ORIGINAL ARTICLE

Surveying the underwater springs of the former Fürdő Island in the Danube by high resolution airborne remote sensing

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ABSTRACT

This Budapest is justly famous for its thermal springs emerging in the zone near the bank of the Danube. However, it is less known that apart from springs on the riverbank, so-called drowned springs also emerge in the bed of the Danube, whose water of considerable volume flow and heat quantity discharges into the river unused. Drowned springs are natural discharges of the Buda Thermal Karst. Their volume flow and temperature are affected by stage changes of the Danube, being in close hydrodynamical relationship with the springs. Our investigations focused on the detection and location of these drowned springs-which emerge in the Danube riverbed and are assumed to have a high volume of flow-by aerial remote sensing.

We have tried to detect the underwater springs near Margaret Island with low altitude aircraft and UAV flights and modern digital thermal imagers. We were looking for a quick and economical method which we can quickly map large areas before we survey the key spots from boats.

Key Words: *Thermal water; Danube; Thermal spring; Remote sensing; Aerial*

The sample area was selected in the northernmost river section in Budapest which belongs to the central discharge area (József Hill, Rózsadomb) of the Buda Thermal Karst, characterised by both hot and lukewarm spring discharge. North of the Margaret Island, in the middle of the Danube, there used to be a shoal called Fürdő Island (Feredő-sziget, Badhaufen), rich in thermal springs (1-3). This shoal, consisting of gravel and sand, accumulated in the Danube riverbed just in a place where the karst aquifer is in an elevated position, nearly at the channel floor due to the combined effect of tectonics and erosion by the Danube (3,4). Thermal water emerged in this environment at the channel floor, ascended through the accumulated material of the former shoal and came to its surface in the form of several hot springs or groups of springs (3). During dredging works at the Fürdő Island, foundations, stones with carved writing and building walls were discovered, some assumed them to be pillar foundations of a Roman "bridge" while others suggested that these were wing walls of a Roman watchtower or port fortress (5). These building remains were initially thought to be ruins of a Roman bath, considering the thermal springs emerging on the island (6) but it is unlikely that they were used as a bath (5). József Szabó geologist mentions in his monograph (1) that poplar and willow trees still grew on the island at the beginning of the 19th century. The destruction of the Fürdő Island started at the end of the 18th and at the beginning of the 19th century with recurring icy floods. The high icy floods of 1811 and 1813 swept away the trees and the topsoil from the island. After losing its surface, the Fürdő Island was only visible at a low stage of the Danube. Its final destruction was caused by dredging in the 1870s during the ill-considered riverbed adjustment of the Danube.

The springs emerging on the Fürdő Island were studied by József Szabó geologist and Antal Kerner in 1854, 1856 and 1857. According to Szabó, the existence of these springs is due to the fact that here the aquifer is in an uplifted position and the overlying formations are also thinner (1). According to the 1856 measurement, the island was 540 m long and 108 m wide, but its size varied depending on the stage of the Danube. Thermal water used to discharge to the surface on the western side of the Fürdő Island in an area of approximately

1850 m^2 in size, in 50-60 hot springs with different flow rates. The water from the springs discharged into the Danube. Their measurements showed that the temperature of the hottest spring was 58.8°C while the coldest one was 23.7°C (1). By digging into the sandy, gravely material of the island, warm water upwelling's were found everywhere. Based on the measurements and observations of the three occasions, the temperature of most springs varied between 34-42°C. The lower was the stage of the Danube, the higher was the temperature of springs. József Szabó (1) explained this by the springs being directly under the effect of the Danube, with a lot of cold water infiltrating into them at high stage, causing their temperature to drop. At low stage of the Danube, less cold water reaches the springs, so their temperature is higher (1).

The Fürdő Island was destroyed by dredging during the riverbed adjustment and regulation of the Danube in the 1870$_s$ (1871-75) in order to ensure navigation paths (2,3,7,8). Those engaged in scientific studies about the island shared the opinion that the barriers to be overcome by the discharging thermal water had been considerably reduced by dredging away the shoal. From then on (and presumably up to present) these waters must have discharged directly in the Danube riverbed as drowned springs (4,3,9). As their point of emergence is deeper, their flow rate is assumed to have increased, too (4,10).

