GeoJournal of Tourism and Geosites Year **XII**, vol. **27**, no. **4**, **2019**, p.**1114-1133**
ISSN **2065-1198**, E-ISSN **2065-0817** DOI **10.30892**/gtg.**27401-420**

KEY FACTORS FOR TOURIST AND RECREATIONAL USE OF QUARRY PONDS OF BELARUS AND POLAND

Svetlana KHOMITCH
Belarusian State University, Faculty of International Relations, Leningradskaja
Str., 20-714, 220030 Minsk, Republic of Belarus, e-mail: khomitch09@mail.ru

Aliaksei RAMANCHUK[*]
University of Silesia, Faculty of Earth Sciences, Będzińska
60, 41-200 Sosnowiec, Poland, e-mail: aleksy.romanczuk@gmail.com

Anna DANILTCHENKO
Belarusian State University, Faculty of International Relations, Leningradskaja Str.,
20-714, 220030 Minsk, Republic of Belarus, e-mail: anna-daniltchenko@yandex.ru

Mariusz RZĘTAŁA
University of Silesia, Faculty of Earth Sciences, Będzińska
60, 41-200 Sosnowiec, Poland, e-mail: mariusz.rzetala@us.edu.pl

Citation: Khomitch S., Ramanchuk A., Daniltchenko A., & Rzętała M. (2019). KEY FACTORS FOR TOURIST AND RECREATIONAL USE OF QUARRY PONDS OF BELARUS AND POLAND. GeoJournal of Tourism and Geosites, 27(4), 1114–1133. https://doi.org/10.30892/gtg.27401-420

Abstract: The paper discusses the potential use of quarry ponds in Belarus for tourist and recreational use. As a result of complex limnologic research the key factors for the sustainable function of recreational use of quarry ponds has been determined. These man-made quarry ponds bare a principal resemblance to the natural lakes of the region through macrophytes production, functional organization, and low trophic status. Among the ten quarry ponds that were investigated, Belarus' water and industrial restoration of former chalk pits revealed that there are two trophic types of quarry ponds. The first type are those with macrophytes orientation, which are ecologically sustainable and would thrive under the impacts of recreational use. The second type are those where phytoplankton can be found, which are less sustainable for recreational use. By examining the morphometry of the base of quarry ponds one is able to determine the type of quarry pond. Sustainable function of artificial water systems for tourist and recreational purposes shall be secured by balancing tourist and recreational use dependent upon the type of quarry pond and level of trophic status.

Key words: quarry ponds, former chalk pit restoration, artificial water systems, bio productive indicators, macrophytes structure, phytoplankton structure, trophic status, sustainable use

* * * * * *

---

[*] Corresponding author

INTRODUCTION

One of the tasks of environmental protection is the restoration of the natural and industrial potency of lands that have been transformed in the process of open mining for non-metallic minerals. One of the ways restore post-industrial lands is to use them for tourist and recreational purposes. Quarry ponds are genetically related to deposits of non-metallic ore represented in the quarry ponds of economically efficient and ecologically relevant water restoration of industrial landscapes (Khomitch, 2002; Khomitch et al., 2012, 2013, 2014). The implementation of water restoration of industrial landscapes requires less effort and presents less of an economic challenge. Simultaneously the natural conditions of these postindustrial landscapes allow for the accumulation of water, creating an artificial water system with the potential for multi-purpose use on degraded post-industrial lands. The successful experience of creating quarry ponds that work in tandem with the current system of regional environmental usage has been confirmed by the water accumulation process seen in the Republic of Belarus. Currently in Belarus there are 2,188 pits that are in use, 442 industrial pits and 1,746 domestic pits. According to the data of combined reporting balance of stocks of construction materials among surveyed deposits, 24% of deposits of sand and gravel, 74% of deposits of clays and 87% of deposits of carbon minerals are watered and potentially fit for artificial water systems restoration on the place of these non-metallic mineral deposits, the natural condition for creation of over 130 newly formed artificial water systems (Khomitch, 2001; Khomitch et al., 2015). The most numerous and those that hold the most potential for tourist and recreational purposes in the Republic of Belarus are chalk deposits (Figure 1).

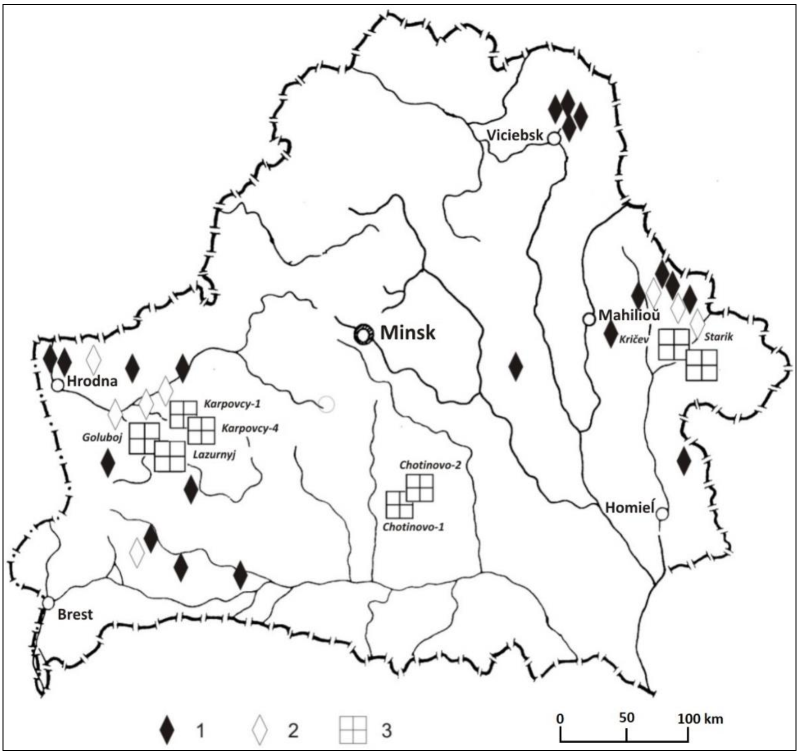

Figure 1. Map of existing and prospective objects suitable for water restoration of chalk quarries in Belarus:1 - existing chalk quarries, that are suitable for water restoration, 2 - proven chalk deposits, 3 - existing quarry ponds in chalk pits

There are numerous examples of the successful repurposing of quarry ponds throughout the world for tourist use (Bacon, 2001; David, 2007; Davis et al., 1982; Gandah et al., 2016; Legwaila et al., 2015; Lintukangas et al., 2012; McCandless et al., 2013; Rzętała, 2008; Dal Sasso et al., 2012; Szabo et al., 2010; Williams, 1998). Newly created landscape forms become an attractive element of the environment (Baczyńska et al., 2018; Iancu et al., 2010; Kaźmierczak et al., 2017; Kherrour et al., 2018; Mossa et al., 2018; Tokarczyk-Dorociak, 2015). In Kent, Great Britain the trade and entertainment center with relevant infrastructure: parks, basins, concert halls, galleries and art-centers is built on the place of former chalk pits. In Sweden, the Dalhalla concert venue was built in a pit once used for limestone mining. In Hungary, the pit in Tokaj is used as a mass events space. On the territory of restored gravel pits in California, USA, the regional recreation zone for beach and environmental tourism was created. In China, 35 km away from Shanghai on the location of a pit at the depth of 90 meters a hotel by the name of The Songjiang Quarry Hotel (aka The Shimao Wonderland Intercontinental) was built. Brownstone Park in Great Britain, is located on a former limestone pit and has become a popular entertainment center and catalyst for development of the area. Butchart Gardens in Vancouver, Canada was created on the territory of limestone pits and is recognized as a national historic park of Canada and attracts over a million visitors a year. Butchart Gardens has helped to develop tourism in the region, created new opportunities for employment, and increased the environmental awareness of the population. Turkusowe Lake, in Wolin National Park in Poland, is considered a major sight for tourists, even though it is a quarry pond (Figure 2). In the Republic of Belarus there are already plans for the spontaneous reclamation of quarry ponds.

