Application of macrophytes to compare the assessment of the ecological status of the Pilica River in years 2012 - 2015

Application of macrophytes to compare the assessment of the ecological status of the Pilica River in years 2012 - 2015

T Orliński[1,*]

[1] Department of Environmental Engineering, Institute of Water Supply and Environmental Protection, Krakow University of Technology, Warszawska 24 street, 31-155 Krakow, Poland

E-mail: t.orlinski1990@gmail.com

Abstract. Directive 2000/60/EC commonly called the Water Framework Directive defined as a new way of assessing the state of surface water based on two types of water bodies: natural and artificial or heavily modified water body. The assessment is made by comparing surface water status with the reference state, that is, a state close to completely natural one, based on biological, physicochemical and hydromorphological elements. The ecological state of surface water, together with the surface water chemical status is used to determine the general surface water status. The ecological state of surface water is responsible for the quality of the structure and the functioning of the aquatic ecosystem, while the chemical state is responsible for appearance in water of particularly harmful substances for the aquatic environment. The present paper compares the ecological status of the Pilica river waters in 2012 – 2015 with the use of aquatic plants as ecological quality indicators according to the requirements of the Water Framework Directive. Research was conducted in three different sections of the Pilica river, which were within the boundaries of separate but adjacent surface water body. The field research were carried out using a Polish research method called The Macrophyte Method for River Assessment (MMRA). The method is based on quantitative and qualitative evaluation of species compositions of macrophytes within a designated river section. MMRA allows the evaluation of the macrofit reaction (bioindicators of ecological quality) mainly on the degradation associated with trophic impurities. This method has been developed and successfully used to assess ecological status of rivers throughout the country. In this article, special emphasis was placed on comparative analysis of results obtained from field measurements in the years 2012 – 2015, supported by theoretical knowledge on the assessment of ecological quality of surface water. The results of the evaluation showed improvement of the ecological status of the Pilica river on two research sections: Przyłęk and Kuźnica Wąsowska, and a slight decrease on quality on the Szczekociny research section.

1. Introduction

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 commonly called the Water Framework Directive (WFD) defined the framework for the European Community's water management activities. Its main purpose is to improve the water environment, ensure access to good water quality, rational use and conservation of water resources in line with the principle of sustainable development. The Directive introduced an innovative way of assessing by comparing the state of a surface water body (SWB) with a reference state, that is, a state close to completely natural.

Flowing water is classified as a component of a complex river ecosystem, which is a living environment of biocenosis, a population of plant, animal and microbial organisms.

Ecological status and potential assessment is based on biological elements such as phytoplankton, phytobentos, macrophytes, benthic macroinvertebrates and ichthiofauna. In addition, physicochemical and hydromorphological assessments are used as supporting elements of biological evaluation. The overall assessment of surface water bodies also includes a chemical state that determines the water content of particularly hazardous substances in the aquatic environment [5].

Field studies on the MMOR method were conducted in the years 1995 – 2007 [9]. The research has shown that the method gives a repeatable and precise results, and the assessment of the error related to the method, field factors and personnel performing the tests allows its use in monitoring [3].

The method should not be used to assess the degradation of rivers caused by non-trophic factors (heavy metals, acidification, hydromorphological transformations or toxic substances) due to the high risk of error. Conditions that impede the research are: high level and low water transparency, insufficient lighting, cutting of water plants and difficult access to the test stand. The section should be characterized by: varied conditions in terms of flow velocity, shading and sediment formation, and researchs should be performed during the advanced development of aquatic vegetation [3].

This article is a comparison of the ecological status of the Pilica river waters in the years 2012 - 2015, carried out by using aquatic plants as ecological quality indicators, which was required by the WFD. The use of macrophytes makes it possible to link the quality of the biotope to the quality of surface water. Aquatic plants are an optimal bioindicator for biological assessment of surface water quality due to the long reaction time to physicochemical changes in water than in case of most aquatic organisms [8].

