Kochanov Formation deposits preserved in the northwest part into the subjacent deposits of the Stretava and Klčov Formations emerging on the surface in the eastern and south-eastern part. The Kochanov Formation is represented by variegated clays and siltstones with occasional intercalations of poorly sorted gravels and sands. The Stretava Formation consists of lithologically similar deposits, although there are beds of polymict gravels as well. In the north-western part of the area studied, Klčov Formation deposits are preserved on the surface. They consist mainly of the Varhaňovce gravels but clays and claystones with thin gravel and sand layers also occur. Locally, redeposited rhyolite tuffs and tuffites known as a Royal (Kaličiak et al. 1991a, 1991b; Kaličiak et al. 1996a, 1996b) are preserved on the surface.

Explanations of the geological map in *Figure 2*:

QUATERNARY, **Holocene**

a – anthropogenic sediments (burdens, dumps)

f – fluvial floodplain sediments (loams, sands, gravels)

Holocene–Pleistocene

d – deluvial sediments (sandy-loamy gravels)

p – proluvial fan sediments and fluvial sediments of the river terraces (loams, sands, gravels)

NEOGENE, **Miocene**

n – Sečovce (non-calcareous kaolinised clays and silts, sand and gravel intercalations, tuff and tuffite interbeds), Kochanovce (clays, silts, gravels and sands), Stretava (clays, gravels, sands, tuff and tuffite intercalations) and Klčov Formations (clays, gravels, Varhaňovce gravel)

nt – ryolite tuffs and tuffites

MESOZOIC

Triassic–Jurassic

t – Veporicum cover (Triassic dolomites, clayey shales, sandstones; Jurassic limestones with cherts)

tl – Lúžna Formation (quartzites, sandstones)

ts – Gemericum cover, Stratená Group (variegated shales, sandstones, marly limestones)

PALEOZOIC

Permian

v – Northern Veporicum, Ľubietová Group (arkosis greywackes with coarse fragments of volcanic detritus)

gsk – Northern Gemericum, Krompachy Group (metaconglomerates, metaryolites)

gsd – Northern Gemericum, Dobšiná Group (alternation of the metasandstones and shales, polymict up to bouldery metaconglomerates)

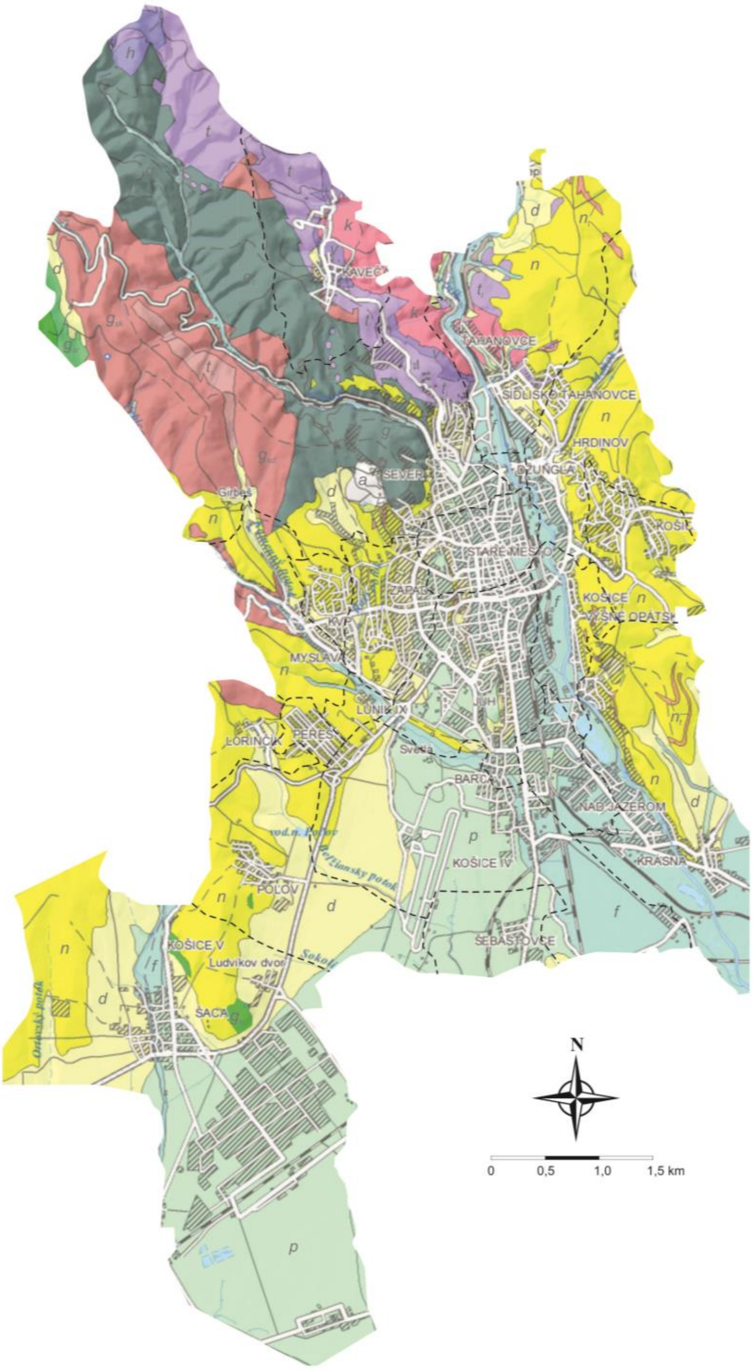


Figure 2. Geological map of Košice City
(Bajaník et al. 1984; Kaličiak et al. 1991a, 1991b;
Kaličiak et al. 1996a, 1996b; Polák et al. 1996)

Carboniferous

gsč – Northern Gemericum, Črmeľ Group (sericitic-chloritic and graphitic phylites, metabasaltic tuffs and tuffites)

gsr – Northern Gemericum, Rakovec Group (amphibolites, phylites with intercalations of metabasaltic tuffs and tuffites)

h – Hronicum, Ipolitic Group, Nižná Boca Formation (sandstones, shales, intercalations of conglomerates)

Crystalline rocks

k – Crystalline of Veporicum, Bujanová Complex (biotitic granodiorites)

Predominantly fluvial, proluvial, deluvial and rarely also anthropogenic burdens and dumps are identified as Quaternary cover. The preserved fluvial sediments are sandy gravels representing relicts of the river terraces, and Holocene loams, sands and clays as floodplain deposits. In the areas of the rivers and streams discharge into the valleys, sandy and loamy gravels or gravelly loams are deposited as alluvial fans. Accompanying them are deluvial gravel-loamy sediments resulting from the weathering of the Neogene and older quaternary deposits.

Regarding the tectonics, similarly to the area of Čierna hora Mts. and also in the Košice Basin, faults of the northwest-southeast, northeast-southwest and north-south direction can be recognised as a result of the structure-tectonic arrangement of the pre-Paleogene basement. Of the Neogene deposits of the Košice area, the most significant is the fault in the northeast-southwest direction representing the contact of the Klčov and Stretava Formations, and the fault of the north-south Košice–Seňa direction, which reflects the decline of the Neogene deposits towards the Gemericum. During the Quaternary period, tectonic activity has had an exclusively declining character. This reflects the reactivation of the Neogene movements after the relatively calm period of the upper Pliocene, but new activity has also been recorded (Kaličiak et al. 1996a, 1996b).

4. Hydrogeological conditions

According to the Government decree 282/2010, the territory of Košice City belongs to the following groundwater units within the quaternary sediments:

- SK1001200P Intergranular groundwater body of Quaternary sediments of the Hornád watershed area (Košice I district – wards Džungľa, Staré Mesto; Košice II district – wards Myslava, Západ, KVP, Luník IX, Pereš, Lorinčík, Poľov, Šaca; Košice IV district – wards Juh, Barca, Nad Jazerom, Šebastovce),

and in the pre-quaternary rocks:

- SK200500FK Fissure and karst-fissure groundwater body of the Slovenské Rudohorie Mts. in the watershed area of Hornád (Košice I district – wards Sever and Kavečany),
- SK200510KF Dominant karst-fissure groundwater body of the Branisko and Čierna hora Mts. in the watershed area of Hornád (Košice I district – wards Sever and Ťahanovce),
- SK2005300P Intergranular groundwater of the Košice Basin in the watershed area of Hornád (Košice I district – ward Settlement Ťahanovce; Košice III district – wards Dargovských hrdinov and Košická Nová Ves; Košice IV district – wards Vyšné Opátske and Krásna),
- SK2005200P Intergranular groundwater body of the Abovská pahorkatina hills in the watershed area of Hornád (Košice II district – western edge of the wards Šaca, Poľov and Lorinčík).

Regarding geothermal water units, the SK 300170FK Košice Basin extends to the eastern part of the city.

According to the hydrogeological regions of Slovakia (Šuba et al. 1992), the area studied belong in the following hydrogeological regions:

- G 118 Paleozoic of the Slovenské Rudohorie Mts. in the Hornád watershed,
- MG 124 Mesozoic and Crystalline of the Čierna hora Mts.,
- NQ 123 Neogene of the eastern part of the Košice Basin,
- NQ 138 Neogene and Quaternary of the Košice Basin and Abovská kotlina Hills in the Bodva watershed,
- Q 125 Quaternary of the Hornád River in the Košice Basin.

The presence of the individual regions in the districts and wards of the Košice city is illustrated in *Figure 3*. Based on it, the most extensive territory belongs to the region Q 125, situated in the central and southern part of the city. The eastern part falls into the region NQ 123, the northern part into regions G 118 and MG 124, and the southwestern part into the region NQ 138.

4.1. Hydrogeological characterisation of the lithological types of rocks

There are various lithological types of rocks preserved in the territory of Košice city. Some of their geological properties are described in this section.

Crystalline rocks

Crystalline shales and granitoid rocks are characterised by fissure permeability. The fissures in the rocks have various genetic origins, but in terms of water saturation, those of tectonic origin are the most important. However, the fissures are largely tightened and mylonized, which results in low water saturation in some granitoid rocks. Recorded values of the coefficient of the transmissivity are of the order 1.10^{-5} m^2s^{-1}. Due to the oriented structure and schistosity of the paragneisses and migmatites, fissures in these rocks are tightened and mylonized. As a result, their hydrogeological importance regarding groundwater movement and accumulation is low. Also, the low amount of the springs and their low yield, which is in most cases maximally 0.1 ls^{-1}, confirm the overall low water saturation of the crystalline rocks. The springs of fissure origin have lower extension and their yield is only rarely higher than 1.0 ls^{-1}.

Paleozoic

Preserved types of Paleozoic rocks were exposed to metamorphosis that destroyed their primary porous permeability. At present, their permeability is related to the tectonic fractures and faults. Better conditions for the infiltration of the atmospheric water and circulation of the groundwater are found in conglomerates and sandstones, while the fractures in shales are often clogged by weathered material. In general, the water circulation is also confined in the Paleozoic rocks due to the formations being characterised by the alternation of relatively permeable rocks with shales. As a result, these formations have only poor permeability, or even none, with the coefficient of the transmissivity being of the order 10^{-6} up to 10^{-5} m^2s^{-1}. Regarding the springs in the described rocks, the predominant are tof talus character with a maximum yield of 0.1 ls^{-1}. Better conditions for groundwater accumulation are provided by gemeric granites and crystalline limestones of the Carboniferous age. In the area of the Volovec Mts. the regime of the groundwater circulation in Paleozoic rocks has been changed by mining activity (Bankov Mine).

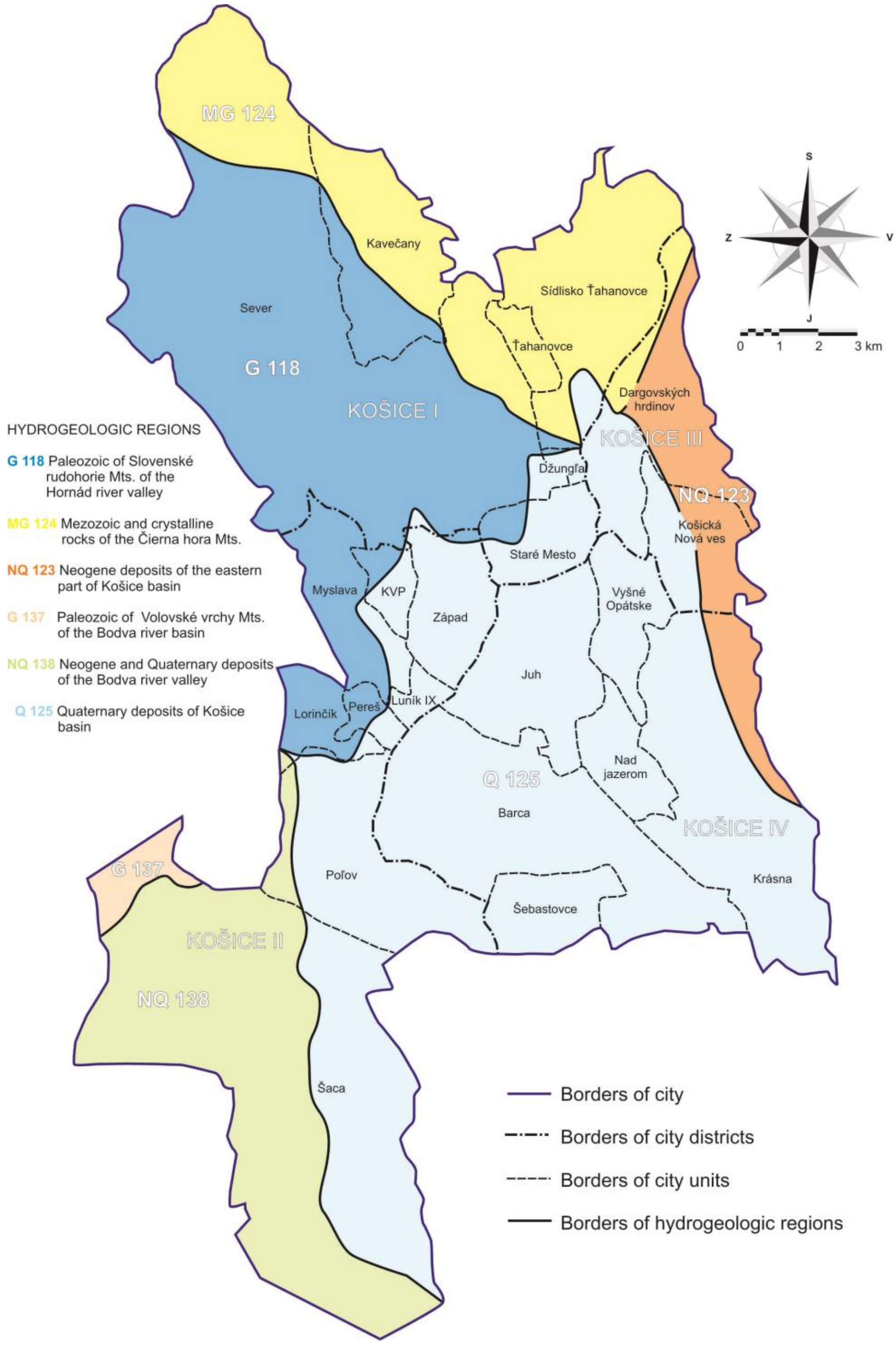


Figure 3. Position of hydrogeological regions with relation to the wards of the Košice city

Mesozoic

The Mesozoic rocks of the Čierna hora Mts. area are the most important groundwater aquifer. Mostly preserved are dolomites, in which the karst processes are limited and therefore the fissure permeability predominates over that of fissure-karst character. The coefficient of the transmissivity is of the order 10^{-4} up to 10^{-3} m^2s^{-1}, only rarely 10^{-5} m^2s^{-1} (Helma 2005). The occurrence of springs is connected to the contact of the carbonates with the Paleozoic rocks and their yield reaches 1–2 ls^{-1}, rarely up to 5 ls^{-1}. In the territory of the carbonate complex fissure or talus springs are common.

Neogene deposits

Neogene deposits have varying conditions for accumulation and circulation of the groundwater that is relates to their lithological features, mainly grain-size heterogeneity. Permeable deposits are gravels or conglomerates, sands and sandstones as well as tuffs and tuffites. The occurrence of these deposits is irregular. They have a small spatial range, relatively small thickness and often are preserved only as lenses. Water saturation of these permeable deposits is affected by the permeability; however, the possibility of sourcing by atmospheric water or water penetration from the neighbouring complexes (the Volovec Mts.) is also important.

Among the Neogene deposits, those that are relatively well saturated are the sediments of the Klčov Formation, detrital beds of the lower brakish Sarmatian and beds of the Košice gravels in the Volovec Mts. The coefficient of the transmissivity is of the order 10^{-4} to 10^{-3} m^2s^{-1} (Jetel in Kaličiak et al. 1996a, 1996b).

Quaternary

Quaternary sandy and gravelly alluvium represents the most preserved aquifer deposits in the area studied. They are characterised by the intergranular permeability. The most extended, spatially and with respect to the thickness, are fluvial sediments of the Hornád River, where three individual accumulations were distinguished – high, medium and low river terrace with alluvial floodplain sediments. In general, the thickness of these accumulations ranges from 5 to 12 m, gravels are more permeable and the coefficient of the transmissivity is of the order 10^{-4} to 10^{-3} m^2s^{-1}, in the central and southern part of Košice City up to 10^{-2} m^2s^{-1}. Gravels of the river terraces are of lower permeability and their coefficient of transmissivity is of the order 10^{-5} to 10^{-4} m^2s^{-1} (Jetel in Kaličiak et al. 1996a, 1996b). The groundwater level is unconfined to softly confined, and the direction of its flow is parallel to the flow of the Hornád River. The trough of the river Hornád is, with the exception of small sections, cut into the water-saturated gravels, which allows a hydraulic connection between the water in the river and the groundwater.

4.2. Occurrence and characterisation of the groundwater sources

Groundwater sources situated in the territory of Košice are represented by natural springs as well as by artificial objects like hydrogeological wells, dug wells (to a lower extent), etc.

