JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535
Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2021.139016
2021, No. 51 (X–XII): 62–71

Hydrographic changes in the area of the Terespol Fortification caused by the construction and operation of the Brest Fortress

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RECEIVED 15.12.2020 REVIEWED 17.02.2021 ACCEPTED 24.05.2021

Abstract: The paper concerns the transformation of water resources induced by the construction and functioning of the Brest Fortress defence structure and presents the current water resources resulting from these changes. The study was conducted by analysing historical materials: maps, plans and written documents. Hydrographic changes were analysed for five study periods covering almost 200 years, from 1823, presenting the hydrographic network before the construction of fortifications, up to 2018, when most of these structures ceased or were repurposed. Hydrographic changes were analysed in detail for the area of the Terespol Fortification. The analysis revealed that almost 80% of the wetland area had disappeared after intensive drainage works, and several dozen originally small and isolated areas had been incorporated into a vast drainage network. One of the consequences of these activities was the creation of significantly transformed artificial catchments within the study area.

Keywords: Brest Fortress, drainage works, human impact, hydrographic changes, Terespol Fortification

INTRODUCTION

Water is one of the most important elements of the ecosystem, on which people are directly dependent, but also a component that can be utilized by humans in many ways. Water bodies also served an important defensive function, and for this purpose rivers, lakes and extensive wetlands were used [BOGDANOWSKI 2000; CZAMARA *et al.* 2014; JUNYENT *et al.* 2012; KUPIEC 2007; KUPIEC, OLEJNICZAK 2020; SŁODCZYK 2014]. Initially, in ancient times, the defensive role was mainly played by fortified towns i.e. Lower Rhine Limes, Upper Moesian Limes or Tell El-Retaba in Egypt [HUDEC *et al.* 2015; JĘCZMIENOWSKI 2013]. Later, in the Middle Ages, the defensive role was taken over by castles, monasteries and strongholds i.e. Pizzighetton (Italy), Eure-et-Loir (France), Basel (Switzerland), Koblenz (Germany) (i.e. BORDERIE *et al.* [2021]). Until the 18th century, water bodies effectively protected important defensive structures i.e. Old Dutch Waterline or Fortifications of Várad. With advances in military technology (mainly the range of artillery) water defences of the previous fortresses lost their significance. For this reason, fortresses built in the 19th century became large-scale defensive structures. They usually had a central structure, i.e. citadel, and forts which formed one or more defensive rings on its foregrounds. Among different types of military objects the greatest area transformations of the natural environment (especially changes in the water resources) were caused by the construction of large-scale fortifications. These military objects, in contrast to the earlier point defence fortresses – castles and strongholds – formed multi-kilometre fortress rings protecting the center of the fortress or town from artillery fire. An example of reconstruction of a point fortress into a fortified area is the fortress Kostrzyn nad Odrą (in German: Festung Küstrin) [ECKERT 2003]. At the end of the 19th century the largest fortress in the Russian Empire was Warsaw. The circumference of the fortress ring surrounding the city was 56 km [KRÓLIKOWSKI 2002]. Other ring fortresses were characterized by smaller size e.g. Poznań, Kraków, Przemyśl, Gdańsk, Toruń or Tczew [BUDNIK 2020; JANCZYKOWSKI 2015; KULCZYKOWSKI, KUBUS 2015; WILKANIEC, URBAŃSKI 2010].

In the first half of the 20th century fortified areas were developed not only in the area of present-day Poland (i.e. BOCHENEK [2003], MAKAR [2010]), but also in various regions of Europe (i.e. KAUFMANN and JURGA [2013], MATEUS [2006]).

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Between 1934 and 1944, the 80 km Międzyrzecki Rejon Umocniony called Fortified Front Oder–Warthe–Bogen was established in Germany, the establishment of which required a lot of hydrotechnical works affecting water resources and construction of water obstacles [HUDAK, KOŁODZIEJCZYK 2017]. In Upper Silesia, in turn, the Fortified Area of Silesia [STANKIEWICZ 2014] and the Neisse Line as an extension of the Oder Line fortifications were established between 1933 and 1939. Wrocław (Festung Breslau), a fortress city whose military protection had long been provided by river waters, is instead an example of the use of defensive flooding in the early 20th century. For this purpose, between 1913 and 1915, 14 fortress weirs were built on the Oder's tributaries, the Widawa and the Ślęza [KOLOUSZEK, PARDELA 2013; PARDELA 2013; PARDELA *et al.* 2012]. A similar type of defence by submerging land was used in the Netherlands on the Old and New Dutch Waterlines [VERSCHUURE-STUIP 2020].

Historically, in the 19th century, in the area of Poland incorporated after partitions to the Russian Empire, began the construction of several fortresses – structures whose main purpose was to provide local defence against the enemy. One of the largest projects of this type aimed at the modernization and construction of the fortresses in the Vistula Fortified Region carried out by the Russian authorities on land under Russian annexation. Construction works were intensified after the suppression of the November Uprising due to the need to protect the western border of the Russian Empire. The key structures of the planned fortified region were three large fortresses by the Vistula River: Warsaw (1883–1890), Modlin (1878–1880) and Dęblin (1878). After securing the frontline the flanks were fortified. The most important was the northern flank, in a vulnerable position with respect to the fortified region in East Prussia. The left wing of this line was protected by the Modlin fortress and a small barrage fortress, Zegrze (from 1893), and the right wing was protected by Osowiec (1882). The southern flank protected Dęblin, and Brest, located further to the east (after 1885) [GŁUSZEK 2015; JASTRZĘBSKI 1932; PRUSKI, SADOWSKI 2000].