2. Scope and methodology of the study

The Pilica River was chosen as the research area. It is located in the south-central Poland, in the Silesian Province. Pilica is the longest left-bank tributary of the Vistula with a total length of 319 km. The catchment area of 9 273 km2 belongs to the Central Vistula water region and the Central Plains ecoregion [10]. According to the "Water Management Plan in the Vistula River Basin", the Pilica fragment covered by the study is SWB No. PLRW20009254157 recognized as a natural part of waters of poor condition and SWB No. PLRW200092541711 recognized as a natural part of waters of good condition [10]. In the abiotic classification of surface water types, the Pilica River within the confines of both SWBs, was identified as a small carbonate upland type 9 [10]. Much of the river valley is within the Natura 2000 network [11].

Field studies were conducted in the second half of August 2012 and 2015 on 3 representative measurement sites of the Pilica River (Szczekociny, Przyłęk and Kuźnica Wąsowska). The study sections reflect different degrees of anthropogenic transformation of the trough and river valley and were within the boundaries of distinct but adjacent homogeneous bodies of surface waters (figure 1). The characteristics of the research stations are presented in the table below.

Table 1. Characteristics of measurement stations

Name of the river	Abiotic type [a]	Surface water body [a]	Measurement stand	Character of the position	Geographical coordinates
Pilica	small carbonate upland - type 9	PLRW20009254157	Przyłęk	natural	N 50°41’48,9’’ E 19°44’5,85’’
			Szczekociny	converted	N 50°37’33.43’’ E 19°49’25,09’’
		PLRW200092541711	Kuźnica Wąsowska	semi-natural	N 50°44’9,49’’ E 19°41’17,97’’

[a] data source: [10]

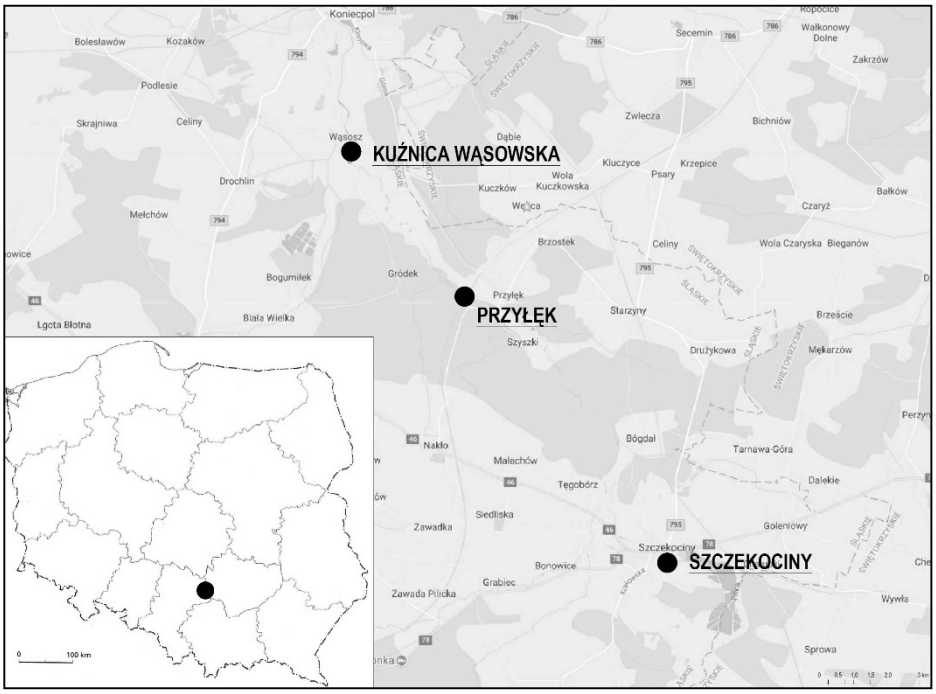

Figure 1. Location of measurment sites (data source: www.googlemaps.pl).

The biological evaluation of analyzed WFDs that has been utilized with The Macrophyte Method for River Assessment (MMRA), is based on the reaction of macrophytes - bioindicators of ecological quality and on the degradation of surface water ecosystems. MMRA uses 153 plant species, including vascular plants, mosses, algae, liverworts, and ferns. The method is based on the quantitative and qualitative assessment of the species composition in the river beds, and can therefore be used to assess the ecological status of all types of surface water [4, 9, 12].

