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CRENOLOGY OF YOUNG POST-GLACIAL AREAS ON THE EXAMPLE OF LUBUSKIE LAKELAND – OVERVIEW OF RESEARCH[1]

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Abstract: The Polish Lowland is an area with rare and relatively poorly studied springs. The present paper review results of recent studies on springs, their hydrology and environments on Lubuskie Lakeland (5.200 km^2) in western part of the Polish Lowland. This area contains over 1,000 springs and seepages outflowing from porous sediments. Most of them are related to thick Pleistocene sediments containing several groundwater bearing layers, which are cut by deep subglacial channels (tunnel valleys). The spring density index is the highest in catchment of the Gryżynka River, with up to 4.8 individual springs and seepages per 1 km^2. The most common in the Lubuskie Lakeland are seepages (65%), descending and hillslope outflows. Their water discharge varies from < 0.001 to 50 000 dm^3/s. Hydrochemistry of spring waters is dominated by calcium and bicarbonate ions, as well as high concentrations of iron and manganese. Due to the lack of a surface insulation layer, contaminants (various forms of nitrogen) easily migrate to groundwater. Generally, the spring waters have good quality. Moreover continuous observations of the water surface levels in spring supplied water bodies revealed daily fluctuations, which are likely due to evapotranspiration and changes of the filtration coefficient in hyporheic zone.

Keywords: springs, groundwater chemistry, porous media, spring index, daily fluctuations

INTRODUCTION

The natural groundwater outflows, where water emerges from below the earth's surface, are called springs if the water flows in a concentrated way or seepage springs, if the water flow is unconcentrated (Fetter 2001). The groundwater outflows are important part of hydrological cycle, being a place of transition between groundwater and surface waters (Alley et al. 2002). They are also very interesting elements of the landscape, increasing its tourist attractiveness. Moreover, their presence affects biodiversity in local and regional scale. The wide variety of groundwater outflow-dependent ecosystems is influenced by a combination of the natural conditions existing in a given area, including geology, relief and climate. These factors result not only in various vegetation occurring in springs vicinity, but also in variability of groundwater outflows forms, their hydrochemistry and water discharge (Kresic and Stevanovic 2009). Springs are also considered very valuable and have gained a status of the European cultural heritage in the so called Habitats Directive of the European Union. Because springs react relatively quickly to anthropogenic impact in the environment, they are a good indicators of the ongoing changes (Jeong 2001; Mazurek 2008; Dragon and Górski 2015). The multiple approaches to the springs, serving as environmental indicators, unique ecosystems and sources of water for humans, cause that they are in scope of interest of various fields of science: hydrogeology (Ghobadi et al. 2018), hydrochemistry (Kuhta et al. 2012), hydrobiology (Culver et al. 2012), as well as landscape and cultural research (Baścik et al. 2009). Thus, studies of springs should be integrated and compiled in a database, which would allow for their thorough analysis by specialists in various fields.

Taking into account all the surveys, there are approximately 1,000 springs mapped on Lubuskie Lakeland. Therefore, we hypothesise that the groundwater outflows occur relatively frequently in the areas shaped by the last glaciation on the Polish Lowland, and it is only the scale of the mapping, which cause that the number of springs on lowlands is significantly smaller than in the uplands and mountain areas, as also pointed out by Chełmicki et al. (2011).

The scope of the present paper is to review the results of hydrological, hydrochemical and ecologicsl studies on groundwater outflows recharged from porous media (sediments), on Lubuskie Lakeland in western part of the Polish Lowland.

STUDY AREA AND METHODS

Study area

Lubuskie Lakeland with the area of 5,200 km^2, is located in the western part of Poland and is known as Lubuskie Lakeland (Kondracki 2002) or as Lubuska Upland (Krygowski 1956) (Fig. 1). It is located within the maximum extent of the last (Baltic) glaciation, and belongs to the catchment of the Odra River, the second largest river in Poland.

The relief of the region is dominated by outwash plains, forming several levels, separated from each other with clear erosion and denudation edges, and by morainic uplands. Outwash plains are diversified by numerous forms, including hillocks, kame terraces, eskers, and subglacial channels, which are now often occupied by rivers and lakes. The highest forms are extensive ridges of push moraines, reaching the height of 227 m a.s.l. (Bukowiec Hill). In the river valleys, there are Late Pleistocene and Holocene fluvial terraces, accompanied by groups of dunes and post-glacial depressions.