The construction of such extensive fortifications had an unquestionable impact on changes in individual elements of the natural environment, including, in particular, the transformation in the hydrosphere. The major hydraulic investments related to the construction of fortresses included, among others, the construction of dense drainage networks and drainage of wetlands, the creation of artificial reservoirs (e.g. moats surrounding fortresses) and regulation of riverbeds. Transformations in individual elements of the hydrosphere caused often irreversible changes in water resources, including the disappearance of large wetland areas [POTYRAŁA, IWANCEWICZ 2018; WILKANIEC, URBAŃSKI 2011].

The aim of the study was the identification of water resources transformations induced by the construction of Brest Fortress large-scale fortification system since 1823 to present. The analyses were i.a. focused on changes of drainage pattern and density, fluvial lakes area, moats and wetlands.

MATERIAL AND METHODS

The fortified area of the Brest Fortress covers 211.6 km^2 and is intersected by the Bug River. Currently, its western part (called the Terespol Fortification), located on the left bank of the Bug River, is within the borders of Poland, and the eastern part belongs to Belarus. The analysed area is located in the Brest Polesye mesoregion, which belongs to the West Polesye macroregion (Eastern Europe) [MARKS, POCHOCKA-SZWARC 2016].

The contemporary hydrographic network of the study area belongs to the Bug River basin. The Bug, which is the eastern border of the study area, is an unregulated river. Its highest flows are recorded in the period of spring thaws. In Włodawa gauge station it reaches maximally 769 m^3·s^{-1}. Minimum flows recorded at this gauging station amounted to only 8 m^3·s^{-1}. The amplitude of water level changes in the studied river section exceeds 400 cm, and the irregularity of flows (Q_{max}/Q_{min}) in Włodawa reached the value of 96 [KOVALCHUK *et al.* 2002]. At this point it should be emphasized that the gauge station in Włodawa is located above the region of Brześć and Terespol, so for the studied area the flow of the Bug River should be increased by the average flow of its right tributary – the Muchawiec River. The average flow of this river is 25 m^3·s^{-1} and the amplitude of water level changes reaches 410 cm. The northern part of the Terespol Fortification is drained by the Krzna River with an average flow of 11 m^3·s^{-1} at Malowa Góra and an irregular flow of 182. The western part of the study area is drained by the left Krzna River tributary – the Czapelka, whereas the eastern part is drained by the Bug River tributaries: the Kosomina River and the Dopływ spod Kolonii Dobratycze. The amplitude of water levels on the Bug tributaries reaches 200–300 cm. Large changes of water levels of the main river and its tributaries cause formation and transformation of other hydrographic features in the Bug valley, such as fluvial lakes.

Detailed analysis related to hydrographic changes caused by the construction and operation of the Brest Fortress was performed for the area of the Terespol Fortification (Pol. Przedmoście Terespolskie, Rus. Terespolskoye Ukrepleniye), covering approximately 80 km^2. This choice was made because of the availability of detailed cartographic materials and archival documents. The strategic position of the Terespol Fortification, covering approximately 40% of the whole defensive system, was associated with the protection of the road and the bridge on the Bug River to the east, towards the Brest Fortress [WAP 2000].

The first written record of a local fortified stronghold comes from 1019, but its exact location is unclear. It was probably situated on the largest of several islands formed by the waters of the Bug and Muchawiec Rivers – at their confluence or on the promontory of the right bank of the Bug River, at the left arm of the Muchawiec River [PYVOVARCHYK 2006].

Over the last centuries the beds of both rivers have changed significantly, as evidenced by numerous oxbow and fluvial lakes. From the north, access to the stronghold was also protected by the valleys of tributaries of the Bug River: Dolna Krzna on the left side, with its north-west tributary Czapelka, and Leśna in the north-east, the right tributary of the Bug River. The boggy valleys of these rivers provided good protection for the stronghold from the west and north. From the south, this area was protected by the Muchawiec River and its boggy valley [VOLCHEK *et al.* 2005; VOLCHEK, KALININ 2002].

After the Third Partition of Poland in 1795 by the Russian Empire, Prussia and the Austro-Hungarian Empire, the studied area was in the border zone of the partitioning empires [BIESZANOW 2012]. The border location of Brest strengthened its defensive functions. In those days, the military requirements not

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only forced the design and diversity of fortification structures, but for many years influenced local transformations in the natural environment and economy. One example of these significant operations was the relocation of Brest, Terespol, and villages, the establishment of new settlements, and the construction of embankments for roads and railways in wetland areas [Mandalski 1929; Pomykała 2019].

In 1836 the construction of the Citadel was initiated on the site of the old town of Brest, on the Central Island located at the confluence of the Bug and Muchawiec Rivers (Fig. 1). New buildings in Brest were constructed approximately 2 km east of the fortress walls [Charichkowa 2000; Pyvovarchyk 2006]. After 7 years work was completed, and after that the construction of the outer fortification began, including three sections, i.e. the Kobryn Fortification (in the north-east), the Volhyn Fortification (in the south-east) and the Terespol Fortification (in the west), located on the left bank of the Bug River. In 1878–1888 the rebuilding of the Brest Fortress began to transform it into a frontline fortress. The first fortress ring was built with a circumference of 30 km, consisting of 10 brick and earth forts located at a 2.5–5.0 km distance from the Citadel (Fig. 1). The construction of forts, which were numbered from I to X, continued until 1888. One exception was Fort X, which was completed much later, in the early 20th century. Forts IV–X were surrounded with wet moats. Forts I–III were surrounded with dry moats. From the first ring of forts, two are now located in Poland: Fort VI (Terespol/Lebiedziew) and Fort VII (Łobaczew). These forts are in a very good technical condition. Other forts are now located in Belarus, and most of them are poorly preserved. Only two forts have survived in a very good state: Fort V, housing a branch of the Brest Fortress Museum, and Fort VIII [Charichkowa 2000].