Field studies were based on the description of the measuring stations, i.e. representative of the WFD, lengths of 100 m, characterized by high abundance and high diversity of macrophytes. The abiotic characteristics of the habitat were supplemented by photographic documentation and sketches of the site. The qualitative assessment includes the species designation of aquatic plants, while the quantitative assessment estimates the area the plants occupy in the river bed. A special MMRA form was used to record the data collected during field measurements, the so-called repository for lowland rivers.

The quantitative and qualitative assessment of species composition and of aquatic plants found in the studied watercourse has allowed calculation of the so-called Macrofit River Index (MRI), a biological indicator of ecological quality of flowing waters. MRI-referring to the reference values for that type of abiotics and macrobiotics river does allow to see the condition of ecological evaluation of testing SWB, in accordance with the requirements of the RDW [5]. The MRI index was calculated according to the following formula [3]:

$$MRI = \frac{\sum\left(L_i \cdot W_i \cdot P_i\right)}{\sum\left(W_i \cdot P_i\right)} \cdot 10 \tag{1}$$

where:

L_i - the number of indicator values of the i-th aquatic plant species; The average trophic level (aquatic fertility) ranges from 1 to 10. Small numbers ($L \leq 3$) are characteristic of plants preferring eutrophic waters, while high indicator values ($L \geq 8$) are characterized by macrophytes occurring in oligotrophic waters, poor in biogene.

W_i - the weight factor of the i-th aquatic plant species is a measure of ecological tolerance of a given macrophytic species for environmental factors and may range from 1 to 3. We distinguish stenotopic plants with narrow ecological tolerance (W = 3) and high - (W = 1).
P_i - coefficient of coverage of the river bed by the i-th water plant species, according to a 9-degree scale, expressed as a percentage.

3. Results of the study

3.1. Macrophytes characteristics of measuring stations

In the study, four to nine species of aquatic plants were identified on each site, of which only one. *Phragmites australis* was not an indicator plant species used in the MMRA method. Such an amount of identified species is sufficient to carry out an ecological quality assessment based on macrophytes. The designated macrofit species, together with their indicator values, weight ratios and coverage ratios used in the MMRA method, are presented in tables 2-4.

In all three research sections, a total of 12 species of macrophytes were identified in 2012-2015. The dominant group was submerged vascular plants (31.3% of all identified species) and vascular plants emerged - monocotyledons (31.3%). A significantly lower proportion were vascular plants with floating leaves (12.5%) and emerged vascular plants - dicotyledons (12.5%), then mosses (6.2%) and macroscopic algae (6.2%) were placed. The species that appeared most often, identified in all three research sections was *Sparganium erectum*. *Veronica anagallis-aquatica* and *Lemna Minor* were also often found and identified in two sections of Pilica.

Table 2. Qualitative and quantitative characteristics of macrophytes in the research section "Przyłęk"

No.	**Identified species of aquatic plants**		**Li**	**Wi**	**Coverage factor (Pi)**	
	Name	Group of plants			2012	2015
1	*Vaucheria sp.*	Macroscopic algae	2	1	4	3
2	*Elodea canadensis*	Submerged vascular plants	5	2	5	6
3	*Potamogeton crispus*	Immersed vascular plants with floating leaves	4	2	3	3
4	*Sparganium erectum*	Emerged vascular plants - monocotyledons	3	1	6	5
5	*Veronica anagallis-aquatica*	Emerged Vascular plants - dicotyledons	4	2	4	5
		MRI			38,82	42,65

Table 3. Qualitative and quantitative characteristics of macrophytes in the research section "Kuźnica Wąsowska"