After the destruction of the Fürdő Island, the upwelling of thermal water is proven by a well drilled in the riverbed at the approximate location of the former Fürdő Island under the direction of Gyula Vígh (9) in the winter of 1939 with the aim of studying the formations of the Danube channel floor. When drilling the 8.5 m deep well, hot water gushed from a clay-sand bed with a significant flow rate of approximately 500 l/min and 40°C temperature, with a static level at 9.75 m above the zero level of the Danube (9). The well site was plugged in because the city did not wish to utilise its water. Gyula Vígh also observed extensive, free hot water upwelling between the well and the left bank of the Danube on the channel floor from clayey sand beds (9) which leads to the conclusion that not only concentrated but also diffuse thermal water upwelling occurs in the Danube riverbed.

Springs of the former Fürdő Island drew attention to the area between the Árpád bridge and the Rákos stream with the aim of establishing a bath (the future Szabadság Bath) (11). The concept proved to be right, a 125.94 m deep, successful well was drilled in 1944 (Béke spring, Béke well) which hit the karstic aquifer at 111 m. From nearly 126 m depth, water came to surface with a very significant flow rate of 250 m^3/hour and 41.5°C temperature. Parallel with the water discharge, a pressure drop was experienced in Well 1 of the Margaret Island (in the Zsigmondy well), and the cascade fed by the well dried up (12,13). Subsequent experiments showed that the water of artesian wells on the Margaret Island is connected to the water of the artesian wells of the Szabadság Bath and the Elektromos Sports Complex (14). The Szabadság Bath, fed by the Béke well, was established in 1948 (today it is called Dagály Thermal Bath, Beach and Swimming Pool). It was officially

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declared a medicinal spa in 1973. The temperature of the Béke well, feeding the bath began to decrease from 1969, so the water was led here from the Széchenyi Bath and later the water of the Magda well on Margaret Island was also led here as a supplementation to the Béke well. Today the water of the Dagály Bath is primarily sourced from the Béke well. Waters of the Széchenyi Bath and the Magda well (Margit II) of the Margaret Island are used for heating the water from the Béke well. In summer, water is taken from the utility network for cooling the water of the pools. Pool wastewater is discharged directly to the Danube through the bath's sewerage facility (15).

Zoltán Keszthelyi (16) made an attempt to detect the presumably large number of drowned springs in the area of the former Fürdő Island in winter. However, due to the large volume of warm water discharged from the Szabadság Bath into the Danube, these could not be detected by field observations (16).

István Sárváry carried out temperature logging on two occasions in the place of the former Fürdő Island in order to detect the assumed drowned springs emerging from there and to determine production limits for the Budapest thermal karst. On 24 November 1990, the area was logged moving upstream along 26 longitudinal sections with 10 m spacing at 0.5-0.8 m/s speed, at 7.4-7.6°C water temperature. On 1 December 1990, East-West sections were logged at 4.1-5.5°C water temperature. A continuously increasing trend was found during the measurement without any local anomalies. During the measurements, no temperature difference greater than 0.1°C was found between the adjacent sections or within the individual sections (7). Sárváry (7), based on the fact that springs discharging on the northern side of the Margaret Island dried up during drilling the Margaret Island I well (Zsigmondy well), suggests that the same was the case with the drowned springs emerging in the place of the former Fürdő Island.

Geomega Ltd. carried out high-resolution water seismic surveys on the Danube in 1996 and 2001. In the 1996 survey, the Duna-10/1996 section crossed the area of the former Fürdő Island and managed to detect an Eocene limestone block bordered by faults in uplifted position, above which Oligocene-Miocene strata considerably thinned out, they were identified in less than 4-5 m thickness (4). This confirms the conclusions of Scheuer and Szlabóczky (17) stating that drowned springs emerging in the Danube riverbed are predominantly of horst origin. These springs emerge in the riverbed where carbonate rocks are covered only by the sediment of the Danube or thin, heavily tectonised Tertiary formations, in an elevated position (17). According to Lorberer and Tóth (4), drowned springs emerging in the place of the former Fürdő Island represent the "largest unused thermal water resource of Budapest" and they could be used for production.

