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LONG-TERM VARIABILITY OF WATER RESOURCES IN MOUNTAINOUS AREAS: CASE STUDY - KŁODZKO REGION (SW POLAND)

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Abstract: The variability of water resources in the Kłodzko region located in SW Poland is presented through the characteristics of total and groundwater runoff. On the basis of daily river flow were determined the average monthly flow (SQ) values were used to determine total runoff and the average low river flows (NQ) were in turn used to determine groundwater runoff. Based on the obtained results, the Nysa Kłodzka river basin should be classified as an area characterized by high hydrological activity. The average water resources for the period 1967-2016 were 13.01 m^3/s and they accounted for 50 % of the precipitation (751 mm). The average values of dynamic groundwater resources were calculated at 4.75 m^3/s, which accounted for 36 % of the total water resources and 19 % of the precipitation. The total runoff variability is relatively high, as evidenced by the ratio of the maximum and minimum long-term annual runoff, which was 2.83. A higher value was found in the case of groundwater runoff (4.4). Based on the analysis of the volume of water resources, in particular during the last decade (2007-2016), we can see the decreasing percentage of groundwater resources in the total water balance of the study area (16 %), while in the hydrological year 2016 the percentage contribution of the groundwater runoff was only 8 percent. In analyzing the variability of total and groundwater runoff, decreasing long-term trends in total and groundwater runoff can be observed. It is primarily affected by very noticeable declining trends during the summer period, which relates to both total and groundwater runoff. During the winter period, a slight decreasing trend in groundwater runoff can only be seen, with simultaneous stabilization of the total runoff. The knowledge of the temporal variability of the river basin runoff can form the basis for further research on the water cycle within the Kłodzko region area.

Keywords: water resources, groundwater runoff, long-term variability, Kłodzko region

1. INTRODUCTION

Poland is one of the countries with the lowest water resources in Europe. The water availability index in Poland is 1590 m^3 per inhabitant (Gutry-Korycka, et al., 2014), in Europe it is on average 4800 m^3 (FAO - Aquastat), whereas the global average in 2014 is about 6000 m^3 per inhabitant (FAO - Aquastat). Poland's groundwater resources are estimated at 5000 km^3, but only 15.5 km^3 per year can be effectively exploited on account of poor replenishment of these resources (Sadurski, 2011; Gutry-Korycka, et al., 2014). Due to relatively small water resources, water should be managed in a rational way in order to maintain the balance between natural conditions and the development of agriculture and industry. The status of water resources is also important in the aspect of the predicted climate change that will contribute to modification in the water cycle structure within the river basin (Gutry-Korycka, 1996; Wibig, et al., 2012). This modification will manifest itself in changes in recharge, evapotranspiration levels, precipitation structure, total runoff and its components. In the first place, it is expected that during the next decades average air temperatures will increase and extreme events, in the form of intense rainfalls and dry periods, will occur more frequently (Wibig, et al., 2012). The above described climate change will affect water resources by increasing the magnitude of evapotranspiration and decreasing groundwater runoff in favor of surface runoff (Olichwer & Tarka, 2015).

The area of the Kłodzko region, which is characterized by natural conditions not heavily disturbed by man, was selected for analysis of water resources. Under such conditions, i.e. in areas with a natural or close to natural landscape, water resources primarily depend on natural environment elements (Gan, 1998; Wrzesiński, 1999; Lindström & Bergström, 2004; Bae, et al., 2008) and changes in climatic factors (Arnell, 1999; Milly, et al., 2005; Oki & Kanale 2006; Fu, et al., 2007).

The main aim of this article is to determine the variability of water resources of the Nysa Kłodzka river basin over the long period (1967-2016), with particular emphasis on the contribution of groundwater in total water resources. In the drought periods, the groundwater runoff is 100% of the river flow.

There are a number of publications, in which the long-term variability of the total runoff of polish rivers is characterized in relation to climate change (Sen & Niedzielski, 2010; Jokiel & Stanisławczyk, 2016; Jokiel & Tomalski 2017; Górnik, et al., 2017). The main conclusions came from these articles are the small long-term variability of the total runoff, the lack of trends in water outflow and the randomness of short-term trends of total runoff. For example, in the Upper Wieprz River basin (highland river – eastern Poland) based on data from the period 1996-2016 in spite of the evident increasing trend in annual atmospheric precipitation totals, water outflow did not increase (Stępniewski, 2018). Similar conclusions confirm studies in the Warta river basin (lowland river - central Poland), where it was stated that the Warta River runoff (period 1848-2010) shows considerable stability, especially in terms of mean annual values and short-term trends are random in character (Ilnicki, et al., 2014; Miler, 2015). The lack of trends in river outflow or weak upward trends on the basis of data from 1964-2006 were observed in rivers located in High Tatra Mountains (southern Poland) (Pociask-Karteczka, et al., 2010). Additionally, no statistically significant trends were observed in river runoff (period 1901–2008) in two major rivers crossing the Poland (the Vistula and the Oder) (Pociask-Karteczka, 2011).