No.	Identified species of aquatic plants		Li	Wi	Coverage factor (Pi)	
	Name	Group of plants			2012	2015
1	*Fontinalis antipyretica*	Mosses	6	2	2	4
2	*Lemna minor*	Submerged vascular plants	2	2	4	3
3	*Spirodella polyrrhiza*		2	2	4	4
4	*Ranunculus circinatus*		5	2	4	5
5	*Potamogeton pectinatus*	I Immersed vascular plants with floating leaves	1	1	3	2
6	*Sparganium emersum*	Emerged vascular plants - monocotyledons	4	2	6	6
7	*Sparganium erectum*		3	1	6	6
8	*Phragmites australis*		Macrofit is not an indicator species in MMRI			
9	*Veronica anagallis-aquatica*	Emerged vascular plants - dicotyledons	4	2	2	2
		MRI			34,15	39,62

Table 4. Qualitative and quantitative characteristics of macrophytes in the research section "Szczekociny"

No.	Identified species of aquatic plants		Li	Wi	Coverage factor (Pi)	
	Name	Group of plants			2012	2015
1	*Lemna minor*	Submerged vascular plants	2	2	2	3
2	*Phalaris arundinacea*	Emerged vascular plants - monocotyledons	2	1	6	5
3	*Sparganium erectum*		3	1	7	6
4	*Phragmites australis*		Macrofit is not an indicator species in MMRI			
		MRI			24,12	23,53

3.2. Identification of ecological status / potential of Pilica river

The characterization of macrophytes, which is within the meaning of the Water Framework Directive, has allowed the biological status of the Pilica River to be determined within the limits of the Surface Water No PLRW20009254157 and PLRW200092541711. The results of the evaluation are presented in tables 5 - 6.

Table 5. Results of the assessment of the ecological status of the Pilica river in individual SWBs in 2012

Episode research			MRI	Quality class	Ecological status	
No.	Name	Character			Episode research	SWB
Surface water body no PLRW20009254157						
1	Przyłęk	natural	38,82	III	Moderate (close to good)	Moderate
2	Szczekociny	converted	24,12	IV	Weak	
Surface water body no PLRW200092541711						
3	Kuźnica Wąsowska	semi-natural	34,15	III	Moderate	Moderate

Table 6. Results of the assessment of the ecological status of the Pilica river in individual SWBs in 2015

Episode research			MRI	Quality class	Ecological status	
No.	Name	Character			Episode research	SWB
Surface water body no PLRW20009254157						
1	Przyłęk	natural	42,65	III	Good	Moderate
2	Szczekociny	converted	23,53	IV	Weak	
Surface water body no PLRW200092541711						
3	Kuźnica Wąsowska	semi-natural	39,62	III	Moderate (close to good)	Moderate

4. Analysis of results and discussion

A reliable assessment of the ecological status of surface water, conducted using the MMRA method, depends not only on the correct identification of water plants occurring in the river bed, but also on diversity of the present species. Compliance with this latter criterion excludes the impact of a random single taxon on the final value of the Macrophytic River Index. In the study sites there were identified from four to nine species of aquatic plants, of which only one - *Phragmites australis* was not an indicator species used in the MMRA method. Such an amount of identified species is sufficient to carry out an ecological quality assessment based on macrophytes.

The greatest biodiversity was characterized by the "Kuźnica Wąsowska" semi-natural section (9 species), while the smallest section was transformed into "Szczekociny", where only 3 species of aquatic plants were identified. An ecological status assessment based on 3 indicator species was possible for two reasons. Firstly, all macrophytes were species specific to eutrophic waters, whose indicator value L ranged from 1 to 3. Secondly, these species predominated in the river bed, i.e. they were characterized by an extremely high coverage of the test section, which was up to 50% of its area. It is worth noting that none of the analyzed pilots of the Pilica River did not exhibit macrophytes characterized by low ecological tolerance, i.e.the high value of the weight factor (W = 3).

All identified plants belonged to the group of eurytopus plants - organisms that are highly tolerant to changes occurring in the aquatic environment. It is also noteworthy that all macrophytes, preferring eutrophic or mesotrophic waters and the total absence of plants preferring oligotrophic waters, so low biogenic water. This is clearly visible in the diagram of the distribution of the indicator L (reflecting the mean water fertility level), which for all identified macrophiles did not exceed 6 (Figure 2). On this basis, it was found that the water in the studied sections of the river was characterized by increased content of biogenic substances, i.e.nitrogen and phosphorus.

