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Estimated soil water storage within a historical bunker during the growth period of vegetation

Łukasz PARDELA[1) ABDEF] ✉, **Tomasz KOWALCZYK**[2) BCDF]

[1)] Wrocław University of Environmental and Life Sciences, Faculty of Environmental Engineering and Geodesy, Institute of Landscape Architecture, ul. Grunwaldzka 53, 50-357 Wrocław, Poland; e-mail: lukasz.pardela@upwr.edu.pl
[2)] orcid.org.0000.0001.6922.1889; Wrocław University of Environmental and Life Sciences, Faculty of Environmental Engineering and Geodesy, Institute of Environmental Protection and Development, Wrocław, Poland; e-mail: tomasz.kowalczyk@upwr.edu.pl

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Abstract

The objective of the study was to estimate the variation of soil water retention on the site of a historical bunker, an element of the former Wrocław Fortress in Poland. Measurements of soil moisture in the study area were taken in the period from March to September, 2017. Measurements of volumetric soil moisture were taken by means of a hand-held gauge, type FOM/mts with an FP/mts probe, operating on the basis of the reflectometric technique TDR. Soil moisture measurements realized in the vegetation period demonstrated that soil moisture resources in profiles situated in the section of the bunker varied within the range of 37–135 mm in the layer of 50 cm, and 66–203 mm in the layer of 100 cm. The maximum differences of the average value of soil moisture of the soil profiles studied in the period covered by the measurements were 31 mm and 56 mm, respectively. This indicates a significant differentiation of the retention properties of soils used for the construction of individual shelter areas.

Key words: *abandoned places, green roofs, post-military landscape, urban green spaces*

INTRODUCTION

Areas occupied by historical fortifications constitute a valuable element of historical urban landscape which combines natural and cultural values [UNESCO 2011]. As a result of urbanisation processes, many of them are now situated within today's towns or cities. This is also the case with the historical infantry bunker No. 20 of Festung Breslau (the fortress of Wrocław). Despite its peripheral location, the structure constitutes a valuable source of information about the engineering solutions used in the early 20th c. It was designed and built under the direction of military engineers, who adapted its form to the local landscape and water and soil conditions. ROLF [2017] reports that in the end of the eighties and nineties of the 19th c. about 500 so-called midfield bunkers were built in the German Empire, including 162 infantry bunkers (I.R.) and the associated earth structures. In Poland such objects still exist in the areas of historical fortresses, e.g. in Grudziądz, Poznań and Toruń. In Poznań alone, in the years 1887–1904 27 infantry bunkers were built, 17 of which remain preserved with their earth covering [BIESIADKA *et al*. 2006]. In Wrocław those bunkers were situated on the circumference of the ring of fortifications around the city. At present there remain at least 9 well preserved infantry bunkers from the various stages of development of those objects (1889–1899). They are accompanied by extensive integral earthworks forms that also constituted defensive structures. So far not much attention has been given to soil conditions and relative water levels in areas of historical fortifications. A similar tendency, consisting in neglecting fundamental research, with the exception of selected urban green areas, e.g. Południowy and Szczytnicki Parks in Wrocław [ORZEPOWSKI *et al*. 2015; 2017], appears to dominate in the available literature related broadly to environmental engineering. For years, the Festung Breslau fortifications (1890–1938) have been an object of study for researchers into selected issues, e.g. earthworks [PARDELA 2015], constructions and building fittings and fixtures [PARDELA, KOLOUSZEK 2017].

The aim of those interdisciplinary studies was to perform an estimation of variations in soil water retention, taking into account varied soil conditions, on the basis of soil moisture measurements in the area of the historical infantry bunker No. 20 in Wrocław (Fig. 1), and to indicate the directions in the management of the earthworks in relation to their historical construction and functions. Those functions comprised the combat and the peacetime functioning of the object; stabilisation of the escarpments and embankments, stabilisation and preservation of designed slopes and earthwork profiles, and drainage of the terrain [BayHStA 1889; WAGNER 1881]. In combination with vegetation, they not only provided camouflage, but also protection against the wind and the sun (reduction of soil erosion and drying) [APT 1905]. The study presented in this paper is convergent with the main research trends allowing a better interdisciplinary understanding of the functioning and use of green urban areas under unfavourable environmental conditions [HAALAND, VAN DEN BOSCH 2015; JAMES *et al*. 2009; KOWALCZYK *et al.* 2010; 2015]. The conducted research provides also new information on the construction and functioning of the historical green roof of the extensive type with the simplest structure possible*,* and practical information on the suitability of the terrain for the preservation of biodiversity (vegetation, various soil morphology and land relief) in the urban environment. It will also allow an estimation of the suitability of objects of this type in the structure of urban green areas which are of high importance in the strategies of adaptation of urbanised areas to climate change.