The dominating surface sediments in the area of the lakeland are sands and gravels of glacifluvial origin. There are also glacial deposits, including

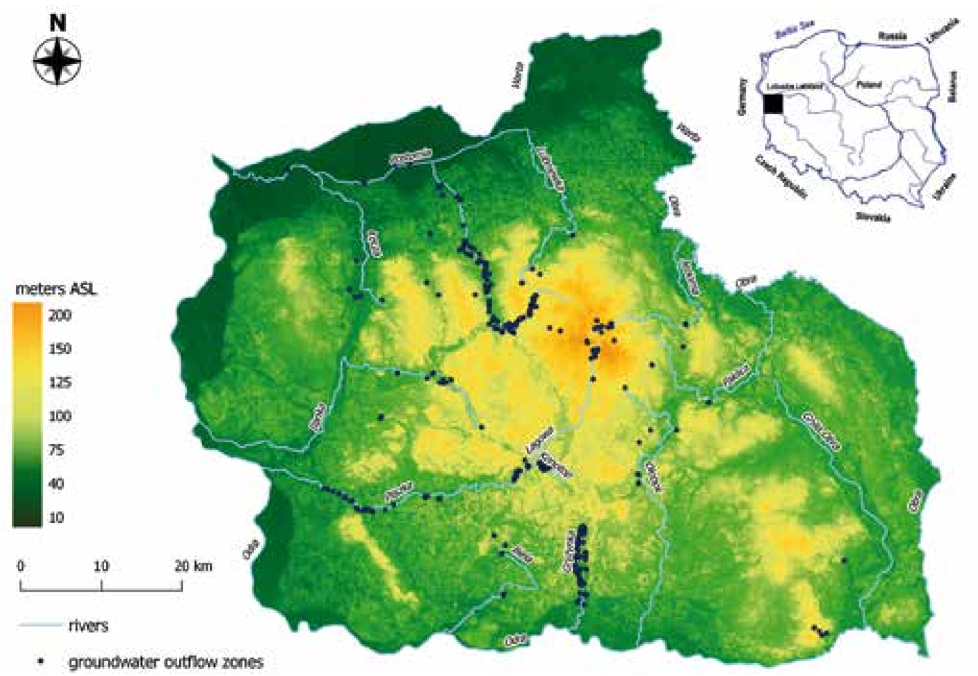

Fig. 1. Distribution of groundwater outflow zones in the area of Lubuskie Lakeland
(data for year 2017)

discontinuous layers of tills reaching thickness of more than 40 m, and sands with boulders. The thickness of the Quaternary formations vary, and range between 3 to more than 60 m, and locally reaches the values up to 200 m in the upland areas nearby Świebodzin and Sulęcin.

The intercalated layers of permeable (sands, gravels) and impermeable sediments (tills), which form often discontinues layers, and varying thickness of Quaternary formations are among the reasons for occurrence of several water bearing layers (aquifers) of various thickness, range and volume. Groundwaters of the shallowest first aquifer are usually in range from 2 to 10 m below the surface of the terrain. Only in the area of push moraines they are deeper, down to 20 m or deeper. Groundwaters are often drained by rivers following networks of subglacial channels, which cut the surface of the area to depths of 30–50 m (Żynda and Kijowska 2016). The deeply indented subglacial channels cause that the continuity of the aquifers is interrupted, and contribute to the formattion of various forms of groundwater outflows, including springs as well as seepages. The presence of groundwater outflows in the area of Lubuskie Lakeland, as indicated in the previous studies (Szczucińska 2014), is related to the network of postglacial channels and river valleys. In the studied area, the following groundwater horizons drained by the groundwater outflows have been distinguished:

surface, intermorainic, sub-clay, and valley horizone (Hydrogeological Map of Poland in the scale of 1 : 50 000).