Forts of the 2nd ring located at approximately 7 km distance from the central point of the Brest Fortress and 2.5–3.0 km from the first ring of forts were constructed between 1913 and 1915.

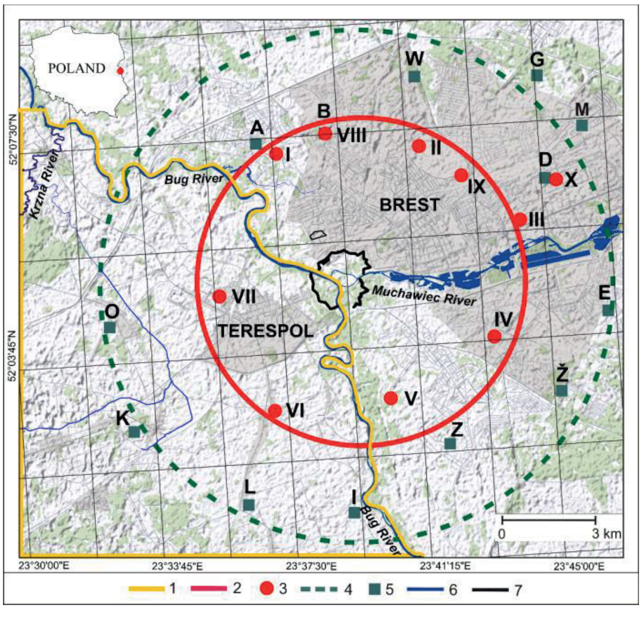

Fig. 1. Major fortifications of Brest Fortress; 1 = area of Terespol Fortification, 2 = 1st ring of forts, 3 = forts of the 1st ring, 4 = 2nd ring of forts, 5 = forts of the 2nd ring, 6 = major surface water bodies, 7 = Brest Fortress; source: own elaboration

The new ring of forts and other fortification structures including the network of roads was to create the major line of defence. The new forts, 12 in total, were marked with letters: A, D, E, G, I, K, L, M, O, W, Z, Ž. The main defensive site also incorporated old modernized forts VIII (was now marked B) and X (now D). From the second ring of old forts only four are now in Poland and form the Terespol Fortification (Przedmoście Terespolskie): I – Żuki, K – Kobylany, L – Lebiedziew, O – Koroszczyn. All of them, apart from Fort I, have been very well preserved. Other forts are now in Belarus, and most of them are in a poor state (Fort Ž) or no longer exist (Fort W, G, D and E). Only Forts A and Z are well preserved [Charichkowa 2000; Michalska, Michalski 2000; Zieniuk 2016].

In the last stage of work to develop military fortifications the outermost defensive belt was built. It included field fortifications: semi-permanent infantry forts, systems of trenches, barbed wire barriers and minefields. The construction of these fortifications was considered that did not cause significant hydrographic changes.

The study relied on the analysis of information acquired from historical materials: maps, plans, and written records [Chiang *et al.* 2020; Gupta, Rajani 2020; Skaloš *et al.* 2011]. Cartographic resources included maps and plans published between the first half of the 19th century and the present day. The whole study area is illustrated with greatest precision on maps prepared in scales of 1:10 000 to 1:25 000. The most valuable of them are maps showing the area around Brest and Terespol before the construction of fortifications (Plan de la ville de Brześć… of 1823, scale 1:16 800, and maps 1:25 000 with subsequent stages of Fortress development: Festungsumgebungs-plan von Brest–Litowsk 1910 [Twierdza.org undated], Rejon Brześć nad Bugiem 1925, and Mapa Topograficzna Polski 1960).

In order to determine the inaccuracy of matching old maps to the reference material, 25 to 64 stable ground control points were selected, whose location did not change during the analysed historical period [Affek 2012; Dai Prà, Mastronunzio 2014; Guerra 2000]. Due to the high hydrological dynamics of the Bug and Muchawiec Rivers, and consequently very frequent transformations of the shape of riverbeds and topographical objects, ground control points (GCP) were selected in non-valley zones. Mainly road junctions [Jaskulski *et al.* 2013] that were located throughout the study area were used as reference points. Historical maps were selected so that their scales were reasonably uniform, while still allowing for detailed content analysis. Contemporary topographic maps at scales of 1:10 000 and 1:25 000 were used as reference for the area located in Poland. Calibration was carried out using cartometric reference materials made available by Geoportal within the WMS service [GUGiK undated], and for the area located in Belarus, the World Imagery service (ArcGIS REST Services Directory undated) was used as a reference. The greatest displacement of the map content in relation to the reference material was recorded for the oldest map from 1823 (Tab. 1). The large average displacements seem to confirm Panecki's [2014] conclusion about the inconsistency of the Rejon Brześć nad Bugiem 1:25 000 (1925) in terms of its mathematical basis.