In Budapest, it is difficult to obtain permits for the expansion of thermal water wells because the establishment of new wells usually leads to volume flow decrease in existing ones. Therefore, it is of particular interest to know where unused underwater springs emerge in the Danube riverbed. As assumed by Árpád Lorberer, 40°C water discharges into the Danube at the approximate location of the former Fürdő Island (4). Based on the water temperature of the well drilled in the riverbed in 1939 in the location of the former Fürdő Island and the initial water temperature of the Béke well drilled in 1944, it can be assumed that 40°C waters discharge into the Danube unused, in the form of drowned springs.

Therefore, it would be useful to elaborate a method which enables the thermal imaging of large water surfaces in a few seconds so that the entire Budapest section of the Danube can be surveyed frequently, providing geophysicists and hydrogeologists with reliable information who can then focus detailed field examinations on well-delimited areas.

The digital images of modern thermal imagers can be georeferenced easily (18). Our aim was the elaboration of a mapping method that maps temperature anomalies in the uniform national projection system cost-effectively, mapped from a fast-moving, fixed-wing aircraft. The anomalies discovered with this method can be studied further by detailed field measurements. The primary aim of our investigation was to test a method that detects areas where it is reasonable to perform riverbed temperature measurements and detailed water seismic surveys. Methods exist for the live transmission of images, enabling aerial thermal imaging to support field work in real-time with the application of UAVs (19,20).

MATERIALS AND METHODS

The river was mapped with a downward-looking survey camera system installed in a fixed-wing aircraft. The survey camera system involves long-wave thermal imagers with a parallel camera axis, high resolution, high sensitivity RGB camera and a D-GPS-INS system. The survey was carried out at dawn, before sunrise at approximately 0°C surface temperature in the winter period. The survey had to be performed before sunrise so that the reflection of electromagnetic radiation from the Sun only affects the temperature range of the acquired image as little as possible, and thermal imagers can reproduce the temperature properties of the surface. The parameters of the applied thermal imagers are listed in Table 1.

Although thermal imagers generally work reliably in the 0°C to 50°C temperature range, they were used in the surface temperature range of -7°C ± 5°C at dawn at a low stage in order to ensure that drowned springs can be clearly distinguished from their environment. At a high stage, the warmer water of springs dissipates readily in the turbulent water of the river so they can only be detected in a smaller area if warm water reaches the surface at all under these conditions. The resolution of RGB camera heads is 35 and 40 MP and the noise level of their images is still acceptable at a sensitivity of ISO 36 000. This is important because the photos providing detailed image even before sunrise are fitted in the geographical projection with photogrammetric image processing by aerial triangulation with bundle block adjustment, therefore extreme image noise would cause a problem for the measurement of tie points. Tie point is a feature that the photogrammetric software can clearly identify in two or more images and they can be selected as a reference point. The survey is performed in a two-hour period before sunrise, so the light for passive remote sensing data acquisition is provided by the moonlight and starlight. According to our experience, 180 km/h ground speed, ISO 36000 sensitivity and 1/600 sec shutter speed enable us to take orthophotos with high noise levels but similar to daylight images. Ortho-rectified RGB images with an 80% overlap within the lines and a 40% overlap between them help to rectify the geometry of thermal images. Thermal images are handled as channel 4 of the acquisition, therefore the true color and thermal maps are both available. The camera system is installed inside but there is no glass cover in front of the equipment at the bottom of the aircraft. The equipment can also be installed below the tie-down points under the wing; exposure can be set by coordinates or by timing with the intervalometer. The equipment records the location of exposures and the angles of the camera system in the exif data of each image.

The acquisition covers the Budapest section of the Danube with four flight lines in the downstream direction, overlapping in 40% with each other (Figure 1). The overlap does not only enable the compilation of a continuous image mosaic but the thermal images of different angles of view can also be checked with the overlap.