Groundwaters within Quaternary sedimentary formations are mainly supplied by infiltration of meteoric waters. The area of Lubuskie Lakeland, due to its lithological structure, is characterised by very good parameters of water infiltration, with infiltration coefficient ranges from $2 \cdot 10^{-6}$ to $9 \cdot 10^{-5}$ m/s. Particularly favourable conditions for alimentation of aquifers are provided by the sandy and gravelly series of glacifluvial outwash areas and gravel-silty sands of morainic uplands. Hydrogeological cross section through Quaternary deposits of southern part of Lubuskie Lakeland is presented in Szczucińska (2014).

Most of the study area is covered by forests (51%) and agriculture land (40.7%). The remaining land belongs to urban areas (villages and towns: 5.1%) and unused land and water bodies (3.2%) (Central Statistical Office, 2012). Most of the groundwater outflows are located in forested areas (Szczucińska 2014).

The average annual precipitation of Lubuskie Lakeland is 590 mm, which takes place mostly in the period from May to October (60%). The average annual air temperature is from 8.0 to 8.5°C (Degirmendžić et al. 2004). The hydrological, hydrogeological, as well as geomorphological, and climatic conditions have a significant impact on the presence of groundwater outflows in the area of Lubuskie Lakeland (Szczucińska 2016).

Methods used in the spring studies on Lubuskie Lakeland

The spring mapping on Lubuskie Lakeland was conducted from March 2011 to April 2013. For each groundwater outflow were noted: the geographical coordinates (using a global positioning system (GPS) by Garmin), the geomorphological situation (under hillside, hillside, valley, stream channel), the type of groundwater outflow (spring or seepage spring, descending or ascending) and groundwater discharge assessment.

The water discharge in bigger outflows was measured in two ways. The first, so-called volumetric method, was based on collecting total water discharge in buckets of known volume and measuring the duration of the water collection. The discharge was then calculated from ratio of sampled water volume to sampling duration. The second was hydrometric method. The water discharge measurements were made in the streams using a hydrometric meter and standard calculation methods. In the remaining outflows, the discharge was assessed by visual comparison (mostly for seepage springs with very little discharge).

The water temperature, electrical conductivity (EC) and pH were measured for about 218 outflows once. In 20 representative springs, measurements were carried out every 3 months for 2 years. The temperature was measured with the electrical thermometer ETI 2001, with an accuracy of 0.1 WC. Electrical conductivity was measured with conductivity meter CC-401 by Elmetron, with automatic compensation to a reference temperature of 25 WC and accuracy ±0.1%. The pH was measured with the handheld pH meter 315i by WTW, with an accuracy of 0.01 pH units.

The analyses of major cations and anions were conducted in the laboratory following Polish and international norms. The analyses included primary components (bicarbonate, sulphate, chloride, silicate, magnesium, calcium, sodium), secondary components (total iron, potassium, nitrate, fluoride), minor components (phosphate, manganese, cadmium, chromium, copper, lead, zinc), and other parameters (ammonium, nitrite), but not all of them were discussed.

Water samples for microbiological analysis were collected once, at the same time in autumn 2014. The analyses were also performed in the certified laboratory. Bacteria from the *Coli* group, studied using the filtration method, included *Escherichia coli* and *Enterococci*. The total number of microorganisms at a temperature of 36°C was determined against the national standard (PN-EN ISO 6222:2004). *Clostridium perfringens* was determined in accordance with the Regulation of the Polish Minister of Health of 29 March, 2007 (Official Gazette no. 61, position 417).

Measurements of water level and in streams draining three outflow zones in Gryżynka river were carried out between October 2011 and November 2014 with MiniDiver microprocessor loggers. MiniDiver records the fluctuations in water level derived from changes in pressure exerted by the water column and measured by a pressure sensor with 0.05% FS (full scale) precision. As MiniDiver measures the absolute pressure above the sensor, the collected data required adjustment for changes in atmospheric pressure. Therefore, this parameter (along with air temperature) was recorded by the BaroDiver logger in the same time. The Diver-Office software was used to correct results obtained with MiniDiver for the BaroDiver pressure records. Water level were measured with ±0.5 cm precision.