Springs

Springs occur exclusively in the mountain and foothill of the city (Map 1), mostly to the left side of the Čermeľ creek valley, where Triassic dolomites predominate over limestones. Since these sources are not used as a key water supply for drinking water in Košice, measured minimal parameters do not acquire special importance in assessment. However, at average (29.28 ls^{-1}) and maximum (40.43 ls^{-1}) efficiencies, the assessed waterworks system provides a valuable amount of quality drinking water. Measured values of the yield in the well point for the years 1994 to 2004 (Máťuš et al. 2006) are recorded in *Table 5*.

Table 5. Minimum, maximum and average annual values of the global yield for the Čermeľ springs

Year		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Efficiency Q [l.s-1]	min.	25,8	23,1	15,31	29,3	26,22	22,3	18,3	14,8	12,5	11,6	12,9
	max.	71,1	50,6	37,8	50,2	42,4	36,6	33,5	39,1	23,7	23,7	36,1
	average	47,4	37,8	29,87	39,8	34,11	31,2	23,8	25,2	16,7	16,5	25,7

Other springs are in most cases connected to the same geological conditions and genetically they can be attributed to the group of above-mentioned springs. They are situated in the Kavečany area as well as in the zoo of Košice *(Map 1)*.

Very rarely also talus springs are captured for the water supply system in the Paleozoic rocks (sericitic-chloritic phyllites) with a yield not higher than 0.2 ls^{1}. In *Map 1*, all of these springs are marked as P-1 and P-28. Other springs within the territory of Košice are not of specific importance; therefore, they are not recorded in the maps presented in this study.

Hydrogeological wells

Hydrogeological wells and dug wells are of particular importance regarding their location and specialised use. There are also sources of drinking water used sometimes for the public water supply but mainly as utility and technical waters needed for the running of various industrial operations. Hydrogeological wells within the works related to the protection of groundwater against pollution cannot be omitted, either.

Based on the compiled hydrogeological maps of Košice *(Maps 1–4)*, the distribution and parameters of the wells in individual parts of the city are characterised in the following text. The maps are supplemented by tables with information about individual wards, i.e. GPS coordinates and the depth of the well, the aquifer lithology and its depth position, the static groundwater level and its drawdown, the yield of the well, the suitability of the water for drinking purpose as well as reference to the author of prospecting works.

4.2.1. Ward Sever

In this ward, 14 hydrogeological wells were documented. Their locations are shown on *Map 1* and a more detailed characterisation in *Table 6*. The wells are mostly located in the Quaternary sediments, at the edge of the Hornád River floodplain, where proluvial gravels and deluvial clayey gravels are deposited. Wells are 6.5 to 14.0 m deep and their yield reaches 0.1 to 23.25 ls^{-1}. Groundwater captured by these wells met guidelines and was determined to be suitable for drinking purposes at the time of the survey.

At the locality Horný Bankov two wells were made for the purpose of the local hotel. The first, DBH-1 of 18.0 m depth, passes through the deluvial talus with the possible withdrawal of 0.15 ls^{-1}. The second, DBH-2 of 20.0 m depth, was realised in the phyllites and confirmed that no significant amount of groundwater ($Q = 0.05$ Ls^{-1}) can be taken from these rocks. Groundwater from both wells was determined as qualitatively nonconforming for drinking purposes.

On the edge of the fluvial gravels of Čermeľ creek, a hydrodynamic test was realised in 1987 in an existing dug well. The well is used as a water source for the restaurant in the holiday house Alpinka. The yield of this well was measured as 4.3 ls^{-1} but the quality of the water is not sufficient to use as drinking water.

4.2.2. Ward Kavečany

According to the archive documentation, only one hydrogeological well was made in this ward as a part of the regional hydrogeological survey of the Čierna hora Mts. (Frankovič 1981). Testing of the well, situtated in the granodiorites with 100.0 m depth, revealed that good quality groundwater can be withdrawn at the rate of 0.96 Ls^{-1} *(Map 1, Table 7)*.

4.2.3. Wards Ťahanovce and settlement Ťahanovce

A substantial part of the territory of this district is situated in the valley of the Hornád River *(Map 2)*, where fluvial sediments identified as gravel aquifers with significant quantities of good quality groundwater are accumulated. In this district, 45 sources of groundwater are present. The depth of realised hydrogeological wells ranges from 9.0 to 18.0 m and their yields vary between 0.77 and 45.0 ls^{-1} *(Table 8)*.

The wells with hydrogeological importance are concentrated in the northern part of the area *(Map 2)*. They were realised within the survey specialised in the drinking water supply for the inhabitants of Košice. Primary documentation of the wells labelled as I to IX *(Map 2, Table 8)* was not retained.

The recreation area Anička is of special interest due to the presence of the sources of the mineral water known under the local name of Gajdovka. For the public there is a well of 35.0 m depth from which the mineral water is pumped and members of the public can refresh themselves. Water quality is permanently monitored and in the case of its deterioration, especially during long-term drought when the content of sulphates in water significantly increases, the sampling stand is closed. More detailed specification of the sources of mineral water is given in Chapter 6 of this study.

In the first half of the 1980s (as seen especially in 1982 and 1985) the water supply for Košice City was very weak. At that time, the Starina Dam was not yet in operation and sources of the grouped water system Turňa–Drienovec–Košice as well as the Bukovec Dam were not able to supply a sufficient amount of water to the city. Therefore, from the strategic point of view, it was necessary to build additional sources directly in the city. For this purpose, sources were built mainly in the northern half of the area concerned (Šťastný 1982; Šťastný et al. 1983; Tometzová and Petrivaldský 1983; Medveď 1985a). Water sources of the whole area of the Košice city are characterised in more detail in Chapters 4 and 5.

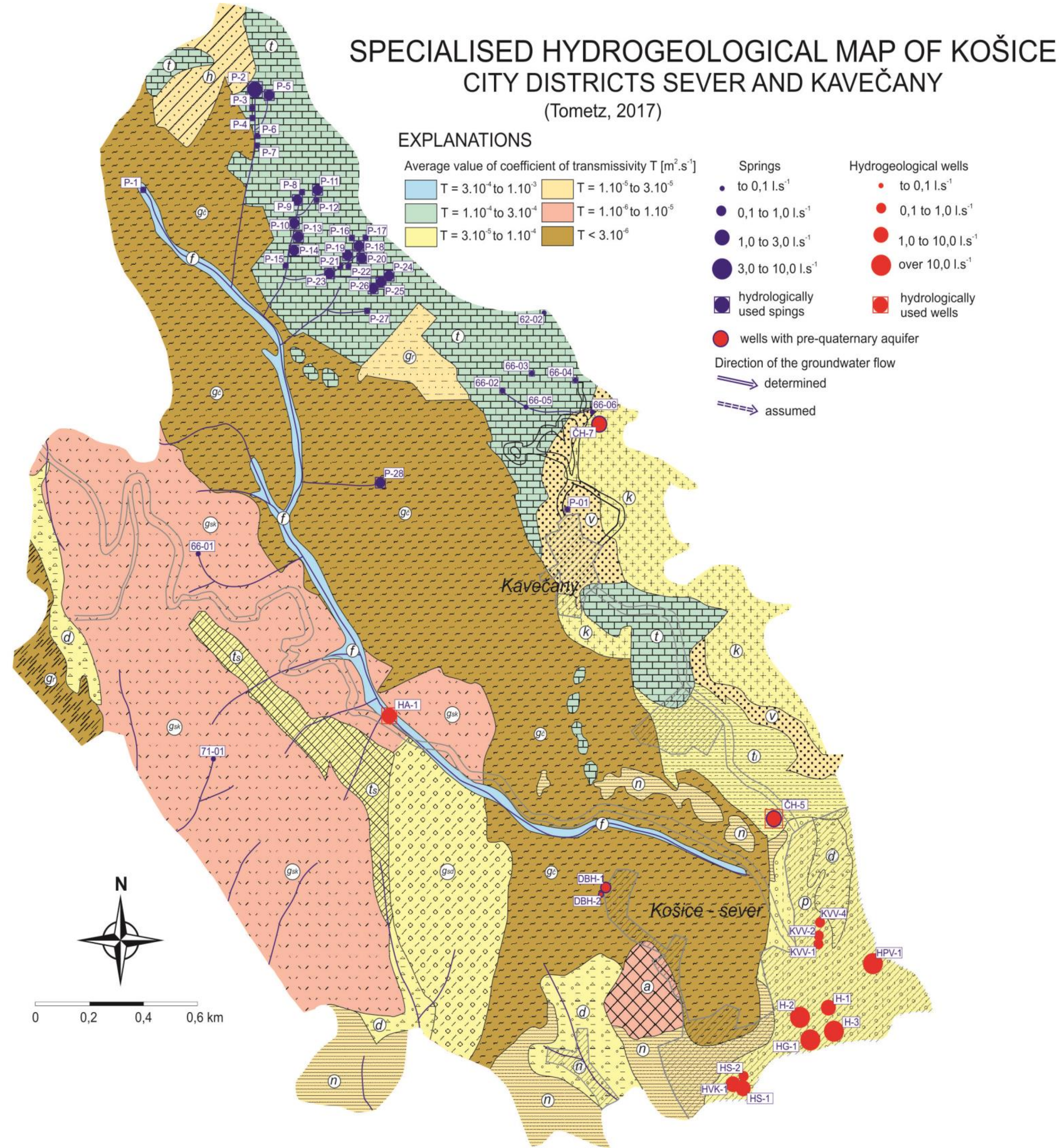
At the southern edge of the ward Ťahanovce, hydrogeological wells were formed to protect groundwater from pollution from the Benzinol terminal, in which fuel was stored for a long time. Surveys carried out by M. Dlouhá (1995) and J. Mojsej (1996) confirmed the presence of petroleum substances in the groundwater. Therefore, long-term remediation works were realised in this area to remove the pollution.

4.2.4. Ward Dargovských hrdinov

This area *(Map 2)* was analysed by an extensive engineering geological survey in the past related to housing estate development. One of the crucial problems associated with the foundation engineering was the groundwater, which is unwanted in terms ensuring slope stability. For the dewatering of the area, more than 130 horizontal wells were realised at the base of the slope. This may be the reason why there are not many wells in this area. If they were made in the past, it was mainly in the western edge of the area, where Neogene deposits gradually passes into the Quaternary alluviums of the Hornád River. This corresponds to the depth of wells (7.7 – 14.0) as well as to their efficiencies (0.2–17.0 Ls^{-1}; *Table 9*).

4.2.5. Ward Košická Nová Ves

Due to the morphological as well as geological conditions (Neogene clayey beds with occasional sandy or gravelly lenses), this area is relatively poor in groundwater content, especially at smaller depths (10–15 m). However, in the southeast part of the area the possibility of the groundwater draining has been verified at up to 5.0 to 5.7 ls^{-1}, documented through two wells of 69.0 and 95.0 m deep (Tůma 1963, 1964; *Map 2*; *Table 10*).



STRATIGRAPHY, LITHOLOGY , HYDROGEOLOGICAL VALUE

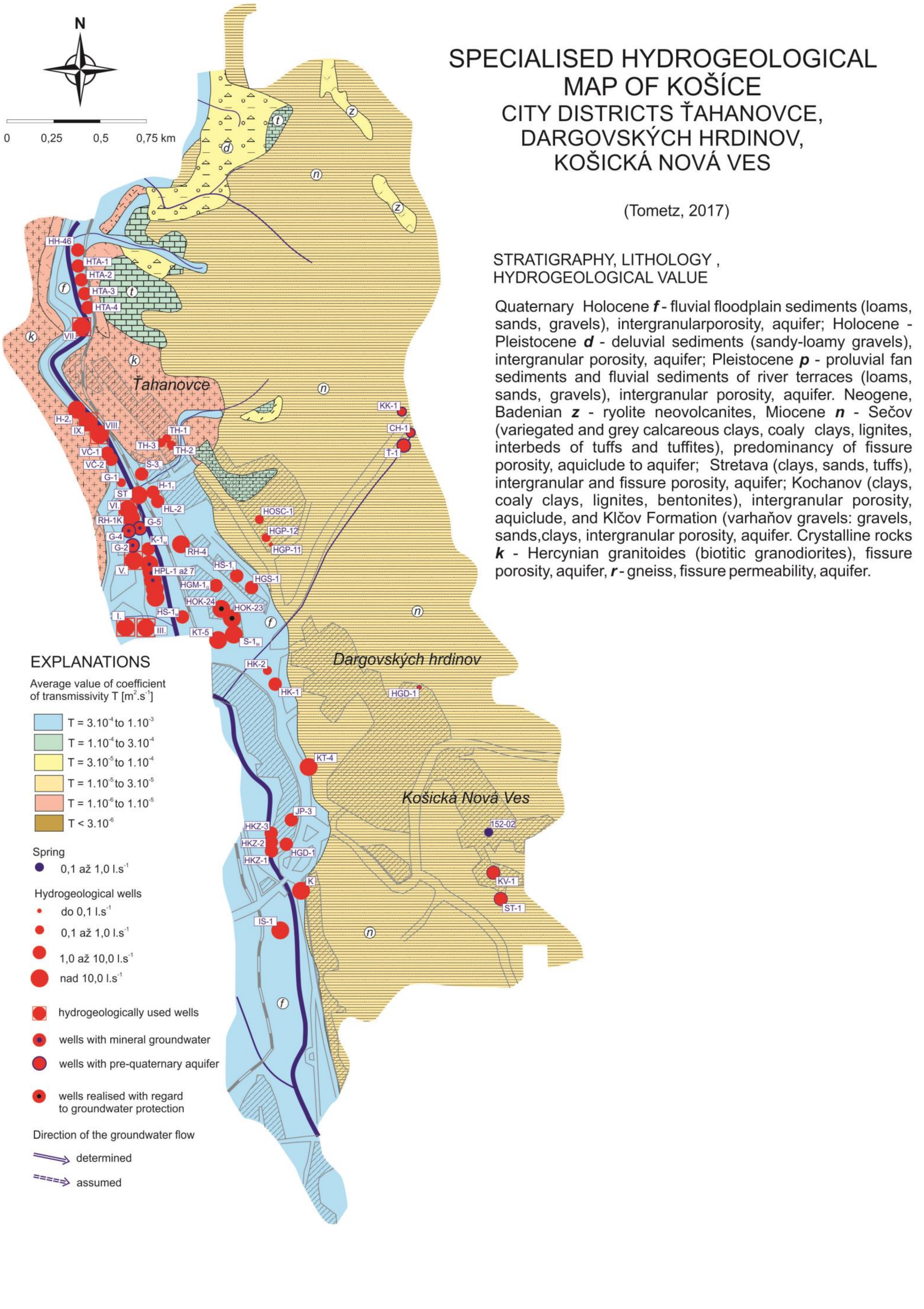
Quaternary Holocene ***a*** - antropogenic sediments (burdens, dumps), without hydrological value; ***f*** - fluvial floodplain sediments (loams, sands, gravels), intergranularporosity, aquifer; Holocene - Pleistocene ***d*** - deluvial sediments (sandy-loamy gravels), intergranular porosity, aquifer; Pleistocene ***p*** - proluvial fan sediments and fluvial sediments of river terraces (loams, sands, gravels), intergranular porosity, aquifer. Neogene, Miocene ***n*** - Sečov (variegated and grey calcareous clays, coaly clays, lignites, interbeds of tuffs and tuffites), predominancy of fissure porosity, aquiclude to aquifer; Stretava (clays, sands, tuffs), intergranular and fissure porosity, aquifer;Kochanov (clays, coaly clays, lignites, bentonites), intergranular porosity, aquiclude, and Klčov Formation (varhaňov gravels: gravels, sands,clays, intergranular porosity, aquifer. Mesosoic ***t*** - predominance of triassic dolomites over jurassic limestones, fissure-karst porosity, aquifer; $\mathbf{t_l}$ - Lúžňa Formation (quartzites, sandstones, conglomerates), fissure porosity, aquifer; $\mathbf{t_s}$ - Lower Triassic (variegated shales, sandstones, marly limestones), fissure porosity, aquifer. Paleosoic, Permian ***v*** - northern Veporicum, Ľubietová Group (arkosis greiwackes with coarse fragments of volcanic detritus), fissure porosity, semi-aquiclude to aquifer; $\mathbf{g_{sk}}$ - northern Gemericum, Krompachy Group (metaryolites to metadacites), fissure porosity, aquifer; $\mathbf{g_{sd}}$ - northern Gemericum, Dobšiná Group (metasandstones and metashales alternation, polymict to bouldery metaconglomerates), fissure porosity, aquifer; Carbonifferous $\mathbf{g_č}$ - Čermeľ Group (sericitic, sericitic-chloritic and graphitic

Table 6.
Information about groundwater sources in the ward Sever

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [$l.s^{-1}$]	drinking water	
City district Sever															
ČH-5	48	45	18.31	21	13	59.40	114.0	dolomite	0.5	114.0	16.0	19.0	3.40	suitable	Frankovič, 1981
HVK-1	48	43	49.67	21	14	24.12	12.0	loamy gravel	5.0	10.0	6.7	3.5	1.20		Tometzová, 1983e
HS-1	48	43	48.72	21	14	24.83	12.5	gravel	8.4	10.5	8.1	3.0	2.32		Protivňáková, 1987a
HS-2	48	43	46.00	21	14	27.35	13.0	gravel	8.7	11.0	8.6	2.0	0.87		
HPV-1	48	44	19.33	21	14	59.17	12.5	gravel	3.0	11.5	6.5	1.4	12.50		Protivňáková, 1987b
HA-1	48	45	36.86	21	10	50.65	6.5	gravel	2.0	5.0	4.2	1.9	4.30	unsuitable	Tometzová, 1987a
H-1	48	44	3.71	21	14	49.99	13.5	gravel	8.6	12.6	8.5	1.8	8.00	suitable	Medveď, 1988b
H-2	48	43	58.75	21	14	41.92	14.0	gravel	7.8	13.0	8.0	1.5	11.00		
H-3	48	43	55.62	21	14	54.72	14.0	gravel	6.6	13.0	7.4	2.1	23.25		
HG-1	48	43	53.20	21	14	44.29	15.0	gravel	7.6	12.5	7.6	7.6	14.20		Hudáček, 1974
DBH-1	48	44	49.76	21	12	29.73	18.0	talus	4.5	16.0	3.4	11.9	0.15	unsuitable	Tometz, 1992
DBH-2	48	44	49.72	21	12	26.86	20.0	phillites	3.9	18.0	3.9	12.6	0.05		
KVV-1	48	44	30.31	21	14	41.74	15.0	loamy gravel	5.2	10.8	7.5	3.0	0.48		Tometz, 2014b
KVV-2	48	44	29.29	21	14	42.54	15.0	loamy gravel	3.8	9.8	7.5	3.5	0.55		
KVV-4	48	44	29.69	21	14	43.42	15.0	loamy gravel	4.8	10.7	8.5	2.7	0.10		