The current preservation status of fortifications and their vicinity was documented based on satellite photographs, orthophotomaps and NMTs included in the collection of the National Geoportal [GUGiK undated]. Cartographic images were geor-

Table 1. Inaccuracies in matching historical maps to the reference standard

Year of map edition	Scale of map	Number of identified GCP (ground control points)	Inaccuracy – mean displacement of a point relative to a reference standard (m)	Average error in map scale (mm)
1823	1:16 800	25	77.9	4.64
1910	1:25 000	64	29.6	1.18
1925	1:25 000	63	39.0	1.56
1960	1:25 000	43	8.6	0.34

Source: own elaboration.

eferenced and digitalized, interpreted and supplemented with information acquired from historical documents describing the study area [Picuno *et al.* 2019]. Since the location of historic defensive settlements was driven by the presence of natural water barriers like rivers, lakes and wetlands, particular attention was paid to these hydrographic features. They were analysed in detail in 6 study plots (1.5 km × 1.5 km) for individual forts of the Terespol Fortification. The general degree of transformation in surface water bodies between the early 19th century and the present day was analysed for 5 periods of time. Contemporary hydrographic features were analysed based on cartographic materials such as Map of hydrographic division of Poland and Hydrographic map of Poland 1: 50 000 [PGW Wody Polskie undated; GUGiK undated]. Information from the database of the National Geoportal [GUGiK undated] and the State Water Holding Polish Waters website was also used.

RESULTS AND DISCUSSION

The analysis of cartographic materials revealed several major trends in hydrographic changes over the last 200 years caused by the construction and operation of the Brest Fortress (Fig. 2). Transformations resulted from natural causes and also human impact. A significant part of the study area is occupied by the middle section of the Bug valley, a river which has retained its natural character. Raised water levels from early spring snowmelt still remodel the valley, forming new and degrading old hydrographic features such as river beds and arms, fluvial lakes and wetlands. In 1823–2018 the length of the meandering Bug River fluctuated between 34.12 km and 29.76 km. The river was shortest in 1925 (27.63 km). These changes were mostly due to natural causes. The exception is the stretch of the Bug River near the Brest Fortress, which has been artificially remodelled in order to use it for defensive operations. The length of the Muchawiec River, the largest tributary of the Bug River in the analysed area, measured along the line of current, has not changed significantly (5.23 km in 1823 vs. 5.16 in 2018).

The construction of fortifications and a network of roads in the studied area forced intensive drainage works. Increased drainage of wetlands was also caused by the expansion of settlements, and directly by the need to acquire new arable land and meadows. These works mainly included the areas located west of the Bug (Terespol Fortification), which was due to their lower altitude (and greater water mass) compared to the areas east of the Bug River. Within almost 200 years, the total length of ditches draining mainly wetland areas increased about 5 times,

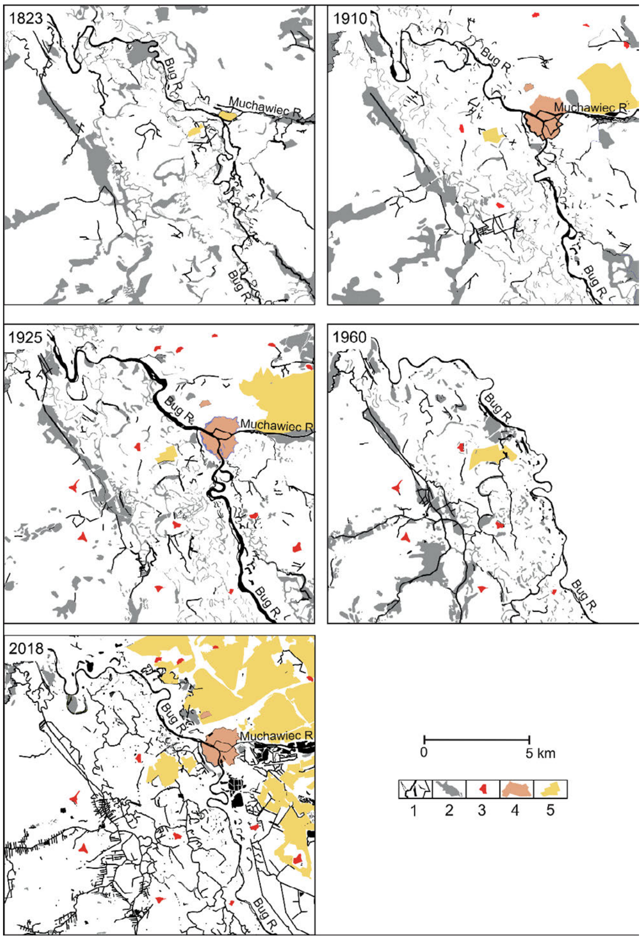

Fig. 2. Location of hydrographic features around the Brest Fortress (1823–2018); 1 = surface waters: rivers, ditches, fluvial lakes (Pol. bużyska), other water bodies; 2 = wetlands; 3 = forts in defensive rings; 4 = Citadel; 5 = urban development; source: own study

from 44.85 km in 1823 to 214.53 km in 2018. In the eastern (Brest) area, the increase during the same analysed period was from 14.42 km to 58.59 km.