The parameter describing the density of springs is the spring density index. It represents the number of springs per area unit, usually expressed for 1 km^2 of the basin area (A). In the following analysis both springs and seepages have been taken into account, but some zones of groundwater contact with ground surface as seeps, which do not form a water course and which occur periodically have been omitted. For Lubuskie Lakeland, the spring density index was calculated in two ways. The first one takes into account the zones of groundwater outflows (GOZ), regardless of whether there are one or more points of water discharge (GOZ/A). The second takes into account all points of groundwater outflows (point outflows/A). The smallest GOZ is a single outflow and the largest are complex spring headwaters, where numerous unconcentrated outflows occur next to concentrated forms.

RESULTS

The Gryżynka basin was subjected to detailed spring hydrology studies, during which more than 350 point groundwater outflows were recorded. In following studies also other parts of Lubuskie Lakeland were covered by the detailed research, including the catchment areas of the rivers (Fig. 1): Pliszka, Ilanka, Struga Jeziorna, Biela, Konotop, Paklica, Łagowa, Lubniewka and Postomia (Szczucińska 2014). During these surveys, there were mapped, in addition to previously mentioned springs, over 610 new point groundwater outflows grouped in 376 groundwater outflow zones (single zone may consist of one or few outflows located next to each other). The majority of the outflows (around 38%) is located under the hill slopes, while the other geomorphological settings include: hillside, valley and stream channel. The dominating way water outflow from the groundwater horizon is descending (94%) following layer boundary (contact springs and erosion springs). Location of these outflows derives from favourable conditions of the drainage, which is a result of high hydraulic gradients in these zones. The ascending (pulse) manner of water outflow was found in less than 2% of the outflows and is related to the pounded conditions at the site of outflow of water to the ground surface, where the water flows under the impact of hydrostatic pressure. About 4% of springs has mixed nature (ascending-descending). The outflow of water in the unconcentrated form is by 26% more common than the outflow in the concentrated form.

The outflows on Lubuskie Lakeland are characterised by small discharge. The maximum measured discharge were in seepage spring area of the Gryżynka River (50 dm^3/s), springs in the catchment of the Pliszka River (up to 20 dm^3/s), and in the catchment of the Ilanka River (up to 15 dm^3/s). Still, most of the outflows (apart from the catchment of the Postomia River, where the outflow discharge measurements were not performed) both in the form of springs, as well as seepages, have the discharge in the range from 0.1 to 1.0 dm^3/s.

When analysing the spring density indexes (tabl. 1) for Lubuskie Lakeland, according to the first method, its highest value was found in the catchment of the Gryżynka River (0.95) and Konotop River, which is a tributary of the Pliszka River (0.47), as well as for the catchment of the Postomia River (0.36). The high abundance of springs may indicate a large amounts of groundwater resources in these catchments. On the other hand, by applying the second method, the index reaches much higher values and is 4.78 in the Gryżynka catchment, 1.09 in the Konotop catchment, and 0.63 in the Postomia catchment. The average spring density index for the studied area of Lubuskie Lakeland is 0.24 outflow zones per 1 km^2 of the catchment area and 0.78 point outflows per 1 km^2 of the catchment area.

The specific electrolytic conductivity (EC), for all springs, is on average 440 μS/cm, which indicates low salinity of these waters. In over 85% of the

Table 1. Spring hydrology indexes for Lubuskie Lakeland, according to the mapping performed until 2017; GOZ – groundwater outflow zone, A – catchment area, Point outflows – the sum of point outflows in the form of springs and seepage springs

River	A [km^2]	GOZ/A	Point outflows/A
Gryżynka	74	0.95	4.78
Konotop	47	0.47	1.09
Postomia	425	0.36	0.63
Struga Jeziorna	120	0.18	0.30
Łagowa	61	0.16	0.28
Pliszka	389	0.13	0.33
Paklica	278	0.04	0.14
Ilanka	495	0.03	0.10
Lubniewka	132	0.03	0.04
Biela	288	0.02	0.08

outflows the EC values were in range of 200–500 µS/cm. The lowest measured value was 111 µS/cm, in the catchment of the Ilanka River, and the highest – 832 µS/cm in the catchment of the Postomia River. The average pH values of spring water ranged from 7.46 to 7.71, putting it in the slightly alkaline class. It is medium-hard, with an average total hardness varying between 213 and 228 mg $CaCO_3$/L. Its average temperature in the studied two-year period was 9.6°C, close to the average air temperature in the region of 8.2°C. Dominant ions in the selected 20 springs of Lubuskie Lakeland in the years 2011–2013 are shown on Fig. 2. Various types of springs were selected, with different basic physicochemical parameters (temperature, specific electrical conductivity (SpC), and pH), discharge and morphological location, and relatively easy access.