On the other side, the subject of variability of the contribution of groundwater runoff in the river's outflow on the basis of long-term hydrological observations is described less frequently, especially for mountainous areas of south-western Poland. The publications characterizing the groundwater runoff of mountainous areas of Poland (eg. the Sudetes) without references to total runoff are dominant (Staśko, 2010; Staśko, et al., 2010; Buczyński & Staśko, 2016). Therefore, this article may be a supplement to the analysis of long-term variability of groundwater runoff in mountain catchments compared to changes of total runoff.

The total and groundwater runoff values calculated by hydrological methods on the basis of continuous river flow data were used for the characteristics. The runoff variability is presented relative to the variability of precipitation, which is the important meteorological factor affecting river discharge. The knowledge of the temporal variability of the river basin runoff can form the basis for further research on the water cycle within the Kłodzko Region, which is a water recharge area of Nysa Kłodzka River. Additionally the study area plays an important role in the water management of the Odra River basin. The water supply systems in Wroclaw city (main city of the SW Poland) take water from the Oława River, which is supplied by switching water system from the Nysa Kłodzka River.

2. STUDY AREA

Assessment of water resources was carried out for the Kłodzko region located at the boundary of the Central and Eastern Sudetes in southwestern Poland. The study area of 1084 km^2 covered the Nysa Kłodzka River basin from springs to the Kłodzko gauging station (river basin A) (Fig. 1). This study area is an example of a region with a natural landscape where permanent but minor changes have occurred due to human activity.

The Nysa Kłodzka River length in study area is 53.3 km. The geographical setting of the study area is associated with its location between mountain chains (the Śnieżnik Massif, the Bystrzyckie Mountains, the Stołowe Mountains). Mean altitude of study area is equal to 567 m a.s.l. (min. 285 a.s.l. – Kłodzko gauging station, max 1425 m a.s.l. - Śnieżnik summit). Mean slope is equal to 8.24 % (Jeziorska & Niedzielski, 2018). The Nysa Kłodzka River is the left side tributary of the Odra River (the second largest river in Poland). There are several tributaries of the Nysa Kłodzka river, most of which are mountainous rivers. The headwater area of the Nysa Kłodzka River basin is mountainous and mid-mountain and composed of crystalline rocks, characterized by considerable groundwater runoff and slow groundwater resources depletion (Tarka, 1997). A significant part of the basin, the middle part of the basin area, is composed of Cretaceous aquifer (the Upper Nysa Kłodzka Graben) with high potential groundwater resources occur (Olichwer, 2007). Three groundwater circulation systems can be distinguished within the study area. The first one, with the largest cover, is a regional system whose drainage base is the Nysa Kłodzka and in which the water infiltrates into the bedrock through tectonic faults and fractures to a depth of 800 – 1500 m (Kryza, 1988). The transitional and local shallow circulation systems include the waters of fissured bedrock and, weathering mantles. The water runoff from this system manifests itself in the springs and rivers. The waters of all these systems are in contact with one another (Fig. 2).

Nysa Kłodzka is characterized by rapid water supplies in the spring and summer as a result of numerous mountain tributaries (Jeziorska & Niedzielski, 2018). On the basis data include the daily discharge of Nysa Kłodzka River (Kłodzko gauging station) in the period 1951–2010 the minimum river discharge (NNQ) is equal to 0,94 m^3/s, mean river discharge (SSQ) 12,97 m^3/s and maximum river discharge 693 m^3/s (Jokiel & Stanisławczyk, 2016). Study area is located in the cool temperate climate zone with marked maritime influences. Average annual air temperature calculated for the entire area of Kłodzko County is 6.3°C (Geographic Characteristic of Counties, 2004). The altitude influence is seen in the annual precipitation sums, which vary from 590 mm in the lower parts of Kłodzko Region to about 1500 mm at the summits (Godek, et al., 2015). The mean annual precipitation rate calculated for the study area is 751 mm (multi-year period 1967-2016). Snow cover is present in the Kłodzko station for average of 63 days (Bednorz, 2011) from November to April.

To analyze in detail the changes in water resources, 3 differential river basins of the Nysa Kłodzka River were additionally delineated within the study area (Fig. 1):

A1) the river basin from the springs of the Nysa Kłodzka river to the Międzylesie profile with an area of 49.7 km^2

A2) the river basin between the Międzylesie and Bystrzyca Kłodzka profiles with an area of 210.3 km^2

A3) the river basin between the Bystrzyca Kłodzka and Kłodzko profiles with an area of 824 km^2.

3. DATA AND METHODS

The water resources of the study area are presented using the determined values of total runoff (total resources) and groundwater runoff (groundwater resources). Due to the complicated structure of the aquifers with varying and little known water-bearing capacity, hydrological methods, which are based on measurement of water flows in rivers, are the most useful methods under such conditions. The simplicity and objective approach to interpretation of input data are an additional advantage of these methods.