Intensive drainage works, the construction of numerous road and rail embankments, permanent dykes, and the initiation of surface runoff caused an irreversible degradation of the wetlands around the fortification structures. Between 1823 and 2018 the area covered by wetlands reduced almost 7 times (from 2274 ha to 328 ha). This drop was noted especially for open wetlands, whose area reduced from 1,489 ha in 1823 (70% of wetlands were located west of the Bug River) to 246 ha in 2018. On both sides of the Bug River, the area of open wetlands decreased more than 6 times compared to the area before the construction of the fortifications.

The hydrographic features least affected directly by the construction and operation of the Brest Fortress were the numerous fluvial lakes in the study area, called "bużyska". Their number and surface area depend on the magnitude of river floods modelling the bottom of the valley. For this reason, in 1823–2018 the total area of these lakes fluctuated from 50.7 to 117.3 ha, and most of them are located on the right bank of the Bug River.

The new hydrographic features created during the construction of fortifications are the moats filled with water and surrounding strategic defensive positions. Their maximum total area in 1925 was 31.4 ha. In 2018, mainly due to the poor technical status of the forts or their liquidation, this area has decreased to 14.9 ha, of which almost 11 ha of water-filled moats are located on the eastern, Belarusian side of the Bug River.

Six permanent forts built on the left, western side of the Bug River, in the area of the Terespol Fortification, were located on small hillocks surrounded by wetlands and water barriers (Fig. 3). Four types of hydrological features were identified in their nearest area: ditches, wetlands, lakes and wet moats surrounding forts. Before the development of the Brest Fortress a number of works were carried out to change water circulation in the region of Terespol. In 1757, Flemming, the owner of Terespol, ordered works aimed at the expansion of the town. The construction of numerous drainage ditches and the regulation (straightening) of small riverbeds resulted in the partial drying of the wetlands surrounding Terespol. To build a new road connecting Terespol and Warsaw in 1757, a dyke across marshes was created near the village of Kobylany, in the Czapelka River valley [Tarasiuk 2002]. This road has survived to the present day and is clearly marked in the landforms south-west from the Fort K in Kobylany (Fig. 3D). During the construction of all defensive structures, dykes were built and connected with roads to enable travel even during floods covering the bottom of the Bug River valley. These dykes, up to 4 m high, ran across depressions occupied by wetlands (Fig. 3, A–D). The excess water from depressions within the Bug River valley was drained by numerous drainage ditches.

Directly around the planned forts (designated measuring ranges, map of 1823) in the Terespol Fortification, watercourses were short or absent (near forts VI, I and L). Because in the 19th century wetlands as natural barriers no longer provided protection, the drainage system in these areas was gradually extended. For example, near forts VI, L, and I, the length of drainage ditches in 2018 was 3.35, 7.15 and 3.65 km, respectively, and the density of the drainage network ranged from 1.49 to 3.18 km·km^{-2}. Near forts K and O the density of the drainage network increased two-fold between 1823 and 2018. A drop in the density of watercourses was only found for the area around Fort VII in Łobaczew. At the beginning of the 19th century, the watercourses in that area discharged water on the bottom of the old river bed, and later the old river bed was the only wetland. The increase in the density of the drainage network was accompanied by a continuous loss of wetlands (Fig. 4). The map of 1823 documents the largest wetland area around the planned Fort L. Back then it covered 63.7 ha, which accounted for 28.3% of the study area. In 2018 only 0.88 ha of wetland was recorded there (0.39% of the study area).

Because the cartographic records of wetlands on the analysed maps was not always precise and clear, this information

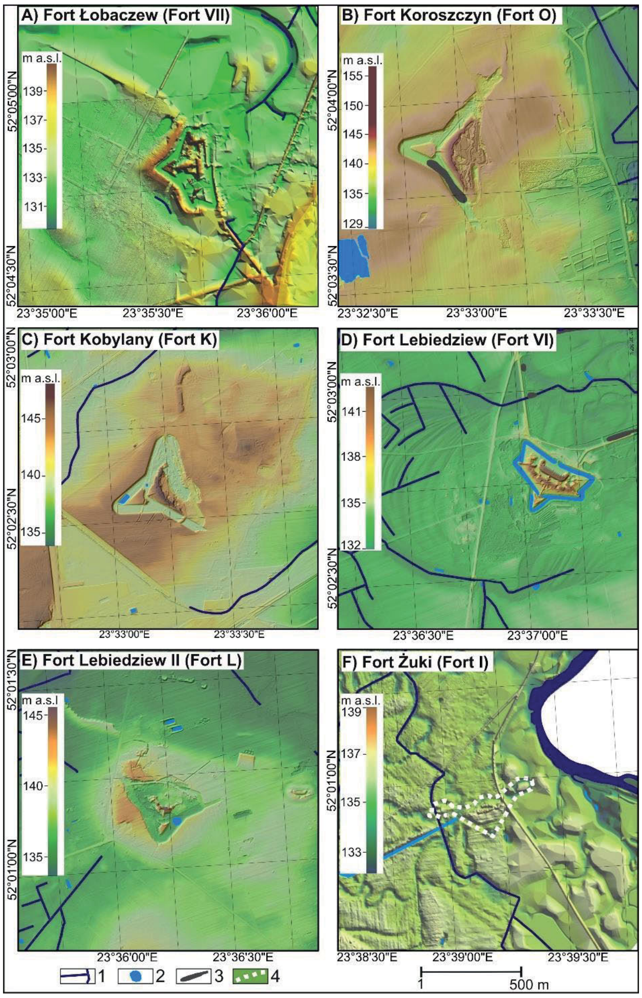

Fig. 3. Transformations of hypsometry area around the forts of the Terespol Fortification (2018); 1 = watercourses; 2 = surface water bodies; 3 = wetlands; 4 = the original range of Fort Żuki; source: own study based on GUGiK [undated]

should be assumed as a rough estimate. For the analysed period (1823–2018), no specific trends or fluctuations were identified relative to changes in the surface area of water bodies located near the forts. There were two reasons for this: natural and anthropogenic. Considering forts located within the impact range of the Bug River floods, fluvial lakes (in the valley) are constantly transformed by waters modelling the valley (Fort VII, Fort I). In areas around the forts located on hillocks small artificial water bodies have been created in recent years (e.g. near Fort O). In 2018 water-filled moats were also recorded in Fort VII (1.96 ha) and Fort L (2.06 ha).