There was also a series of microbiological research carried out. The presence of significant number of microorganisms was found, and in some springs the presence of *Escherichia coli* and *Clostridium perfringens* was registered. It is probable that the presence of these two bacteria is connected with the pollution with domestic sewage.

In the Gryżynka River catchment the water levels in hyporheic zone of headwaters were monitored in the years 2011–2014. The results showed that diurnal fluctuations in water level ranged from 2 to 4 cm. It is approximately 10% of total water depth in hyporheic zone. The observed water level fluctuations likely have resulted from processes occurring in the headwaters and were correlated with the changes in evapotranspiration (Marciniak, Szczucińska 2016).

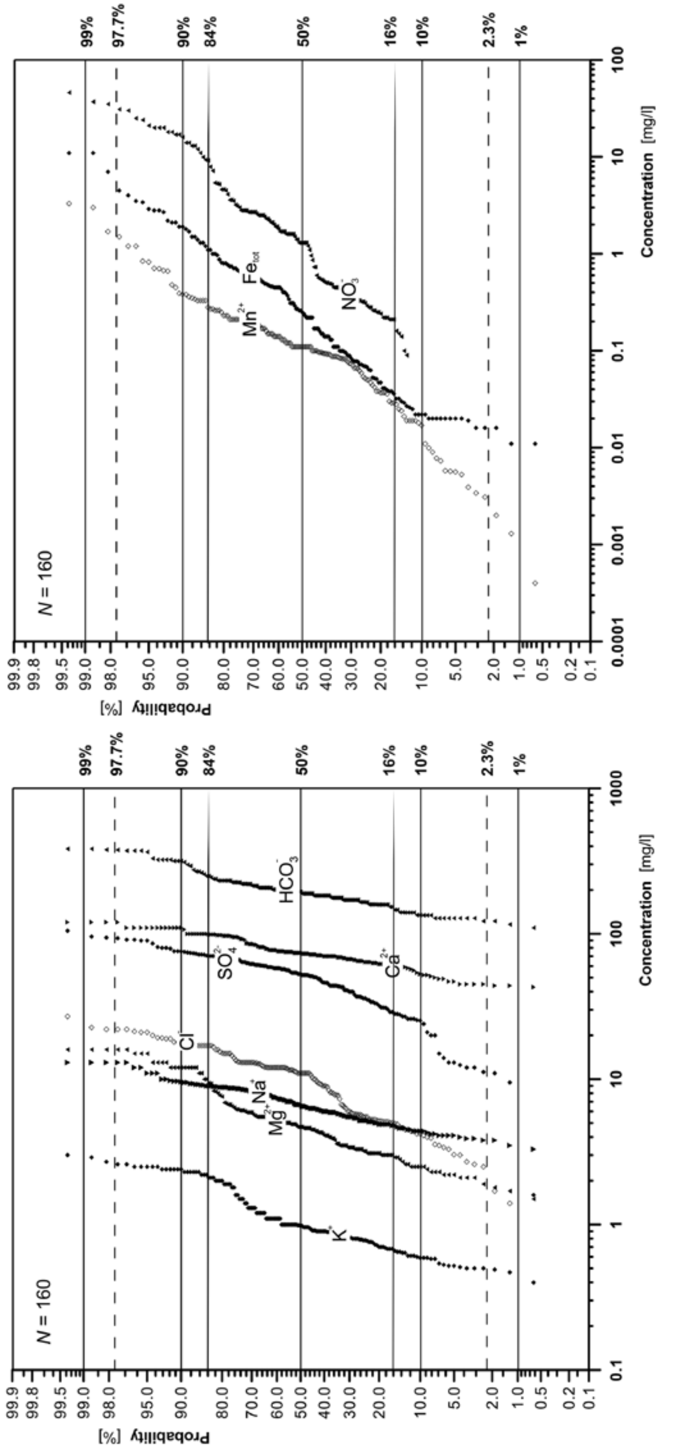

Fig. 2. Dominant ions in 160 analyses of samples collected in selected 20 springs of Lubuskie Lakeland in the years 2011–2013 (Szczucińska, 2016)