Table 7
Information about groundwater sources in the ward Kavečany

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [$l.s^{-1}$]	drinking water	
City district Kavečany															
ČH-7	48	47	13.26	21	12	18.44	100.0	granodiorite	10.0	100.0	1.0	2.5	0.96	suitable	Frankovič, 1981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0 0,25 0,5 0,75 km
SPECIALISED HYDROGEOLOGICAL
MAP OF KOŠÍCE
CITY DISTRICTS ŤAHANOVCE,
DARGOVSKÝCH HRDINOV,
KOŠICKÁ NOVÁ VES
(Tometz, 2017)
STRATIGRAPHY, LITHOLOGY ,
HYDROGEOLOGICAL VALUE
Quaternary Holocene ***f*** - fluvial floodplain sediments (loams, sands, gravels), intergranularporosity, aquifer; Holocene - Pleistocene ***d*** - deluvial sediments (sandy-loamy gravels), intergranular porosity, aquifer; Pleistocene ***p*** - proluvial fan sediments and fluvial sediments of river terraces (loams, sands, gravels), intergranular porosity, aquifer. Neogene, Badenian ***z*** - ryolite neovolcanites, Miocene ***n*** - Sečov (variegated and grey calcareous clays, coaly clays, lignites, interbeds of tuffs and tuffites), predominancy of fissure porosity, aquiclude to aquifer; Stretava (clays, sands, tuffs), intergranular and fissure porosity, aquifer; Kochanov (clays, coaly clays, lignites, bentonites), intergranular porosity, aquiclude, and Klčov Formation (varhaňov gravels: gravels, sands,clays, intergranular porosity, aquifer. Crystalline rocks ***k*** - Hercynian granitoides (biotitic granodiorites), fissure porosity, aquifer, ***r*** - gneiss, fissure permeability, aquifer.
Ťahanovce
Dargovských hrdinov
Košická Nová Ves
EXPLANATIONS
Average value of coefficient of transmissivity T [$m^2.s^{-1}$]
T = 3.10^{-4} to 1.10^{-3}
T = 1.10^{-4} to 3.10^{-4}
T = 3.10^{-5} to 1.10^{-4}
T = 1.10^{-5} to 3.10^{-5}
T = 1.10^{-6} to 1.10^{-5}
T < 3.10^{-6}
Spring
0,1 až 1,0 $l.s^{-1}$
Hydrogeological wells
do 0,1 $l.s^{-1}$
0,1 až 1,0 $l.s^{-1}$
1,0 až 10,0 $l.s^{-1}$
nad 10,0 $l.s^{-1}$
hydrogeologically used wells
wells with mineral groundwater
wells with pre-quaternary aquifer
wells realised with regard to groundwater protection
Direction of the groundwater flow
determined
assumed

Table 8.
Information about groundwater sources in the ward Tahanovce

Well	GPS coordinates N [° ′ ″]			GPS coordinates E [° ′ ″]			Depth H [m]	Lithology of aquifer	Aquifer [m] from	Aquifer [m] to	Static level h [m]	Drowdown s [m]	Yield Q [l.s⁻¹]	Quality of drinking water	Refference
City district Ťahanovce a sídlisko Ťahanovce															
H-1_T	48	45	24.01	21	15	10.85	10.40	gravel	6.2	7.2	6.20	2.00	2.90	suitable	Tkáčik, 1957a
H-2_T	48	45	27.10	21	14	59.36	18.00	sand gravel	3.5 7.0	7.0 10.1	3.50	5.50	12.00		
RH-1K	48	45	18.43	21	15	8.34	11.00	gravel	4.1	9.0	4.05	2.50	8.80	unkown	Tkáčik, 1957b
S-3_U	48	45	24.82	21	15	10.08	10.00	gravel	5.0	8.5	3.60	3.00	5.00		Turlík, 1959
KT-5	48	44	31.15	21	15	30.66	15.00	gravel	5.2	8.4	5.20	1.26	7.70		Šindler, 1961
Ť-1	48	46	19.64	21	17	44.43	42.00	sand	10.0	34.0	8.00	17.00	3.07		Tůma, 1962a
HH-46	48	46	43.86	21	14	31.71	8.80	gravel	4.5	7.7	2.80	1.20	5.80		Frankovič, 1964
CH-1	48	46	20.44	21	17	44.18	27.00	gravel	4.2	15.0	4.00	5.20	0.77		Tůma, 1965
HS-1_M	48	44	38.36	21	15	16.34	11.80	gravel	4.0	9.1	7.70	0.40	4.80	suitable	Mičák, 1966
ST	48	45	23.99	21	15	10.66	11.00	gravel	3.0	10.0	3.40	2.00	17.20	unkown	Wagner, 1967
KK-1	48	46	25.36	21	17	20.01	54.00	gravel	6.4	8.0	6.40	12.00	0.15		Bajo, 1975
G-1	48	45	24.15	21	15	3.47	13.00	gravel	3.3	9.5	3.30	1.50	0.90	suitable	Frankovič, 1978
G-2	48	45	3.77	21	15	5.88	171.00	gravel dolomite	3.3 70.0	10.8 171.0	3.50	15.00	1.89	unsuitable	
G-5	48	45	3.29	21	15	10.51	30.00	dolomite	9,6 22,0	10,0 28,0	2.80	2.50	1.50	unsuitable	Haluška, Petrivaldský 1996
VČ-1	48	45	24.93	21	15	1.80	15.00	gravel	4.6	11.5	6.00	3.35	17.00	unsuitable	Verčimák, 1981a
VČ-2	48	45	23.13	21	15	2.26	21.00	gravel	3.5	10.1	4.20	5.00	3.00	suitable	
G-4	48	45	3.69	21	15	12.79	310.00	dolomite	10.0	195.0	preliv	18.50	4.90	unsuitable	Haluška, 1982
HPL-1	48	44	51.56	21	15	18.21	12.50	gravel	4.7	11.0	4.00	4.02	10.00	suitable	Šťastný ,1982
HPL-2	48	44	50.71	21	15	18.58	12.50	gravel	4.1	10.5	3.55	2.80	6.20		Šťastný et al., 1983
HPL-3	48	44	49.88	21	15	18.91	10.50	gravel	4.2	10.5	3.69	1.50	17.30		
HPL-4	48	44	48.83	21	15	19.35	12.50	gravel	3.9	10.0	3.60	3.03	16.60		
HPL-5	48	44	47.95	21	15	19.70	12.50	gravel	3.8	10.5	3.50	3.20	16.60		
HPL-6	48	44	46.84	21	15	20.11	12.50	gravel	3.8	10.5	3.30	3.81	12.20		
HPL-7	48	44	46.06	21	15	20.32	12.50	gravel	4.1	10.5	3.81	2.09	6.80		
HTA-1	48	46	41.38	21	14	31.84	8.70	gravel	2.0	8.2	2.60	1.90	3.50	suitable	Medveď, 1985a
HTA-2	48	46	37.20	21	14	32.39	9.20	gravel	1.3	8.6	2.40	2.00	3.50		
HTA-3	48	46	33.15	21	14	33.84	9.20	gravel	2.5	8.5	2.40	1.90	3.50		
HTA-4	48	46	28.76	21	14	35.40	9.20	gravel	2.5	8.2	2.70	1.65	4.00		
HS-1_L	48	44	44.93	21	15	15.49	10.00	gravel	6.4	9.2	5.70	1.50	3.44		Lokajová, 1988a
K-1_M	48	44	52.64	21	15	17.14	10.50	gravel	3.0	9.2	5.10	2.00	2.50	unsuitable	Medveď, 1988a
HGP-11	48	44	43.98	21	16	17.14	12.00	gravel	8.0	9.0	7.60	1.97	0.07		Protivňáková 1988
HGP-12	48	44	44.80	21	16	16.80	12.00	gravel	8.0	9.0	7.60	1.80	0.15		
HOSC-1	48	44	51.57	21	16	11.67	17.00	gravel	2.5	10.0	2.50	7.50	0.12		Tometzová, 1988a

Continuation of Table 8

HL-2	48	45	23.25	21	15	11.04	10.00	gravel	3.5	9.5	3.50	0.68	5.55	unsuitable	Medveď, 1990
HOK-23	48	44	46.14	21	16	4.56	13.50	gravel	8.0	11.5	8.00	2.40	7.14		Dluhá, 1995
HOK-24	48	44	42.74	21	16	1.66	11.00	gravel	6.2	9.5	5.00	1.50	1.43		
S-1_M	48	44	39.72	21	15	57.23	11.10	gravel	2.3	9.0	3.65	0.58	8.62		Mosej, 1996
I.	48	44	33.83	21	15	4.69	9.71	gravel	6.0	9.0	7.02	1.50	20.00	suitable	Tometz et al., 2009
III.	48	44	34.98	21	15	13.43	10.75	gravel	6.0	10.0	5.91	2.00	30.00		
V.	48	44	44.31	21	15	15.83	10.31	gravel	4.0	10.0	4.85	0.80	23.00		
VI.	48	45	18.41	21	15	8.33	10.65	gravel	4.0	10.0	4.34	2.50	45.00		
VII.	48	46	14.77	21	14	34.21	13.80	gravel	6.0	12.0	6.75	1.20	40.00		
VIII.	48	45	27.23	21	14	59.26	9.61	gravel	4.0	9.0	4.40	2.00	35.00		
IX.	48	45	32.58	21	14	55.23	9.80	gravel	4.0	9.0	4.35	2.50	35.00		
HGM-1_G	48	44	46.82	21	15	48.38	9.00	gravel	3.2	7.8	3.50	1.21	3.77	unsuitable	Grexová et al., 2009a

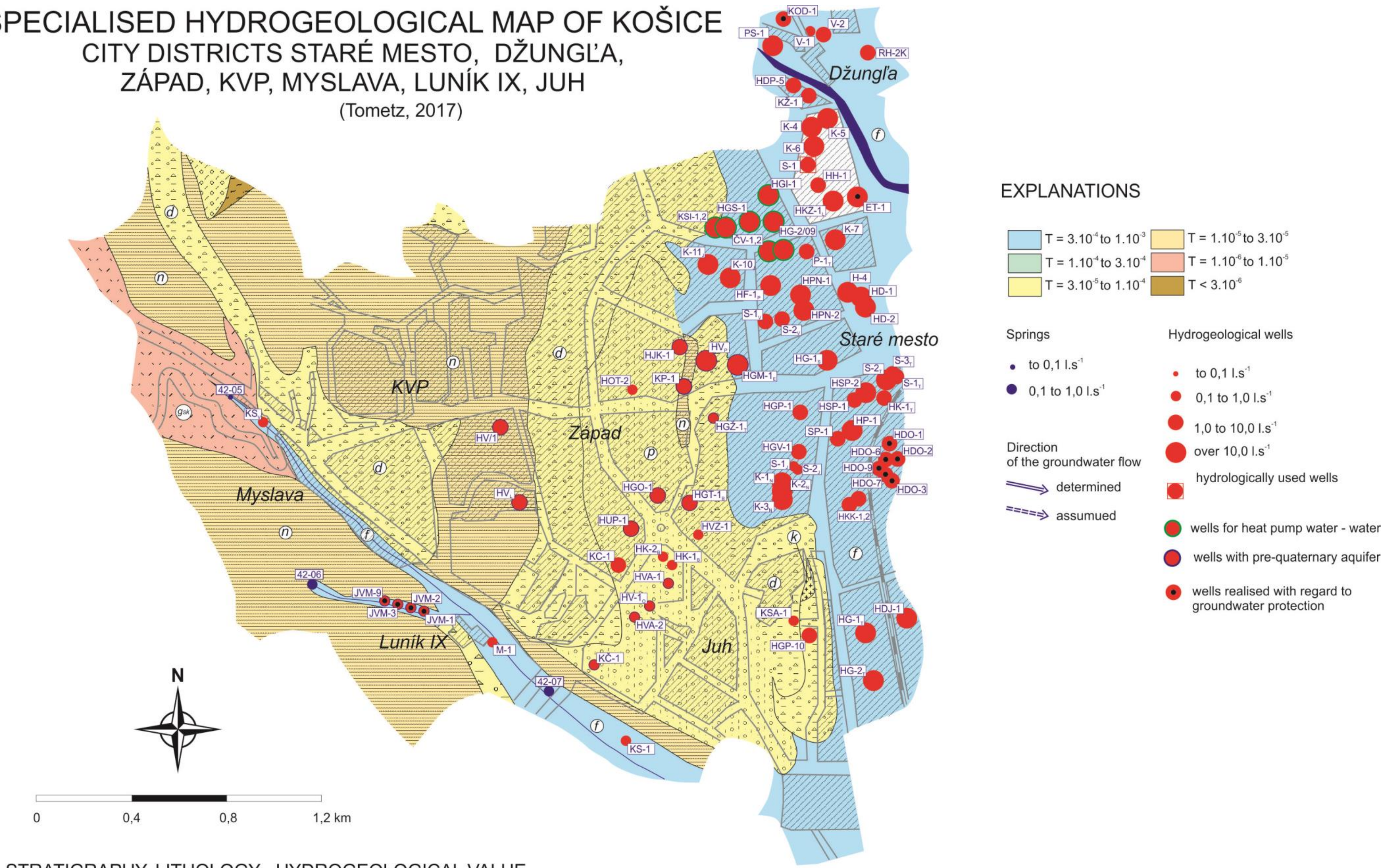
Table 9
Information about groundwater sources in the ward Dargovských hrdinov

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Dargovských hrdinov															
KT-4	48	43	58.24	21	16	35.71	14.50	gravel	2.8	12.5	2.80	3.50	11.00	unknown	Šindler, 1961
HKZ-1	48	43	27.01	21	16	22.43	8.00	gravel	2.0	7.0	3.00	1.50	6.17	unknown	Tometzová, 1980
HKZ-2	48	43	28.52	21	16	20.91	7.70	gravel	1.5	6.7	3.00	1.50	6.09	unknown	
HKZ-3	48	43	30.69	21	16	18.63	8.30	gravel	3.0	7.3	3.00	1.50	5.88	unknown	
HK-1	48	44	23.42	21	16	5.98	12.00	gravel	5.0	11.0	5.20	1.52	1.00	suitable	Jelínek, 1982
HK-2	48	44	25.05	21	16	0.65	12.00	gravel	5.0	8.5	5.80	0.93	0.20	suitable	
JP-3	48	43	47.83	21	16	16.33	10.00	gravel	5.5	6.5	5.50	2.00	1.19	unsuitable	Protivňáková, 1987c
IS-1	48	43	9.51	21	16	31.54	13.00	gravel	4.5	11.0	4.30	2.10	17.00	suitable	Protivňáková, 1987d
HGD-1	48	43	28.49	21	16	25.88	10.00	gravel	5.0	9.0	5.00	1.50	6.25	unknown	Daňková, 1989a

Table 10
Information about groundwater sources in the ward Košická Nová Ves

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Košická Nová Ves															
ST-1	48	43	32.72	21	18	15.17	69.00	gravel	38.6	47.0	43.00	6.50	5.00	unkwnown	Tůma, 1963
KV-1	48	43	33.35	21	18	11.18	95.00	gravel	63.0	77.0	73.00	10.00	5.70	unkwnown	Tůma, 1964
HGD-2	48	44	22.85	21	17	30.86	25.00	sand	4.0	5.0	6.80	12.00	0.002	suitable	Daňková, 1990a

SPECIALISED HYDROGEOLOGICAL MAP OF KOŠICE
CITY DISTRICTS STARÉ MESTO, DŽUNGĽA, ZÁPAD, KVP, MYSLAVA, LUNÍK IX, JUH
(Tometz, 2017)



STRATIGRAPHY, LITHOLOGY , HYDROGEOLOGICAL VALUE

Quaternary Holocene ***f*** - fluvial floodplain sediments (loams, sands, gravels), intergranularporosity, aquifer; Holocene - Pleistocene ***d*** - deluvial sediments (sandy-loamy gravels), intergranular porosity, aquifer; Pleistocene ***p*** - proluvial fan sediments and fluvial sediments of river terraces (loams, sands, gravels), intergranular porosity, aquifer. Neogene, Miocene ***n*** - Sečov (variegated and grey calcareous clays, coaly clays, lignites, interbeds of tuffs and tuffites), predominancy of fissure porosity, aquiclude to aquifer; Stretava (clays, sands, tuffs), intergranular and fissure porosity, aquifer; Kochanov (clays, coaly clays, lignites, bentonites), intergranular porosity, aquiclude, and Klčov Formation (varhaňov gravels: gravels, sands,clays, intergranular porosity, aquifer. Paleosoic, Permian $\mathbf{g_{sk}}$ - northern Gemericum, Krompachy Group (metaryolites to metadacites), fissure porosity, aquifer. Crystalline rocks ***k*** - Hercynian granitoides (biotitic granodiorites), fissure porosity, aquifer.