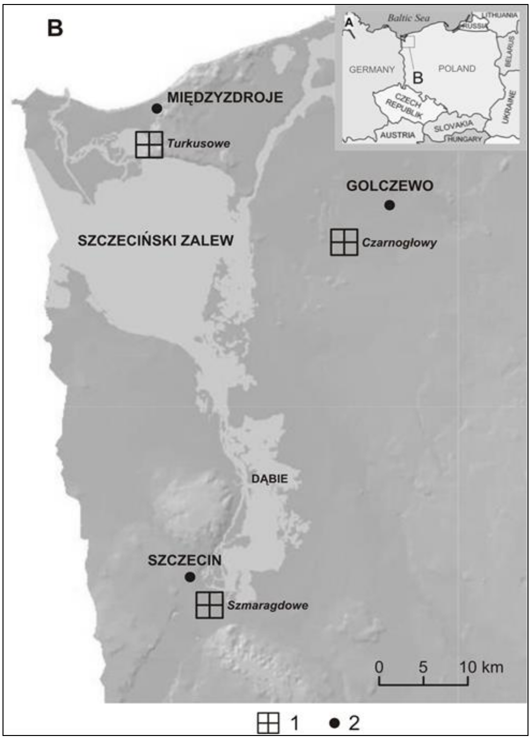

Figure 2. Quarry ponds in Poland
1 – existing quarry ponds in chalk pits, 2 – more important localities

The present research aims to examine and study of the necessary prerequisites for sustainable tourist and recreational use of quarry ponds in Belarus. Due to the principal similarities between natural lakes of the region and quarry ponds in the same regions of Belarus it was determined that quarry ponds could be used for tourist and recreational purposes. Quarry ponds are created as the result of excavated chalk pits being filled with water from rainfall, ground water, drainage, and other natural sources. The natural water accumulation in these chalk pits leads to them being considered as natural and industrial systems. They are considered industrial systems while the chalk pits are being excavated and they are then transformed into natural and technogenic systems through water accumulation. As a quarry pond continues to develop they differentiate according to their morphometry that determines if it will be a macrophytes of phytoplankton type. Sustaniable fuctions of quarry ponds is determined by the following conditions: trophic status, recreational impact, and whether it is a quarry pond with macrophytes or phytoplankton. The use of traditional methods of classical limnology is based upon the working assumption of the resemblance of quarry ponds to the natural limnic systems of the region. In accordance with the goal of research, the following objectives are formulated:

- conduct complex limnologic research of quarry ponds of Belarus to evaluate the present condition and perspectives of quarry pond functions in terms of recreational impact;
- to determine the qualities necessary for sustainable quarry pond use: size, trophic conditions of quarry ponds, natural and industrial related features of their water accumulation, the type of productive and functional structures. Through the investigation of the mechanisms of resistance to growth of trophic status and decrease of water quality in relation to recreational impact;
- to conduct comparative analysis of the functional features of the quarry ponds in Belarus without significant recreational impact with the genetically similar quarry ponds in Poland that are successfully involved in regional tourist and recreational activity to determine the necessary factors for tourist and recreational usage of quarry ponds.

For complex limnologic study and comparative characteristic analysis of the modern state of genetically similar quarry ponds in Belarus and Poland the following artificial water systems have been chosen: Kričev, Starik, Chotinovo-1, Chotinovo-2, Goluboi, Lazurnyi, Karpovcy-1, Karpovcy-4 in Belarus and Turkusowe, Szmaragdowe, Czarnogłowy in Poland. The model quarry ponds are formed in previously excavated chalk pits and have similar characteristics to water hollows. The above-mentioned quarry ponds are either currently in use or plan to be used for tourist and recreational purposes. The factual base of research is composed of morphometric, hydro chemical, hydro biological and geomorphological characteristics of the selected quarry ponds

MATERIALS AND METHODS

Study of actual morphometric parameters of quarry ponds, the collection of surface water and their hydro chemical analysis were performed in seven quarry ponds in Belarus: Kričev, Starik, Chotinovo-1, Chotinovo-2, Goluboi, Lazurnyi, Karpovcy-1, Karpovcy-4 and in three quarry ponds in Poland: Turkusowe, Szmaragdowe and Czarnogłowy, situated within West Pomeranian Voivodeship. For the study of the dynamic processes of formation of productive and functional structures of the newly formed artificial water systems, the earlier data of hollows morphometric parameters, the temperature stratification, transparency, the color of the water, pH, presence of dissolved gas, salt content, biogenic elements, organic material in the water, biological mass of immersed macrophytes, primary production of phytoplankton, biological mass of phytoplankton, quantity of species phytoplankton, and species composition of phytoplankton (Khomitch, 2001). Morphometric study of subjects of industrial water restoration has been conducted based on the data of mensal and batimetric mapping. The calculation of morphometric indicators in hollows was made with the use of common limnology formulas (Yakushko, 1981). The water transparency was measured with the use of Sekki disc (Rumiantsev, 1977). The water samples to determine the hydro chemical indicators have been taken from the deepest depths of the quarry ponds accounting for the stratification of water temperatures and in shore littoral zones accounting for the reclamation by immersed macrophytes. The data of the stratification of temperature distribution was collected by use of electric thermometer GP 41M1. The PH value was determined with the use of a field ionometer I-102 and glass electrode ESL-14. Dissolved oxygen content was determined through the use of Winkler's method, carbon dioxide and carbonates – by method of volume titration (Alekin et al., 1973). The coloring of the water was measured with use of the imitational chrome and cobalt scale. The values of the salt content components have been obtained with the use of the generally accepted method of hydro-chemistry (Arinushkina, 1970). The concentrations of biogenic elements were measured using the colorimetric analysis. For determining the values of common phosphor and mineral phosphor, nitrogen compounds were used (Shilkrot, 1979).

The common phosphor was found in non-filtered water samples, phosphor-containing organic compositions were destroyed in the presence of Sulphur acid and persulphate upon boiling for 30 minutes (Zukhovitskaya & Generalova, 1991). The concentrations of nitrate and ammonium nitrogen were determined in the first case with use of a-naphtolimine and sulfanilic acids, in the second case – with the use of Nessler's reagent. The determination of nitrate nitrogen has been done by ion-selective method with use of EM-NO3-01 membrane electrode. The mineral nitrogen was calculated as the sum of ammonic, nitrate and nitride ones. The picking of samples for determination of bio mass of immersed macrophytes was done with the use of Bernatovitch dredge.

The abundance and life capacity of higher water plants was measured through the Katanskaya method (1981). The intensity of phytoplankton photosynthesis was measured with the Winberg oxygen light-and-dark-bottle method (Vinberg, 1960). To determine the functional features of the Polish quarry ponds in terms of recreational capacity, the data obtained in 1986-2010 was used (Kubiak et al., 2018; Nędzarek et al., 2011; Poleszczuk et al., 2013; Poleszczuk et al., 2014; Tórz, 2010). As of August 2017 through January 2018 the single collection of surface water samples has been performed in each of the investigated quarry pond to determine the actual concentrations of salt components and biogenic elements. During the field work the measurement of key physical and chemical characteristics of water was directly conducted: temperature, pH and electrolyte conductivity with use of pocket conductometer by Elmetron CPC-105. The measuring of salt content components and concentration of biogenic elements in the samples from Polish quarry ponds was performed at West Pomeranian University of Technology in Szczecin. The research included measuring of the concentrations of hydrocarbons, chlorine, sulphates, natrium, kalium, calcium, magnum and biogenic elements, and common water hardness. Investigation of samples taken from the quarry ponds in Belarus were conducted in affiliation with the "Central Lab" of Republican unitary venture "Scientific and production center for Geology". Chemical investigations have been conducted with the use of the generally accepted methods. The data were processed with the Statistica v. 9.0 software (StatSoft, Inc., 2009)

Quarry Ponds in Belarus

The "Chotinovo" group of quarry ponds, located in the Lyuban District of the Minsk Region, consists of two quarry ponds – Chotinovo-1 and Chotinovo-2 – located 200 meters from one another. The restoration of these chalk pits was achieved by the subsequent filling of the chalk pits by ground water. Neither of these quarry ponds have any tributaries. Chotinovo-1 has a narrow stretched trapezoidal form. The coastline of this quarry pond is intended to be constructed on the North-Western territory. On the Southern side of the quarry pond the height of the slopes are between 6-8 meters, whereas the remainder of the slopes are 2 meters high. The littoral zone is narrow with a width of one meter, whereas on the East side of the quarry pond the littoral zone reaches between 4-15 meters. The grade of the sublittoral zone is up to 80°.

Chotinovo-2 is a horseshoe shaped quarry pond with a smooth coastline. The slopes that surround the quarry pond have a significant grade of up to 60-80° that were once the extraction points for chalk. In some places surrounding this quarry pond there is a narrow beach that has been formed by the processes of erosion, abrasion, and denudation. The littoral zone is narrow, with a width of 0.5 -1.5 meters. The grade of the sublittoral zone is characterized with a steep angle that varies between 45-60°.

Goluboi, Lazurnyi, Karpovcy-1, Karpovcy-4 quarry ponds are formed as the result of mining for mineral chalk located at a depth of 10-30 meters (Ross, Kolyadichi, Pogorany deposits), these quarry ponds have a narrow stretched form, with a steep pitch and a mineral bed with a thickness of 10-60 meters. In the resulting territory the ground water is at a depth of up to 10 meters. The distance between the topsoil and the chalk deposits varies from 0.2-0.8 to 23.0 meters. The removal of the topsoil to uncover the chalk deposits results in the creation of the techno genic-mounds that surround the quarry pond. As a result, chalk mining in the Vaŭkavysk District there is a series of compact quarry ponds with a stretched narrow form and with depths varying between 10-25 meters. The techno genic-mounds – of a height of 3-10 meters – are located at the border of the quarry pond. The mounds and high sloped walls have a steep drop off of 50-70°, with terraced layers varying in length from 5-60 meters. The majority of the base of the quarry ponds are shallow and filled with ground water. Goluboi and Lazurnyi quarry ponds were formed in the 1970s. Neither quarry ponds do not have tributaries. Goluboi was formed several years earlier than the Lazurnyi. The surface area of the Goluboi is 5,4 ha more than double the surface area of Lazurnyi and Goluboi also has a greater maximum depth of 14.0 meters compared to Lazurnyi's 5.4 meters. Both quarry ponds feature almost vertical banks that reach a height of 50-60 meters. Both quarry ponds have small surfaces of water collection of 1.67 km2 (Goluboi) and 1.51 km2 (Lazurnyi).