DISCUSSION

The location, type and discharge of groundwater outflows are primarily controlled by the local geological structure, hydrogeological conditions and relief. These factors affecting the occurrence of springs on study area. Lubuskie Lakeland, located within the area shaped by the last glaciation, may be considered to be representative for majority of Polish Lowland in the context of groundwater outflow characteristics. A very characteristic feature of the groundwater outflows in these areas is wide range of forms of outflows from single springs, seepages, to groups in the form of seepage spring areas (Manga 2001). A noticeable feature is the differences in the discharge result from the type and size of the groundwater reacharge area, the conditions of the aquifer reacharge, and the hydraulic gradient. The smallest discharges are in the catchment areas, where the outflows are supplied mostly from the surface water bearing layer, e.g. the Paklica River catchment. The largest discharges are in the outflows, which drain water from the layers between glacial till layers, or from below glacial till layers. Such outflows occur in the catchments of the Gryżynka, Pliszka and Ilanka rivers. Springs with discharge over 0.5 dm^3/s are characterised by stable discharge, and the Mailette's variability index, calculated as the maximum/minimum discharge ratio, is from 1.0 to 2.5. In the area of the Polish Lowland, the studies on the outflows from porous formations, similar to these on Lubuskie Lakeland, were carried out in the basin of the Parsęta river (Mazurek 2008; Dobrowolski et al. 2010), Reda-Łeba Valley, interfluve of Warta and Noteć (Chełmicki et al. 2011). Springs with diversified water discharge are also observed in other areas covered by the last glaciation. In Latvia, values from several to 23 dm^3/s were recorded (Gosk et al. 2007), almost 0 to 22 dm^3/s similar values were found in the area of Finland, from nearly 0 do 22 dm^3/s (Särkka et al. 1997; Rossi et al. 2015). Diversity of outflow discharges is observed also in Germany (Schweiger and Beierkuhnlein 2014). The individual discharge rates are mostly low, mean discharge is 0.3 dm^3/s, but they are relatively constant throughout the year. Springs also occur in the bottoms of water reservoirs. The springs that supply lakes (Choiński et al. 2008; Cieśliński and Piekarz 2014), the so-called underwater springs, are poorly studied. They were registered in study area, for instance at bottom of lakes: Wapienne (Gryżyńskie), Lubińskie, Lubie, Trześniowskie, as well as in ponds located in the Gryżyńsko-Grabińska tunnel valley.

An indicator that enables comparison of areas in respect to the density of springs is spring density index. In the following analysis both springs and seepages have been taken into account, but some zones of groundwater contact with ground surface as seeps, which do not form a water course and which occur periodically have been omitted. Relatively high densities of groundwater outflows occur locally in the Polish Lowland areas covered during the last glaciation. A higher number of springs in the river valleys is clearly visible, in particular in those valleys that occupy the deeply cut sub-glacial channels. The values in the lowland area of Poland were compared with those obtained in the upland and mountain areas (Fig. 3). During the analysis of spring density indexes, it must be taken into account that they may be calculated in different ways. However, taking into account both methods of calculations for Lubuskie Lakeland, it is clear that the index is similar to that of the upland areas of Poland, which confirms the hypothesis that the groundwater outflows occur relatively frequently in the areas shaped by the last glaciation. In each of the analysed catchments, this index is higher than the previously reported average spring density index of 0.01 for the Polish Lowland (Chełmicki et al. 2011). Similar values of spring density indexes are reported also from other areas shaped during the last glaciation, including Suwalskie Lakeland – 0.3 (Chełmicki et al. 2011), Drawskie Lakeland – from 0.06 to 0.75 (Mazurek 2011) and Międzychodzko-Sierakowskie Lakeland – 0.54 (Chełmicki et al. 2011).