Table 11
Information about groundwater sources in the ward Staré Mesto

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Staré Mesto															
HDP-5	48	44	11.24	21	15	57.35	13.5	gravel	3.0	11.0	4.40	3.00	5.81	unsuitable	Kašová, 1989
KŽ-1	48	44	8.77	21	15	52.29	10.0	gravel	4.8	7.8	5.55	1.40	5.30		Adamčík, 1967
S-1$_V$	48	43	14.26	21	15	15.48	15.0	gravel	4.0	12.0	2.80	2.30	6.25		Verčimák, 1981b
S-2$_V$	48	43	15.89	21	15	16.64	15.0	gravel	3.5	10.0	2.90	2.30	6.25		
HPN-1	48	43	28.15	21	15	41.85	10.5	gravel	2.7	8.5	3.50	0.45	16.60	suitable	Tometz, 1983
HPN-2	48	43	25.38	21	15	42.76	11.5	gravel	4.0	10.5	4.60	0.22	11.90	unsuitable	
HH-1	48	43	47.03	21	15	27.57	14.0	gravel	5.1	12.0	6.20	3.00	9.25		Tometzová, 1983a
HP-1	48	42	49.74	21	15	46.87	12.5	gravel	5.0	10.4	4.10	7.37	19.20	suitable	Tometz, 1984
HK-1$_T$	48	43	10.77	21	15	59.75	11.0	gravel	6.0	10.0	5.80	2.50	4.80	unsuitable	Tometzová, 1984a
HG-1$_S$	48	43	3.49	21	15	40.02	13.0	gravel	5.5	12.0	5.20	3.00	18.00	suitable	Tometzová, 1987b
KP-1	48	42	55.99	21	14	48.15	150.0	gravel intercalations	103.0 126.0	109.0 133.0	18.02	23.00	5.00	unsuitable	Tometz, 1985
HKZ-1$_L$	48	43	47.64	21	15	29.34	12.0	gravel	3.6	10.8	3.50	1.68	24.00		Lokajová, 1987a
HSP-1	48	43	1.08	21	16	2.73	11.5	gravel	4.4	9.5	3.80	2.45	3.12		Protivňáková, 1987e
HSP-2	48	42	56.90	21	16	5.50	11.5	gravel	4.8	9.5	4.50	2.48	21.00		
HGP-1	48	42	59.90	21	15	54.13	11.0	gravel	5.0	10.5	4.80	3.50	7.00		Varga et al., 2014
HD-1	48	43	31.84	21	15	56.44	10.5	gravel	3.2	9.5	3.10	1.50	16.00	suitable	Daňková, 1988
HD-2	48	43	30.11	21	15	56.13	10.5	gravel	3.2	9.6	3.20	1.50	11.50	unsuitable	
HGM-1$_E$	48	43	0.62	21	15	2.69	58.0	gravel	43.0	58.0	12.85	13.00	13.30		Eristavi, 1988
K-4	48	43	54.62	21	15	23.62	12.5	gravel	5.5	11.5	5.60	2.20	14.92		Jelínek, 1988a
K-5	48	43	55.04	21	15	30.54	9.5	gravel	5.5	8.5	5.50	1.08	10.00		
K-6	48	43	49.78	21	15	22.36	10.5	gravel	5.7	10.0	5.55	1.60	16.66	suitable	
K-7	48	43	47.64	21	15	50.32	10.0	gravel	5.2	9.5	5.20	0.97	11.11		
S-1	48	43	59.05	21	15	4.35	14.4	gravel	6.6	13.2	6.30	1.85	12.70		Brandner, 1960 Bajo, 2007

Continuation of Table 11

K-10$_J$	48	43	30.77	21	14	53.74	11.0	gravel	5.0	9.0	5.25	0.78	7.40	suitable	Jelínek, 1988b
K-11$_J$	48	43	36.69	21	14	27.48	10.5	gravel	7.5	9.5	7.29	1.41	6.89		
H-4	48	43	30.72	21	15	51.53	11.0	gravel	3.5	10.0	3.6	2.4	11.10		Medveď, 1988b
P-1$_T$	48	43	32.31	21	15	24.91	12.0	gravel	5.0	11.0	5.00	3.25	9.70		Tometzová, 1988b
HV$_P$	48	43	2.76	21	14	48.36	80.0	gravel intercalations	23.5	58.5	10.34	17.00	17.00	unsuitable	Eristavi, 1989a
SP-1	48	42	46.21	21	15	44.25	12.5	gravel	4.5	12.0	4.10	0.22	6.60		Petro, 1991a
HF-1$_P$	48	43	16.28	21	15	26.95	13.0	gravel	4.0	12.0	5.50	1.20	20.00	unknown	Petro, 1991b
ET-1	48	43	46.09	21	15	37.88	10.0	loamy gravel	2.7	8.0	3.40	1.10	15.00	unsuitable	Pramuk, 1995
HG-2/09	48	43	42.72	21	15	17.38	11.0	gravel	5.0	10.0	5.72	0.20	9.80	suitable	Varga, Petercová, 2009
HGI-1	48	43	47.40	21	15	14.71	12.3	gravel	3.3	12.3	5.00	1.00	21.50		Grexová et al., 2013
S-1$_T$	48	43	13.73	21	16	1.85	11.0	gravel	5.5	12.0	4.85	3.02	5.50		Tometz, 2014a
S-2$_T$	48	43	12.87	21	15	59.86	11.5	gravel	5.5	12.0	4.82	3.33	10.00	unsuitable	
S-3$_T$	48	43	14.93	21	15	56.60	10.8	gravel	5.5	12.0	4.75	2.49	2.50	suitable	
HGŽ-1$_T$	48	42	53.52	21	15	2.32	24.0	sand intercalations	10.5	16.2	5.90	2.20	0.90	unsuitable	Tometz et al., 2016a
HGS-1	48	43	43.61	21	15	12.15	12.0	gravel	3.9	12.0	5.70	0.25	10.00		Tometz et al., 2017
ČV-1	48	43	38.46	21	15	22.54	13.1	gravel	6.2	13.0	6.10	0.27	15.00	suitable	Petercová a Varga, 2017
ČV-2	48	43	38.46	21	15	22.54	13.0	gravel	6.0	12.8	6.00	0.26	15.00		

Table 12
Information about groundwater sources in the ward Džungľa

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Džungľa															
PS-1	48	44	27.19	21	15	41.93	9.6	gravel	6.0	9.0	6.0	1.80	12.5	suitable	Tartal, 1964
RH-2K	48	44	9.58	21	16	21.22	16.5	gravel	7.0	15.0	6.04	5.00	2.20	unsuitable	Tkáčik, 1957
V-1	48	44	9.7	21	16	20.19	25.3	gravel	6.0	11.0	5.90	3.50	0.49		Wagner, 1971
V-2	48	44	10.43	21	16	23.19	13.8	gravel	5.9	13.8	5.90	2.50	1.34		
KOD-1	48	44	12.90	21	16	19.35	12.0	gravel	6.0	7.6	5.40	1.60	2.00		Ostrolucký et al., 1991

Table 13
Information about groundwater sources in the ward Západ and KVP

Well	GPS coordinates N [° ′ ″]			GPS coordinates E [° ′ ″]			Depth H [m]	Lithology of aquifer	Aquifer [m] from	Aquifer [m] to	Static level h [m]	Drowdown s [m]	Yield Q [l.s^{-1}]	Quality of drinking water	Refference
City districts Západ a sídlisko KVP															
KČ-1	48	41	32.50	21	13	55.04	30.0	sandy clay	9.2	27.0	3.20	7.93	0.78	unknown	Jelínek, 1981
HVA-1	48	42	9.20	21	14	43.88	76.0	gravel intercalations	10.0	70.0	9.80	22.05	0.70	unsuitable	Bajo, 1982
HVA-2	48	41	39.86	21	14	35.82	76.0	gravel intercalations	15.0	70.0	9.50	22.35	5.00		
HGT-1	48	42	19.11	21	14	51.83	84.0	sand intercalations	22.0	52.0	14.55	5.00	1.43		Bajo, 1985
HV/1	48	42	47.04	21	13	33.21	57.0	clay with gravel	10.0	57.0	24.20	15.00	7.14		Eristavi, 1985
HV-1$_O$	48	41	53.52	21	14	54.30	12.0	gravel	2.0	10.0	4.00	2.50	0.80	suitable	Orvan, 1985e
HVZ-1	48	42	12.71	21	14	55.17	38.0	clayey sand	14.6	28.0	5.52	7.70	0.71	unsuitable	Lokajová, 1988b
HK-1$_B$	48	41	59.06	21	14	46.61	80.0	sand intercalations	18.0	68.0	6.00	13.55	5.55		Bindas, 1989
HK-2$_B$	48	42	2.50	21	14	32.76	80.0	sand intercalations	20.0	69.0	5.50	14.21	4.04		
HV$_L$	48	42	8.03	21	13	38.60	75.0	gravel intercalations	7.0	62.5	19.00	20.00	3.30		Eristavi, 1989b
HUP-1	48	42	20.11	21	14	7.56	65.0	gravel intercalations	11.0	65.0	4.27	25.73	6.06		Protivňáková, 1989a
HJK-1	48	43	9.32	21	14	34.60	40.0	gravel intercalations	18.0	40.0	19.80	37.00	0.96		Forberger, 1990
KC-1	48	41	55.46	21	14	13.36	20.0	gravel intercalations	10.0	20.0	9.80	2.70	1.00	unknown	Jelínek, 1994
HGO-1	48	42	24.38	21	14	27.94	33.0	gravel intercalations	2.1	26.0	4.07	6.33	1.40	unsuitable	Ostrolucký, 2003a
HOT-2	48	43	16.22	21	14	34.23	81.0	gravel intercalations	28.7	72.6	28.72	2.99	0.87	unsuitable	Petercová et al., 2016

Table 14
Information about groundwater sources in the ward Myslava and Luník IX

Well	GPS coordinates N [° ′ ″]			GPS coordinates E [° ′ ″]			Depth H [m]	Lithology of aquifer	Aquifer [m] from	Aquifer [m] to	Static level h [m]	Drowdown s [m]	Yield Q [l.s^{-1}]	Quality of drinking water	Refference
City districts Myslava a Luník IX															
M-1	48	41	49.63	21	13	26.92	23.5	gravel	0.8	1.3	1.20	5.90	0.50	unknown	Príhoda, 1967
KS$_V$	48	42	49.45	21	11	46.77	7.3	gravel	3.5	4.8	2.70	3.60	0.70	unsuitable	Verčimák, 1987
JVM-1	48	41	59.02	21	12	52.60	21.0	gravelly clay	5.5	18.5	5.70	8.56	0.19		Dluhý et al., 1988
JVM-2	48	41	59.43	21	12	38.84	25.0	gravelly clay	4.0	20.2	7.15	7.51	0.25		
JVM-3	48	42	1.56	21	12	26.51	25.0	gravelly clay	11.7	20.4	11.40	6.02	0.15		
JVM-9	48	42	5.93	21	12	7.32	10.0	loamy gravel	4.8	7.5	0.80	4.11	0.25		

Table 15
Information about groundwater sources in the ward Juh

Well	GPS coordinates N [° ´ ´´]			GPS coordinates E [° ´ ´´]			Depth H [m]	Lithology of aquifer	Aquifer [m] from	Aquifer [m] to	Static level h [m]	Drowdown s [m]	Yield Q [l.s^{-1}]	Quality of drinking water	Refference
City district Juh															
S-1$_J$	48	42	10.67	21	16	31.62	8.00	gravel	3.80	7.00	3.53	1.25	5.60	unsuitable	Mičák, 1975
S-2$_J$	48	42	14.37	21	16	28.09	11.00	gravel	5.00	9.00	4.05	1.25	5.30		
HKZ-1	48	43	30.08	21	16	17.68	8.00	gravel	3.00	7.00	3.00	1.50	6.17	unknown	Tometzová, 1980
HKZ-2	48	43	31.46	21	16	13.26	7.70	gravel	3.00	6.70	3.00	1.50	6.09		
HKZ-3	48	43	35.03	21	16	12.61	8.30	gravel	3.00	7.30	3.00	1.50	5.88		
HG-1$_T$	48	41	58.12	21	16	4.88	11.0	gravel	4.0	9.5	2.80	1.20	10.00	unsuitable	Tometzová, 1984b
HG-2$_T$	48	41	29.28	21	16	7.55	12.0	gravel	5.2	11.0	4.80	3.00	11.70	suitable	Tometzová, 1984c
HGP-10	48	41	40.10	21	15	47.90	8.5	gravel	4.3	7.7	4.30	3.50	5.40		Protivňáková, 1989b
KSA-1	48	41	42.71	21	15	40.32	8.0	gravel	3.0	8.0	3.50	2.00	0.42	unsuitable	Tometz, 2018
K-1$_N$	48	42	31.25	21	15	14.85	9.7	gravel	4.0	8.0	3.67	2.38	40.99		Lokajová, 1987b
HDJ-1	48	42	23.65	21	16	2.68	11.0	gravel	3.0	10.0	3.00	3.00	13.56		Daňková, 1989b
KS-1	48	41	17.62	21	14	45.31	4.2	loamy gravel	2.0	4.0	2.40	1.00	0.11		Varga, Š., 1989
K-2$_N$	48	42	30.99	21	15	18.49	9.0	gravel	4.0	7.0	3.90	4.90	16.00		Daňková, 1990b
K-3$_N$	48	42	30.86	21	15	21.01	9.0	gravel	4.0	7.0	3.80	4.80	14.00	suitable	
HGV-1	48	42	44.13	21	15	22.80	11.0	gravel	3.5	9.0	4.80	3.70	8.69		Varga, Š., 1990
HDO-1	48	42	53.96	21	16	8.10	14.0	gravel	3.0	9.0	3.40	0.52	3.80	unsuitable	Sihelníková, 1992
HDO-2	48	42	51.47	21	16	15.88	13.5	gravel	6.2	11.5	6.70	0.89	5.40		
HDO-3	48	42	46.12	21	16	14.18	10.6	gravel	4.4	8.6	3.30	0.52	5.50		
HDO-6	48	42	51.75	21	16	10.43	10.0	gravel	5.0	8.0	5.00	1.50	4.50		
HDO-7	48	42	47.33	21	16	10.94	12.0	gravel	5.5	10.0	4.00	0.85	5.00		
HDO-9	48	42	47.12	21	16	9.26	10.0	gravel	3.8	8.0	3.80	0.76	6.20		
HKK-1	48	42	24.35	21	16	2.87	9.5	gravel	4.5	9.0	3.86	0.49	3.00		Petercová et al., 2016
HKK-2	48	42	24.88	21	16	4.92	9.0	gravel	2.0	8.5	3.86	0.96	5.00		
HKO-1	48	41	41.75	21	15	44.77	8.5	gravel	3.5	7.7	4.20	0.60	1.46		Ostrolucký, 2003b

4.2.6. Ward Staré Mesto

As is evident from *Map 3*, this area is typified by a higher concentration of the hydrogeological wells with a yield higher than 10.0 Ls^{-1}. Other geological and technical information is documented in *Table 11*. The depth of the wells ranges from 9.5 to 12.5 m and gravels of the Hornád River valley are recorded as an aquifer. There are also wells with even higher efficiencies (18.0–24.0 Ls^{-1}) situated in the vicinity of the Technical University and Clinic Sever (Park Komenského Street; Jelínek 1988a, b; Lokajová 1987a, b). A similar situation exists in the area of the City Park, where the measured yield of the wells reached 11.0 to 17.0 Ls^{-1} (Tometz 1983a; Daňková 1988; Medveď 1988b). Another area with favourable conditions regarding groundwater is the area of the city swimming pool (Protivňáková 1987e; Tometz 2014a). One more well, HF-1 of 13.0 m depth and with a yield of 20.0 Ls^{-1} (Petro 1991b), was realised on Hlavná Street near the Urban Tower for the purpose of constructing a fountain.

Towards the western edge of the centre of city, the amount of the groundwater is reduced to 0.5–5.0 Ls^{-1} due to spatial and thickness changes in the fluvial gravels. Consequently, a survey focusing on the occurrence of the more deeply deposited Neogene gravels and sands was carried out in this part of the city. As a result, two wells – one of 43 m depth at the intersection of the Kuzmányho and Štúrova Streets (Eristavi 1988) and one of 150 m depth in the area of Stará sladovňa on Moldavská Street (Tometz 1983) – were realised to confirm efficiencies of 13.3 and 5.0 Ls^{-1} respectively. For energy purposes, the possibilities of using groundwater for heat pumps working in the water-water mode were documented mainly on Garbiarska Street (Varga and Petercová 2009; Grexová et al. 2013; Tometz 2016a).

The good quality of the groundwater in the centre of the city is rather surprising, particularly chemical indicators, where the iron and manganese contents are within the legislatively defined limits.

4.2.7. Ward Džungľa

In this ward are situated a built-up area of older individual houses, a business centre, industrial buildings, garages of the Transport Company of Košice and the Faculty of Aeronautics of the Technical University of Košice. Groundwater sources in this area capture exclusively Quaternary aquifers represented by fluvial gravels of the Hornád River valley. Yield of the wells ranges from 0.59 up to 12.5 Ls^{-1} *(Table 12)* and their realisations were related mainly with access to groundwater for the water utility purpose. J. Ostrolucký (1991) reported on the protection of the groundwater in the area of the Transport Company of Košice.

4.2.8. Wards Západ and settlement KVP

The area of these wards is characterised by the occurrence of Neogene deposits *(Map 3)*. Wells *(Table 3)* are concentrated mainly in the earlier "sport complex", which has been almost completely replaced by shopping centres today. Aquifers recorded by the wells at 20.0 to 84.0 m deep are represented by several beds of gravel, sand, clayey gravel and clayey sand and their yield ranges from 0.7 to 7.14 Ls^{-1}.

Hydrogeological objects of the ward settlement KVP could not be identified from the available data. In this area mainly engineering geological surveys have been realised, but even in this documentation hydrogeological wells are not found. This most likely is connected with the geological conditions (exclusively clays), because aquifers were not identified even at depths of 30 to 80 m.

A surprising result of the survey is associated with wells HV/1 and HVL. These are situated in the territory of Popradská Street in the settlement Terasa *(Map 3)*. Their depth is 57.0 and 65.0 m and their efficiencies are 7.14 and 3.3 Ls^{-1}, respectively.

4.2.9. Wards Myslava a Luník IX

Geologically, these areas are very similar to the ward Západ and the settlement KVP. Due to the prevailing built-up area of individual houses, mainly dug wells are constructed here. There has been a problem with obtaining documentation to these wells in relation to their quantity, although some private persons owning homes allow registration of works related to the groundwater survey.