Biological restoration of the water collection territories are composed of planted pine trees and various other plants growing on the mineral rich techno genic- mounds. On the northwestern coast of Goluboi there is a small village. This small village was built on restored lands in 1980 (Khomitch, 2001). Kričev quarry pond was formed 80 years ago, with a surface area of 37.67 ha. This quarry pond is known for being the deepest quarry pond with the deepest point of the pond measuring 23 meters. Kričev quarry pond is located at the right bank of the river Sozh, one kilometer from the river bank with no tributaries. The quarry pond without tributaries are called closed type quarry ponds.

Kričev has a surface area of 0.38 km2, with a water mass volume of 4410 thousands m3, and a water collection surface of 2.73 km2. The water balance of Kričev is influenced by surface water (which contributes about 50% in an average year and 40% in a dry year) and ground water. As demonstrated by water balance calculations, Kričev quarry pond has a poor water exchange condition (conditional water exchange indicator in a dry year is 1,3) (Khomitch, 2002). The Western territory of the quarry pond is affected by natural spring water that is located near the coast. From the North, the concrete sluice, snow melt, and rain water drain from the nearby personal gardens of the village of Kričev and flow into the quarry pond. Drainage of the quarry pond Kričev is achieved by the use of an artificial channel to the quarry pond Starik, situated one kilometer away from Kričev. Starik is significantly smaller than Kričev and also absorbs the waste water from a nearby cement slate plant. This results in the poor water quality in Starik. The coastal shallow water zones of Kričev are found near the northwestern, western, and southwestern coasts, meanwhile the eastern and southeastern coasts are significantly deeper. The water collection space of Kričev quarry pond is 3.13 km2.

Quarry Ponds in Poland

Turkusowe quarry pond was formed by the filling of the chalk pit near the village Wapnica in the 1940's by ground water (Fig. 3). The most notable feature of this quarry pond is that there is not littoral zone. Jezioro Turkusowe is surrounded by high slopes with a height of 30-40 meters, excluding separate parts of the water collection territory located on the northern territory. The depth of the pond is 8-10 meters not far from the shore. The main water sources for filling the quarry pond are surface water –rainfall and snow melt—and ground water. The ground water that drains into the quarry pond is polluted with biogenic materials from the village of Wapnica (Poleszczuk et al., 2014).

Czarnogłowy quarry pond is situated 80 km North of Szczecin at the Szczecin Depression (Figure 2). The artificial water system was created by the restoration of a chalk pit in 1968. The quarry pond has a narrow stretched form, oriented from North-west to North-east (Kubiak et al., 2010; Kubiak et al., 2018).

Szmaragdowe quarry pond is located within the administrative borders of Szczecin near Puszcza Bukowa nature reserve (Figure 2.). Szmaragdowe quarry pond was created on June 16, 1925 as the result of ground water accumulation in the chalk pit. The water level is 42.2 meters above sea level. The surface area of the quarry pond 2.5 ha with a maximal length of 275 m, a maximal width of 150 m, and a maximal depth of approximately 16 m. The coast is precipitous and only on the Southern part of the quarry pond is it a gentle slope. The water collection territory is forested. Szmaragdowe quarry ponds does not have any tributaries. Recently there has been a decrease in ground water levels. Szmaragdowe has a triangular form, in the Northern part there is a concrete bridge, which is presently used as an observation point (Kubiak et al., 2013).

RESULTS

The specifics of open chalk pit mining and the potential formation of a future quarry pond is determined by the limnologic type of the chalk pit. The following factors were analyzed: size of the quarry pond, form of the quarry ponds, the volume of water mass, the depth of the basin, the size of the littoral zone, the balance of shallow and depths of the quarry pond, and the type of coastline (Table 1). The oxygen regime of quarry ponds is the integral indicator for physical and bio chemical conditions. The intensity of productive processes and trophic status is indicated by data reported regarding water transparency, water color, and bio productive indicators of quarry ponds and accompanied by oxygen regime data. The majority of temperature stratified quarry ponds have positive and hetero grade vertical distribution of dissolved oxygen – the maximum oxygen is revealed in the metalimnion layers. The deepest and most transparent quarry ponds are Kričev and Goluboi. The maximum methalimnal oxygen is determined by the possibility for photo synthesis of phytoplankton at methalimnion due to high transparency of water (Table 2). Prosperous vertical oxygen distribution is only present in the oxygen regimes of Kričev, Goluboi and Lazurnyi quarry ponds during the winter (Table 3). They demonstrate high levels of oxygen saturation in the water in winter and there is no deficit of oxygen near the base layers in the summer (Table 2).

The surface water of these quarry ponds is oversaturated with oxygen in the summer (103-118% in Kričev and 103-107% in Goluboi). The maximum quantity is found at the methalimmion layer of the quarry ponds. In the quarry ponds of Goluboi and Kričev that have flora present in the littoral zone, in summer the oxygen content in their littoral zones exceeds the pelagic zone respectively at 10.63 and 10.33 mg/l; 11.20 and 10.40 mg/l. The distribution of carbon dioxide in the investigated quarry ponds have an inverse dependence on oxygen. In Kričev the carbon dioxide in summer was not detected at the depths of 7-10 meters, which is well within the range for active photosynthesis of submerged macrophytes, dense tangles of which are common for the littoral part and witness the production of macrophyes functional type.

Absence of carbon dioxide in the vertical profile in summer is also present in Starik quarry pond. This is the result of the usage of Starik as a waste water receptacle for the cement-slate plant. The carbonates concentrations in the quarry ponds are very high and reach 78.10 mg/l at the surface and 522.50 mg/l at the bottom layer.

Table 1. Morphometric parameters of investigated pit basins, formed in the chalk pits in Belarus and Poland

Quarry pond	Surface of basin [ha]	Surface of water collection [ha]	Volume of water mass [millions of m³]	Basin length [m]	Maximal basin width [m]	Hyow index S/V	Shadrin index L/H	Average basin width [m]	Length of coastal line [m]	Coefficient of coastal line intentness	Maximal basin depth [m]	Average basin depth [m]	Basin prolateness [m]	Basin capacity	Surface of shallow zone (up to 2 m)	
															[ha]	[%]
Kričev	37.67	313	4.412	975.0	725.0	0.08	226.30	386.85	2650.0	1.22	23.0	11.71	1.34	0.51	2.03	5.4
Goluboi	5.40	167	0.456	580.0	164.0	0.12	148.10	93.19	1250.0	1.44	14.0	8.44	3.54	0.60	0.40	7.4
Lazurnyi	4.9	151	0.086	410.0	98.0	0.27	245.33	55.81	920.0	1.72	5.10	3.75	4.18	0.74	2.38	48.7
Chotinovo-1	4.57	150	0.112	470.0	180.0	-	110.0	108.51	1230.0	1.54	18.8	7.7	4.3	0.41	0.83	16.2
Chotinovo-2	2.22	90	0.119	380.0	120.0	-	70.0	65.78	900.0	1.61	19.4	6.7	5.4	0.34	0.39	15.6
Turkusowe	6.74	-	0.513	430.0	246.0	-	-	129.5	1050.0	1.26	21.2	9.2	-	0.43	-	-
Szmaragdowe	2.5	-	0.214	255.2	159.2	-	-	101.8	790.0	1.38	15.8	8.2	-	0.52	-	-
Czarnoglowy	35.7	-	-	1150.0	330.0	-	-	-	2850.0	-	28.8	-	-	-	-	-

Notations: (-) – no available data

Table 2. Limits for containment of oxygen and carbon dioxide in quarry ponds in summertime

Quarry pond	Horizon [m]	O_2 [mg/l]	O_2 [%]	CO_2 [mg/l]
Kričev	surface	10.44–10.56	103–118	0
	bottom, 22,0	6.97–10.35	55–82	2.85–4.95
Starik	surface	11.02	132	0
	bottom, 12,0	0.24	2	0
Goluboi	surface	9.21–10.33	103–107	5.5
	bottom, 13,0	1.30–3.02	11–24	––
Lazurnyi	surface	8.59–11.58	98–120	––
	bottom, 5,0	7.09–9.55	74–94	1.65

Table 3. Limits for containment of oxygen and carbon dioxide in quarry ponds in wintertime

Quarry pond	Horizon [m]	O_2 [mg/l]	O_2 [%]	CO_2 [mg/l]
Kričev	surface	8.18–20.37	56–140	2.20–5.72
	bottom, 23,0	4.68–17.28	35–124	2.2–13.2
Goluboi	surface	11.44–16.83	82–117	0 – 1.76
	bottom, 11,0	10.18–10.51	72–79	3.6–6.6

The concentration of hydrogen ions is dependent on the oxygen regime. In each of the quarry ponds that were investigated during the summer months alkalization of the surface layers occurs, as a result of the photosynthesis process activated by warm temperatures. For highly transparent quarry ponds of macrophytes orientation, such as

Kričev and Goluboi, the most sustainable pH surface level is (7.60-8.21). When pH was measured in the winter of 2017-2018 the pH indicators for the following quarry ponds were lowered: Czarnogłowy (7.3), Szmaragdowe (7.4), Turkusowe (7.42), Kričev (7.88), Starik (8.36). Transparency, measured with a Sekki disc, has a large diapason of fluctuations in quarry ponds: from 0.30 (Starik) to 6.90 m (Kričev), and is similar to the transparency of natural lakes. The highest transparency indicators are reported for deep quarry ponds annually populated by submerged macrophytes: Kričev and Goluboi. The lowest transparency indicators are reported at Starik. Seasonal transparency distribution for all of the investigated quarry ponds increases in winter, due to the reduction of phytoplankton photosynthesis activity. Chromaticity values vary from 3 to 158 degrees on the PlCo scale. Its lowest values are reported for Kričev, created on the place of a chalk pit by low chromatic (up to 3 PlCo scale) ground water. Starik is the recipient of dark yellow waste water. Salt composition components and biogenic elements in the surface water of Belarusian and Polish quarry ponds conducted in 1981-2015 and 2017-2018 (Table 4-6).