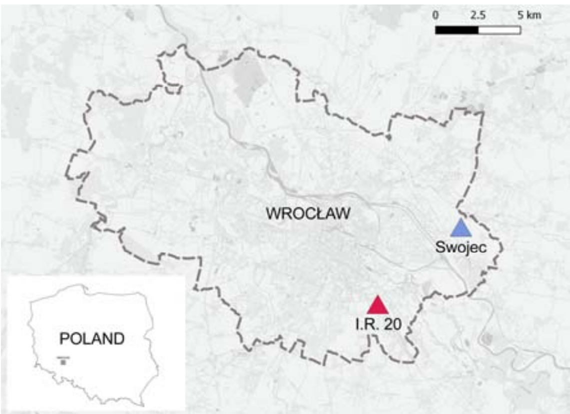

Fig. 1. Location of the study area and the meteorological station at Swojec; source: own elaboration KOWALCZYK

CHARACTERISTIC OF THE RESEARCH OBJECT

The research was conducted in the historical infantry bunker No. 20 (N 51°4'26.654", E 17 4'23.994", Wiaduktowa Street) (Fig. 1), which is part of the ring fortifications of Festung Breslau (Wrocław Fortress). The main criterion for the selection of the facility for study was the original state of preservation of the earthworks, which we established on the basis of archival research (2012–2016) and site visits (2005–2016). In our work we made use of the inventory plan drawn up for the Military Inter-Allied Commission of Control in 1920, currently in the collection of the League of Nations Archives in Geneva [UNA/LN 1920]. Because the object of study is not a commonly known type of structure, we have decided to present it here in as much detail as possible. In our opinion, this is a *sine qua non* requirement for proper understanding of the nature of the site and the nature of the research.

The bombproof bunker was built in the years 1899–1900 at the embankment of a freight bypass railway, near intersecting railway lines. It was designed to defend the nearby viaduct and the approach to the bypass from the south. The facility was erected on a small hill in the east part of the fenced fortress plot with an area of 0.72 ha. The area was considerably transformed, the surface horizon of the soil was removed, together with the original vegetation. The ground-water conditions were disturbed due to the deep digging. The plot is the location of a bombproof bunker and its surrounding earthen embankment (Photo 1, Fig. 2). The bombproof bunker probably has drainage around the external walls, and drainage at the base of the escarpment facing the facade, in an undetermined state of preservation. Currently, it stands empty and the area is open to the public. The bombproof bunker has an earth overlay in


Photo 1. Infantry bunker No. 20 in March (left) and September (right) (phot. *Ł. Pardela*)