There are two sewage discharge points in the area; these had to be located before starting the surveys. Two canals flow into the Danube near the sample area, their water temperature was checked with a preliminary UAV survey. When processing the thermal images of a few centimeters of field resolution (GSD) taken by drone flights at low altitude (80 m above ground level), we found that the water of the two canals is not significantly warmer than the river, no warm water discharge can be detected.

RESULTS

An aircraft survey flight was carried out on two occasions. The first flight was carried out on 25 February 2016, at 0°C air temperature, at 304 cm stage of the Danube according to the staff gauge at the Vigadó Square, Budapest. The second flight was carried out on 18 February 2019 at 211 cm stage, at 15°C surface air temperature. Flights were performed at 300 m and 400 m relative flight altitude (Figure 2). While temperature conditions were ideal at the time of the first flight, the weather was warmer than planned during the second one.

The orthophotos of the first flight located the drowned springs of the former Fürdő Island and the warm water discharged underwater from the Dagály Bath could also be detected on them as a reference temperature anomaly

TABLE 1

Parameters of the applied thermal imagers

	1st flight	2nd flight	2nd flight
Digital output	14-bit	14-bit	14-bit
Sensor resolution	80 × 60 pixels	160 × 120 pixels	320 × 240 pixels
Pixel size	12 µm	17 µm	38 µm
Spectral range	7.5-13.5 µm	7.5-13.5 µm	7.5-13.5 µm
Thermal sensitivity	0.050°C	± 5°C	± 5°C
Optimum temperature range	-10°C to +80°C	0°C to +50°C	-10°C to 75°C

Figure 1) *Active flight lines are marked with yellow tracks. Imaging can be performed within 15 minute*

Figure 2) *The study area and the Piper PA-32-300 CherokeeSix aircraft, converted for photogrammetry measurements, during the first Danube survey (photo by Kinga Páll-Somogyi)*

(Figure 3). The second flight was not performed at optimal conditions, so it is less suitable to detect temperature anomalies (Figure 4).

CONCLUSION

Increasing the volume flow of nearby wells results in the decrease of temperature and volume flow of drowned springs, while the higher air temperature also renders the detection of underwater hot springs impossible. Therefore the aerial remote sensing surveys of water bodies in search of drowned springs should be carried out when the temperature is lower than 0°C, preferably at low river stage, during the night hours or before sunrise at a time when the nearby thermal water facilities only produce with low volume flow. We recommend applying this method with repeated acquisitions. With this cost-effective method, up to 500 km of river section can be surveyed in one night with 1 km or narrower survey cross-section.

RECOMMENDATIONS

From the hydrogeological aspect, the drowned springs emerging in the Danube riverbed are still unknown discharge components of the Buda Thermal Karst, and an untapped potential regarding their use for energetic purposes. By their volume flow and temperature, drowned springs undoubtedly affect the surface temperature of the Danube, therefore aerial thermal imaging is excellent for their detection and location. The thermal plume of thermal waters emerging in the Danube riverbed is affected by several factors. Among these, the current stage of the Danube at any one time has the most important effect, being in close hydrodynamical relation with the springs. Additional important factors include the temperature and volume of wastewaters discharged in the river from surrounding areas (pool wastewater, communal wastewater), production volumes of wells operated near the measurement area and other factors that can be observed at field visits (vegetation, etc.). As such, adequate knowledge of these factors is indispensable for the analysis of the system. If thermal maps are prepared in order to locate drowned springs, it is very important that their interpretation should be placed in the geological and hydrogeological context.