In the ward Myslava there is a closed dump where several wells were situated to evaluate the impact of the waste on the quality of groundwater (Dluhý et al. 1988). Wells were maximally 25.0 m deep and had confirmed efficiencies of 0.25 Ls^{-1} *(Map 3, Table 14)*.

4.2.10. Ward Juh

Geologically, this area is characterised by the lithological unit of Quaternary fluvial deposits with gravelly aquifer *(Map 3, Table 15)*. The total thickness of the unit does not exceed 12 m, which corresponds to the depth of the realised wells (4.0–11.5 m). The range of verified efficiencies of these wells is 0.11 to 41.0 Ls^{-1}. Regarding the use of groundwater, the most valuable are located in the area of the L. Pasteur University Hospital on Rastislavova Street, where the high-capacity dug well K-1_N with yield 41.0 Ls^{-1} as well as dug wells K-2_N (16.0 Ls^{-1}) and K-3_N (14.0 Ls^{-1}) are used for drinking purposes for local health facilities.

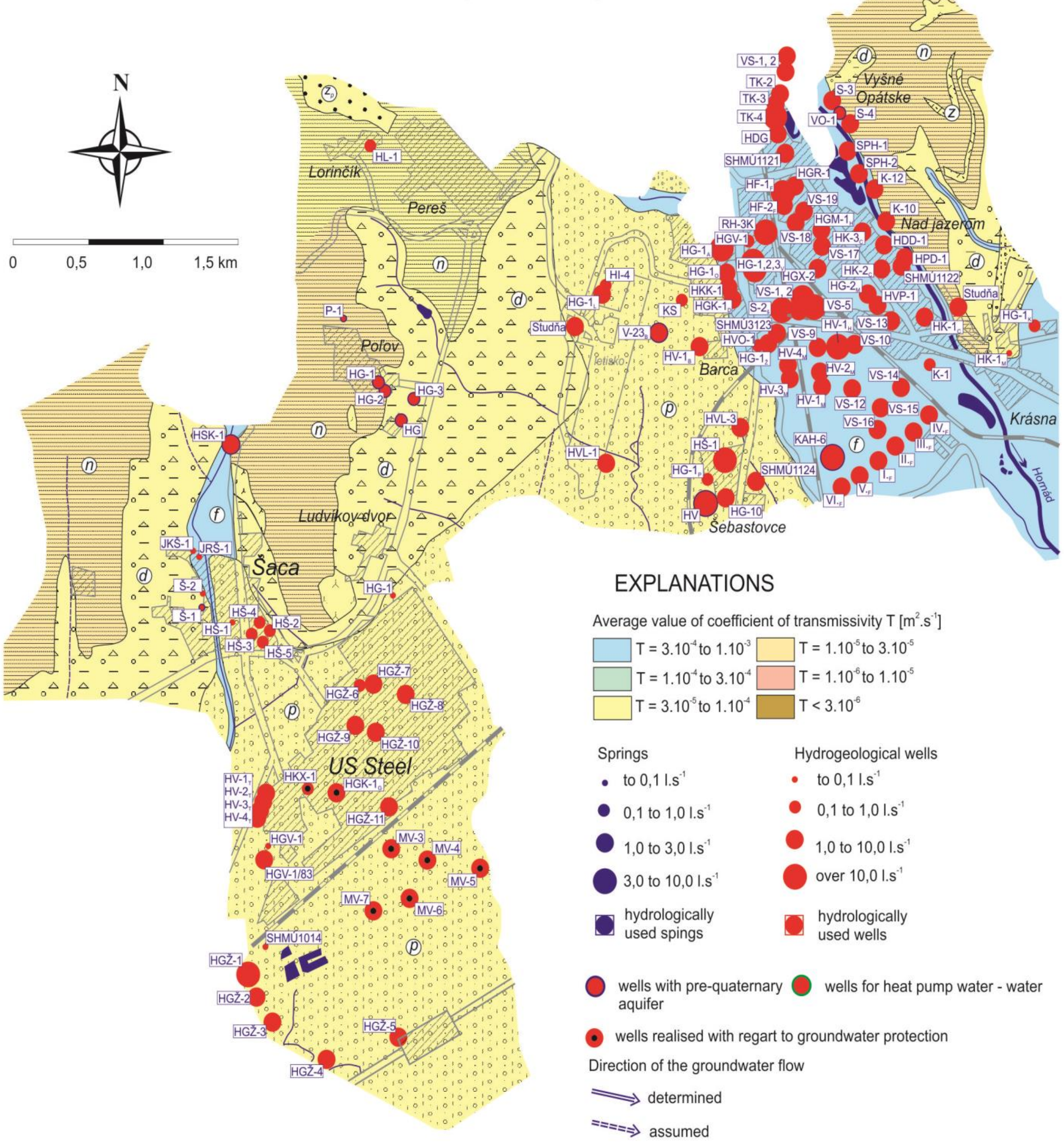
In addition, some industrial facilities are situated in this ward. In particular, there is railroad station, which even today represents a significant source of groundwater pollution. Mainly Sihelniková (1992) was concerned by the groundwater protection of this territory and within the works dealing with this issue, wells HDO-1 up to HDO-9 of 10.0 to 14.0 m depth were realised with a confirmed yield of 3.8 to 6.2 Ls^{-1}.

Industrial complexes are present in the southernmost part of the ward as well. Wells are in this case situated mainly on the left side of the Južná trieda Street. The depth of wells HDS-1, HG-1_T and HG-2_T is maximally 12.0 m and their efficiency ranges between 10.0 and 13.56 ls^{-1}.

SPECIALISED HYDROGEOLOGICAL MAP OF KOŠICE

CITY DISTRICTS VYŠNÉ OPÁTSKE, BARCA, NAD JAZEROM, KRÁSNA, PEREŠ, LORINČÍK, POĽOV, ŠACA, ŠEBASTOVCE

(Tometz, 2017)



STRATIGRAPHY, LITHOLOGY AND HYDROGEOLOGICAL VALUE

Quaternary Holocene ***f*** - fluvial floodplain sediments (loams, sands, gravels), intergranularporosity, aquifer; Holocene - Pleistocene ***d*** - deluvial sediments (sandy-loamy gravels), intergranular porosity, aquifer; Pleistocene ***p*** - proluvial fan sediments and fluvial sediments of river terraces (loams, sands, gravels), intergranular porosity, aquifer. Neogene, Miocene ***n*** - Sečov (variegated and grey calcareous clays, coaly clays, lignites, interbeds of tuffs and tuffites), predominancy of fissure porosity, aquiclude to aquifer; Stretava (clays, sands, tuffs), intergranular and fissure porosity, aquifer; Kochanov (clays, coaly clays, lignites, bentonites), intergranular porosity, aquiclude, and Klčov Formation (varhaňov gravels: gravels, sands, clays), intergranular porosity, aquifer. Paleosoic, Devonian $\boldsymbol{a_f}$ - amfibolites of the Klatova Group.

Table 16

Information about groundwater sources in the ward Vyšné Opátske

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ′ ″]			E [° ′ ″]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Vyšné Opátske															
VO-1	48	41	56.88	21	17	0.00	70.0	tuffit gravel	58.0	63.0	50.0	11.50	0.40	unknown	Tůma, 1966
S-3	48	41	58.38	21	16	55.82	11.0	gravel	4.5	8.5	4.5	0.80	3.33		Medveď, 1978
S-4	48	41	56.38	21	17	2.65	11.0	gravel	5.0	9.0	4.6	1.48	1.50		

Table 17

Information about groundwater sources in the ward Barca

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ′ ″]			E [° ′ ″]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Barca															
SHMÚ 3123	48	40	6.17	21	16	16.81	9.0	gravel	2.7	7.0	1.6	2.00	2.01	unknown	Frankovič, 1969
RH-3K	48	41	2.20	21	16	22.30	16.4	gravel	6.0	14.4	5.6	3.00	15.90	suitable	Tkáčik, 1957
HGV-1	48	41	14.15	21	16	1.10	10.0	gravel	5.4	10.0	5.4	0.91	1.00		Petercová et al., 2017
S-2š	48	40	30.01	21	16	53.07	10.0	gravel	4.0	11.0	3.0	2.10	10.00	unsuitable	Šimala, 1958
VS-1	48	40	44.05	21	16	41.74	11.0	gravel	4.0	10.2	3.8	1.65	15.00	unknown	Halva, 1964
VS-2	48	40	39.27	21	16	44.09	10.5	sand	1.6	9.0	3.2	2.20	5.90		
VS-5	48	40	34.15	21	17	0.26	10.5	gravel	3.1	8.8	3.2	2.10	11.40		
VS-6	48	40	14.54	21	16	49.51	10.3	gravel	4.0	8.5	4.0	1.50	3.30		
VS-7	48	40	24.19	21	17	15.19	10.0	gravel	2.2	4.0	4.0	2.10	10.60		
VS-9	48	39	55.49	21	16	57.06	8.0	gravel	0.7	7.0	3.5	1.20	1.42		
VS-10	48	40	8.94	21	17	41.75	8.7	sand	4.0	8.5	3.8	1.20	7.14		
VS-12	48	39	46.79	21	17	17.68	10.2	sand	2.5	8.4	3.5	1.35	2.32		
VS-13	48	40	1.12	21	17	54.94	8.5	sand	2.5	8.2	3.8	1.10	7.60		
VS-14	48	39	50.13	21	18	19.57	8.5	sand	4.0	7.0	3.8	1.05	4.16		
VS-15	48	39	33.86	21	17	43.90	8.5	sand	3.7	7.8	3.2	1.50	14.20		
VS-16	48	39	12.85	21	17	31.53	8.2	gravel	3.6	7.2	3.5	1.50	3.30		
VS-17	48	40	56.28	21	16	48.40	9.6	sand	4.0	9.3	4.5	1.50	3.64		
VS-18	48	40	57.85	21	16	38.69	10.4	sand	4.0	10.2	4.0	2.10	6.88		
VS-19	48	41	5.24	21	16	37.49	10.2	sand	2.8	9.7	4.0	2.10	3.20		

Continuation of Table 17

HV-1$_M$	48	40	23.79	21	17	56.60	8.0	gravel	3.1	7.1	3.0	1.25	3.40	suitable	Mičák, 1970
HV-2$_M$	48	40	26.96	21	17	26.96	7.7	gravel	3.5	6.6	3.3	1.25	1.06		
HV-3$_M$	48	40	8.52	21	17	42.47	8.0	gravel	4.5	7.1	3.3	1.25	5.40		
HV-4$_M$	48	40	16.77	21	17	28.67	8.0	gravel	4.7	7.8	3.7	1.25	6.20		
HF-1$_F$	48	41	7.10	21	16	38.78	11.1	gravel	5.1	10.3	4.0	2.40	10.68	unsuitable	Mičák, 1974
HF-2$_F$	48	41	6.00	21	16	45.74	12.0	gravel	8.5	11.2	4.1	2.40	6.80		
HV-1$_B$	48	40	10.71	21	15	43.69	15.0	gravel	7.0	14.0	7.0	1.80	2.70	suitable	Medveď, 1983
HG-1$_V$	48	40	50.63	21	16	27.80	13.5	gravel	4.0	12.0	5.2	2.00	12.50	unsuitable	Orvan, 1985a
HG-2$_V$	48	40	59.44	21	16	27.49	14.5	gravel	4.0	13.0	5.0	2.20	12.50		
HG-3$_V$	48	41	4.90	21	16	24.74	14.7	gravel	5.0	12.0	4.7	0.70	6.20		Oravn, 1985b
HG-1$_Z$	48	40	52.81	21	16	27.91	15.0	gravel	5.0	15.0	5.0	1.70	8.50		Orvan, 1983
HG-1$_O$	48	41	4.43	21	15	53.37	12.5	gravel	7.6	13.5	7.6	2.10	3.26		Orvan, 1985c
HG-1$_L$	48	40	33.38	21	14	20.44	18.0	gravel	6.0	18.0	8.5	1.50	1.00	suitable	Orvan, 1985d
HG-1$_A$	48	41	10.64	21	15	56.83	15.0	gravel	6.1	13.5	7.6	1.80	13.30		Tometzová, 1983d
HKK-1	48	41	2.68	21	15	50.47	14.0	gravel	7.6	12.0	7.5	1.50	1.60	unsuitable	Protivňáková, 1987g
HGK-1$_D$	48	41	0.93	21	15	51.26	15.0	gravel	8.0	14.0	7.5	1.14	3.00		Daňková, 1990c
HI-4	48	40	49.17	21	14	19.63	23.0	gravel	12.0	20.0	11.0	1.50	0.30		Lokajová, 1989
KS$_L$	48	40	13.28	21	14	4.24	24.0	gravel	10.0	13.0	10.0	6.00	1.25	suitable	Petro, 1992
Studňa	48	40	19.43	21	14	5.05	12.3	gravel	3.8	10.4	3.1	2.96	3.80	unsuitable	Verčimák, 1956
KS	48	40	29.31	21	15	42.32	18.0	gravel	8.0	16.0	8.0	8.00	0.50		Verčimák, 1982
HVL-1	48	39	5.79	21	14	28.01	24.0	sand	17.0	23.0	16.0	2.00	1.90		Mlynarčík a Szabová, 1975
V-23	48	40	16.67	21	15	24.57	20.0	gravel	19.0	22.0	15.0	2.50	2.50	unknown	Bujalka, 1958
HVO-1	48	40	20.96	21	16	30.00	9.5	gravel	5.0	8.5	5.5	1.00	0.40	suitable	Grexová, 2005

Table 18

Information about groundwater sources in the ward Nad jazerom

Well	GPS coordinates N [° ′ ″]			GPS coordinates E [° ′ ″]			Depth H [m]	Lithology of aquifer	Aquifer [m] from	Aquifer [m] to	Static level h [m]	Drowdown s [m]	Yield Q [l.s^{-1}]	Quality of drinking water	Refference
City district Nad jazerom															
SHMÚ 1121	48	41	37.71	21	16	45.79	10.7	gravel	4.0	8.7	3.9	1.60	6.75		Frankovič, 1969
SHMÚ 1122	48	40	53.12	21	17	41.27	9.2	gravel	4.2	7.2	4.1	1.00	3.37		
K-10	48	41	7.31	21	17	42.51	10.0	gravel	2.0	5.4	1.9	1.55	2.90	unknown	Medveď, 1972
K-12	48	41	31.40	21	17	32.51	6.3	gravel	1.9	4.8	1.8	1.50	5.60	unknown	
HGM-1$_H$	48	40	43.63	21	16	58.42	11.0	gravel	7.5	9.0	4.7	1.50	5.40	unknown	Halešová, 1978
SPH-1	48	41	43.20	21	17	10.90	8.0	gravel	2.5	6.5	1.2	4.18	4.20	unknown	Tometz, 1983
SPH-2	48	41	32.95	21	17	23.31		gravel	1.0	4.0	1.2	2.72	6.60	unknown	
HVP-1	48	40	29.22	21	17	30.88	10.5	gravel	3.4	9.0	3.4	3.00	5.72	unknown	Halešová, 1983
TK-2	48	41	46.72	21	16	29.87	9.5	gravel	4.0	8.5	4.0	2.00	2.51	unsuitable	Tometzová, 1983c
TK-3	48	41	50.86	21	16	30.65	10.0	gravel	3.8	9.0	3.8	3.00	8.62	unsuitable	
HG-2$_M$	48	40	29.41	21	17	35.51	9.5	gravel	3.7	9.5	3.7	3.00	9.00	unsuitable	Tometzová, 1984d
HV-1$_H$	48	41	4.65	21	16	46.62	12.0	gravel	3.1	10.0	3.1	2.30	25.00	unsuitable	Halešová, 1985
HDG	48	41	42.93	21	16	35.51	10.0	gravel	4.3	10.0	4.5	3.04	2.94	unsuitable	Verčimák, 1985
HDD-1	48	41	2.61	21	17	27.48	11.0	gravel	4.3	8.5	4.0	1.30	3.00	unsuitable	Halešová, 1987
HPD-1	48	40	46.69	21	18	6.72	11.0	gravel	1.8	9.0	3.6	2.30	4.44	unsuitable	Protivňáková, 1987f
HK-1$_C$	48	41	12.26	21	14	8.19	7.5	gravel	3.5	6.5	3.8	1.16	5.12	unsuitable	Medveď, 1988c
HK-2$_C$	48	41	5.13	21	17	22.11	7.5	gravel	3.7	6.5	3.9	0.78	7.14	suitable	
HK-3$_C$	48	40	53.68	21	17	42.82	8.5	gravel	4.7	7.5	4.7	0.80	6.89	suitable	
VS-1	48	41	55.06	21	16	42.39	12.5	gravel	5.8	9.2	5.8	0.33	7.00	unknown	Varga et al., 2013
VS-2	48	41	56.27	21	16	41.16	12.5	gravel	5.8	9.2	5.8	0.69	7.00	unknown	
TK-4	48	41	47.20	21	16	29.77	12.0	gravel	4.0	10.0	5.1	0.96	14.30	unsuitable	Cangár, 1992
HGX-2	48	40	56.04	21	17	19.30	8.5	gravel	4.0	7.5	3.5	1.50	6.00	suitable	Grexová, 2008
HGR-1	48	41	12.86	21	16	56.05	9.5	gravel	4.5	8.5	4.5	1.11	3.70	suitable	Grexová et al., 2010

Table 19
Information about groundwater sources in the ward Krásna

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Krásna															
I.$_F$	48	39	39,98	21	17	32,01	8,80	gravel	2,00	7,60	3,20	1,50	6,60	unsuitable	Frankovič, 1976b
II.$_F$	48	39	43,08	21	17	44,09	8,40	gravel	3,50	7,20	3,80	1,50	3,40	unsuitable	
III.$_F$	48	39	45,65	21	17	56,51	8,00	gravel	3,80	7,00	3,80	1,50	8,10	unsuitable	
IV.$_F$	48	39	48,78	21	18	10,58	9,00	gravel	3,90	8,30	4,08	1,50	7,70	unsuitable	
V.$_F$	48	39	35,66	21	17	13,74	8,60	gravel	4,00	7,60	3,50	1,50	6,30	unsuitable	
VI.$_F$	48	39	32,06	21	17	3,46	6,80	gravel	3,60	5,80	3,20	1,20	3,10	unsuitable	
HK-1$_M$	48	40	22,10	21	18	48,08	10,0	gravel	4,5	7,0	4,0	4,00	0,001	unsuitable	Medveď, 1985b
Studňa	48	40	14,23	21	18	44,00	7,5	gravel	3,5	5,5	3,5	0,20	2,140	suitable	Wagner, 1963
HG-1$_K$	48	40	28,93	21	19	57,60	10,5	gravel	5,0	7,8	4,0	4,50	0,75	unsuitable	Varga, Š., 1985