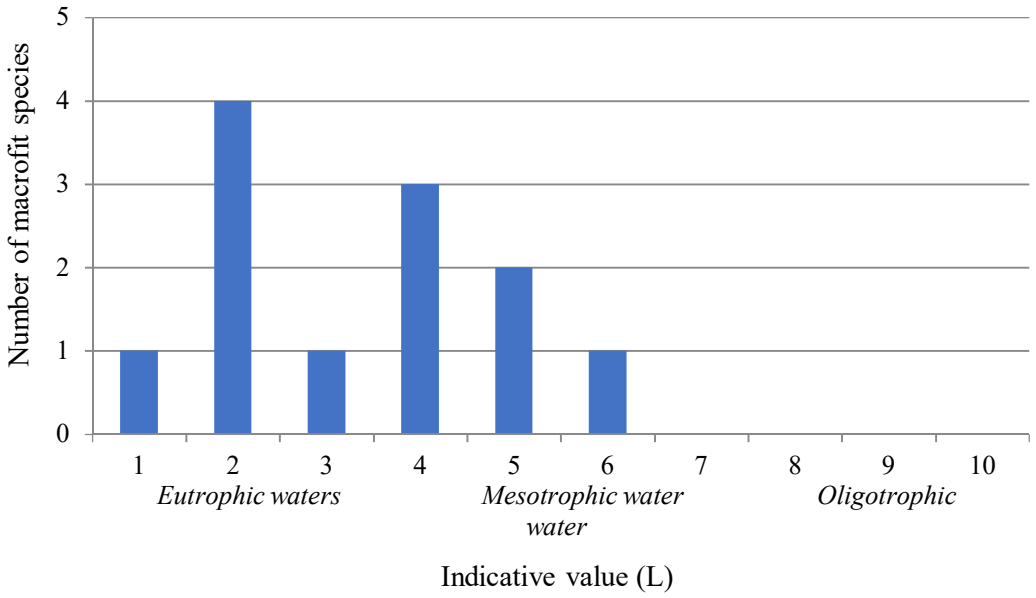

Figure 2. Distribution of indicator values of macrophytes identified during Pilica river research.

It is also worth to pay attention to one more aspect of research. Two of the three species occurring in the transformed section of "Szczekociny", also appeared in the semi-natural section "Kuźnica Wąsowska", whereas 60% of the macrophytes occurring at the "Przyłęk" natural site were not identified in the remaining sections (Table 7). This allows us to come up with a hypothesis about the relationship between the degree of anthropopressure and the diversity of the share of particular species of aquatic plants - as human influence on the river is bigger, the diversity of macrophytes is smaller.

The largest surface area of the bottom in the three study sections (coverage factor 6 – 7) was occupied by the *Sparganium erectum*, which is characterized by a low indicator value (L = 3), which means that it prefers fertile water, i.e.rich in biogens. This is another proof of the eutrophicity of Pilica waters within the surface water body tested. Next to *Sparganium erectum*, the remaining dominant species, which occupy the largest surface area in the study sections, were: *Phalaris arundinacea* and *Sparganium emersum*. These aquatic plant species show low indicator value and often prefer converted habitats. Thus, they can be considered as good indicators of the pollution of the aquatic environment at Pilica biogenes.

Table 7. The species diversity of macrophytes in studied sections of the Pilica River, depending on the degree of anthropogenic transformation of the trough and the river valley.

No.	Identified species	The nature of the river and the valley (research section)		
	Name	Natural „Przyłęk”	Semi-natural „Kuźnica Wąsowska”	Transformed „Szczekociny”
1	Phalaris arundinacea			+
2	Lemna minor		+	+
3	Sparganium erectum	+	+	+
4	Ranunculus circinatus		+	
5	Sparganium emersum		+	
6	Potamogeton pectinatus		+	
7	Spirodella polyrrhiza		+	
8	Fontinalis antipyretica		+	
9	Veronica anagallis-aquatica	+	+	
10	Vaucheria sp.	+		
11	Potamogeton crispus	+		
12	Elodea canadensis	+		

The influence of anthropogenic transformations in river channel morphology on the species diversity of plants present in it was also observed. A slight modification of the trough, in the form of a water level in the "Kuźnica Wąsowska" section, has resulted in the increase of species diversity among water vegetation in relation to the completely natural section of the "Przyłęk" stand. However, the advanced transformations observed at the "Szczekociny" stand (the consolidation and profiling of the banks stretching across the city) have resulted in a significant decrease in species diversity over the remaining research stretches on the Pilica River.