Reasons for locating the forts of the Terespol Fortification in the context of water resources are well illustrated in Figure 5. Permanent forts in the outer ring were built on elevated landforms, where underground water occurs at a depth of 2–5 m (Fig. 5). Two of these forts, K and O, which belong to the 2nd ring of fortifications were built in the watershed zone, which ensured a good view of the area surrounding the fortress. On the other hand, the wrongly planned original location of Fort I, designed as a permanent fort, near the Bug riverbed, forced the builders to move the investment to the area of the village of Żuki. Because this land lies in the river valley, there were also problems with high groundwater level on the new construction site.

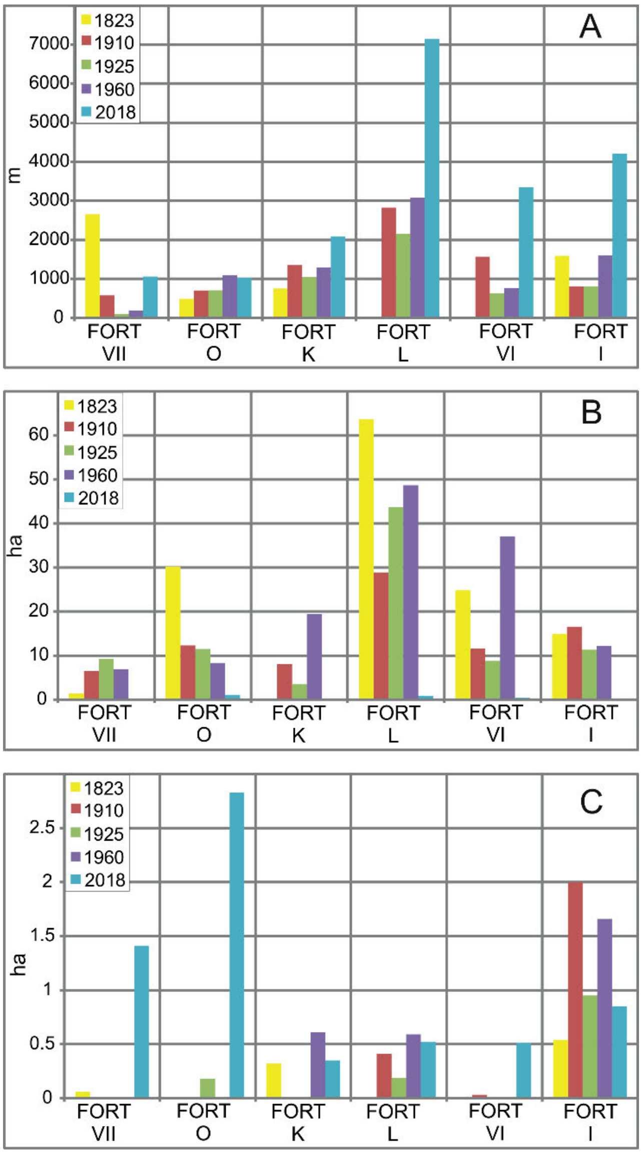

Fig. 4. Changes in selected hydrographic features in the nearest area around the forts of the Terespol Fortification (1823–2018): A – watercourse length; B – wetland area; C – area of surface water bodies; source: own study

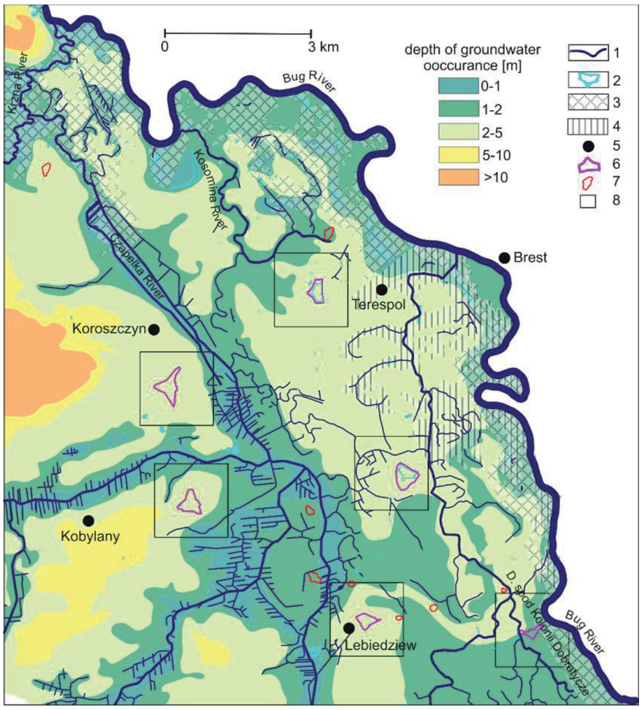

Fig. 5. Contemporary water resources within the Terespol Fortification; 1 = major watercourses and minor drainage ditches; 2 = surface water bodies; 3 = area flooded with water from the Bug river (risk of flood every 10 years); 4 = flood zone acc. to map of 1910; 5 = selected villages; 6 = remains of permanent forts; 7 = remains of field forts; 8 = study plots area (1.5 km × 1.5 km) for individual forts of the Terespol Fortification; Source: own study based on GUGiK undated and PGW Wody Polskie undated