Table 4. Diapasons of biogenic elements containment
in the waters of quarry ponds of Belarus and Poland (1981-2015)

Pit basin	NO_3^-	NO_2^-	NH_4^+	TN	PO_4^{3-}	TP
	mg/l					
Kričev	0 - 0.48	0.0014-0.0260	0.01-0.083	0.038-1.176	0.0027-0.0050	0.0027-0.0130
Starik	0.24 - 1.09	0.0580-0.0780	0.12-0.30	0.414-1.466	0.0027-0.0056	0.0050-0.0780
Lazurnyi	0.02-0.07	0.0006-0.0010	0.02-0.16	0.047-0.183	0.0015-0.0025	0.0023-0.0025
Goluboi	0.03 - 0.05	0.0002	0.02-0.40	0.074-0.430	0.0023-0.0034	0.0030-0.0040
Chotinovo-1	0.025	-	-	-	-	-
Chotinovo-2	0. 025	-	-	-	-	-
Turkusowe	0.01-0.19	0.001-0.094	0.01-0.26	0.23-0.60	0.01-0.83	0.08-1.26
Szmaragdowe	0.021-0.320	0.007-0.233	0.025-0.464	0.239-3.860	0.051-0.780	0.088-1.123
Czarnogłowy	0.102-2.732	0.008-0.150	0.015-0.278	0.67-3.413	0.011-2.411	0.055-2.897

Notations: TN – total nitrogen; TP – total phosphorus; « - » – no available data

Table 5. Components of salt composition in the
waters of quarry ponds of Belarus and Poland (1981-2015)

Pit basin	Reaction	Conductivity	SO_4^{2-}	Cl^-	HCO_3^-	Na^+	K^+	Mg^{2+}	Ca^{2+}	TH
	pH	µS/cm	mg/l							$mgCaCO_3/l$
Kričev	8.22	601.7	128.45	37.46	120.17	15.35	3.96	24.21	60.42	250.25
Starik	9.0	603.75	144.57	25.94	76.25	25.98	96.25	7.11	16.33	70.07
Chotinovo-1	6.8	318.6	3.2	10.42	146.45	1	2.9	7.78	35.27	
Chotinovo-2	8.1	178.3	3.7	7.09	61.02	2.7	2.8	2.43	24.05	-
Goluboi	8.06	312.1	26.27	3.9	131.15	4.12	4.85	5.42	34.43	116.6
Lazurnyi	8.26	583.2	167.44	5.46	88.45	4.45	12.36	2.11	84.57	214.7
Turkusowe	7.85	295	53	37	-	-	-	17	70	292.8
Szmaragdowe	7.88	604.7	168.9	21.7	-	-	-	-	-	-
Czarnogłowy	-	556.8	42.2	39.6	-	23.4	3.96	11.3	81.1	-

Notations: TH – Total Hardness; (-) – no available data

The hydro-biological features of quarry ponds in Belarus have been thoroughly investigated. The most important factor for determining the development of water flora in both quarry ponds and natural lakes are their morphological features (size, depth, coast intensity, presence of shallow spaces with depth up to 2.5–3.0 m, littoral slopes), optical properties of water masses (transparency and color), dynamic characteristics (swash action), chemical indicators (containment of mineral and biogenic materials, concentration of hydrogen ions, gas regime), features of bottomsediments (material, mechanical composition, active enrichment by trophic materials), water temperature etc. (Khomitch, 2001). As you can see in table 7, Kričev is characterized by significant quantitative development and a relatively rich variety of species.

Table 6. Components of salt composition and biogenic elements in the waters of quarry ponds of Belarus and Poland (2017-2018)

Quarry pond	Water temperature	Reaction	Conductivity	SO_4^{2-}	Cl^-	HCO_3^-	Na^+	K^+	Mg^{2+}	Ca^{2+}	TH	PO_4^{3-}	NO_3^-
	°C	pH	µS/cm	mg/l							mgCaCO^3/l	mg/l	
Kričev	0.1	7.88	727.5	87.2	59.2	219.6	28	5.9	29.3	61.7	274.5	<0.01	0.8
Starik	0	8.36	824	122.2	60.5	231.8	35	30	28.1	65	277.5	0.05	2
Chotinovo-1	26.3	8.43	269	18.1	7.7	128.1	3.2	2.8	1.9	45.5	121.6	0.15	<0.1
Chotinovo-2	25.6	8.47	204	3.3	4.7	109.8	2	2	1.9	33.8	92.6	0.02	<0.1
Karpovcy-1	24.2	9.03	200	6.2	5.3	109.8	3.6	3.3	3.9	27.5	84.6	0.03	<0.1
Karpovcy-4	23.8	8.58	309	37.9	4.7	134.2	4.4	4.7	7.7	42.3	137.1	<0.1	<0.1
Goluboi	24.2	8.55	308	28.4	7.1	143.4	4.6	5	5.8	45.5	137.6	<0.1	<0.1
Turkusowe	6.2	7.42	409	88.8	24.2	122	5.6	3.4	12.4	26.2	104.5	0.31	0.05
Szmaragdowe	4.6	7.4	688	196.3	14.3	170.8	18.6	4.4	15.6	112.3	346.5	0.14	0.56
Czarnogłowy	4.8	7.3	572.6	41.3	43.2	216.55	16.8	3.6	14.8	96.6	303.2	0.36	36

Table 7. Species composition, abundance and life capacity of quarry ponds water flora

Quarry ponds	Higher water flora	Abundance	Life capacity
Kričev	Elodea canadensis Rich.	Cop.3	3
	Ceratophyllum demersum L.	Sol	2
	Chara sp.	Cop.2	3
	Phragmites australis (Cav.)	Sol	2
	Polugonium amphibium f. aquaticus Leyss.	Sol	2
	Potamogeton lucens L.	Sp.	3
	Potamogeton pectinatus L.	Sp.	2
	Potamogeton perfoliatus L.	Cop.2	3
	Potamogeton praelongus Wilf.	Cop.	2
	Ranunculus circinnatus Sibth.	Cop.1	3
	Scirpus lacustris L. Trin. ex Steud.	Sol.	2
	Typha latifolia L.	Sol.	2
	Typha latifolia L.	Sol.	2
Starik	Elodea canadensis Rich.	Sol.	1
	Phragmites australis (Cav.) Grin ex Stend.	Sol.	1
	Typha latifolia L.	Sol.	1
Goluboi	Alisma plantago-aquatica L.	Sol.	2
	Chara sp.	Cop.2	3
	Elodea canadensis Rich.	Cop.2	3
	Potamogeton pectinatus L.	Cop.1	2
	Sparganium simplex Huds.	Sp.	2
Lazurnyi	Potamogeton alpinus Balbs.	Sol.	1
	Potamogeton compressus L.	Sp.	2
	Sparganium erectum L.	Sol.	2

In Kričev submerged macrophytes are commonly found around the entire perimeter. Their absence is only seen on a small portion of the quarry pond in the south-east where until recently solid waste of the cement-slate plant was stored. The density of macrophytes tangles in quarry ponds differs. In the north, the following tangles can be found separated from one another: Potamogeton perfoliatus, Potamogeton lucens, Sagitaria sagittifolia, Polygonum amphibium f. aquaticus and Elodea canadensis. The depth of water flora areal reaches 2-4 m.

At the northwestern, western and southwestern coasts, shallow waters the density of tangles increases significantly. Here Potamogeton perfoliatus and Potamogeton lucens, Potamogeton pectinatus, Potamogeton crispus, and Ranunculus circinatus can be found. Elodea Canadensis and Characae occupy vast spaces. The bio mass of submerged macrophytes in the shallow southwestern part of the basin reaches 85.36 g/m^2 in accordance with Table 8. Dense tangles of macrophytes in the western and southwestern parts of the basin are common up to the depth of 5.5–7.0 m. At the maximal depth the only flora that can be found is Characeae. Only on the southwestern surface of Kričev flora (Typha angustifolia, Equisetum fluviatile, Phragmites australis) can be found.