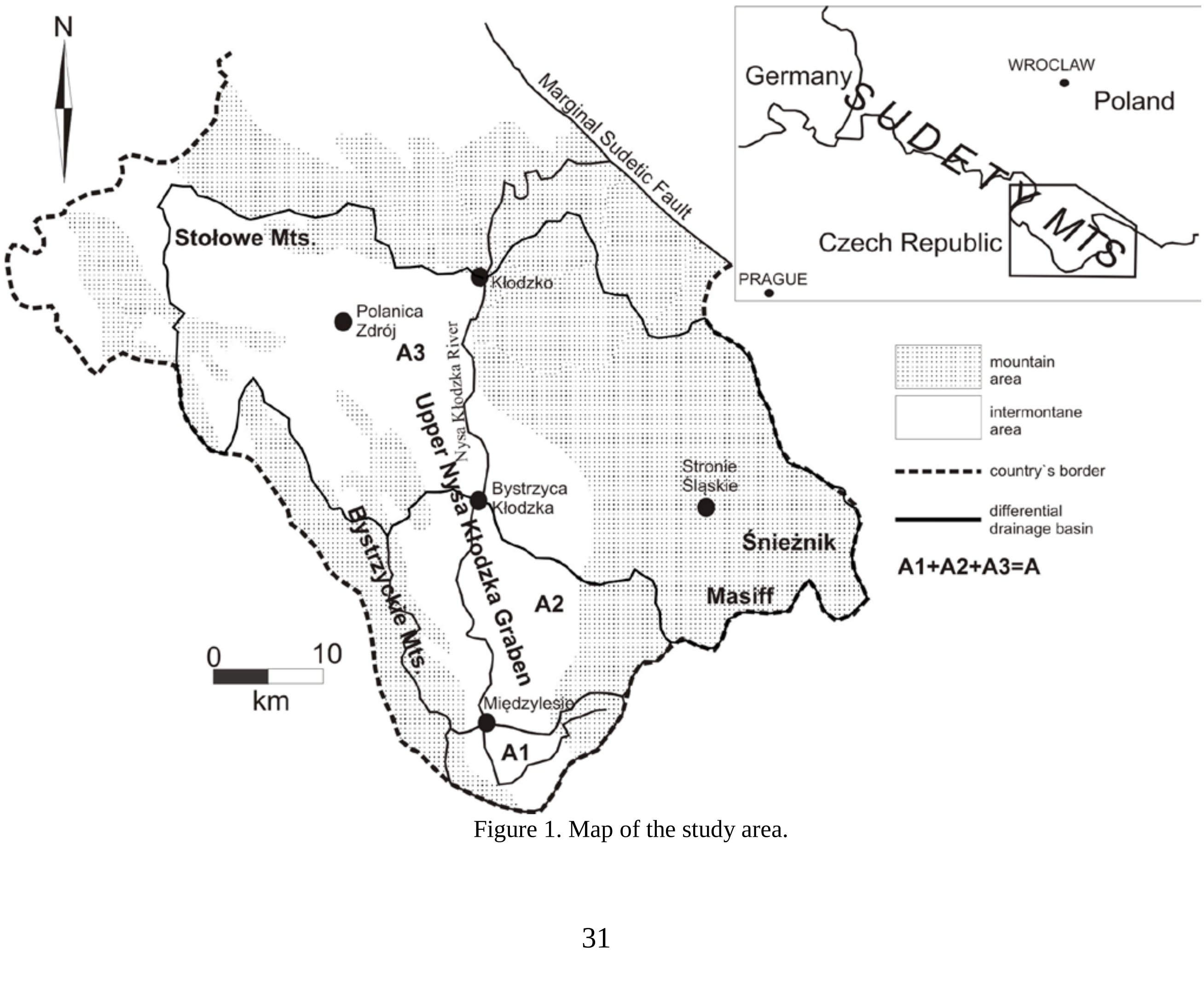

Figure 1. Map of the study area.