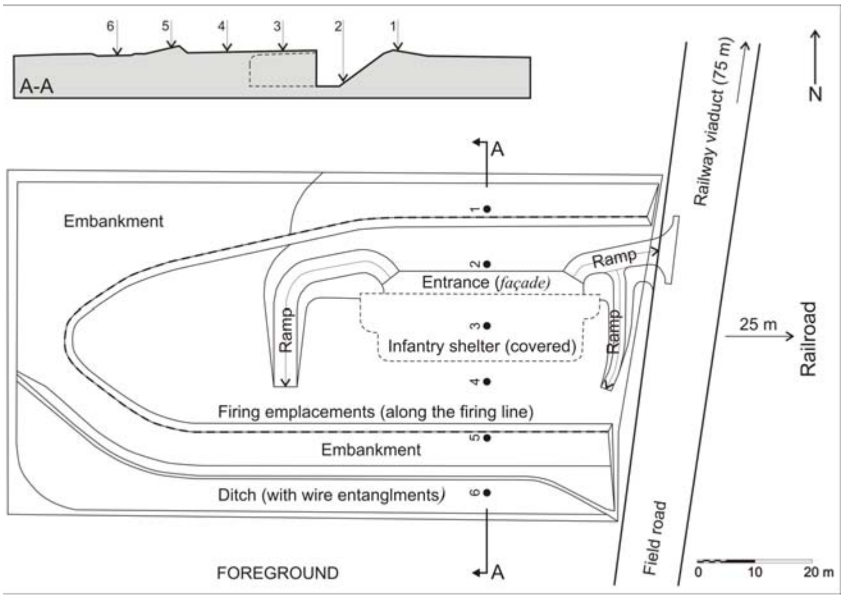

Fig. 2. The location and distance between profiles 1–6 within infantry bunker No. 20; source: own elaboration Pardela based on UNA/LN [1920]

the form of a green roof, on which no trees or bushes were allowed to be planted. Thanks to a preserved technical regulation [BayHStA 1889], we know its historical thickness. It amounted to 50 cm and was dictated by the need to limit the harmful impact of shrapnel of artillery munitions. The earthen embankment that was part of infantry bunker No. 20 had a low profile. The embankment performed several important functions. Firstly, it prevented the interior from being observed from the foreground and from direct fire. Secondly, it was adapted for the use of weapons. The post-fortification plot of infantry bunker No. 20 has relics of its designed plant camouflage arrangement. Its core is made up by old-growth black locust (*Robinia pseudoacacia* L.) and small-leaved lime (*Tilia cordata* Mill.). Black locust trees also grow along the plot edge and on the crowns of the earthen embankments near the historical firing line. The remaining vegetation is a result of succession, in which plants colonised the plot spontaneously and received no management for decades. Among those plants, in relation to the occurrence of black locust, many are nitrophilous species. In the story of bushes those are *Crataegus monogyna* Jacq., *Syringa vulgaris* L., *Symphoricarpos albus* L., *Lonicera xylosteum* L. and *Rubus caesius* L. with climbing plants such as *Humulus lupulus L.* The plot understory is covered with common plants like: *Chelidonium majus* L., *Veronica arvensis* L., *Ficaria verna* Huds., *Lamium purpureum* L., *Alliaria petiolata* M. Bieb, *Galium aparine* L., and *Urtica dioica* L. The green roof layer of the bunker is dominated by shallow rotting grasses. The post-fortification plot of infantry bunker No. 20 is currently an attractive vegetated environment increasing biodiversity and offering nesting for protected birds and shelter for other animals.

METHODS

The structure and physical properties of soil profiles were analysed on the basis of sensory evaluation of samples acquired by means of a hand-held auger in more than a dozen drillings. Analysis of soil moisture distribution within the studied object was conducted on the basis of measurements taken at six selected topographic profiles, characteristic of the location and soil conditions, plotted along the crosswise section of the fortification (Fig. 2). Soil sampling and measurements were made using a hand-held auger, on the breastwork banks in the neck and front parts, at their base, on the flat roof of the bunker, the earth overlay, and in the yard. At the points of soil moisture checks appraisal wells were drilled to the depth of about 1.5 m, and on the basis of sensory identification of the collected samples the soil profiles were characterised. The basic physical and water properties of the soils were adopted on the basis of literature data [WALCZAK *et al*. 2002]. The moisture of the soils was measured with a direct method, using a hand-held gauge for volumetric soil moisture measurement, operating on the basis of the TDR technique, type FOM/mts with an FP/mts probe, designed and manufactured at the Institute of Agrophysics PAS in Lublin. The TDR (time domain reflectometry) probe was placed in vertical holes drilled with an auger. Measurements were made in selected characteristic layers of soil (measurement in 2–4 layers at 1.0 m from the wells), corresponding to the previously determined characteristics of the soil profiles. Soil moisture measurements in the test object were conducted systematically, on average once a month in the period from March to September, 2017. The meteorological conditions during the period of the soil moisture measurements were characterised on the basis of data from the meteorological station at Swojec (N 51°4’25.9”, E 17°4’22.8”, Bartnicza Street) (Fig. 1).