In the northern region where the concrete waste water sluice is located as well as where most of the snow melt and rain water run off from the nearby village accumulates there is a significant presence of (Anabaenna sp., Oedogonium sp., Shizomeris sp. и Spirogyra sp.) and blue-green algae (Nostoc sp.). Other aquatoria flamentous algea are rarely noted and when found they exist in small quantities.

Table 8. Bio mass of submerged macrophytes in quarry ponds

Quarry pond	Place of samples picking	Picking depth [m]	Species composition of association	Bio mass [g/m]
Kričev	North-Western part of basin	0.70	Potamogeton Friesii Potamogeton perfoliatus	48.88
	Same	0.50	Potamogeton Friesii Potamogeton perfoliatus	44.18
Kričev	Western part of basin	0.70	Elodea canadensis Chara sp.	25.02
	South-Western part of basin	1.00	Potamogeton perfoliatus Elodea canadensis	85.36
Goluboi	Eastern part of basin	0.50	Elodea canadensis Chara sp.	23.93
	Western part of basin	1.00	Elodea canadensis Potamogeton pectinatus	17.31

Table 9. Concentration of some chemical elements
in the tissues of higher water plants (% of absolutely dry material)

Quarry pond	**Species of submerged macrophytes**	P	N	K	Ca	Mg
Kričev	Potamogeton pectinatus	0.61	1.93	2.37	2.60	0.16
	Potamogeton perfoliatus	0.31–0.44	3.51–4.37	1.20–1.84	0.54–5.26	0.28–0.51
	Panunculus cirsinatus	0.27	3.30	1.25	5.63	0.40
	Elodea canadensis	0.46	2.85	2.15	6.00	0.40
	Polygonum amphibium f.aquaticus	0.35	5.91	0.88	1.69	0.39
	Potamogeton lucens	0.44	3.12	0.88	2.94	0.42
	Sagitaria sagittifolia	0.65	4.86	3.51	0.99	0.35
	Chara sp.	0.11	0.50	0.20	16.32	0.21
Goluboi	Elodea canadensis	0.44–0.96	2.35–3.12	1.20–2.55	1.95–5.72	0.21-0.26

In Lazurnyi the flora is limited to single samples of Potamogeton alpinus and Potamogeton compressuss.The accumulation of water flora in quarry ponds is measured by the concentration of P, N, K, Ca, Mg. To examine this, fresh samples of macrophytes tissues of about 10-15cm in length were collected. The tissues of macrophytes contained varied levels of different chemical elements, providing the different capacity of separate species of water flora to absorb chemical elements from environmental chemicals (Table 9). The data obtained from separate samples of submerged macrophytes in Kričev and Goluboi quarry ponds states that the critical level of nitrogen (1.3% of absolutely dry material) and phosphorus (0.3% of absolutely dry material) (Pokrovskaya, 1983). The investigation of the clean production of phytoplankton through photo synthesis is seen in Kričev and Goluboi quarry ponds.

In the deep and highly transparent quarry ponds of Goluboi and Kričev phytoplankton photosynthesis occurs at a depth exceeding double or triple the levels of transparency, and in some cases the maximum of photo synthetic activity falls on the methalimnion layer. The dominating species of phytoplankton in Goluboi is green algea (Table 9), and in Kričev it is green and diatomic algea (Table 10, Table 11).

Table 10. Species composition, quantity and bio mass of phyto plankton in Goluboi quarry pond

Species of algae	Number of species	Quantity		Bio mass	
		mln/l	[%]	[g/m^3]	[%]
Blue-green	2	0.300 000	6.3	0.06	4.1
Green	13	4.457500	93.1	1.11	76.0
Diatomic	1	0.017500	0.3	0.01	0.7
Pyrophyte	3	0.015000	0.3	0.28	19.2
Total	19	4.79000	100	1.46	100

Table 11. Species composition, quantity and bio mass of phyto plankton in Kričev quarry pond

Species of algae	Number of species	Quantity		Bio mass	
		mln/l	[%]	mg/l	[%]
Diatomic	10	0.195417	33.6	0.20	40.8
Green	6	0.200000	34.6	0.05	10.3
Golden	1	0.183333	31.6	0.11	22.4
Pyrophyte	2	0.001666	0.2	0.13	26.5
Total	19	0.580416	100	0.49	100

DISCUSSIONS

Analysis of the listed limnologic characteristics of the investigated quarry ponds as potential objects for tourist and recreational purposes is determined by the following characteristics: type of mineral mined, geological conditions of deposit, mining technology determine the morphological features of hollows and “small water collections” for the basins in chalk pits. Other features that influence whether a quarry pond could be used for tourist and recreational purpose are terrain of the lakebed, composition and size of littoral zone, expressiveness of processes of coastal abrasion, intensity of slope erosion and chemical denudation. Investigation of morphometric parameters of quarry ponds are similar in morphology of newly created artificial water systems and natural limnic systems of the region. The quarry ponds in Belarus and Poland are small in size (2.5-37.5 ha). As a rule they accumulate volumes of water mass (0.09-4.5 mln.m3).

They are smaller in size than the natural lakes of the region. They are characterized by weak inertial properties of small water mass volumes, vulnerable to pollution and eutrophication in early stages of their development in terms of local use for water collection. The volume of water mass determines the features of hydro dynamic, hydro chemical and hydro biological processes of newly formed artificial water systems (Table 12). Specific morphological elements that are common in quarry ponds are complicated topographic bottom terrain, absence in certain cases of littoral shallow waters, and non-formed coasts this is a result of their industrial origin.

In the quarry ponds investigated it is noted that there is a connection between water mass, its thermal and hydro chemical regimes of hollow morphometric parameters. This allows for the preparation of chalk pits for future tourist and recreational purposes and the accumulation of ground water allowing for a quarry pond to begin to form.

Table 12. Comparative characteristic of quarry ponds in chalk pit and natural lake basins of Belarus

Indicators, measurement units	Values intervals	
	Chalk pits of Belarus	Natural lakes of Belarus
Water-surface area [km^2]	0.02 – 1.25	below 0.1 – over 20.0
Depth [m]		
maximal	5.10 – 23.0	below 2.5 – over 25.0
average	3.75 – 11.71	below 2.5 – over 20.0
Volume of water mass [mln m^3]	0.086 – 4.412	below 1.0 – over 100.0
Capacity coefficient	0.51 – 0.74	below 0.33 – over 0.66
Openness indicator	0.61 – 3.22	below 0.1 – over 5.0
Coefficient of coastal line intentity	1.22 – 1.72	below 1.5 – over 2.5
Water collection area [km^2]	1.51 – 3.13	below 5.0 – over 80.0
Conditional water exchange	0.22 – 7.3	
Thermal stratification (gradient at methalimnion layer), °C	2 – 6	1.5 – 4.0
Mineralization of water mass [mg/l]	193.60 – 601.68	below 50 – over 800
Active water reaction (summer) [pH]	7.51 – 10.33	below 6 – over 9
Chromaticness [degrees]	4 – 48	below 10 – over 160.1
Transparency [m]	0.2 – 8.0	below 1.0 – over 8.0

The data for vertical temperature distribution in quarry ponds in summer in Kričev, Starik, Goluboi and Lazurnyi shows that there are distinct layers of direct water mass stratification dependent upon the temperature. In the deep type of quarry pond (maximal depth 12.1-23.0 m) with low values of openness coefficients (0.61 to 3.22) basins of Kričev, Starik, Goluboi the stratification is expressed in three layers: epilimnion, methalimnion, and hypolimnion. The thickness of hypolimnion in deep type quarry ponds (depth coefficient 0.16 to 0.22), changes from 4-5 m in Goluboi to 11-12 m in Kričev. In winter, all of the investigated quarry ponds experience reversed thermal stratification, with insignificant increase of temperatures from the surface to the base of the quarry pond. The temperature of surface layers under ice are 0.3-0.5°C, in the base layers it varies as of 1.9 °C in Kričev. The health of the gas regime, neutral values of hydrogen ions concentration of surface layer (pH) characterizes the deepest and highly transparent chalk pit basins of Kričev and Goluboi.

The absence of large fluctuations of active water reaction in conjunction with the data for containment of O2, CO2 и CO_3^{2-}, indirectly points to the secondary role of phytoplankton production of organic material. The main producers in these basins are submerged macrophytes. Values of pH in open parts of Kričev and Goluboi quarry ponds and coastal littoral spaces points to the existence of constant alkalescence of littoral waters due to phytosynthetic activity of submerged macrophytes. In vertical distribution of pH values from surface to bottom for the majority of quarry ponds the decrease of water reaction values is reported for both the summer and winter. Differences between surface layers and base layers are most intensively expressed in the highly polluted Starik quarry pond. Despite their short period of existence when compared with natural lakes of the same region (10-100 years), the chalk pits filled by ground water, surface water, rain water and snowmelt have identical chemical compositions, such as hydro carbonate sulphates and calcium, as natural lakes of the same region (Yakushko, 1981). According to the data from P.S. Lopukh (2000) the quarry ponds as well as natural lakes are moderately mineralized.