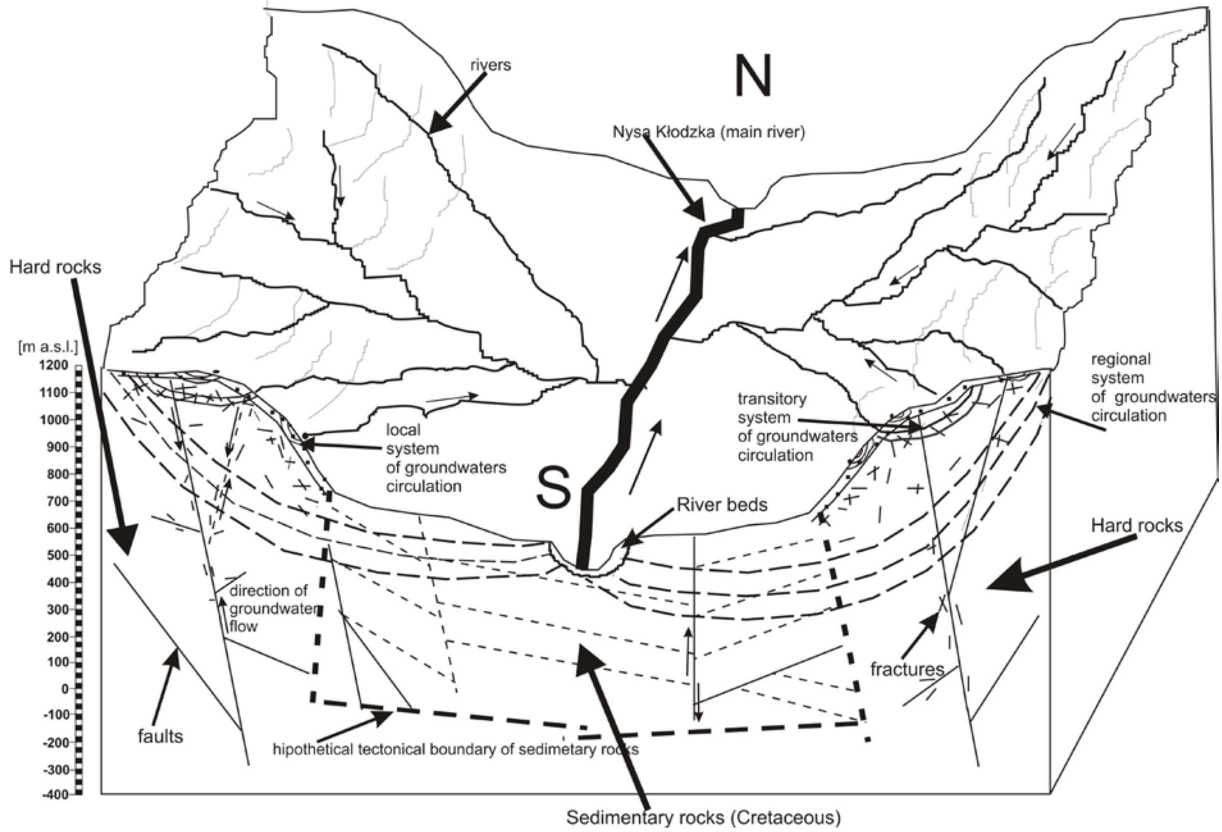

Figure 2. Scheme of groundwater circulation in the Kłodzko region (Olichwer, 2007).

The average monthly flow (SQ) values were used to determine total runoff. The Wundt method, which is based on average low river flows (NQ) and which assumes that the value of one of the characteristic flows is equal to the groundwater runoff value, was in turn used to determine groundwater runoff. In the Wundt method, the average long-term groundwater runoff from European rivers of the temperate zone is close to the average value of the minimum monthly flow (Sokołow & Sarkisjan, 1981). On the other hand, the average of the minimum annual values informs about the average long-term recharge.

The SQ and NQ values for the Nysa Kłodzka as well as the meteorological characteristics came from the Institute of Meteorology and Water Management (IMWM) (https://dane.imgw.pl). The data on hydrological years for the 50-year period (1967 – 2016) included the following: daily flows, monthly NQ and SQ values from 3 stations (Międzylesie, Bystrzyca Kłodzka, Kłodzko), average daily temperatures from the Kłodzko weather station, and average daily precipitation from the weather stations in Kłodzko, Bystrzyca Kłodzka, Międzylesie, Stronie Śląskie, and Polanica Zdrój. These data were mathematically and statistically transformed in order to obtain the following:

- annual precipitation totals for the period 1967-2016;
- average annual air temperature for the period 1967 – 2016;
- average annual values from the average and low flows (SQ and NQ) for the period 1967 – 2016.

In analyzing water resources, it is important to check the homogeneity of the river runoff observation series. Such investigation is carried out, among others, by analyzing the summation curves. If the series considered are homogenous, in such case the summation curves can be smoothed with straight lines. If any summation curve must be smoothed with two or more straight sections, it evidences that the homogeneity is not maintained and the balance should be determined for each section separately. The obtained summation curves for the river runoff values confirm the homogeneity of the data used for the characteristics. An example is Figure 3.

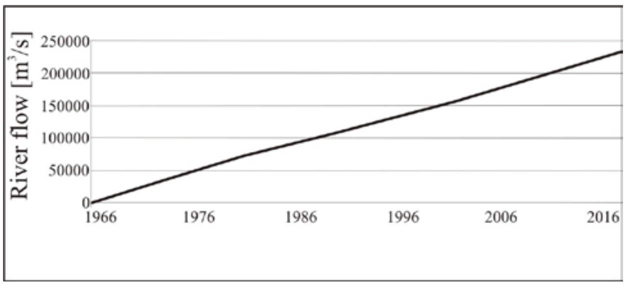

Figure 3. Summation curve of the Nysa Kłodzka river flow in Kłodzko.

Moreover, the analysis of the variability of runoff from the study area was performed separately for 5 ten-year periods as well as for the periods covering the winter half-year (November-April) and the summer half-year (May-October).

To assess the trends in changes in long-term runoff for the period 1967-2016, the linear trend function method was employed using Excel software. This method was applied to determine increasing or decreasing trends in precipitation based on the annual totals from the precipitation stations located within the study area. The same method was used to determine trends in total and groundwater runoff based on the average and minimum annual flows obtained from the Kłodzko gauging station. Nevertheless, the determined trend line for the entire long-term period does not reflect the fluctuations in precipitation and runoff which manifest themselves in short periods of the long-term period analyzed.