There is also a slight deviation from the observed regularity, which indicates that along with the course of a given river the ecological quality of the river decreases, reflecting the decreasing value of the Macro River Index. Pilica within the boundaries of the SWB did not show such dependence, since its ecological status ranged between weak (Szczekociny) and moderate (2012) and good (2015) (Przyłęk). This situation was caused not only by the point inlet of biogens, e.g. in the form of discharge of treated wastewater but also by the way of development of areas directly surrounding the river bed. The section showing a weak ecological state was in the middle of Szczekociny. The city is canalized only in 30% and only 50% of the total amount of sewage discharged directly to Pilica is purified [7]. In addition, near the river there are single-family buildings and roads, which are respectively area and linear source of pollution of surface water.

Going further along the river (Szczekociny - Przyłęk section), Pilica flows through natural areas, dominated by forests, meadows and farmland, belonging to the Natura 2000 area, where the river is self-purifying. Significant importance in the self-purification of Pilica waters has a wide belt of buffer vegetation forming a so-called ecotonic zone, which separates the river from the extensively cultivated meadows and fields. As a result, the area charge of the inflow is reduced.

Another section of the river, i.e. Przyłęk - Kunica Wąsowska, is characterized by partial human pressure on the river ecosystem, through intensive farming conducted in the river valley. The arable land is directly adjacent to the river bed, and unoccupied villages are nearby. Area contaminants, mainly in the form of nitrogen and phosphorus from mineral fertilizers used in agriculture, cause a decrease in the ecological quality of Pilica.

In summary, the main reason for the moderate ecological status of the Pilica River is pollution from point sources (discharges of sewage) and areas located along the riverbed (urban or agricultural areas). Elevated biogen levels in Pilica waters result in moderate ecological status and dominance of macrophytes preferring the eutrophic environment.

It should be emphasized that the quality of water in the Pilica River at the turn of the last years is partially improving. According to a study carried out by WIOŚ 2011b, the waters of the Pilica River in the section Szczekociny - Koniecpol (both examined in the SWB) showed a weak ecological status (IV quality class) [13]. In the meantime, the results of this study showed an improvement to moderate (2012) and good state (2015).

Within 3 years no new species of macrophytes have been observed at research sites. The identified water plants changed only the percentage of river bed bottom coverage (Pi). On the research sites, oligotrophic and oligootrophic plants, with narrow ecological tolerance, began to dominate. This demonstrates the reduction of the charge of biogenic impurities occurring in the watercourse.

This result was mainly influenced by the new high efficiency effluent treatment plant of the dairy cooperative in Szczekociny. Putting into operation of the sewage plant in the third quarter of 2014, significantly reduced the amount of pollutants discharged into the river, so the self-cleaning process has improved.

5. Conclusions

The results of the study lead to the following conclusions:

1. The Pilica River within the boundaries of the Surface Water Body No. PLRW20009254157 and PLRW200092541711 is characterized by a moderate ecological status.
2. Pilica's ecological state within the SWB limits - within three years has significantly improved.
3. The studied pathway should be included in eutrophic waters contaminated with excessive nitrogen and phosphorus, as evidenced by the following results on water vegetation identified in Pilica:
    a. all macrophytes were species preferring eutrophic or mesotrophic waters, very often well tolerating morphological changes in the river bed;
    b. *Sparganium erectum*, which prefers eutrophic waters rich in biogens, has the highest surface area in all research sections;
    c. no species specific to oligotrophic waters have been identified.
4. The moderate ecological quality of the Pilica River is further confirmed by two facts:
    a. most species of macrophytes identified during the study belonged to eurytopus plants, which are highly tolerant to changes occurring in the aquatic environment;
    b. no stenotopic species with low ecological tolerance have been identified.
5. There was no observed deterioration of the ecological status of the Pilica River along its course - the trail showed a variable ecological state independent of the distance from its source.
6. The influence of river channel anthropogenic transformations on the species diversity of macrophytes in it was observed. Minor modifications have resulted in a slight increase in diversity compared to natural conditions, but already advanced transformations, such as the strengthening and contouring of banks on significant lengths of water, have led to a marked decline in biodiversity.
7. The main reason for the moderate ecological status of the Pilica River is seen in the spot and area stream of biogens from the catchment area.