In addition, the area is in the flood zone of the Bug valley (Fig. 5). Ultimately, the construction of a permanent fort was abandoned here, and its status was changed to semi-permanent. Hillocks on which permanent forts were built also separated the boggy valleys, preventing the direct invasion of the enemy into the fort. However, these water barriers created problems with the delivery of supplies and access of people (soldiers).

A convenient connection between the individual outer forts and the Brest Fortress was ensured by the newly built system of roads. These roads in the area of the Terespol Fortification were built gradually with the development of the fortress's defensive line, i.e. in 1871–1915. The height of the dyke had to be adjusted to the level of flood waters. Therefore, the construction of roads required the transport of a significant volume of rocks, the creation of drainage networks, culverts, etc. Because in 1914–1915 the defensive zone of the Fortress was strengthened in the Terespol Fortification by adding semi-permanent infantry forts made of earth and concrete, they also required the construction of new roads. Semi-permanent infantry forts were located near villages: Dobryń, Małaszewicze Duże, Morderowicze, Kobylany, Koroszczyn, Borek, Lechuty, and Łobaczew Mały (Fig. 5).

Transformations of individual hydrographic features, including, in particular, the extended network of drainage ditches and the creation of numerous dykes and embankments, resulted in changes in the water cycle within the analyzed area [Pardela 2013]. These construction works altered the location of watersheds, caused the inclusion of originally isolated areas into the drainage network, and thus a significant enlargement of the catchment area. Before the construction of the Brest Fortress (Fig. 6, 1823) water from the area of the Terespol Fortification was discharged only to the Bug River from relatively small river catchments situated in its northern part: Dolna Krzna, Czapelka and Kosomina (Tab. 2). The direct catchment of Bug covered back then approximately 1/6 of the whole study area. Changes in the course of the Bug riverbed resulted from changes in the area of the Terespol Fortification, from 128.14 km^2 at the beginning of the 19^{th} century to 129.08 km^2 in modern times. The central and southern part of the Terespol Fortification, i.e. over 65% of the total analysed area, was covered by numerous isolated catchments.

Currently, because of the connections between many periodically-filled ditches draining local and once isolated wetlands, the study area is now in the catchment of 5 rivers (Fig. 6, 2018). These catchments and the watercourses draining them are of artificial character. The total surface of riverside directly adjacent to the Bug River, the main recipient of this area, decreased to 16.01 km^2 after 1823, which resulted from changes in

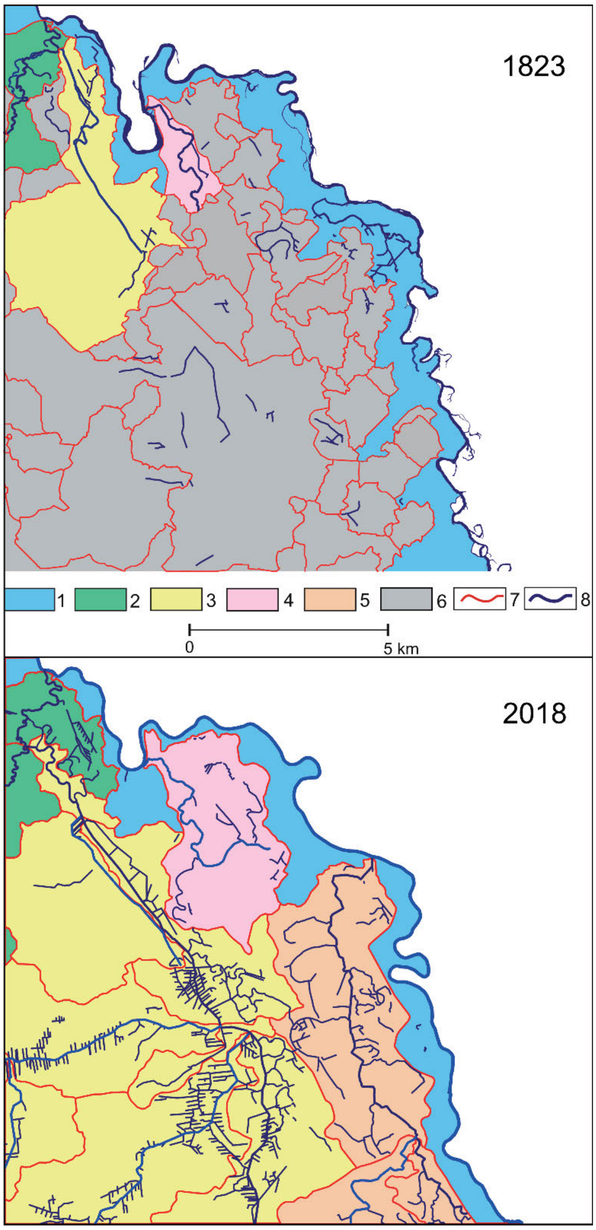

Fig. 6. Changes in the catchment area and watersheds within the Terespol Fortification: 1823 – before the construction of the Brest Fortress; 2018 – at present according to Map of Hydrographic Division of Poland; 1 = direct catchment of Bug; 2 = Dolna Krzna catchment; 3 = Czapelka catchment; 4 = Kosomina catchment; 5 = Dopływ spod Kolonii Dobratycze catchment; 6 = isolated or poorly drained catchments; 7 = topographic watersheds; 8 = watercourses; source: own study