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Table 20
Information about groundwater sources in the ward Lorinčík

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Lorinčík															
HL-1	48	41	11,34	21	11	46,82	60,0	gravel intercalations	3,0	56,0	13,8	17,93	0,680	unsuitable	Medveď, 1990

Table 21
Information about groundwater sources in the ward Poľov

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ´ ´´]			E [° ´ ´´]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Poľov															
P-1	48	40	21,85	21	11	9,75	49,0	sand	17	31,5	37,5	7,4	0,25	unknown	Adamčík, 1969
								gravel	42,2	46,6					
HG	48	39	35,25	21	12	16,20	40,0	gravel	3,0	40,0	1,2	11,60	0,410	unsuitable	Forberger, 1980
HG-1	48	39	43,15	21	12	3,12	20,0	gravel	4,7	7,3	0,5	10,70	0,200	unsuitable	
HG-2	48	39	43,45	21	12	6,84	15,0	gravel intercalations	2,7	12,2	3,8	8,70	0,120	unsuitable	
HG-3	48	39	41,75	21	12	16,63	50,0	gravel intercalations	4,0	50,0	0,9	12,30	0,25	unsuitable	

Table 22

Information about groundwater sources in the ward Šaca

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ′ ″]			E [° ′ ″]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Šaca															
Š-1	48	37	54.30	21	9	35.53	59.6	gravel	6.2	10.8	4.4	16.50	2.60	unknown	Tartal, 1965
Š-2	48	38	2.37	21	9	34.53	13.0	loamy gravel	1.5	10.0	3.4	6.40	0.40		Adamčík, 1966
HV-1$_T$	48	36	23.31	21	10	27.84	15.0	gravel	3.4	11.8	3.4	8.00	2.17		Tometzová, 1983b
HV-2$_T$	48	36	23.44	21	10	33.60	11.0	gravel	4.0	11.0	4.0	5.00	1.66		
HV-3$_T$	48	36	24.80	21	10	35.34	20.0	gravel	4.0	18.1	4.0	7.00	2.31		
HV-4$_T$	48	36	22.70	21	10	27.26	20.0	gravel	9.0	17.0	9.0	1.60	5.00		
HGV-1/83	48	36	5.81	21	10	38.49	11.0	gravel	8.7	11.0	8.7	0.90	0.04	unsuitable	Frohmannová, 1983
HSK-1	48	39	16.02	21	10	7.04	60.0	loamy gravel	25.0	55.0	1.9	11.90	1.21		Bindas, 1987
HŠ-1	48	38	1.68	21	10	34.65	9.0	gravel	2.2	6.0	1.5	4.30	0.01		Cangár, 1987
HŠ-2	48	38	0.91	21	10	38.43	30.0	gravel	3.2	7.0	3.0	15.00	0.70	suitable	Cangár, 1988
									20.0	21.8	9.6				
HŠ-3	48	38	3.37	21	10	31.65	30.0	gravel	3.4	7.5	3.3	4.00	0.35		
HŠ-4	48	38	0.29	21	10	29.48	21.0	gravel	3.4	7.0	3.3	15.00	0.40		
									17.5	19.0	11.3				
HŠ-5	48	37	56.39	21	10	34.27	24.0	gravel	2.8	7.0	2.7	15.00	0.70		
									8.0	12.0	3.4				
									19.0	22.0	9.8				
HGŽ-1	48	35	20.30	21	10	20.76	11.0	gravel	1.8	9.0	1.2	2.50	10.20	unsuitable	Halešová, 1988
HGŽ-2	48	35	12.06	21	10	37.88	10.0	gravel	1.0	8.0	0.8	2.50	5.95		
HGŽ-3	48	34	48.13	21	11	5.80	9.0	gravel	2.0	7.0	1.1	2.50	5.31	suitable	
HGŽ-4	48	34	34.30	21	12	0.39	8.5	gravel	2.4	6.5	1.6	2.70	2.55	unsuitable	
HGŽ-5	48	34	41.73	21	12	32.65	9.0	gravel	3.5	7.0	3.3	2.50	1.95		
HGŽ-6	48	37	33.24	21	12	1.59	14.0	gravel	5.4	12.0	5.2	3.30	0.25		
HGŽ-7	48	37	33.11	21	12	6.15	22.0	gravel	7.0	10.5	6.8	4.00	5.55		
									11.0	21.0	10.2				
HGŽ-8	48	37	35.99	21	12	38.33	18.0	gravel	8.9	16.0	8.8	2.80	9.52		
HGŽ-9	48	37	12.82	21	12	0.80	16.5	gravel	9.8	14.5	9.7	2.30	1.85		
HGŽ-10	48	37	15.69	21	11	58.00	18.0	gravel	9.2	16.0	9.1	2.60	1.66		
HGŽ-11	48	36	27.76	21	11	53.49	14.0	gravel	6.5	12.0	6.3	1.50	1.59		

Continuation of Table 22

MV-3	48	35	50.40	21	11	49.96	13.5	loamy gravel	1.7	13.5	4.7	0.14	1.25	unsuitable	Masiar et al., 2003
MV-4	48	36	9.37	21	12	14.55	13.5	loamy gravel	4.0	9.5	5.8	0.90	1.42		
MV-5	48	36	35.07	21	13	24.40	13.5	loamy gravel	1.4	11.5	5.9	0.10	0.90		
MV-6	48	35	37.09	21	12	37.60	13.5	loamy gravel	3.0	8.5	3.6	0.43	1.62		
MV-7	48	35	32.41	21	12	1.01	13.5	loamy gravel	3.5	13.5	3.2	0.32	2.50		
HGK-1_G	48	36	20.75	21	11	27.83	10.4	gravel	6.2	10.4	5.3	3.59	1.00		Grexová, Mlynarčík, 2009
HKX-1	48	36	18.74	21	11	4.00	12.5	gravel	4.5	10.2	6.3	0.32	0.47	suitable	Pramuk, 2013
JKŠ-1	48	38	30.32	21	9	46.30	10.0	gravel	3.5	8.0	3.5	3.00	0.40	unsuitable	Tometz, 2017a
JRŠ-1	48	38	28.06	21	9	46.37	16.0	loamy gravel	3.5	13.0	3.5	5.00	0.45	unsuitable	Tometz, 2017b

Table 23
Information about groundwater sources in the ward Šebastovce

Well	GPS coordinates						Depth	Lithology	Aquifer [m]		Static	Drowdown	Yield	Quality of	Refference
	N [° ′ ″]			E [° ′ ″]			H [m]	of aquifer	from	to	level h [m]	s [m]	Q [l.s^{-1}]	drinking water	
City district Šebastovce															
HG-1_P	48	39	16.02	21	15	51.87	6.5	gravel	2.0	4.5	3.8	0.30	0.11	unsuitable	Prídala, 1966
HVL-3	48	39	29.42	21	16	8.03	13.0	gravel	5.0	11.0	1.2	2.50	4.00	unsuitable	Mlynarčík, Szabová, 1975
SHMÚ 1124	48	39	11.06	21	16	20.16	13.0	gravel	1.3	11.0	1.3	2.00	7.30	unknown	Frankovič, 1969
KAH-6	48	39	34.87	21	17	3.19	163.6	sandy clay gravel	46.9 70.6 82.6	49.6 79.6 88.6	preliv	2.00	14.50	unsuitable	Frankovič, 1976a
HG-10	48	39	18.61	21	15	59.57	25.0	gravel	19.0	23.5	3.7	3.10	2.50	unsuitable	Frankovič, 1977
HŠ-1	48	39	7.90	21	16	10.87	18.3	gravel	12.0	17.3	2.3	3.00	5.00	unsuitable	Tometzová, 1982
HG-1š	48	39	4.50	21	16	15.42	35.0	gravel	12.0	32.0	7.0	5.00	1.00	suitable	Tometzová, 1988
HV	48	39	15.57	21	15	50.53	31.0	gravel sandy clay	10.0 25.0	21.0 31.0	3.4	7.10	12.50	unsuitable	Eristavi, 1989

4.2.11. Ward Vyšné Opátske

The character of this area is similar to that of ward Dargovských hrdinov. The slope movements also affect it, but no sanitary processes have been realised here. The western edge of the Vyšné Opátske falls into the Hornád River valley. In this territory, mainly built-up areas of individual houses occur, sometimes with dug wells. However, information about technical and hydrogeological parameters of these wells is not available.

The only relevant information on local conditions is provided by wells VO-1, S-3 and S-4 located on the southern edge of this ward *(Map 4)*. As is evident from *Table 16*, well VO-1 is 58.0 m deep and passes through gravels in the upper part and tuffites in the lower part, but its yield is only 0.4 Ls^{-1}. Wells S-3 and S-4 are located in the floodplain gravels. Their depth is 4.5 and 5.0 m and efficiency 3.33 and 1.5 Ls^{-1}, respectively.

4.2.12. Ward Barca

As was mentioned in the previous chapter, this ward is on the eastern part adjacent to ward Nad Jazerom. The border is represented by the Košice–Čierna nad Tisou railway line *(Map 4)*. A massive hydrogeological survey was carried out in the area between this track and railway leading to Hungary for the purpose of planning for the food processing industry (Halva 1964). A total of 15 hydrogeological wells labelled VS were realised within this survey. Their depth ranges from 8.5 to 11.0 m *(Table 17)* and the efficiency of the wells ranges from 1.42 up to 15.0 Ls^{-1} (Σ 100 Ls^{-1}).

An additional survey was carried out by Mičák (1970, 1974) for the mills and bakery industry and through 6 wells of 7.7 to 12.0 m depth he documented the possibility of groundwater utilization for a total amount of 33.5 Ls^{-1}. Orvan's work (1983, 1985a, b, c, d) can be described similarly, but these relate to the area with engineering industry (VSS). Relatively surprising are results of a survey carried out on the right side of Južná trieda Street opposite the former factory of East Slovakian Machine Plant (VVS), where bus repair services were located in the past *(Map 5)*. The yield of the well in this area (HG-4_A, Tometzová 1983d) is up to 13.3 Ls^{-1}.

On the western edge of the ward, in the area with an airport, a hydrogeological survey prospecting for sources of groundwater available for drinking uses (Mlynarčík and Szabová 1975) was made, as well as a survey focused on groundwater protection (Lokajová 1989).

4.2.13. Ward Nad jazerom

A substantial part of the groundwater sources are located on the right side of the Hornád River *(Map 4)*. In the area between this surface stream and the lake (northern part of the ward) two more hydrogeological wells were realised (SPH-1 and SPH-2; Tometz 1983b) in order to obtain the base information for subsequent sanitation works relating to seepage at the base of the levee. The reason for these works was that during the extreme flows on the surface, suffosion occurred at the shoreline of the lake due to the communication between surface water and groundwater. Because of this filtration failure, the stability of the levee was in danger. However, the survey provided base information for recommendations for and realisation of the sanitary works, which consisted of a grout wall constructed between the dam's surface to the impermeable basement (about 6.0 m p.t.). The structure was constructed in 1987.

In addition, there are two wells of the Slovak Hydrometeorological Institute (SHMÚ; 1121 and 1122) carried out in the framework of a survey led by Frankovič (1969). The wells are operational within the observation network at present.

In the territory of this ward, some other hydrogeological surveys of local character were realised *(Table 18)*. The efficiencies of included wells range from 2.51 to 25,0 ls^{-1} and indicate a trend for values to be higher the greater the distance from the Hornád River. In the area where efficiencies are higher, there is an industrial zone with mainly food facilities. Mainly the canning factory, dairies and the meat industry have a large demand for drinking water. This area is adjacent to the ward Barca, where numerous hydrogeological wells have been realised in the past.

4.2.14. Ward Krásna

This ward is located predominantly in the floodplain deposits of the Hornád River valley *(Map 4)*, where all hydrogeological objects are situated. The most important wells are thosee labelled I.F to VI.F (Frankovič 1976b), which were drilled to examine the possibility of obtaining groundwater for the planned local industrial park. A total amount of 20.8 Ls^{-1} *(Table 19)* was documented by these wells of 6.8 to 9.0 m in depth.

4.2.15. Wards Pereš, Lorinčík and Poľov

From the hydrogeological point of view, the location of these wards is restricted to the lithological units (clays with aquiclude character) with no potential for obtaining groundwater. Locally, some wells were realised here but their efficiencies were never higher than 1.0 Ls^{-1} *(Table 21)*. In general, the yield of this area is lower than 0.5 Ls^{-1}.

In the ward Pereš, no hydrogeological wells using groundwater are registered in the Geofond archive.

4.2.16. Ward Šaca

The territory of this part of Košice is located on its southwestern edge *(Map 4)*. The cadastral area of Železiarne is also associated with it. Today, the steel complex USS is situated here, although a smaller part of it falls into the cadastral area of the village Sokoľany. The essential part of the hydrogeological works for the steel complex is located in this territory. Wells are most often situated in proluvial sediments, in which loamy gravel makes up the aquifer character. Through wells of not more than 20 m, yields of 0.04 up to 2.6 Ls^{-1} have been determined *(Table 22)*.

Higher efficiencies were measured on the south-eastern edge of the Železiarne area, which is related to the fact that hydrogeological conditions are affected by the Ida River. Efficiencies reach 5.0 to 10.2 Ls^{-1} here and are documented in 11.0 to 13.5 m deep wells. The purpose of these wells was not for water use but to drain the building-pits (Tometzová, 1983b) as well as for to solve the problem of groundwater pollution (Halešová, 1988; Masiar et al. 2003; Pramuk 2013).

Due to its geological position, the urban area of the ward Šaca is poor in groundwater content. This was confirmed by works of Cangár (1987, 1988) who realised 30.0 m deep wells in Neogene sediments and captured groundwater with a rate of no more than 0.7 Ls^{-1} per well. Similar results are found in works of other authors (Adamčík 1966; Frohmanová 1983). Deeper wells (59.6 m – Tartal 1965; 60.0 m – Bindas 1987) have higher efficiencies, ranging between 1.21 and 2.6 Ls^{-1}.

In conditions of alluvial sediments of the Ida River in the northern part of ward Šaca, the possibility of groundwater capture in the amount of about 0.5 Ls^{-1} was confirmed by a well of 16.0 m depth (Tometz 2017).

4.2.17. Ward Šebastovce

In total, 9 wells were documented in this ward *(Map 4* and *Table 23)*. One of them (KAH-6) was oriented to Neogene layers preserved in the higher depth and was realised within the survey of artesian layers in the area in the south of Košice (Frankovič 1976a). This well was 163.0 m deep and the artesian aquifer was verified at 700–88.6 m depth. The yield was determined to be 14.5 Ls^{-1} by a pumping test. Similarly, a yield of more than 10 Ls^{-1} was also obtained at the well HV of 31.0 m depth (Eristavi 1989) passing through the Neogene gravels at 25.0 to 31.0 m. However, for both aquifers insufficient groundwater quality for drinking purpose is characteristic due to the high values of Fe and Mn as well as biological and microbiological contamination

Wells situated in the quaternary gravels do not reach such high efficiencies. In such sediments, values of 0.11 to 7.3 L s^{-1} were documented.

5. THE USE OF GROUNDWATER AS PUBLIC DRINKING WATER SUPPLY IN KOŠICE

The city of Košice is supplied with drinking water from several resources managed by the joint stock company Východoslovenská vodárenská spoločnosť Košice (East Slovak Water Company Košice). Major water supply facilities are located outside of the city. In particular, this is the Starina–Košice water system whose source – the Starina water reservoir – is located in the Prešov region, Snina district. In the early 1980s, when this system did not yet exist, Košice was supplied by the Bukovec water reservoir, located no more than 10 km from the city. Prior to the mentioned period, the decisive resource was the water supply system Turňa–Drienovec, which uses groundwater from the resources of the eastern part of the Slovak Karst National Park. Important resources at that time were the abandoned wells situated in Quaternary sediments, the fluvial gravels in the Hornád Rver plain. These are situated to the north of Košice between the villages of Trebejov and Tepličany. Such resources are also located in the city's territory, on the northern outskirts of the Košice-Sever city part, in the cadastral territories of Čermeľ (well VII) and Severné Mesto (wells I, III, V, VI, VII, VIII and IX). Their location is shown on *Map 2* and the documentation in *Table 8*. In addition to wells I and III, these wells are still used today.

The oldest water supply system of the city is an historic Čermeľ water aqueduct, capturing the groundwater of springs located in the Čermeľ River valley. On 25 November 2011, this interesting work celebrated its 100th anniversary. For this reason, it will be given special attention here.

5.1. History of drinking water utilization from the Čermeľ creek area

The primary intention for utilization of Čermeľ Creek valley springs reaches back to the turn of the 19th century. It is testified by a document compiled for this purpose (by Schustler and Éder 1899) and dealing with preparatory works, projecting and construction of the first Košice aqueduct and sewer system. It is evident from the introductory part of this document, stating "by the decision of the town council No. 4809/118 from June 27, 1899", that it was decided to construct an aqueduct in Košice, apart from sewerage.

The strategy for appropriate water sources choice was an especially important element of the aqueduct construction. The older wells, utilizing groundwater from Hornád River accretions, were situated in the town residential area of Košice City and appeared to be unsuitable due to their heavy pollution. From the point of view of acquiring new water sources, i.e. acquisition of water with appropriate qualitative parameters, and also from the point of view of sufficient water amount, the choice fell on the possibility of exploration of the Čermeľ Creek valley springs interception. The authors of the original project proposed to capture 20 “greater” springs situated in this valley for water supply purposes.