To assess the long-term fluctuations, the runoff and precipitation coefficients were used according to the following formula:

$K=\frac{Q_r}{Q_w}$ where:

K – runoff (precipitation) coefficient

Q_r – average annual flow [m^3/s] (annual total precipitation [mm])

Q_w – average long-term flow [m^3/s] (annual total precipitation [mm]).

This method allows us to distinguish years with higher or lower runoff (precipitation) relative to the long-term average – wet or dry years, and long-term fluctuations in the characteristics analyzed.

The results of the calculations for water resources are presented in tables (Tables. 1-4) and graphically (Fig. 4, Figs. 6-8).

On the basis of the total and groundwater runoff and meteorological data, the following different analyses and evaluations were carried out:

- estimation of the groundwater recharge coefficient ($\alpha=\frac{Q_g}{Q_t}$);
- estimation of the total and groundwater runoff modules (M_t, M_g);
- comparison of the total and groundwater runoff in the winter and summer seasons;
- variation in total and groundwater runoff in the following decades: 1967-1976, 1977-1986, 1987-1996, 1997-2006, 2007-2016;
- variation in total runoff and groundwater runoff over the long-term period 1967–2016 for the Nysa Kłodzka river river basin and the 3 differential river basins;
- long-term precipitation changes in the study area;
- long-term average temperature changes at the Kłodzko weather station.

Additionally, the HYSEP (Hydrograph Separation Program) program was used for determination of base runoff (groundwater runoff) and to verify the Wundt`s method. HYSEP is a computer program used to separate a streamflow hydrograph into groundwater discharge and the surface-runoff with precipitation that enters the stream as overland runoff (Sloto & Crouse, 1996; Barlow, et al., 2014). Groundwater runoff was calculated using fixed-interval method. According to this method, to determine the groundwater runoff the lowest value of the flow on the hydrograph is determined for a fixed time period (7 days) for all days, starting with the first day of the period of record.

4. RESULTS AND DISCUSSION

The total water resources Q_t (total runoff) of the study area are 13.01 m^3/s (382 mm) (Tab. 1), which is a 50 percent contribution to the water balance of the Nysa Kłodzka river basin terminated by the Kłodzko hydrological gauging station. For comparison, the average long-term precipitation for the period 1967-2016 was 751 mm. The average value of the total runoff module (M_t) for the 50-year period was 12.1 dm^3/s· km^2 (Table 2).

Table 1. Characteristics of the average annual total and groundwater runoff [mm].

Nr.	Gauging station	Surface A [km^2]	Q_t	Q_t winter	Q_t summer	Q_g	Q_g winter	Q_g summer	α [%]		
									1	2	3
A	Kłodzko	1084	382	416	348	138	119	121	36	29	35
The differential river basin											
A1	Międzylesie	49.7	437	558	317	133	114	95	30	20	30
A2	Bystrzyca Kłodzka	210.3	498	599	399	100	77	82	20	13	21
A3	Kłodzko	824	348	336	360	154	129	133	44	38	37

Q_t – total runoff, Q_g – groundwater runoff, α - groundwater recharge coefficient, 1 – annual, 2 – winter, 3 - summer

Table 2. Average total and groundwater runoff: 1967-2016

	Q_t [m^3/s]			Q_g [m^3/s]			M_t dm^3/s· km^2]			M_g dm^3/s· km^2]		
	1	2	3	1	2	3	1	2	3	1	2	3
A	13.01	14.29	11.96	4.75	4.09	4.19	12.10	13.18	11.03	4.38	3.77	3.87
The differential river basin												
A1	0.69	0.88	0.5	0.21	0.18	0.15	13.88	17.71	10.06	4.23	3.62	3.02
A2	3.32	4.00	2.66	0.67	0.52	0.55	15.79	19.02	12.65	3.19	2.47	2.62
A3	9.10	8.80	9.42	4.04	3.39	3.49	11.04	10.68	11.43	4.90	4.11	4.24

M_t – total runoff module, M_g – groundwater runoff module, 1 – 1967-2016, 2 – winter, 3 – summer

For the period 1967-2016, the average groundwater runoff, associated with dynamic groundwater resources, was 4.75 m^3/s (138 mm) (Tables 1-2), which accounts for 36 % of the total runoff and for 19 % of the precipitation. For comparison on the basis hydrograph separation (HYSEP program) the groundwater runoff was equal to 5.15 m^3/s, which accounted for 38 % of the total water resources and 20 % of the precipitation. The average value of the groundwater runoff module (M_g) was 4.38 dm^3/s· km^2 (Table 2). Both in the summer and winter seasons, similar groundwater runoff values are recorded at a level of 120 mm (Tab. 1). A much greater variation in groundwater runoff is observed in the case of interannual values. The lowest value of the average groundwater runoff was found in 2016 (1.77 m^3/s), and it was almost 4.5 times lower than the maximum value recorded in 1967 (7.8 m^3/s) (Fig. 4).