RESULTS

In the area under study, the surface layer of the soil is formed mainly, acc. to the PTG (Pol. Polskie Towarzystwo Gleboznawcze – Soil Science Society of Poland) classification [2008], of sands and loamy sands and of sandy loam (the vegetation layer of the flat roof). They most often overlay sand, and in profiles 5 and 6 there are also loamy sands. In general, it can be concluded that they are soils with a poor or moderate retention capacity, and the characteristic states of moisture in the soils can be estimated as follows: field water capacity (FWC at pF ~ 2.0) = 15–25%, drought period capacity (DPC at pF ~ 2.9) = 5–15% (the field water capacity increases proportionally to an increase in the content of clay particles in sand). Due to the particle size distribution of the soils, the largest amounts of water can potentially be retained in profiles 2 and 6, and also in profile 3, though the last one, due to its small thickness, is at the same time liable to excessive drying in case of long-lasting deficits of atmospheric precipitation.

Table 1. Monthly, periodic and annual precipitation totals *P* (mm) in the hydrological year 2017 on the background of multi-year period according to the meteorological station at Wrocław-Swojec

Years	*P* (mm)															
	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI–X	XI–IV	V–X	IV–IX
2017	44	37	14	26	34	64	40	65	143	64	66	71	668	219	449	442
2001–2010	45	35	36	33	32	35	63	61	85	77	45	40	587	216	371	366
1961–2000	42	34	27	24	31	38	60	71	84	71	46	38	567	197	370	370

Source: own elaboration based on the meteorological station at Wrocław-Swojec.

Table 2. Mean monthly, periodic and annual air temperature *T* (°C) in the hydrological year 2017 on the background of multi-year period according to the meteorological station at Wrocław-Swojec.

Years	*T* (°C)															
	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI–X	XI–IV	V–X	IV–IX
2017	3.7	1.6	–3.2	1.2	6.9	8.0	14.6	19.1	19.6	19.9	13.5	11.1	9.7	3.0	16.3	15.8
2001–2010	5.2	1.0	–0.7	0.8	3.9	9.6	14.7	17.7	20.1	19.1	13.9	9.1	9.5	3.3	15.8	15.9
1961–2000	3.9	0.2	–1.3	-0.1	3.5	8.4	13.5	16.7	18.2	17.7	13.7	9.0	8.6	2.4	14.8	14.7

Source: own elaboration based on the station Wrocław-Swojec.

Analysing the amounts and distribution of atmospheric precipitation (Tab. 1), it can be concluded that the hydrological year 2017 was wet, with a precipitation total of 668 mm (standard precipitation – 567 mm). In the summer half-year (May–October) and in the vegetation period (April–September), precipitations amounted to 449 mm and 442 mm, respectively, and were higher than the norm by more than 70 mm. Precipitation distribution was non-uniform – the highest rainfalls were noted in July (143 mm, multi-year mean: 84 mm), while in May the total rainfall amounted to 40 mm (67% of the standard).

It was also a warm year (Tab. 2) – the mean air temperature amounted to 9.7°C and it was higher than the multi-year average by 1.1°C, and in the summer half-year (16.3°C) the difference was as much as 1.5°C. This contributed to intensive vegetation of plants, and the high evapotranspiration related with that process was, over the entire vegetation period, balanced by atmospheric precipitation.

In April and May, water reserves in the layers of 50 cm and 100 cm were close to or slightly below FWC, with an easily noticeable variation in the moisture reserves between the profiles dominated by light or medium compact soils, where the reserves in spring amounted to an average of 45 mm in the layer of 50 cm and 61 mm in the layer of 100 cm. Throughout the vegetation period, those differences were, on average, 31 mm and 56 mm. Over the growth period of vegetation a gradual decrease in water reserves in the soil was observed. However, it did not pose any problem to the plants, due to the high atmospheric precipitation totals recorded in June and July, thanks to which soil moisture did not drop below DPC.