The expected start of the aqueduct construction was 1901 – after the acquisition of financial credit, investigation of summary yield of springs and project documentation development. Definite plans for aqueduct and sewerage construction, assembled by the Division of Public Health Engineering of the Hungarian royal state directorate for waterworks construction, were elaborated by G. Göndör in July 1901.

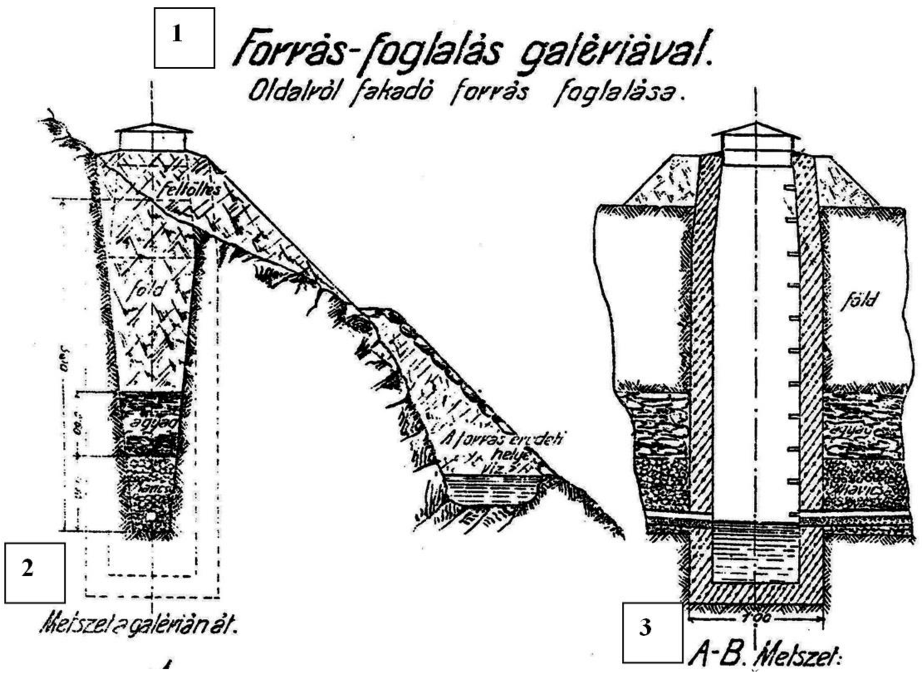

Figure 4. Fragment from original project documentation depicting capturing of Čermeľ springs. (1 – Capturing by a gallery; 2 – Cross-section of a gallery; 3 – Section A-B)

The originality of the aqueduct construction consisted in its technical realization, when individual springs were captured by shafts and galleries fluming water from numerous small dells of the branching Čermeľ Creek valley. In the project, the total pipeline length (with pipes of different diameters, from 40 to 500 mm) was 19,501 m: closed concrete pipes (length 17,123 m); perforated concrete pipes (895 m); and closed cast iron pipes (1.483 m). This created an extensive aqueduct system consisting of more than 200 objects, which is up to the present made up of springs and mixing, interrupting and flow-through shafts. *Figure 4* presents one part of the original project documentation and depicts a method of spring capturing by a shaft and by a gallery.

Construction of the first Košice aqueduct started on 22 April 1905 and was completed on 25 November 1911. The Zellerin Company provided the supply of pipeline and participated also in cutting work *(Figure 5)* and in the construction of individual installations. The company was represented by Ulrik Kitzbichler Jr. with a partner. Steel shaft covers were provided by Fleischer and Co. from the Košice machine works. Supervision during the construction was performed by Dezső É. Újváry, who considered the construction works realised well according to the approved projects (Göndör 1905).

Figure 5. Historical photo depicting cutting works of the first Košice aqueduct

5.2. Geology and hydrogeology of Čermeľ springs

The southeast slopes of the Čierna hora Mts. and Volovec Mts. have a complicated geological-tectonic structure, which is also reflected in complicated hydrogeological conditions. Hydrogeological evaluation of this area is very problematic due to frequent alternation of petrographic-lithological rock types having different hydrogeological properties. Considerable segmentation of relief, which substantially affects drainage of surface and underground water (Helma 2005), also plays an important role in hydrogeological evaluation of the area.

The evaluated area is typical in its variegated composition of lithological rock types belonging to the different tectonic units. The present geological structure of the area is a result of multiple orogenetic cycles, which have influenced present relations among individual aquifers and insulators, their character and permeability values.

Carboniferous rocks of the Gemericum unit

These rocks form the predominant part of the study area. They are represented prevailingly by chlorite-sericitic phyllites intercalated by diabase metavolcanoclastic rocks, graphite phyllites and lydites. All present rock types are metamorphic; consequently, they lost their original intergranular permeability. From a hydrogeological point of view, they represent the same quality – i.e. groundwater insulators. Multiple springs with a yield not exceeding 0.1 Ls^{-1} were documented in this rock milieu by hydrogeological mapping.

Carbonate rocks of Mesozoic

Carbonate rocks are the most important groundwater aquifers in the study area.

Quartzites of the Lower Triassic are distributed only in a small area in the central part of the territory. These highly rigid rocks are disintegrated with open fractures, which enables deeper groundwater circulation (not only in the subsurface zone), and are present due to multiple orogenic stages. Quartzites belong to the Lúžňanské beds of the Vepricum unit. No springs were documented and no hydrogeological borehole was drilled in this unit.

Shales of the Lower Triassic are many-coloured, locally metamorphosed rocks, intercalated locally by quartzose sandstones. Shales are part of the Werfen strata of the Veporicum unit. Shales are scarcely present in the study area. No spring rises from them. When compared with the non-carbonaceous rocks, they could be classified as insulators with an interval of average permeability from 1.0×10^{-6} to 1.0×10^{-5} m^2s^{-1}. In general, we can state that these strata act like a rectifier of groundwater circulation in the top wall of Middle Triassic carbonates. Contact springs are usually situated in the contact area of these shales.

Ramsauer Dolomites crop out on the surface in a discontinuous belt in the central part of the territory. Dolomites are typical for fracture to fracture-karst permeability. Springs with an average yield of about 0.5 Ls^{-1} were documented by hydrogeological mapping in this rock milieu.

Variegated carbonates of the Jurassic crop out in the studied area along the Margecany thrust zone (further only MTZ) from its eastern side and are present in more-or-less continual belt. Springs with an average yield above 1.0 Ls^{-1} were documented in these rocks by hydrogeological mapping. Situated in the top wall of Lower Triassic quartzites, variegated clayey to clayey-sandy shales of Lower Triassic reach a maximum of 20 m in thickness. These shales belong to Werfen beds and perform a hydrogeological insulator task between quartzites and Middle to Upper Triassic carbonates. The Triassic carbonate complex crops out to the surface in the northern and the southern part of the territory. Ramsauer dolomites are the most widespread part of the carbonate complex.

Rain water, infiltrated through covering geest, enters the weathering and loosening zone of a rock massif where it descends from the watershed to the local erosion bases. Part of water comes out again on the earth's surface, either within the carbonate complex in the form of fissure to fissure-karst springs or in the form of contact springs on the boundary with the footwall's less permeable Lower Triassic shales.

Together with Jurassic limestones, Ramsauer dolomites form an important hydrogeological structure drained by springs in the evaluated territory. Several springs, situated on the contact with impermeable Carboniferous sediments of the Gemericum unit, rise on the western side of this structure.

As far as Mesozoic rocks are concerned, Jurassic carbonates – mainly limestones – are relatively good aquifers. They crop out to the surface in a discontinuous belt along the MTZ. Jurassic limestones, together with Triassic dolomites, form an important hydrogeological structure, part of which is drained by a form of contact (barrier) springs on the contact with graphite phyllites, representing the Čermeľ group of the Gemericum unit.

Quaternary sediments

As a result of deep erosion, Quaternary sediments are only discontinuously well preserved in the studied area. Widespread are mainly fluvial and proluvial sediments, which are represented by the Holocene accumulation of Čermeľ creek and its tributaries. Proluvial sediments create very noticeable conical forms in the majority of outfalls of the smaller tributaries of the Čermeľ creek; Hlinný creek and Senný creek are examples of such tributaries in the study area. Proluvial sediments, which have a character of loam, sand and gravel, are of no hydrogeological importance.

5.3. Present state of waterworks utilization of the Čermeľ valley springs

As already mentioned in the introduction, the current administrator of the first Košice aqueduct is eminently interested in its conservation. The basic duty of the detailed mapping of all the objects of this waterworks, and not only groundwater trapping objects, but also shafts in the pipeline route to the consumer, consisted of technical state checks.

This mapping consisted of physical documentation of every existing object – either a shaft intercepting groundwater from a spring, or a shaft used for manipulation of transported water, or a shaft for supervising purposes.

In total, 209 out of 215 shafts (this number is mentioned in the original historical document) were documented in cooperation with the administrator of the evaluated waterworks facility. For each object (especially in the case of springs), first basic hydrogeological parameters were documented, which consisted of the measurement of:

a) Water inflow yield to the shaft Q [Ls^{-1}],
b) pH value [–],
c) Specific electrical conductivity value C [μSm^{-1}],
d) Water temperature T_{vo} [°C],
e) Air temperature T_{vz} [°C],
f) Determination of position and absolute altitude of documented object by GPSMAP 60CSx from Garmin Comp.

Figure 6.
Roots in inlet piping of shaft S6

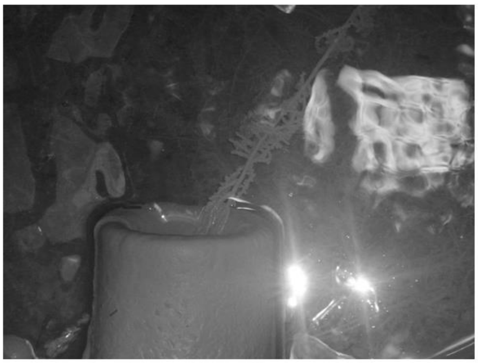

Figure 7.
Carbonate crust on an outlet piping in shaft S66

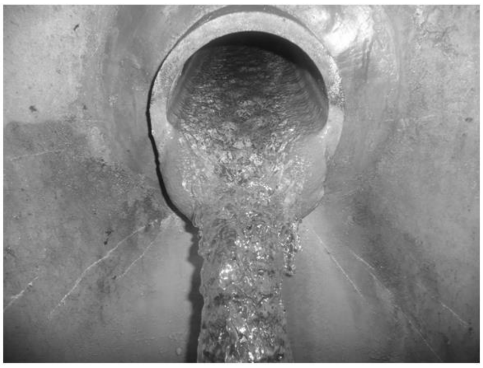

Figure 8.
Carbonate incrustation in an inlet piping in shaft S64

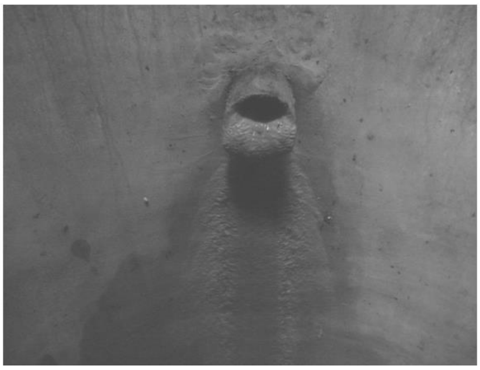

Figure 9.
A clear reduction of piping cross-section as a result of incrustation (shaft S 117)

Figure 10.
An example of destruction
of concrete heading – shaft S20

Figure 11.
An example of destruction
of concrete heading – shaft S132

Technical monitoring consisted of shaft wall tiling inspection and functionality inspection of closing and security elements. Photographic documentation of every object from inside and outside was an integral part of the field work. Documented by successive field mapping were: 18 shafts having the character of a spring with a protection zone; 2 shafts having the character of a spring without a proposed protection zone; 15 flow-through shafts with a spring – 8 of them with a proposed protection zone; 2 mixing shafts with a spring – 1 of them with a proposed protection zone; 1 flow-through mixing shaft with a spring without a proposed protection zone; 1 flow-through shaft with 2 springs without proposed protection zones; 1 flow-through shaft with 2 springs and interrupting chamber without a proposed protection zone; 125 flow-through shafts; 25 flow-through shafts with interrupting chamber; 4 mixing shafts; 4 flow-through mixing shafts; and 2 flow-through shafts with a gate valve. The predominant majority of these technical objects were found to be in a satisfactory technical state.

As field measurements had a limited extent, the results of older laboratory analyses were still a prime source of data for the determining the drinking water quality of Čermeľ Creek valley springs. An assay of these results leads to the conclusion that no activity occurs in the infiltration (seeping) area of these springs that could influence groundwater quality from a physical or chemical aspect, either in the field of inorganic or organic contamination. However, coliform bacteria and Escherichia coli, whose presence is not permitted in drinking water by law, sometimes occur in the water; these bacteria suggest that the contamination is related to insufficient protection. Insufficient protection consists of the present insufficient technical state of some springs. Pprotection zones of the 1st protection stage of Čermeľ springs are not fenced and some of the shafts located outside of these protection zones are insufficiently ensured against access by animals and unauthorized persons. In this place, it is to emphasize some activities, which could negatively affect quality and quantity of utilized water. Increasing timber exploitation in the municipal forest of Košice, where the 1st and 2nd hygienic protection zones of evaluated springs are located, seems to be a threat to water quality.

6. LOCAL GROUNDWATER RESOURCES

In addition to the above-mentioned groundwater resources, there are also water resources in the city of Košice that are considered reserve resources and were implemented as part of the city's initiative in the 1980s. At this time, the city was feeling the effects of a significant supply deficit of drinking water. A number of wells were thus implemented not only in the boundary areas (Medveď 1985a – *Map 1* and *Table 8*), but also in the town residential area (Jelínek 1988a; Medveď 1988a, 1988b – *Map 3* and *Table 11*).

In addition to such resources, local drinking water resources, which are still supplying various institutions, were implemented within the territory of the city. These are mainly medical facilities; in the case of the Polyclinic Sever resource S-1 is located close to the builiding (Brandner 1960 and Bajo 2007 – *Map 3* and *Table 11*). Likewise, wells (K-1N, 2N a 3N – *Map 3* and *Table 15*) were installed for the medical facility of L. Pasteur Hospital that are still functioning. The original documentation of their implementation is not available, but their revitalization was documented by Lokajová (1987) and Daňková (1990b). These resources are not used to their capacity to meet the needs of the polyclinic and hospital: the actual sampling rate is from 2 to 5 Ls^{-1}, but their yields range from 12 to 41 Ls^{-1}. All of these water bodies were constructed as large-capacity drop wells with a diameter of 2 to 3 m.

In the second half of the last century, due to the industrialization of the city of Košice, numerous hydrogeological surveys were carried out to provide either drinking or service water. These kinds of resources are mainly located in the industrial parts of the city (wards Sever, Barca, Nad Jazerom, Šaca). Many of these resources are not currently being used, but as a result of a pricing policy with water, current owners of industrial plants and facilities are returning to their use.

Following the logs of hydrogeological documentation in the archive of Geofond ŠGÚDŠ Bratislava the number of new water resources is increasing. In total, hydrogeological documentation was recorded for 20 new sites (Bajo and Grexová 2015; Grexová 2005, 2008; Grexová and Mlynarčík 2009; Grexová et al. 2009a, b; 2010, 2013, 2018; Ostrolucký 2003a, b; Petercová and Varga 2017; Petercová et al. 2016a, b; Tometz 2016a, b; 2017, 2018; Varga et al. 2013, 2014). The vast majority of these resources were intended for industrial use. This group also includes resources for energy use by heat pumps operating in water-to-water mode. This is especially the case for the territory located in the city center (wells HGI-1 and HGS-1, at Garbiarska Street, wells KSI-1 and 2 at Strojárenská Street, wells ČV-1 and 2 at Továrenská Street – *Map 3*, *Table 11*).

7. MINERAL WATERS

Mineral waters are present in the territory of Košice City. A mineral water resource known from the 14th century is located in the northern part of the town, in the recreation area of Anička (district Košice I, ward Košice-Sever). Mainly the population of the nearby ward Ťahanovce drew mineral water from a dug well of a depth of 3.0 m. In 1863, a new resource called Lajos forrás (Ľudovít Spring, *Figure 12*) was built here. The spring was named after the Hungarian revolutionary Lajos Kossuth. The widow of Fridrich Legányi, a town deputy, created a spa with a park and a spa building here. At that time, the prosperous spa had a games room, a reading room and a dance hall, and an attending physician supervised the curative treatment.

Figure 12. Historical postcard of the spa house at Ľudovít Spring

At the time when General Radola Gajda with his army served as commander of the 11th Infantry Division and was a successful organizer of cultural and political life (1922–1924), the spa was rebuilt and renamed the Gajda Baths *(Figure 13)*. The local mineral water was also named "Gajdovka" and this term is still common among the inhabitants of Košice.

Figure 13. Historical postcard of the swimming pool in Gajda Spa

Figure 14. Remains of resource KE-06 (Kiosk)

Figure 15. Mouth of the well G-2 located in Anička

According to Mynarčík et al. (2009), well G-1 was carried out at a depth of 13.0 m as a part of a survey for additional drinking water resources (Frankovič 1978) in the position of the original dug well.

The mineral water was captured by this well at the top of the faulted Triassic dolomites on a basis of Quaternary alluvium, where it was mixed with ordinary groundwater. The groundwater level was tapped at 3.3 m below the surface.

Geological drilling log:

Quaternary
0.0–1.2 m sandy loam
1.2–3.3 m gravelly loam
3.3–6.3 m loam-sandy gravel
6.3–9.5 m sandy gravel
9.5–11.0 m clay loam with gravel
Mesozoic
11.0–13.0 m gray dolomite.

Well equipment:

The well was completed by a pipe with a diameter of 273 mm with a perforated part from a depth of 11.0 m to the bottom of the well (13.0 m). The filter was placed between 8 and 10 m depth.

Well test:
A 14-day pumping test was carried out on the completed well. The groundwater level was reduced from 2.8 m to 2.93 m from the casing pipe level. The free CO_2 value (measured by the Heartland equipment) ranged from 1470–1580 mgL^{-1}.