Mineralization varies from 200-375 mg/l. High mineralization is reported only for quarry ponds that are filled only with ground water. In regards to the salt composition when comparing quarry ponds to natural lakes the containment of chlorum and sulfur ions Na+ and K+ cations is significantly increased in quarry ponds. This increase is related to the recharge and the receiving of polluted waste water, such is the case of Starik (Lopukh, 2000). The chemical composition of the quarry ponds water content is determined by the most prominent water source for filling the quarry ponds i.e. ground water, surface water, rain water and snowmelt. The water source that fills the quarry ponds contributes a variety of salt components (Cl^-, $SO_4{}^{2}$-, K^+, Na^+).

The main sources of pollutants for quarry ponds in their infancy are the byproducts created by nearby industrial plants (Kričev cement-slate plant). In addition to the cement-slate plant, Cl^-, $SO_4{}^{2}$-, Na^+, K^+ and other biogenic materials that flow into the quarry ponds as the result of nearby industrial and agricultural plant that are not associated with mining, but rather are located near water collection systems where they dump their waste water. In some cases the source of pollutants is the result of spontaneous and unsanctioned recreational use of the quarry ponds (Kričev, Goluboi, Lazurnyi, Turkusowe, Szmaragdowe, Czarnogłowy). Presently, the chemical composition of the water content of the investigated quarry ponds shows anthropogenic transformations, such as high containment of Cl^-, $SO_4{}^{2}$-, Na^+, K^+ (Figure 3, Figure 4, Figure 5) to 196.3 mg/l). Pollution from Cl compositions is detected in the basins of Kričev (up to 60.5 mg/l) and Starik (up to 59.2 mg/l). High levels of K^+ can be found in Starik up to 30 mg/l, which is the result of the accumulation of water from industrial water collections. In Kričev and Starik high containment of Na^+ was detected, with results of up to 28 mg/l and up to 35 mg/l respectively. In the quarry ponds Szmaragdowe (112.3 mg/l) and Czarnogłowy (96.6 mg/l) one can also find high concentrations of Na^+. In Czarnogłowy quarry pond a change in the proportion of anions common to zonal type of natural lakes (HCO3- > $SO_4{}^{2}$-> Cl) with a shift towards Cl can be seen (Table 4). A comparison of the data of the salt composition of the water present in quarry ponds from 2017-2018 to that of 1918-2001 indicates significant growth of concentrations of salt in the quarry ponds that were investigated.

In the Starik quarry pond HCO3- increased from 76.25 to 219.6 mg/l. Cl^- in Starik increased from 25.94-60.5 mg/l and Kričev from 37.4 to 59.2 mg/l. In Kričev Na^+ increased from 15.35 to 28.0 mg/l (Khomitch, 2001). In accordance with the chloride content in the surface water of quarry ponds the quarry ponds investigated were divided into three groups: high, medium, and low levels of mineralization. Kričev and Starik at 59.2-60.5 mg/l are members of the high level of mineralization group. Czarnogłowy, Szmaragdowe, and Turkusowe at 14.3-43.2 mg/l are members of the medium level of mineralization. Chotinovo-1, Chotinovo-2, Karpovcy-4, Karpovcy-2, Goluboi and Lazurnyi quarry ponds are members of the low level of mineratlization at 4.7-7.1 mg/l (Table 4).

According to the indicator of electrolytic conductivity among the investigated quarry ponds there are three groups: low mineralized, moderately mineralized, and highly mineralized. The low mineralized quarry ponds range from 100 to 300 µS/cm including the quarry ponds Chotinovo-1, Chotinovo-2, Karpovcy-1. The moderately mineralized quarry ponds range from 300 to 600 µS/cm including the quarry ponds Karpovcy-4, Goluboi, Turkusowe. The highly mineralized quarry ponds range from 600 to 900 µS/cm including the quarry ponds Starik, Kričev, Szmaragdowe, Czarnogłowy). The distribution of phosphorus in the surface water of quarry ponds if lower in summer can correlate with significant increases in the concentration of phosphorous in Winter. This increase in the concentration of phosphorous in the winter is the result of the death of vegetation and water autotrophs. In low trophic status basins in Kričev, Lazurnyi and Goluboi where there is a relatively high containment of oxygen in the bottom layer and low level of phosphorous bottom sediments the containment of phosphorous is as a rule low and experiences insignificant changes at great depths in both the summer and winter.

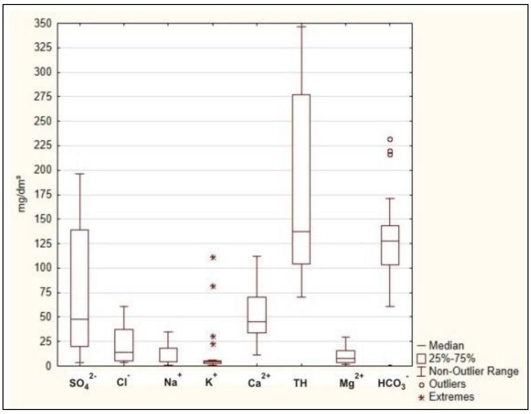

Figure 3. Diapasons of changeability of components of the salt composition in quarry ponds of Belarus and Poland

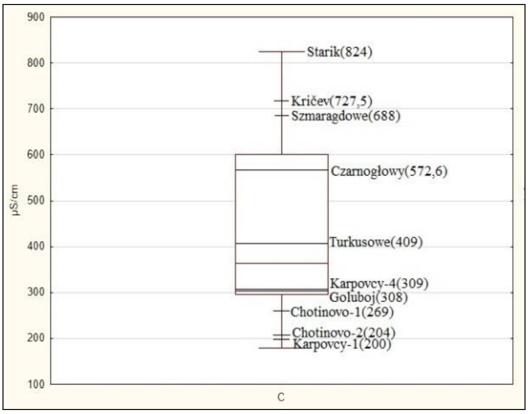

Figure 4. Diapasons of changeability of electrolytic conductivity of sulphates in quarry ponds of Belarus and Poland

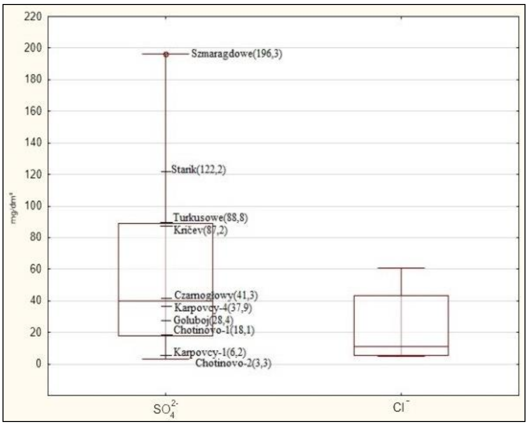

Figure 5. Diapasons of changeability of sulphates and chlorides in quarry ponds of Belarus and Poland

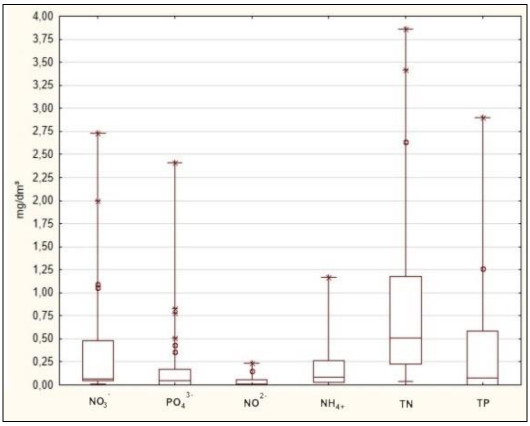

Figure 6. Diapasons of biogenic elements changeability in quarry ponds of Belarus and Poland

The containment of phosphates and its accumulation from water collections and seasonable distributions may indicate the intensity of the process of producing phosphates in the form of PO42- is consumed by hydrobionts. The vertical distribution of phosphates in the majority of the quarry ponds investigated is characterized by the increased presence of phosphates at the surface level and lower levels of phosphates being found near the bottom of quarry ponds. It is important to note the summer growth of PO42- in Starik and Lazurnyi. Kričev and Goluboi were discovered to be macrophyte type quarry ponds due to the presence of phytoplankton and a uniquely stable phosphate distribution are indicators of their type. The distribution of PO42- in Starik is unstable.

Both phosphate content and the nitrogen components of autotrophic hydrobionts play an important role in determining the trophic status of both quarry ponds and natural lakes (Onoshko, 1985). Low concentrations of mineral nitrogen are common for low trophic status quarry ponds of macrophyte type (Goluboi (up to 1.047 mg/l)). The concentration of mineral nitrogen in natural lakes, according to the data by M.P. Onoshko (1985), does not exceed 1.55 mg/l on average (Table 5). Quarry ponds with low containment of mineral nitrogen such as Goluboi and Kričev the vertical distribution of nitrogen is the same throughout. In the quarry ponds that receive waste water that contain nitrogen, it is accumulated in the bottom layer. Accumulation of mineral nitrogen, specifically ammonium, in the bottom layers of these quarry ponds in the presence of an O2 deficit. In the high trophic status and polluted basin of Starik the mineral nitrogen content, in the form of nitrate, is high at the surface level (Khomitch, 2002).