the course of the riverbed (Tab. 2). These areas were connected to the catchment of three tributaries of the Bug River: Czapelka, Dopływ spod Kolonii Dobratycze, and Kosomina. The length of the Bug River also reduced quite considerably by 4.48 km, mainly due to natural causes. However, the most significant changes concern the tributaries to the Bug River: Czapelka, Dolna Krzna and Kosomina, whose length increased after the riverbed regulation, (by 7.2 km, 2.58 km and 2.13 km, respectively), the connection of drainage system and river network. The greatest increase was observed for the Czapelka catchment (by almost 18 km^2, a two-fold increase in the supply area). Originally, the stretch at the mouth of the Czapelka River was connected via an artificial canal with the direct catchment of Dolna Krzna, but today the mouth of the Czapelka River is located approximately 1 km upstream of the Dolna Krzna River. The catchment area of the Kosomina River increased more than five-fold. However, the greatest changes were found in the south-eastern part of the analysed area. Originally, small isolated areas were connected by a canal parallel to the Bug River bed, called the Dopływ spod Kolonii Dobratycze, whose gradient is only 0.21‰. Gradients of the contemporary artificial watercourses created in the area of the Terespol Fortification are very small, not higher than 0.39‰. Such small gradients, characteristic of lowland rivers, do not always ensure the efficient discharge of meltwater. During severe droughts most drainage ditches are empty.

CONCLUSIONS

Documented hydrographic changes caused by the construction and operation of fortifications within the Brest Fortress indicate most of all the negative impact of one of the largest projects of this type in Eastern Poland. The pressure on individual hydrographic features in the study area and the degree of interference in local water resources increased with the development of fortifications and associated infrastructure. The establishment of the first, oldest defensive settlements was strongly driven by natural conditions. For the analysed area, protection was provided by water barriers such as the wide riverbeds of the Bug and Muchawiec, numerous wetlands around the defensive sites, as well as shallow fluvial lakes. With advances in military technology (mainly the impact range of artillery) these structures required the construction of additional lines of defence, usually rings of forts (permanent or field forts) and a system of transport infrastructure (e.g. roads, railway embankments or culverts). The

Table 2. Drainage density changes in the area of the Terespol Fortification in 1823 and 2018

Name of river	1823			2018		
	length of river (km)	direct catchment area (km^2)	drainage density (km·km^{-2})	length of river (km)	direct catchment area (km^2)	drainage density (km·km^{-2})
Bug	34.12	19.48	1.75	29.64	16.01	1.85
Dolna Krzna	3.88	3.99	0.97	6.01	7.19	0.84
Czapelka	8.56	16.66	0.51	15.76	34.57	0.46
Kosomina	4.16	2.41	1.73	6.74	12.54	0.54
Dopływ spod Kolonii Dobratycze	non-existent	non-existent	–	12.62	24.47	0.52

Source: own study.

immediate vicinity of the forts in the Terespol Fortification was affected by marked, usually irreversible hydrological transformations. Most of all, the area of wetlands reduced due to the creation of a dense network of drainage ditches. Some wetlands, e.g. around Fort K in Kobylany and Fort I in Żuki, dried out completely. The construction of a dense network of drainage ditches also resulted in the inclusion of numerous originally isolated areas in the catchment. Some relatively small catchments of tributaries to the Bug River, located in the northern part of the study area, increased in size several times. In the south-eastern part of the Terespol Fortification, a completely new catchment was formed, for the Dopływ spod Kolonii Dobratycze. All currently existing river catchments are of a highly artificial character. Only the riverside of the Bug (except the stretch near Brest and Terespol) has retained a high degree of naturalness.

Nowadays, the areas of large-scale fortifications have definitely lost their military significance. Some of them have been destroyed and changed into other forms of land use, and some have been preserved as historical areas and objects. The uniqueness of hydrographic changes in the area of the Brest Fortress is due to the fact that they were caused by political factors. This, in turn, influenced various directions of changes in the forms of use of the post-fortress areas. After the Second World War, the eastern part of the studied area was incorporated into the Soviet Union (now Belarus), and the Terespol Fortification remained within Poland. The Bug River, crossing the fortification area, became a border river. The eastern part of the fortifications was built-up by Brest, whose expansion required numerous hydro-technical works, including the regulation of the Muchawiec riverbed and draining of wetlands. On the other hand, the area of the Terespol Fortification, treated as a guarded border zone, was used for agriculture with scattered rural settlement. In this area, hydrographic changes (mainly land reclamation) served only to improve agricultural activity. Thus, a clear asymmetry of hydrographic transformations became evident. On the Belarusian side, these changes served the development of the Brest agglomeration, on the Polish side – the development of agriculture.

The presented analyses show the consequences of human impact associated with military activity. Studies have demonstrated that only a detailed retrospection of the conducted works allows for the assessment of the degree of human interference in the water resources in a specific area. These transformations, once identified, allow to better understand the contemporary functioning of the natural environment.

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