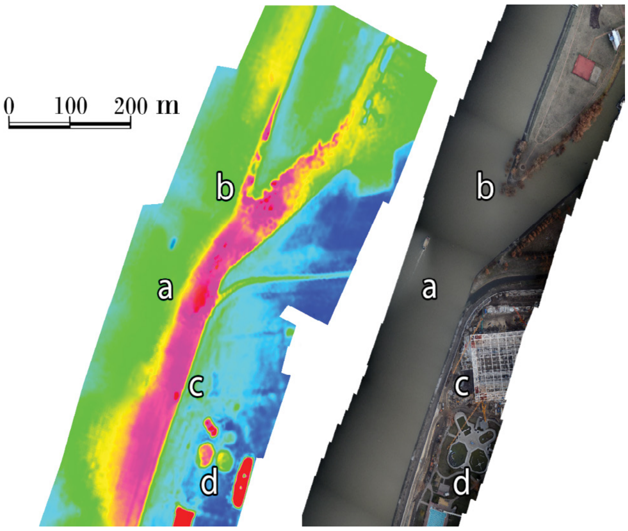

Figure 3) *Hot springs of the former Fürdő Island in the Danube (a): assumed hot springs of the Marina Bay among turbulent currents; (b): discharge of the Dagály Bath; (c): and pools of different temperature in the Dagály Bath; (d): in the thermal map and night RGB orthoimage mosaic taken during the first flight (Bakó-Molnár INTERSPECT)*

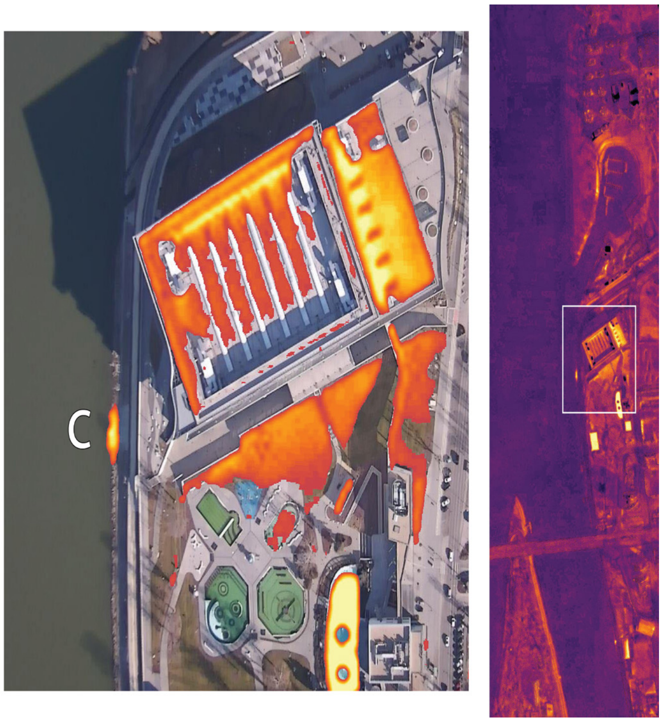

Figure 4) *The thermal map prepared from the acquisition of the second flight performed on 18 February 2019 in warmer weather (15°C air temperature), the thermal image of the hot pools of the Dagály Bath and its underwater discharge (marked as "c") but the temperature anomalies detected by the previous flight did not appear*

Based on the results of our investigations carried out so far, the geological and hydrogeological literature on drowned springs and the current concept for the utilization of the springs, we recommend to perform aerial thermal imaging of the examined section of the Danube at least three times at low stage, low water temperature and low air temperature, completed with field water temperature measurements. Parallel with field measurements, the orientation of the crew of the measurement boat can be facilitated by the thermal camera installed on the UAV because the high resolution of UAV surveys and the capacity to derive quantitative time series support the better recognition of the situation.

The elaborated technology is excellent for the detection and location of natural springs, cooling waters and wastewaters discharged into both lakes and watercourses, contributing to the comprehensive research and planning of their utilisation for energetic purposes.