The total resources of the differential river basins are from 348 mm (river basin A3) to 498 mm (river basin A2). The total runoff values are higher during the winter period (Tables 1-2). The lowest groundwater runoff was recorded in river basin A2 (100 mm), while the highest one in A3 (154 mm). The winter period is not observed to have a dominant contribution to the groundwater resources, as in the case of the total water resources. In the differential river basins, the percentage of groundwater recharge in the total resources ranges from 20 to 44 % (Table 1).

There is no clear spatial variation in groundwater resources. The groundwater runoff modules of the differential river basins range 3-4 dm^3/s· km^2 (Table 2), without a clear predominance of the summer or winter period. The situation looks different in the case of total resources where a larger variation in resources can be seen. The highest values of the total runoff module were calculated for river basin A2 (15.79 dm^3/s·km^2), while the lowest ones for river basin A3 (11.04 dm^3/s· km^2) (Table 2). It can also be seen that the winter period has a distinctly higher percentage in the total resources (Table 1).

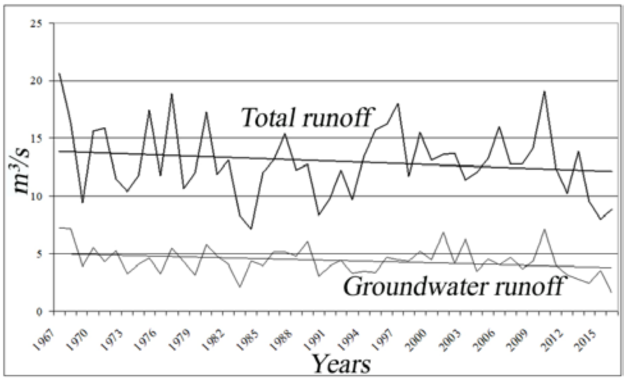

Figure 4. Trends in changes in total and groundwater runoff in the Nysa Kłodzka river river basin.

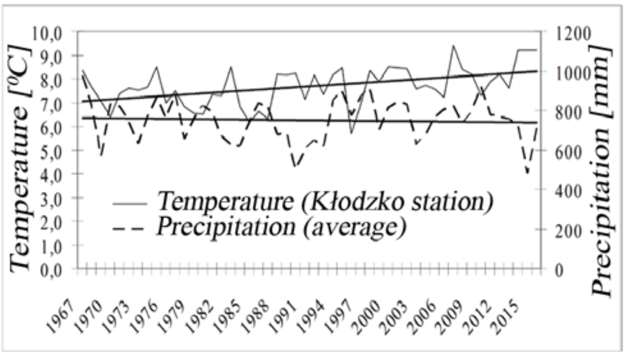

Figure 5. Long-term temperature and precipitation changes in the study area.

Table 3. Average total and groundwater runoff by decade.

	Q_t [m^3/s]					Q_g [m^3/s]				
	1	2	3	4	5	1	2	3	4	5
A	14.08	12.43	12.57	13.82	12.16	5.26	4.66	4.59	5.16	4.06
The differential river basin										
A1	0.60	0.67	0.67	0.82	0.68	0.17	0.21	0.18	0.20	0.18
A2	4.22	3.12	3.45	3.38	2.35	1.01	0.58	0.51	0.71	0.56
A3	9.25	8.64	8.44	9.62	9.13	4.38	4.01	4.08	4.35	3.39

1 - 1967-1976, 2 - 1977-1986, 3 - 1987-1996, 4 - 1997-2006, 5 – 2007-2016

Table 4. Groundwater runoff in the summer and winter seasons.

	Q_g [m^3/s]									
	1967-1976		1977-1986		1987-1996		1997-2006		2007-2016	
	1	2	1	2	1	2	1	2	1	2
A	4.67	5.04	3.93	4.19	3.92	3.85	4.18	4.15	3.67	3.40
The differential river basin										
A1	0.17	0.17	0.18	0.21	0.18	0.10	0.20	0.15	0.17	0.08
A2	0.61	0.98	0.38	0.48	0.45	0.26	0.61	0.49	0.52	0.45
A3	3.88	3.89	3.37	3.50	3.28	3.47	3.36	3.50	2.98	2.86

1-winter season, 2- summer season

The highest average groundwater resources (5.26 m^3/s) were found in the decade 1967-1976 (Table 3), whereas the lowest ones (4.06 m^3/s) during the period 2007-2016. The differences in groundwater runoff between the individual 10-year periods reach almost 23 %. As far as the total runoff is concerned, only the decade 1967-1976 is characterized by higher resources, while in the other periods there is no large variation in total runoff (Table 4).