According to the biogenic elements present in quarry ponds three groups were created: mesotrophic, eutrophic, and hyper trophic (Tables 4-5, Figure 6). Mesotrophic quarry ponds are Chotinovo-1, Chotinovo-2, Karpovcy-1, Karpovcy-4, Goluboi. Eutrophic quarry ponds are limited due to the necessity of containing nitrogen compositions or phosphate compositions, these include Turkusowe, Kričev, Lazurnyi. Hyper eutrophic quarry ponds are those where the eutrophic process is no longer limited by the containment of biogenic elements and is only partially hidden by productive macrophyte orientation, these include the quarry ponds Czarnogłowy and Szmaragdowe.

Chemical and biogenic pollution impact different quarry ponds to different extents. The reaction of quarry ponds to the pollution depends on the intensity of the pollution and the biogenic materials that are introduced to the quarry pond through water collection and limnic features of the basins themselves i.e. their productive, functional organization, and trophic status. The highest quality of water of the macrophyte type is seen in Chotinovo-1, Chotinovo-2, Karpovcy-1, Goluboi, and Kričev.

These quarry ponds share the qualities of high water transparency and the absence of an oxygen deficit in both summer and in winter. For Starik, Czarnogłowy, and Szmaragdowe have notably different degradation of physical and chemical indicators that shows that these quarry ponds are incapable of resisting the eutrophic impacts. These degradations are seen in the intensely polluted high trophic phytoplankton basin of Starik. Where there are signs of the oxygen regime worsening, low levels of water transparency, increased accumulation of carbon dioxide in base layers, and base sediments enriched by biogenic compositions. Carbon dioxide content is high in summer at the surface level as well as the concentration of biogenic elements in water being high.

The most sustainable function for the quarry ponds Kričev, Goluboi, and Turkusowe is determined by their morphological features and size of hollows, the availability of littoral zones, and the barrier functions of macrophytes against the process of eutrophication. In process of natural evolution, the macrophyte basins as systems producing organic material, accumulating it with biogenes in base sediments and smoothly eutrophing, are stronger and more sustainable than the phytoplankton types. Despite the process of eutrophication, the water is still highly transparent without mass clusters of phytoplankton. In the process of development, quarry ponds may come to complete eutrophy, with unchanging low levels of phyto-plankton production, which guarantees the high quality of quarry pond waters (Pokrovskaya, 1983). Macrophyte type quarry ponds have the capacity to maintain high levels of water transparency due to the ability of macrophytes to intercept nutritional minerals that accumulate in the quarry pond as the result of the accumulation of drainage water from surrounding areas. Macrophytes when compared with phyto-plankton have a significantly longer life cycle, whereas phytoplankton in the summer die off and being to accumulate in the sediment at the base of the quarry pond. Macrophytes, have the ability to store internal reserves of biogenic elements during opportune nutritional periods, which accumulate in the roots and tissues of the plants.

Concentrations of bio genes, exceed several times the critical accumulation level (1.3% of absolutely dry material for nitrogen and 0.3% for phosphorus), showing the high trophic status of the quarry pond and the inability of submerged macrophytes to compete with phytoplankton in absorption of nutritional elements. Nitrogen and phosphorus levels present in macrophyte type quarry ponds are not at critical levels and have the potential to increase in artificial water systems (Pokrovskaya, 1983).

The hydro chemical and hydro biological regimes of the investigated quarry ponds for multipurpose tourist and recreational use, with the development of programs for active, industrial, excursion, educational, and scientific tourist use. The following macrophyte type quarry ponds are recommended for this type of use: Chotinovo-1, Chotinovo-2, Karpovcy-1, Karpovcy-4, Goluboi Kričev, and Turkusowe.

The morphometric parameters, features of water collection territories, productive status, trophic status, and macrophyte function type of quarry ponds allow us to recommend their usage for tourist and recreational use. The above listed quarry pits are recommended for sustainable tourist and recreational use for the domestic and international tourist markets of the Republic of Belarus and the Republic of Poland.

The phytoplankton type of quarry ponds – Lazurnyi, Czarnogłowy, Szmaragdowe – with high trophic status, imperfect coping mechanisms for the impacts of recreational use, and limited tourist attractions within water collection territories, leads to the recommendation that these quarry ponds be used for local and regional tourist programs for the organization of active and industrial tourism.

The results of complex limnologic study of quarry ponds of the macrophyte and phytoplankton types, evaluation of their trophic status, and resistance to the process of anthropogenic eutrophy may serve as the basis for restoration of territories previously used for industrial purposes. These territories may be successfully restored through the creation of innovational and responsible tourist and recreational use of these resources.

Most important for using quarry ponds for tourist and recreational purposes is finding a way to balance the impact of tourist and recreational use to ensure a smooth transition from a post-industrial territory to a tourist or recreational destination. The introduction of balanced recreational use of quarry ponds and their surrounding ecosystems is essential to ensuring the long term sustainable use of quarry ponds.

CONCLUSION

The restoration of these post-industrial lands by creating quarry-ponds has the largest economic potential. The creation of quarry-ponds for tourist and recreational purposes is the most profitable way to restore post-industrial lands and provides an innovative source of resources. The restoration of post-industrial lands by creating quarry-ponds reduces the need for using technical mining equipment needed to level or fill in the violated surface and apply a fruitful humus layer. Another benefit of artificial water system restoration is that it decreases the cost of foresting a pit and its surrounding areas. A major appeal of artificial water system restoration is that it solves the challenge of the short supply of the top soil that is necessary to restore these post-industrial lands through the process of forestation. Artificial water system restoration over time creates the conditions for the accumulation of ground water and underground water drainage. These newly created artificial water systems are fit for tourist and recreational use.

These quarry ponds are similar to natural lakes of the region making them ideal for tourist and recreational use. Like natural lakes, the quarry ponds have similar morphometric parameters, a slow rate of water exchange, sustainable levels of oxygen, nitrogen and phosphorous, similar levels of salt content, containment of biogenic elements, their thermal gas regimes function and change in the same way, bio productive, and sediment processes. These similarities between natural lakes and quarry ponds allows us to use all of the methods and theoretic visions of limnology upon evaluation of conditions and perspectives for usage of newly formed artificial water systems for tourist and recreational purposes. Resemblance to natural limnic systems does not, however, negate that presence of features in the quarry ponds that are the result of their industrial origin. Over the course of their relatively short period of existence, 10-100 years, the majority of quarry ponds did not form coastal or littoral zones, sustainable productive structure, sustainable functional structure, and sediment processes that are typically expressed in natural lakes of the same region.

If these newly created quarry ponds are excessively used for tourist and recreational purposes rather than used sustainably, there will be a decrease in water quality, increased speed in the anthropogenic eutrophy, and the degradation of the artificial water system as a whole. Due to these specific technogenic differences between quarry ponds and natural lakes it is necessary to limit the tourist and recreational use of quarry ponds. As well as require the geo-ecological supervision of artificial water systems.

Through complex limnologic research of the structural and dynamic characteristics of quarry ponds in Belarus and Poland have presented two types of development of artificial water systems: macrophyte type and phytoplankton type. These types of artificial water systems are different by their level of resistance to external and internal eutrophic factors. Macrophyte type quarry ponds are the most resilient and have the highest capacity for long term maintenance of water mass. This is the result of submerged macrophytes ability to accumulate the excessive quantitates of eutrophic materials – nitrogen and phosphorous – in their tissues. Thus, removing the nutritional properties necessary for phytoplankton to grow. Among the most important conditions for sustainable tourist and recreational use of quarry ponds of the macrophyte type is their low trophic status, which makes them particularly attractive to tourists as well as the presence of basic tourist infrastructure i.e. roads, hotels, restaurants.

Newly formed artificial water systems require well managed restoration and monitored tourist and recreational use as a result of their similarities they share with natural lakes. The water mass parameters of artificial water systems resemble that of natural lakes. The region of these newly formed artificial water systems is technogenic in nature. The restoration and future tourist and recreational use of artificial water systems should be discussed and decided upon before the restoration process begins. This geo-ecological process that occurs before restoration begins because of the potential that these artificial water systems might one day be self-sustaining.

Through this diligent planning process it is possible to ensure the sustainability of tourist and recreational use. The geo-ecological project of using artificial water systems, which are created from post-industrial land where chalk was mined, for tourist and recreational use in Belarus could be considered one way of ecological restoration. The formation of a reliable mechanism to ensure stability of newly formed artificial water systems can be achieve through balancing tourist and recreational us that can be calculated through the creation of a system of accounting for tourist visitors to the artificial water systems. Systematic mastering of this new tourist and recreational resource provides numerous potential benefits to the Republic of Belarus. Through the restoration process there will be the creation of sustainable social and economic development of post-industrial lands, creation of new tourist destinations in the place of landscapes once degraded by open mining. This also allows for the creation of design and promotion of innovational tourist products at the local level as well as the further development of auxiliary tourist infrastructures.

The design of environmentally safe tourist products could allow tour companies and the local tourist market to prosper as a result of using these quarry ponds. This would help satisfy the demand for innovative tourist products in the Republic of Belarus.

Aknowlegments

We would like to thank Professor B.P. Vlasov and Professor J. Kubiak and our colleagues from Belarusian State University and the University of Silesia for their help in conducting this research. We would also like to give a special thanks to our native English proof-reader for completing the linguistic corrections of this manuscript.

REFERENCES

Alekin, O.A., Semenov, A.D., & Skopintsev, B.A. (1973). Chemical analysis guide for land waters. Gidrometeoizdat, Leningrad [in Russian].