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REFERENCES

1. Szabó J. Fürdő Island between Pest and Buda (Fürdősziget Pest és Buda között). A Magyar Term Tud Társulat Évkönyvei. 1857:250-6.
2. Salamon F. Land of Buda-Pest (Buda-Pest földje).(Vasárnapi újság 1875). 1875;22:598.
3. Scheuer Gy. The karstic hydrological evolution of the Pilis part of the Buda Thermal Karst on the basis of lime-forming thermal springs in the Quaternary period. (A budai termálkarszt pilisi szakaszának karsztvízföldtani fejlődése a negyedidőszakban a mészképző hévforrások alapján). Hidrológiai Közlöny. 2007;87:45-52.
4. Lorberer ÁF, Tóth T. Utilization of the capital's Fürdő Island and its thermal springs (A fővárosi Fürdő-sziget és hőforrásainak hasznosítása). Hidrológiai közlöny. 2017:59-65.
5. Csiki JA. Was there a permanent Roman bridge on the Danube at Aquincum? (Állt-e állandó római híd a Dunán Aquincumnál? In: Szabó Á (ed)). Ókori Hadtörténeti és Fegyvertörténeti Konferencia tanulmányai, Pécs. 2013:21-32.
6. Németh M. Budapest III district, Hajógyári Island (Budapest III ker, Hajógyársziget). Aquincumi Füzetek 7. 2001:141-2.
7. Sárváry I. Dangerous over consumption of water supply of the Budapest thermal karst (A budapesti termál-karszt vízkészlet veszélyes túlfogyasztása). Hidrológiai Közlöny. 1992;72:222-30.
8. Schweitzer F. Watercourses and karst springs in the surroundings of Aquincum (Aquincum környezetének vízfolyásai és karsztforrásai). In: H. Kérdők. és Schweitzer F. szerk.: Aquincum. Ókori táj- ókori város. Elmélet-Módszer-Gyakorlat 66. MTA Földrajztudományi Kutatóintézet, Budapest. 2010:34-8.
9. Vígh Gy. Exploring new thermal springs in the line of estuary of Rákos stream (Új hőforrások feltárása a Rákos-torok vonalában). Hidrológiai Közlöny. 1941;21:215.
10. Kalecsenszky S. On the temperature conditions of water in the Margaret Island artesian well (A margitszigeti artézi-kút vízének hőmérsékleti viszonyairól). Földtani Közlöny.1908;5:337-45.
11. Vitális Gy. Dr. Szabó József's announcement: The geologie of Buda's thermal springs, The geologie of Buda'bitter-water springs and The Fürdő Island between Pest and Buda was published 150 years ago (150 éve jelent meg dr. Szabó József: A budai meleg források földtani viszonyai, A budai keserűvízforrások földtani viszonyai és a,Fürdősziget Pest és Buda között).. című közleménye Hidrológiai Tájékoztató 2007:9-11.
12. Papp F. Mineral and medicinal water occurrences in Hungary. Mineral and medicinal water occurrences in Hungary. Minerals and medicinal waters of Budapest. (Magyarországi ásvány és gyógyvíz előfordulásai). Budapest ásvány és gyógyvizei. In: Schulhof Ö. Magyarország gyógy és ásványvizei. Akadémiai Kiadó Bp. 1957:142-202.
13. Vitális Gy. The artesian well of Margaret Island is 100 years old (100 éves a margitszigeti artézi kút). Hidrológiai Tájékoztató. 1967:17-9.
14. Cziráky S. Domestic thermal waters (A hazai termális vizek). Hidrológiai Közlöny. 1960.
15. Zsuppán K. The thermal potential of the effluent water of the Budapest thermal baths (A budapesti hévízfürdők kifolyó vizének hőpotenciálja). Hidrológiai Tájékoztató. 2011:45-6
16. Keszthelyi Z. Underwater springs of Danube reach of Budapest (A budapesti Duna-szakasz szökevényforrásai). Hidrológiai tájékoztató. 1975.
17. Scheuer Gy, Szlabóczky P. New underwater thermal springs on the Pest side (Új szökevény hévforrások a pesti oldalon). Hidrológiai Tájékoztató. 1984:23-5.
18. Hartmann W, Tilch S, Eisenbeiss H, et al. Determination of the UAV position by automatic processing of thermal images. Int Arch Photogramm Remote Sens Spatial Inf Sci. 2012:111-6.
19. Pardo JA, Aguilar WG, Toulkeridis T. Wireless communication system for the transmission of thermal images from a UAV, Conference: 2017 CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON). 2017:5.
20. Sluijs J, Kokelj SV, Fraser RH, et al. Permafrost terrain dynamics and infrastructure impacts revealed by UAV photogrammetry and thermal imaging. Remote Sens. 2018,10:1734.