Precipitation provides the main water input to the river basin. It affects the water balance structure, water availability, and the runoff regime. The average precipitation in the study area was determined based on data from IMWM's five precipitation stations (Kłodzko, Bystrzyca Kłodzka, Międzylesie, Stronie Śląskie, and Polanica Zdrój) using the arithmetic average method. Over the long-term period, the average annual total precipitation for the study area ranged from 478 mm in 2015 to 974 mm in 1967 (Fig. 5). The average annual total precipitation for the study area was 751 mm. The highest average annual total precipitation is recorded in the eastern and western parts of the study area represented by mountainous areas where the highest recorded annual total precipitation was 1133 mm (Stronie Śląskie – 1975). The lowest precipitation was recorded in Kłodzko in 2015 (321 mm).

The river basin water balance is also influenced by thermal conditions, resulting in a higher or lower proportion of evaporation in the balance. The analysis was performed based on the data from the Kłodzko weather station. The average air temperature for the long-term period 1967-2016 was 7.7 ^{0}C. The highest average air temperature of 9.4 ^{0}C was recorded in 2007, while the lowest one (5.7 ^{0}C) in 1996 (Fig. 5).

Based on the analysis of the total and groundwater runoff and meteorological data (precipitation, temperature), the contribution of groundwater resources to the total water balance in the study area is observed to be decreasing, in particular during the last decade 2007-2016 (Fig. 6).

Over the long-term period 1967-2016, the average percentage of groundwater runoff in precipitation was 19 %, reaching the minimum value during the last decade (16%), whereas in the hydrological year 2016 the percentage contribution of groundwater runoff to the total water balance was only 8 percent.

The above described situation is not reflected in the total runoff, which is on average 50 % of the precipitation and does not change in the individual decades since this percentage ranges from 48 to 52 %. It is affected by the increased percentage of surface runoff in the river basin water balance at the expense of groundwater runoff.

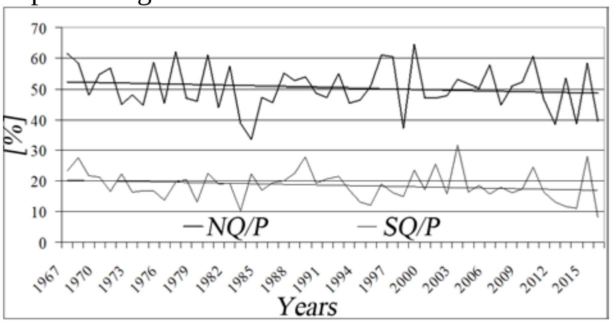

Figure 6. Percentage of total and groundwater runoff in precipitation.

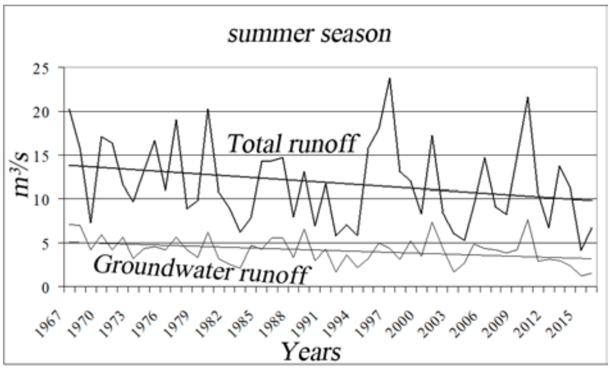

Figure 7. Trends in total and groundwater runoff in the summer season.

In analyzing the variability of total and groundwater runoff over the period 1967-2016, decreasing trends in total and groundwater runoff are observed over this entire long-term period (Fig. 4). This is primarily due to very visible decreasing trends during the summer period (May – October)

(Fig. 7) and it relates to both total and groundwater runoff. During the winter period, a slight decreasing trend in groundwater runoff can only be seen (Fig. 8), with simultaneous stabilization of the total runoff.

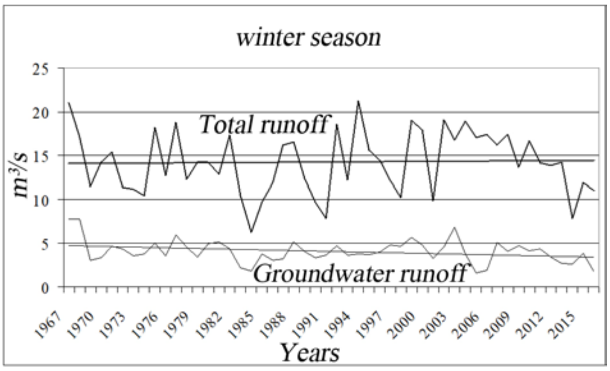

Figure 8. Trends in total and groundwater runoff in the winter season.

The above analysis shows that groundwater recharge primarily occurs at the turn of winter and spring when substantial amounts of water are released from snow cover and snow melt, which is additionally accompanied by high rainfalls. Therefore, the winter period plays a decisive role in determining the water regime of the study area (Tarka, 1997). Rainfall during the summer half-year, even though it accounted for more than 50 % of the annual total precipitation, was of lesser importance for groundwater recharge than the precipitation during the winter half-year. The rainfall in the summer half-year was predominantly "consumed" by plants being in the growing season at that time and by increased evapotranspiration.