Arinushkina, E.V. (1970). Soil chemical analysis guide. Moscow: Moscow University Press. 488 p. [in Russian]

Bacon, C.A. (2001). Strategy – The rehabilitation of abandoned mining lands (Revision 1). Record Tasmanian Geological Survey, 04.

Baczyńska, E., Lorenc M. W. & Kaźmierczak, U. (2018). The Landscape Attractiveness of Abandoned Quarries. *Geoheritage*, no.2, vol. 10, 271–285. https://doi.org/10.1007/s12371-017-0231-6.

David, L. (2007). Anthropogenic geomorphological and after-use problems of quarrying: case studies from the UK and Hungary. Geografia Fisica e Dinamica Quaternaria. 30, p. 161–165.

Davis, B.N.K., et al., (1982). Ecology of quarries: the importance of natural vegetation. NERC/ITE, Cambridge.

Gandah, F. & Atiyat, D. (2016). Re-Use of Abandoned Quarries; Case Study of Eco-Tourism and Rangers Academy Ajloun – Jordan. *Journal of Civil and Environmental Engineering*. 6, p. 1–238.

Iancu (Merciu), F.C. & Stoica, I.V. (2010). Tourist capitalization of industrial heritage elements: A strategic direction of sustainable development. Case study: The Petrosani Depression. *GeoJournal of Tourism and Geosites*, no. 1, vol. 5, 62-70.

Katanskaya, V.M. (1981). Higher aquatic vegetation of continental waters. Study methods. Nauka, Leningrad [in Russian].

Kaźmierczak, U., Lorenc M. W. & Strzałkowski P. (2017). The analysis of the existing terminology related to a post-mining land use: a proposal for new classification. *Environ Earth Sci* 76:693. https://doi.org/10.1007/s12665-017-6997-7.

Kherrour, L., Rezzaz M.A. & Hattab S. (2018). Rehabilitation of geographical areas for a tourist development the case of Batna region's mountains (Algeria). *GeoJournal of Tourism and Geosites*, 22(2), 455–469. https://doi.org/10.30892/gtg.22215-302.

Khomitch, S. A. (2001). Geoecological aspects of water management of disturbed lands. Belorussian State University, Minsk [in Russian].

Khomitch, S.A. (2002). Geoecological foundations of water management of land dumping complexes in Belarus: (*Thesis*) 25.00.36 [in Russian].

Khomitch, S.A., Anoshko Y.I., Daniltchenko A. O. & Dikareva, J.I. (2013). Key elements of the concept of geoecological support of tourist and recreational use of quarry reservoirs in Belarus. *Bulletin of the Foundation for Fundamental Research*. 1, p. 67–79 [in Russian].

Khomitch, S.A., Daniltchenko, A.O., Zubriakov, A. A., Kazarina, N.V. & Yanochkina, N.V. (2015). Geoecological support of tourist and recreational use of quarry reservoirs in Belarus. Belorussian State University, Minsk [in Russian].

Khomitch, S. A. & Gaydukievich, L. M. (2014). Geoecological support of tourist and recreational use of watered quarries in Belarus). Belorussian State University, Minsk [in Russian].

Khomitch, S. A., Anoshko, Y. I. & Daniltchenko A. O. (2012). Prerequisites for the use of the innovative resource of the career reservoirs of Belarus. Abstracts of the XI International Scientific Conference "Belarus in the Modern World". Minsk, 30 October 2012, p. 262–264 [in Russian].

Kubiak, J. & Machula, S. (2013). Water thermal regimes in selected antropogenic resorvoirs in Western Pomerania. *Oceanological and Hydrobiological Studies*. 42(2), p. 155–163.

Kubiak, J., Machula, S. & Choiński, A. (2018). Particular example of meromoxis in the anthropogenic reservoir. *Carpathian Journal of Earth and Environmental Sciences*. 13(1), p. 5–13.

Kubiak, J. Nędzarek, A., Tórz, A. & Machula, S. (2010). Wstępne dane o termice wód zbiornika Czarnogłowy. Przemiany jezior i zbiorników wodnych. PTLim, Poznań.

Legwaila, I. A., Lange, E. & Cripps, J. (2015). Quarry reclamation in England: a review of techniques. *Journal American Society of Mining and Reclamation*. 4(2), p. 55–79.

Lintukangas, M., Suihkonen, A., Salomäki, P. & Selonen, O. (2012). Post-mining solutions for natural stone quarries. *Journal of Mining Science*. 48(1), p. 123–134.

Lopukh, P. S. (2000). Regularities of nature development of water bodies of the slow water exchange of the forest zone: their use and protection. Belarusian State University, Minsk [in Russian].

McCandless, C. & Spirn, A. W. (2013). No longer just a hole in the ground: The adaptive re-use of resource depleted quarries. Massachusetts Institute of Technology 4.213J/11.308J (Urban Nature and City Design: presentation).

Mossa, A., Camúñez-Ruiz, J. A. & Morandi, F. (2018). Current state of the first UNESCO global geopark: A case study of the Geological and Mining Park of Sardinia, Italy. *GeoJournal of Tourism and Geosites*. 22(2), 403–418. https://doi.org/10.30892/gtg.22211-298.

Nędzarek, A., Tórz, A., Kubiak, J. & Machula, S. (2011). Warunki siedliskowe ichtiofauny w antropogenicznym Jeziorze Szmaragdowym (Szczecin, Polska) w latach 2009-2010, in: Jankun, M., Furgała-Selezniow, G., Woźniak M., Wiśniewska A. M. (Eds.), Gospodarowanie ichtiofauną w warunkach zróżnicowanego środowiska wodnego. Agencja Wydawnicza "Argi" SC R. Błaszak, P. Pacholec, J. Prorok, Olsztyn, p. 209–217.

Onoshko, M. P. (1985). Nitrogen and its mineral forms in Belarusian landscapes: Thesis: 04.00.02/ Onoshko, M. P. Minsk [in Russian].

Pokrovskaya, T. N. Mironova, N. Y. & Shilkrot, G. S. (1983). Macrophyte lakes and their eutrophication. Nauka, Moscow [in Russian].

Poleszczuk, G., Bucior, A., Tokarz, M. & Miller, T. (2013). Turkusowe Lake on the Wolin Island - surfaces water quality in 2011 vegetation season. *Ecological Chemistry and Engineering*, Seria A. 20(3), p. 401–414.

Poleszczuk, G., Svobodova, Z., Bucior-Kwaczynska, A. & Miller, T. (2014). Turkusowe Lake (Wolin Island, Poland) – Surface Waters Quality Changes in Years 1986-2010. *Ecological Chemistry and Engineering*, Seria S. 21(2), p. 201–214.

Rumiantsev, V., B. (1977). Transparency of water. Kubenskoe Lake). In: Collection of scientific papers of the Academy of Sciences of the USSR). Gidrometeoizdat, Leningrad [in Russian].

Rzętała, M. (2008). Funkcjonowanie zbiorników wodnych oraz przebieg procesów limnicznych w warunkach zróżnicowanej antropopresji na przykładzie rejonu górnośląskiego, Wydawnictwo Uniwersytetu Śląskiego, Katowice.

Dal Sasso, P., Ottolino, M. A. & Caliandro, L. P. (2012). Identification of Quarries Rehabilitation Scenarios: A Case Study Within the Metropolitan Area of Bari (Italy). *Environmental Management*. 49(6), p. 1174–1191.

Shilkrot, G., S. (1979). Typological changes in lakes in cultural landscapes. Minsk [in Russian].

Szabo, J., David L. & Loczy, D. (2010). Anthropogenic Geomorphology: A Guide to Man-Made Landforms. Springer.

Tokarczyk-Dorociak, K., Lorenc, M. W. Jawecki, B. & Zych-Głuszyñska, K. (2015). Post-industrial landscape transformation and its application for geotourism, education and recreation – an example of the Wide Mt. near Strzegom, Lower Silesia/Poland. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, no. 2, vol. 166, 195-203(9). https://doi.org/10.1127/zdgg/2015/0018.

Tórz, A. Nędzarek, A., Kubiak, J. & Machula, S. (2010). Wstępne dane o zawartości fosforowych i azotowych substancji biogenicznych w wodach zbiorników Czarnogłowy i Szmaragdowe, in: *Anthropogenic and natural transformations of lakes*. 4, p. 135-142.

Vinberg, G. G. (1960). Primary production of reservoirs. Publishing House of the Academy of Sciences of the BSSR, Minsk [in Russian].

Williams, G. (1998). After-use of quarries, in: Earthwise – *British Geological Survey*, Issue 12.

Yakushko, O.F. (1981). Limnoology: Geography of lakes of Belarus. Vysheushaya Shkola, Minsk [in Russian].

Zukhovitskaya A. L. & Generalova V. A. (1991). Hydrochemistry of lakes of Belarus. Nauka i Tekhnika, Minsk [in Russian].

***StatSoft, Inc. 2009. STATISTICA (data analysis software system), version 9.0. www. statsoft.com.

http://www.geoportal.gov.pl.

Submitted:	Revised:	Accepted and published online
17.07.2019	29.11.2019	03.12.2019