Within the section of the analysed bunker No. 20, one can note significant variation in the water retention capacity in individual soil profiles (Fig. 3). This is determined primarily by the content of clay particles in the soil, while the location of the profiles within the section of the study object appears to have a notably lesser effect on the amount of retained water. Based on the measurements, it was concluded that the largest amounts of water can be retained in profiles 2, 3 (in the surface horizon) and 6. The lowest reserves of water are retained in profiles 1 and 5, which are formed of sands. Profile No. 2, situated at the foot of the escarpment, probably owes its good retention capacity to the natural development of the humus horizon that slid down the steep slope of the escarpment, forming at its foot a fertile layer with a thickness of about 50 cm. Of some importance is also the relief of the area, which causes an enhanced supply by water runoff down the slope of the escarpment to its foot. Relatively much water was available in the shallow profile No. 3, formed of light loam, situated on the roof of the bunker. The decisive effect was that of the amount and distribution of atmospheric precipitation with a simultaneous lack of infiltration into the deeper layers and only a moderate surface runoff from surfaces with small slope angles. Observations of water resources in such conditions as the covering of the flat roof of the bunker in profile 3 can be related directly to green

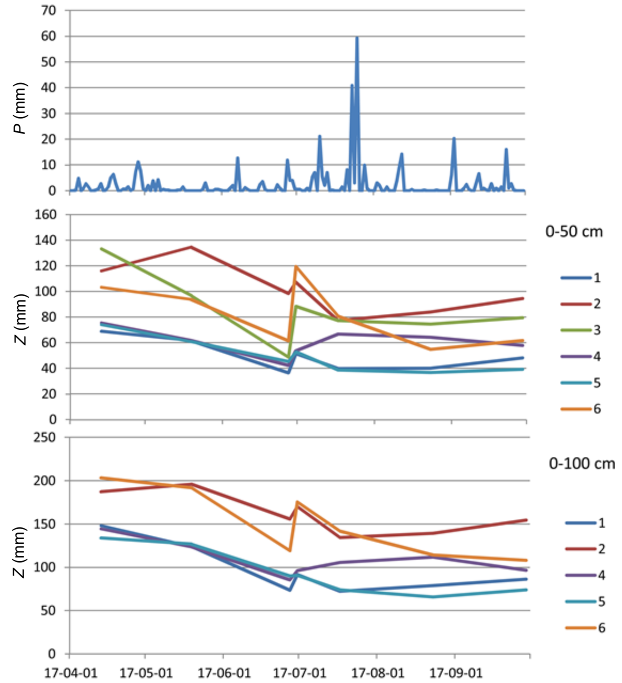

Fig. 3. Changes in moisture reserves Z (mm) in soil profiles of 0–50 cm and 0–100 cm in the period April–September 2017 on the basis of daily atmospheric precipitation; *1–6* = profiles; last measured 29 September 2017; source: own study

roofs of the extensive type with the simplest structure possible that are increasingly used in a number of applications.

It should be emphasised that both the soil moisture measurements and the observations conducted on the object directly in the course of and after atmospheric precipitations did not reveal any excessive accumulation of water both on the surface of the object and in the soil profile. This is proof of the use of engineering solutions, including the application of soil layers with suitable features and structure, that ensure effective drainage of excess water from the object.

DISCUSSION

Measurements taken at points along a selected section by means of a method commonly used in hydrology provided valuable information on the functionally diverse earth structures of the historical fortification. Artificially formed soil profiles, or rather the structure of the bunker and the site as a whole, in spite of the varied surface configuration, have proved insensitive to periodic excessive amounts of water after torrential rainfalls. It was expected that results would be obtained indicating susceptibility of certain profiles to drying (mainly those elevated in the form of embankments, cover layers on roofs etc.), especially as they are usually formed of sands without any particularly good water retention properties. The run of the hydrometeorological conditions during the period covered by the monitoring did not allow for an estimation of a drought threat, which is a major problem that occurs periodically in the green areas of Wrocław [ORZEPOWSKI *et al*. 2017]. Research conducted in parks and woods within Wrocław has shown that the areas are sensitive to disturbances of water relations, and periodic excessive levels of water may lead to serious damage to the tree stand [KOWALCZYK *et al*. 2012; SZAJDA *et al*. 2008].