Hydrochemistry of spring waters fed from porous sediments is formed mainly by the natural hydrogeochemical processes conditioned by lithological and hydrogeological variability of Quaternary sediments (Szczucińska 2016; Retike et al. 2016; Kløve et al. 2017). Waters from the basins supplying the outflows belong mainly to the shallow circulation system. Because, recharge of groundwater aquifers, drained by the outflows, is mainly by infiltration of meteoric water through glacial and glacifluvial deposits, this contributes to enrichment

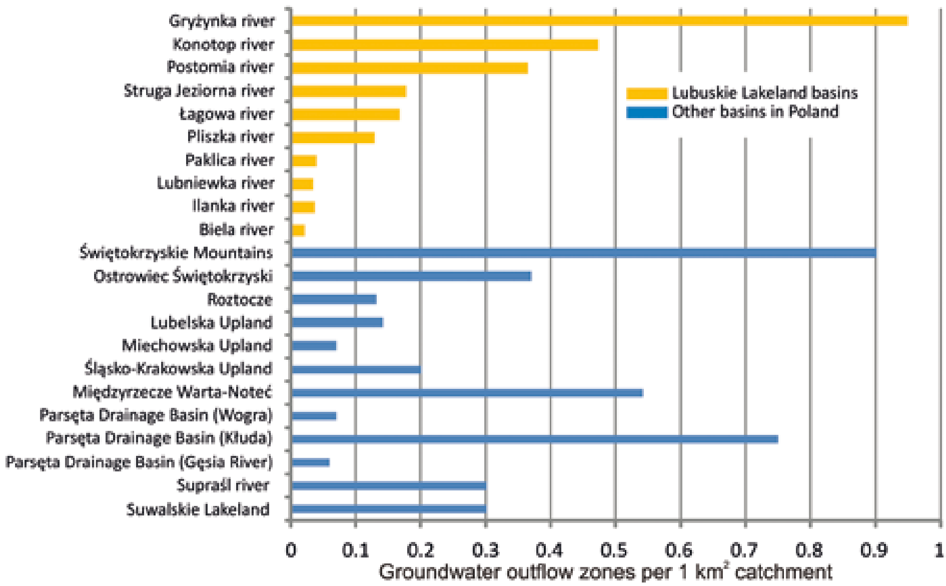

Fig. 3. Comparison of values of spring density index in catchments of Lubuskie Lakeland and other regions of Poland

of the waters with products of leaching of the glacial tills, mainly with calcium and bicarbonates (Rossi et al. 2015). Variations of the EC values depend primarily on calcium carbonate content in aquifer sediments and on the hydrodynamic conditions that determine the flow rate and paths, and thus the period of time when water is in contact with sediments in the aquifer. Therefore, as in other recently glaciated areas of Polish Lowland are usually lowly mineralized waters of HCO_3-Ca type (Jekatierynczuk-Rudczyk 1999; Macioszczyk 1999; Mazurek 2008). Such hydrochemical type of spring waters is typical for shallow groundwaters of a hypergenesis zone and it has also been found in the other young glacial areas (Apello and Postma 2005; Neven and Stevanovic 2010).

Groundwater covered with glacifluvial sediments often are not isolated from the inflow of contaminants. As a consequence, water drained with springs is often polluted (Apello and Postma 2005). The area of Lubuskie Lakeland is a non-industrialised region, thus over-normative concentration of trace elements, mainly lead, were observed only in several springs (Szczucińska 2016). Concentrations exceeding the Polish standards were found in four springs in the case of Pb^{2+}. The permissible concentration of lead in drinking water is 0.01 mg/L and it was found maximum 0.09 mg/L. The compounds that indicate large spatial variability and often exceed the norms for groundwaters for drinking water are iron and manganese. It is a typical feature of the outflows that are supplied from glacifluvial sands and gravels (Dragon and Górski 2015; Retike et al. 2016). The highest concentration of Mn^{2+} was 4.2 mg/L, and of total Fe was 14 mg/L (Szczucińska 2016). The Polish standards for drinking water put the limit for the Mn^{2+} concentration at 0.05 mg/L, and for total Fe, at 0.2 mg/L. Periodically and locally increased levels of nitrates have been found, especially in the springs in the vicinity of farmlands and rural buildings. Migration of anthropogenic pollutants to groundwater in the areas covered by glacifluvial sediments with good filtration parameters is enhanced by the lack of insulation of groundwater horizone. In the study area, the highest observed value for nitrates amounted to 37 $mgNO_3$/L and was much lower than in other areas of Polish Lowland. Among the analyzed catchments, the Pliszka river and its tributary Konotop have been identified as particularly sensitive to pollution with nitrogen compounds from agricultural sources according to EU Nitrates Directive (Council Directive 91/676/EEC). Following the Directive, actions need to be undertaken in these areas in order to reduce the pollution of waters with nitrates of agricultural origin. In other parts of Polish Lowland higher concentrations of nitrates resulting from human impact were observed; for instance in the basin of the Parsęta River, where they reached 323 $mgNO_3$/L (Mazurek 2008).