The recorded CO_2 content was 1600 mgL^{1}, the water temperature was in the range of 12–14 °C, and sulfate was present in a higher concentration, whereby the water was characterized as sulfuric.

The water was biologically and microbiologically unsuitable for drinking purposes. Despite this fact, a kiosk was built here and later a mineral water drinking stand. After 1948, the spa and local park were renamed the Anička Spa, due to the fascist engagement of General R. Gajda during World War II, and it has kept this name until today. At the end of the 1980s, however, the spa experienced a significant decline with complete devastation of the sampling place. The wild privatization in the early nineties struck the last historic bath building, which had become so dilapidated that it had to be completely demolished.

The mayor of Košice and the later president of the Slovak Republic, Rudolf Schuster, took care of the reconstruction of the mineral water resource in 1995. A new source of mineral water, labeled G-5, was implemented at his initiative (Haluška and Petrivaldský, 1995). Nowadays, there is a gazebo with a drinking fountain on the site of the former G-1 well *(Figure 16)*, which is supplied with mineral water from the 30 m deep G-5 well. Well G-5 is located about 25 m east of the gazebo *(Figure 17)*.

Figure 16. Wooden gazebo with drinking fountain of mineral water

Figure 17. Well G-5 and its protection zone

Geology drilling log:

Quaternary 0.0–1.1 m sandy loam
1.1–3.2 m gravelly loam
3.2–6.3 m sandy gravel, loamy
6.3–9.5 m sandy gravel

Mesozoic (Middle – Upper Triassic)
9.4–11.0 m dolomites highly faulted into small fragments and mixed with clay material (rock mantle)
11.0–22.0 m less faulted dolomites
22.0–30.0 m more compact dolomites.

Well equipment:

The method of the completion allows the entry of mineral water into the well at intervals of 9.6–10.0 m and 20.0–28.0 m. The well equipment is a 160 mm perforated PVC pipe, with a steel pipe with a diameter of 133 mm, with two packers. The bottom packer was set to allow water to flow through the perforation at an interval of 9.6–10.0 m.

Well test:

After the packer is set, the optimal chemical composition of the mineral water has been achieved. The underground water is poorly mineralized (3695.5 mgL^{-1}), slightly acidic (pH = 6.42) and cold in the classification of mineral waters. The presence of sulfate at a concentration of 5.1 mgL^{-1} classifies the water as moderately sulfate. The sensorial properties of water were slightly influenced by the yield of fine dolomite sand from the aquifer, which was adjusted during the pumping test, and the water was clear and colourless. On the basis of the Gazda classification (Gazda 1971), the groundwater is a basic calcium-magnesium-hydrogen carbonate type. Soluble chlorides with alkali are also present in the solution. According to the classification of mineral waters, water in the G-5 well is natural, poorly mineralized, bicarbonate, chloride, calcium-sodium-magnesium, carbonate, sulfur-water, hypotonic, cold water. The radiological composition of mineral water allows it to be used in a volume of no more than 1.5 liters per day per person.

In 1996, an additional hydrogeochemical survey was carried out in the G-5 borehole (Petrivaldský 1996). After its assessment, it was found that the groundwater under investigation is a deep circulatory system with long-term detention ($HCO_3/Cl = 2.1$). The water is metamorphic r(Na-K)/rCl = 1.39; with considerable influence of Neogenic sediments (Cl/Na = 0.75), which nourish the chloride-sodium component. Mineralization of water is obtained by dissolving sedimentary carbonate rocks.

After leaving the reduction environment and the original thermodynamic conditions (reduction in carbon dioxide partial pressure, formation of free CO_2 phase, change in temperature), contact with air (dissolution of oxygen in mineral water solution), iron sulfides (FeS, FeS_2) of black color began to precipitate out of the water solution, which adversely affected the sensory-appearance properties of water.

The quantitative presence of iron in the mineral water was high (6.35 mgL^{-1} Fe) and it originated from disseminated pyrite minerals in sedimentary carbonate environment. The isomorphous mixture of this mineral is most often arsenic (representing sulfur). Subsequently, this element is introduced into a water solution by hydrolytic decomposition, whereby the mineral water in the well G-5 contains a significant amount of arsenic. After dilution with water, the mineral water from the drinking stand was rated as natural, slightly mineralized, bicarbonate-chloride, calcium-sodium-magnesium, carbonate, sulfur, cold, hypotonic water.

At present, the mineral water from well G-5 is pumped and discharged through a pipeline into the gazebo with a discharge and sampling device. The well G-5 is protected by a closed structure and fenced in a circular plan area with a diameter of 15 m.

A reservoir with a capacity of about 150 l is situated under the roof of the gazebo and there are 3 drains for water sampling from the reservoir. Parameters of mineral water were measured on the outflow into a round-shaped spring vase. Excessive and unused water flows into the public sewer.

Well G-5 has not yet been recognized as a resource of mineral water pursuant to the Act of the National Council of the Slovak Republic no. 538/2005 Coll.

Well G-4, which was implemented in 1982 at the initiative of the former Cultural and Recreation Park in Košice, is also the resource of mineral water. The role of the exploratory works (Haluška and Petrivaldský 1982) was to obtain thermal water for spa purposes in the territory, i.e., in the vicinity of sports and recreation complex PKO Anička.

Well G-4 is located about 130 m northwest of the gazebo with the mineral water drinking fountain *(Figure 18)* and was drilled to a depth of 310 m. Under a 10 m thick layer of Quaternary fluvial sand and sandy gravel, a 195 m deep layer of light gray Middle to Upper Triassic severely faulted dolomites. The bedding is from 195 m to the final depth of the bore at 310 m and is formed by sericitic-chloritic phyllonites (Permian).

The drill was equipped with anticorrosive tubes with a diameter of Ø 216 (0–72 m), or more precisely 168, 146 and 133 mm with a filter part set in sections from 72 to 152 m (Ø 168 mm), 152–234 m (Ø 146 mm) and 249–273 m (Ø 133 mm). In the section from 234 to 249 m and from 273 to 310 m there is a stainless-steel smooth pipe with diameter Ø 133 mm.

A well test lasting 31 days was performed. The pumping test was started by the step-drawdown of the groundwater level. This method was used while pumping at 5.0 and 10.0 meters drawdown. A further drawdown could not be done because of gas safety (Haluška and Petrivaldský 1982). For this reason, pumping was carried out at the maximum output of the submersible pump, i.e. at a constant yield.

Figure 18. Location of the well G-4 (Hradová Hill in the background)

The pump output had a tendency to fluctuate slightly depending on the gas content of the water. Well yield values and groundwater level drawdown are reported in *Table 24*.

Table 24

Groundwater level and well yield step-drawdown pumping from well G-4 (b.s. – below the surface, a.s.l. – above sea level)

Grade	Groundwater level		Drowdown s [m]	Yield Q [l.s^{-1}]	Pumping time t [day]
	[m b.s.]	[m a s.l.]			
1	5,00	208,37	5,0	2,0	2
2	10	203,37	10,0	3,0	3
3	18,5	194,87	18,5	4,9	26

The results of the physico-chemical analysis of the water from the G-4 well show that the water is classified as slightly mineralized (4.497 gL^{-1}) and low thermal (26.0 °C). The water has the highest content of sodium, with lower content of calcium and magnesium of predominant cations. Of the anions, hydrogen carbonates with chlorides predominate. The quantitative occurrence of cations and anions was stabilized during the pumping test.

Free CO2 plays an essential role in the mineralization processes; it had an average value of 1,332.3 mgL^{-1}. The H_2S content showed steady values, on average 11.11 mgL^{-1}, excluding the sampling on 30 March 1982 (23.94 mgL^{-1}). The total iron content was about 3.3 mgl^{-1} during the pumping test and the manganese content was 0.6 mgL^{-1}. Mineral water from well G-5 is classified as naturally slightly mineralized, hydrogensulphite, chloride, sodium-calcium-magnesium, carbonate, sulfate, warmish andhypotonic with a total mineralization of 4.497 mgL^{-1}.

For sustained sampling, a quantity of 4.0 Ls^{-1} was recommended from the well when the groundwater level was drawn down to 15 m below the surface.

Unfortunately, the results of Haluška and Petrivaldský (1982) did not confirm the possibility of building a thermal swimming pool. For such purposes, groundwater should have a temperature of more than 30.0 °C and a resource yield of 10 or more Ls^{-1}.

Figure 19. View of the drilling rig during the drilling of well G-4

In the work of Mlynarčík et al. (2009), nine sources of mineral water, have been proposed for registration in the Ministry of Health of the Slovak Republic – the Institute of Springs and Spas, in the area of Košice city, in place of the original ones, which are nowadays unidentifiable sources marked as KE-06 and KE-07. In addition to the previously mentioned and described wells G-1, G-4 and G-5, there are also the wells G-2, HPL-4, HPL-5 and HPL-6 located in district Košice I, ward Košice-Sever. Location of the objects in the Anička area in terms of their amount and position is shown in *Figure 20.*

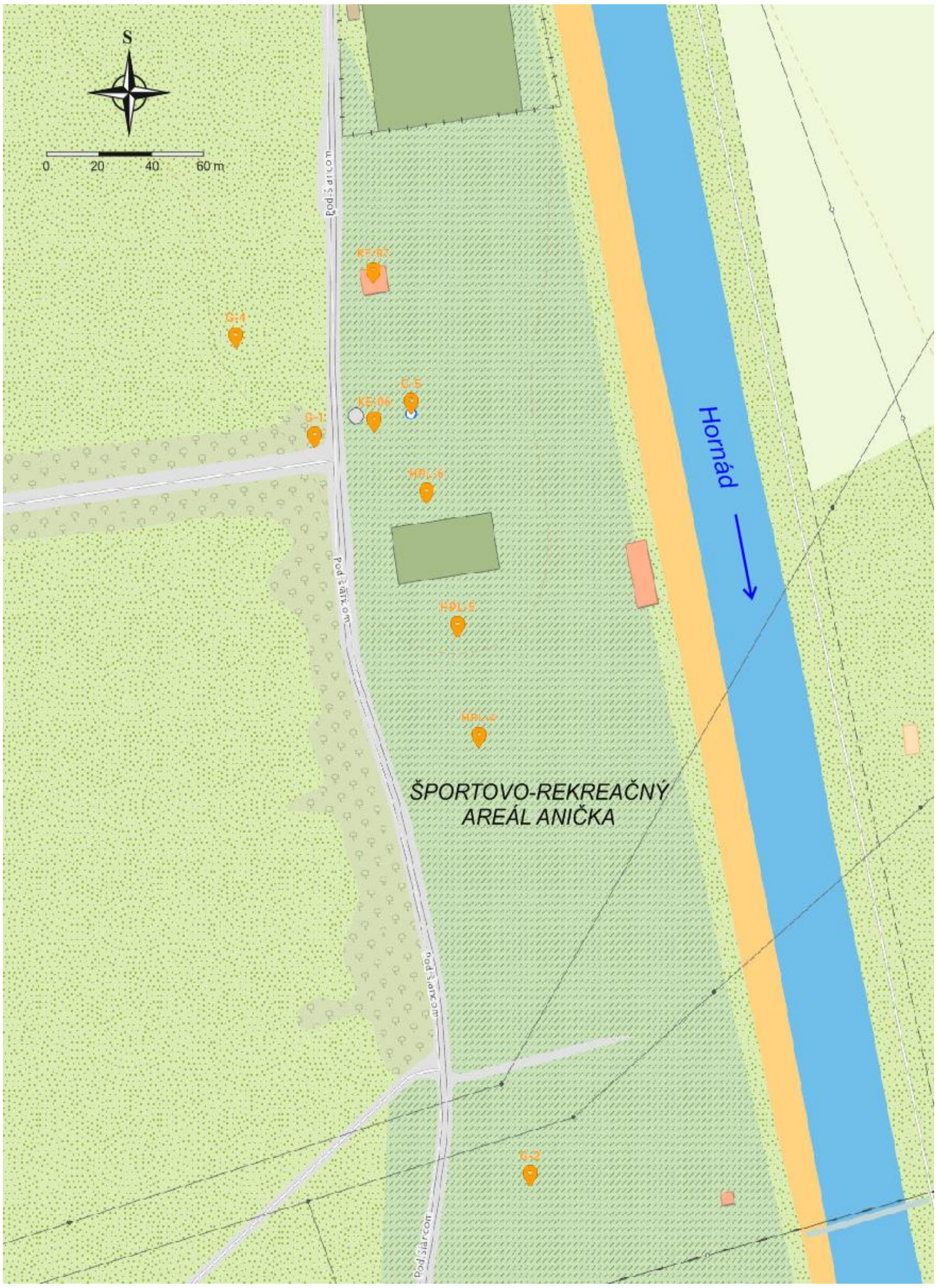

Figure 20. Location of mineral water resources in the sports-recreational area Anička

Outside of this area there are mineral water wells with the appellation HV-5 (local district of Ťahanovce) and KAH-6 (Frankovič and Szabová 1978) situated in the cadastral area of Šebastovce (district Košice IV).

The forecast conditions for the establishment of further mineral water resources are very negative, as confirmed by the results of the survey from 1982. In this case, it would be necessary to explore the area on the left side of the Hornád River, where the deeper range of dolomites (500 m or more) is possible, with the assumption of groundwater being more than 10.0 Ls^{-1} and with the temperature higher than 30 °C.

The territory of today's sports and recreation complex Anička as well as Košice itself would benefit from a thermal swimming pool with year-round operation. Given the uncertainty of obtaining a suitable resource of thermal water, it would be more appropriate to focus on the existing potential of groundwater bound to Quaternary fluvial sediments of the Hornád fluvial plain.

The lithological unit with its gravel-sandy aquifer offers a significant amount of water under the given conditions, which can also be utilized for energy by heat pumps operating in the water-to-water mode. The quantity and good quality of the groundwater in the area of the Anička complex was also confirmed by the older exploratory works (Tkáčik 1957; Verčimák 1981; Šťastný and Tometzová 1983).

8. CONCLUSIONS

This monographic study evaluates our knowledge about the hydrogeological conditions of the Košice territory. The monograph is focused on the topography of individual identifiable resources of groundwater.

To sum up such resources archival material stored since the 1950s has been used. The oldest documentation of this kind is the work of Tkáčik (1957a, b) and the most recent are works by Grexová et al. (2018) and Tometz (2018).

When it comes to the natural effluence of underground springs, the work is focused mainly on the objects used in the oldest Košice aqueduct. These are situated in the most northern part of the city in the Čermeľ Valley. This resource is represented by 25 captured, mostly talus springs with a total long-term average yield of 29.8 Ls^{-1} and with a good groundwater quality. The total number of 285 hydrogeological wells located in the area of Košice city was documented. A decisive part of these boreholes was located in quaternary sediments, the drained collectors of which form fluvial gravels (204 wells). The second most frequent lithological unit with hydrogeological significance is the Neogene sediments in the form of gravels, tuffites and sands (48 boreholes). Then there are proluvial sediments with dominating loamy gravels (26 boreholes). There are far fewer wells in the Mesozoic rocks (dolomites of the middle Triassic period – 4 boreholes) and, exceptionally, in the Gemeric unit rocks (2 boreholes) and crystalline complex (borehole CH-7).

From the point of view of the total amount of boreholes belonging to the wards dominating are Ťahanovce with 45 wells, followed by Barca (42 boreholes) and Staré Mesto (40 boreholes). In Šaca there are 32 wells, 24 wells in Juh, 23 wells in Nad jazerom, in Sever 15 and in Západ there are 14 wells.

The other wards are poor in hydrogeological wells mainly due to their geological position, as well as the demands for groundwater. The number of wells in these areas ranges from 1 to 9. Wards Krásna and Dargovských hrdinov have 9 wells, Džungľa and Poľov 5 wells, Košická Nová Ves and Vyšné Opátske 3 wells and Kavečany and Lorinčík each have one well.

From a hydrogeological point of view, as already mentioned, the quaternary fluvial sediments (gravels, less sands and loamy gravels) of the Hornád fluvial plain dominate in the number of wells but also in the usable quantity of groundwater.

Drills are from 4.2 to 27.0 m deep with an aquifer with a thickness of 0.5 to 14.1 m. The static groundwater level was between 1.2 and 9.0 m below the surface at the time of the drilling. The yields of the wells were recorded from 0.001 Ls^{-1} to 45.0 Ls^{-1}, but most often with a modus Q_m = 10 Ls^{-1}. The total usable quantity of groundwater in quaternary fluvial beds therefore has a value Q_v = 1645.51 Ls^{-1}.

From the qualitative point of view, the groundwater of the fluvial plain sediments of the Hornád river generally meets the conditions for its use for drinking purposes. If there are water resources unsuitable for drinking, it is usually due to biological and microbiological pollution. The exceeiding legislative limits chemical indicators like Fe, Mn, NO_2, NO_3 and NH_4 ions occur only rarely.

In areas with potential sources of pollution (e.g. the railway yard in the city part Juh), organic substances (petroleum products) contaminating the groundwater have also been confirmed. The occurrence of increased amounts of iron and manganese ions is frequent for lithological units of sedimentary Neogen origin.

Dolomites of the Middle Triassic Period were captured by wells situated in the sports and recreation area Anička. Their groundwater is classified as natural mineral water. In the area of the Kavečany and Sever city parts, one well (ČH-7) with groundwater suitable for drinking purposes is situated in dolomites. Another drill (ČH-7) situated in the crystalline (granodiorites) is used by some gardeners in Suchá valley.

Finally, we can conclude that the city of Košice has good prospects in the supply of groundwater in the long term. It is true that the crucial sources of supply of drinking water for the city are located outside the city's territory (potable water system Starin–Košice, potable water reservoir Bukovec, aqueduct Turňa–Drienovec). However, the city is self-sufficient in the case of other demands for individual supply as well as the needs of industrial complexes, for energy use (heat pumps operating in the water-water mode) and other local supply.

Currently, there is an eminent interest by business entities in the use of geothermal water in the city of Košice. Unfortunately, favourable geological and hydrogeological conditions are not equally distributed over the whole territory of the city.

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