The monitoring of soil moisture conducted in the area of the arboretum of Wrocław University of Environmental and Life Sciences, situated in Pawłowice near Wrocław, demonstrated that water interception by diversified vegetation significantly modifies the level of soil water reserves [KOWALCZYK *et al*. 2010]. In the object under analysis, the effect of a plant cover on the variation of supply by precipitation and on water management in soils is also significant. The first priority as regards the bunker was to select proper vegetation to mask the structure, which – as in the case of sand-stabilising *Robinia pseudoacacia* L. – would tolerate well soils that were periodically dried up, light, well aerated and elevated. Next, the vegetation grew spontaneously, without care or cultivation. The flat roof of the bunker, on which lots of water accumulates in the shallow profile, is now covered with turf. With the absence of care, bushes started to grow along its edges. Research conducted in Wrocław on an extensive green roof with a structure and retention parameters similar to those of profile 3 indicates that it can be sensitive to variation in water reserves, and especially during dry periods requires supplementary water supply through irrigation [SZAJDA *et al*. 2008].

The preserved historical earthworks provide plenty of information, not only regarding their former functions, but also the possible development for future use. However, it should be borne in mind that the very disturbance of the over-century-old soil structure and texture might adversely affect the entire site. In particular, this applies to changes to the grassy surfaces and so to the surface runoff conditions. We know that originally the hard-surfaced areas (with cobblestones or chipped field stone) were only made where needed. They were used for internal communication and were located in the forecourts. This was not only dictated by practical considerations, but also military ones – the intent was not to exacerbate the effects of a possible artillery shelling. While the other threat was done away with by the very flow of time, the first one – an undesirable 'sealing' of the surface – as an adverse effect of revitalisation, is still possible. The issue of appropriate regulation of water conditions within historical fortifications remains topical, because of the increasingly numerous adaptations of such sites to be used for modern functions.

CONCLUSIONS

Soil moisture measurements realized in the vegetation period of 2017 demonstrated that soil moisture resources in profiles situated in the section of the bunker varied within the range of 37–135 mm in the layer of 50 cm, and 66–203 mm in the layer of 100 cm. Significant differences were noted, related with the retention properties of soils used in the construction of the particular zones of the bunker. Over the entire vegetation period they amounted to, on average, 31 and 56 mm. The largest amounts of water in the surface horizon can be retained in two profiles (No. 2 and No. 6) of the escarpment and the ditch (supply with runoff from the upper parts of the escarpment), and profile No. 3 at the green roof. The lowest reserves of water are retained in profiles No. 1 and No. 5 at the embankments along the historical firing line. It was in those places that black locust trees, heliophilous plants with low soil requirements, were planted, that additionally stabilise the embankments. The defensive earthworks of the bunker retained its distinct profile in spite of the passage of time. In the case of potential development of the area, the shallow profile of the green roof will require periodical irrigations.

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Łukasz PARDELA, Tomasz KOWALCZYK

Ocena zmienności zasobów retencji glebowej zabytkowego schronu w okresie wegetacyjnym

STRESZCZENIE

Przedmiotem badań była ocena zmienności zasobów retencji glebowej na terenie zabytkowego schronu wchodzącego w skład fortyfikacji zabytkowej Twierdzy Wrocław w Polsce. Pomiary uwilgotnienia gleb na obiekcie mierzono systematycznie metodą bezpośrednią, średnio raz w miesiącu od marca do września 2017 r. i okresowo z większą częstością. Zastosowano ręczny miernik do pomiaru wilgotności objętościowej gleby, działający z wykorzystaniem techniki reflektometrycznej TDR FOM/mts z sondą FP/mts. Pomiary uwilgotnienia wykonane w okresie wegetacyjnym wykazały, że zapasy wilgoci glebowej w profilach zlokalizowanych w przekroju schronu kształtowały się w zakresie 37–135 mm w warstwie 0–50 cm oraz 66–203 mm w warstwie 0–100 cm. Maksymalne różnice średnich wartości zapasów wilgoci badanych profili glebowych w okresie objętym pomiarami wyniosły odpowiednio 31 mm i 56 mm. Świadczy to o istotnym zróżnicowaniu właściwości retencyjnych gleb wykorzystanych do konstrukcji poszczególnych stref schronu.

Słowa kluczowe: *krajobraz powojskowy, tereny opuszczone, tereny zieleni w mieście, zielone dachy*