With the outflows of groundwater recharged from porous sediment is associated a so-called hyporheic zone. This zone is connected with the site of outflow of groundwater to the surface of the area. It is a zone of contact of groundwaters with surface waters (White 1993; Bencala 2000). The waters drained by the springs feed small basins, which are created in the niches formed as a result of spring-related morphogenetic processes. The studies carried out in the catchment of the Gryżynka River showed that in these niches occur daily water level fluctuations, which may have their consequences in the size of the outflow discharge rate, and which may also influence the variability of the physico-chemical properties of the spring waters in the outflow zone (Jekatierynczuk-Rudczyk 2006). The studies (Marciniak and Szczucińska 2016) proved that the fluctuations are likely a result of daily variations in the evapotranspiration changes, however this is not the only factor causing water level fluctuations in the hyporheic zone. Presently, there are tests carried out on the permeability coefficient, changes of which may also affect the fluctuations. The permeability coefficient is connected with the phenomenon of fluidisation of bottom sediments, that is fluidisation of sands. It takes place as a result of an increase in the permeability coefficient and an increase of the hydraulic gradient in the hyporheic zone (Ryan and Boufadel 2006). Its consequence is the increased supply of groundwaters to the surface waters, intensified erosion, which in turn can lead to rapid transformations in geomorphology of the seepage spring niches, and risings in the watercourses supplied by the springs. Currently, there are observations made intended to identify the details on the factors responsible for water level fluctuations in the seepage spring niches. The daily water level fluctuations, sometimes called as hydrosphere pulses, now constitute the most advanced direction of research in the seepage spring areas of Lubuskie Lakeland.

CONCLUSIONS

The conducted studies revealed that the groundwater outflows from porous sediments have a relatively high significance resulting from their widespread occurrence in the area covered with glacial sediments. Thus, they may serve for monitoring research in such areas. The extensive spring hydrology mapping made covered 10 catchment areas of the rivers of Lubuskie Lakeland. The spring density index is the highest in catchment of the Gryżynka River, with up to 4.8 individual springs and seepages per 1 km^2. The most common in the Lubuskie Lakeland are seepages (65%), descending and hillslope outflows. Their water discharge varies from < 0.001 to 50 000 dm^3/s. Hydrochemistry of spring waters is dominated by calcium and bicarbonate ions, as well as high concentrations of iron and manganese. Periodically and locally increased levels of nitrates have been found, especially in the springs in the vicinity of farmlands and rural buildings. The highest observed value for nitrates amounted to 37 $mgNO_3/L$. The groundwater outflows are both an important component of the water balance, as well as the place of contact of chemically different groundwaters and surface waters. Moreover, the groundwater outflows are a unique environment for plant growth, and habitats of animals. An important aspect of spring protection is to conduct activities focused on maintaining biodiversity in the headwaters and counteracting their devastation. Thus, it is necessary to properly manage the surroundings of springs, especially these identified as being of exceptional biological and landscape values.

The underwater springs in lakes are also worthy of note, the role of which in lake water balance and their influence on the chemical composition of waters may be significant, particularly in terms of delivery of pollution. The ongoing observations carried out in the hyporheic zone of seepage spring niches will provide information on functioning in the areas covered by the last glaciation. In the formerly glaciated areas, especially on the Polish Lowlands, further detailed spring hydrology studies are necessary.

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