References

[1] Directive 2000/60/EC of the European Parliament and of the council of 23 October 2000 establishing a framework for Community action in the field water policy.

[2] Szoszkiewicz K, Jusik S and Zgoła T K*ey to macrofit analysis for the purpose of assessing the ecological status of surface water*. Biblioteka Monitoringu Środowiska, Inspekcja Ochrony Środowiska, Warszawa, 2010.

[3] Szoszkiewicz K, Zbierska J, Jusik S and Zgoła T *Development of methodological basis for biological monitoring of surface water in the scope of macrophytes and their pilot application for water bodies representing selected categories and types. Stage II. Tom I – the river.* Institute of environmental protection. Warsaw - Poznan – Olsztyn 2006.
[4] Szoszkiewicz K, Zbierska J, Jusik S and Zgoła T *Macrofit Test Guidelines. Methodical manual for the assessment and classification of ecological status of waters flowing from aquatic plants.* Wydawnictwo Naukowe Bogucki, Poznań, 2010.
[5] Rozporządzenie Ministra Środowiska z dnia 21 lipca 2016 r. w sprawie sposobu klasyfikacji stanu jednolitych części wód powierzchniowych oraz środowiskowych norm jakości dla substancji priorytetowych Dz.U. 2016 nr 257, poz. 1187.
[6] Rozporządzenie Ministra Środowiska z dnia 9 listopada 2011 r. w sprawie klasyfikacji stanu ekologicznego, potencjału ekologicznego i stanu chemicznego jednolitych części wód powierzchniowych. Dz.U. 2011 nr 258, poz. 1549.
[7] Update of the Environmental Protection Program for the Szczekociny municipality for 2009-2012. Library of Public Information Bulletin - Local Law - Environmental Information - Programs and Regulations, Szczekociny 2009.
[8] Bielak S R, Borek K, Pijar K and Staszkiewicz K Application of macrophytes in assessment and classification of ecological state of upland rivers and streams in south Poland, in accordance with requirements of the water framework directive. *Technical Transactions Cracow University of Technology*. Publisher Cracow University of Technology. Environmental Engineering, Cracow 2012.
[9] Pietruczuk K and Szoszkiewicz K Assessment of the ecological status of rivers and lakes in the Wielkopolska region [central Poland] based on macrophytes according to requirements of the Water Framework Directive. *Science Nature Technologies*, vol. 3, no 3. Publisher of the University of Life Sciences in Poznan. Poznan 2009.
[10] Water management plan in the Vistula river basin area. National Water Management Board (M.P. 2011 No. 49 pos. 549). Warsaw 2011.
[11] Government portal dedicated to the protection of nature in Poland and Natura 2000 sites [on-line]. General Directorate for Environmental Protection, Warsaw 2017. Access mode: http://www.gdos.gov.pl/
[12] Raven P, Holmes N, Dawson H, Ławniczak A, Bulánková E, Topercer J and Lewin I 2011 *River Habitat and Macrophyte Surveys in the High Tatra Mountains of Slovakia and Poland*. United Kingdom Environment Agency Report. Bristol, Great Britain.
[13] State of the environment in Silesian Voivodeship in 2010 [on-line]. Environmental Monitoring Library, Voivodship Inspectorate for Environmental Protection, Katowice. Access mode: http://www.katowice.pios.gov.pl/monitoring/raporty/2010/raport2010.pdf