5. CONCLUSIONS

On the basis of the obtained results, the Nysa Kłodzka river basin should be classified as an area of high hydrological activity. The average annual total runoff for the period 1967-2016 was 13.01 m^3/s (0.410 km^3). The variability of the total runoff from the study area is relatively high, as evidenced by the ratio of the maximum (0.632 km^3 in 1994) and minimum (0.223 km^3 in 1984) annual runoff, which is 2.83. Expressed on a unit area basis, the average values of the water resources are from 6.55 $dm^3/s \cdot km^2$ in extremely dry years through 12 $dm^3/s \cdot km^2$ in average years to 19 $dm^3/s \cdot km^2$ in extremely wet years. These values are in good agreement with the average unit runoff for the mountainous parts of the Odra River basin (Gutry-Korycka, et al., 2014).

The groundwater runoff variability was greater than the total runoff variability. The ratio of the maximum (7.8 m^3/s in 1967) and minimum (1.77 m^3/s in 2016) annual groundwater runoff was 4.4. The high temporal variability of runoff is proportionately translated into changes in the river basin water resources.

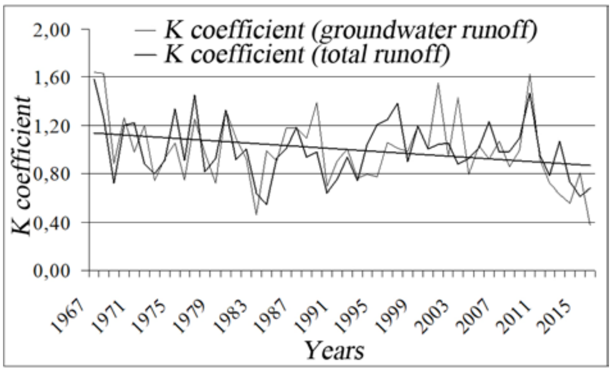

Figure 9. Variability of the K coefficient for total and groundwater runoff.

The K coefficient (the quotient of the average annual value and the long- term average) for the total runoff ranged from 0.55 (1984) to 1.58 (1967), whereas for the groundwater runoff from 0.37 (2016) to 1.64 (1967). Moreover, a trend towards a decrease in the K coefficient over time is noticeable (Fig. 9), which averages an increasingly greater downward deviation of the annual water resources of the river basin in relation to the average long-term values.

When analyzing the spatial variation in groundwater runoff, in the central part of the area in question, which corresponds to river basin A2 (Fig. 1), the groundwater resources were found to have lower values compared to the remaining part of the study area. Both the groundwater runoff and the modules have the lowest values (Table 2). Additionally, the percentage contribution of groundwater recharge to the total runoff was also lowest (20 % - Table 1). Furthermore, the relatively highest total runoff modules were found in river basin A2 (15.79 $dm^3/s \cdot km^2$ - Table 2). This is due to the fact that in this part of the Nysa Kłodzka river basin the surface runoff (4 times higher than the groundwater runoff) and evapotranspiration play a decisive role in determining the water balance.

The HYSEP program was used to verify the method used in the characteristics of the runoff variability in study area. Mean river flow from period 1967-2016 was equal to 13.21 m^3/s and on the basis hydrograph separation the groundwater runoff was equal to 5.15 m^3/s, which accounted for 38 % of the total water resources and 20 % of the precipitation. Similar values were obtained, as in the case of SQ and NQ values (13.01 m^3/s and 4.75 m^3/s).

The climatic scenarios show a quite

significant increase in air temperature (+ 0.9 ^{0}C for SW Poland) and small differences in precipitation levels (a decrease during the summer and autumn period and an increase during the winter and spring period) (Wibig, et al., 2012). Moreover, the precipitation structure is predicted to change over the next several dozen years, which can have a great effect on the groundwater resources. It is anticipated that rainfalls of great intensity will occur more frequently and that rainless periods will become longer. Given that the annual total precipitation shows little variation, it will result in decreased infiltration of precipitation at the expense of increased surface runoff, in particular in mountainous areas.

The long-term decreasing trends in the runoff from the Nysa Kłodzka river basin, in particular during the summer season, are the result of the greater contribution of evaporation to the river basin water balance. An increasing trend in average annual air temperatures can be seen in the study area over the last 50 years (Fig. 5), which is confirmed on the example of observations in Kłodzko where an increase in temperature by about 1.3°C was recorded.

The variation in the annual total precipitation and temperatures, or even in the total runoff, was lower than the variation in the groundwater runoff. The probable reason for the high groundwater runoff variability is the impact of a greater number of elements which are characteristic for the defined study area than in the case of precipitation or air temperature. Apart from precipitation, such elements can include infiltration capacity, groundwater recharge, or forest cover.

The temporally variable water resources within the study area should be used in a well thought-out and rational manner. The above results confirm the need to slow down surface water runoff and to improve the water retention capacity through various types of hydraulic measures. In the event that the not very optimistic climate change scenarios prove true, the small groundwater resources will periodically become a barrier to further economic development, in particular tourism in the Kłodzko region, the more so that already now periodic water deficits are noticeable, especially during the summer period.

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