Copper ore post-flotation settling tanks in Poland: social acceptance or objection?

Katarzyna Pactwa¹ · Justyna Górniak-Zimroz¹

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Abstract

The issues concerning mining have been causing a wide variety of emotions. Objection to and disagreement with new investments, but also social acceptance for the operation of mining plants offering stable employment. Production in this sector is associated with the generation of waste. In the case of copper ore mining, the result of the entrepreneur's activity consists of waste treatment facilities in the form of post-flotation settling tanks. In addition to the inactive facilities in Lower Silesia, there is also the settling tank Żelazny Most, which is used and expanded. The large area and risk to the environment allow to suppose that the existence of settling tanks in social space generates conflicts or it is conducive to the emigration of the residents. In order to verify the above-mentioned hypothesis, the authors used geographic information systems to analyse the current population status and expansion of the road and rail network, the residents' drinking water sources and soil permeability in five impact zones. The achieved results allow to conclude that the facilities belonging to KGHM PM S.A. coexist with their surroundings, thus gaining social acceptance. The proposed research methodology can be used by the entrepreneurs, but also local authorities to evaluate the acceptance of mining waste disposal facilities.

Keywords Mining · Social aspect · Community · Mining waste · Poland

1 Introduction

During the performance of its activities, the mining industry interferes with its surroundings (Monjezi et al. 2008). While disturbing the original conditions, including changing the landform, eliminating green areas, crops, disrupting the structure of surface waters and underground waters, it affects the living organisms present in the area, where the works associated with exploration, opening and mining of the deposit, processing of the mineral and treatment of the obtained raw material, are performed. The living organisms consist

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✉ Katarzyna Pactwa
katarzyna.pactwa@pwr.edu.pl

Justyna Górniak-Zimroz
justyna.gorniak-zimroz@pwr.edu.pl

¹ Department of Geodesy and Geoinformatics, Faculty of Geoengineering, Mining and Geology, Wrocław University of Science and Technology, Wrocław, Poland

of fauna and flora, but also people. The effects of works carried out are felt by employees, who are directly engaged in them, but also by communities living in areas near the mines or processing plants. It can be assumed that residents exposed to noise, atmospheric air pollution, dust or light pollution will leave the areas located near the mining and processing plants. In addition, this hypothesis is supported by the fact that some of the initiatives in the mining industry are associated with taking over large areas of land for their activities, and this is associated with resettlement (Hilson, 2002). The following can be considered to be the counterarguments:

- Mining companies are attractive in terms of wages and often they are the largest employers in the region, just like in the case described in the article KGHM PM SA employs 18,000 people, and the entire Capital Group over 30,000 (Sustainable Report of KGHM Polska Miedź S.A. 2018), or in Canada where the mineral sector is a pillar of the national economy and offers 634,000 direct and indirect jobs (according to 2017 data) (website of Natural Resources Canada), while implementing the principles of social responsibility employs nearby residents (Hilson, 2000), or in Australia where the industry offers indirect jobs (Fleming & Measham, 2014),
- The budgets of local government units, in the area of which the mining companies operate, are supported by mandatory fees (Pactwa et al., 2018),
- Good practices of the companies implemented in compliance with the idea of corporate social responsibility and sustainable development (Pactwa, 2019; Woźniak, 2019).

The matters focused on social issues are associated with the concept of social licence to operate (SLO). The issues of social licence discussed in the literature (Hall et al., 2015; Moffat et al., 2016) also apply to (and even primarily apply to) the mining industry (Owen & Kemp, 2013; Woźniak & Jurczyk, 2020). The social licence is understood at two different levels: as continuous social approval, i.e. having a positive opinion or consent, and even satisfaction associated with the performance of such activities, and as a social acceptance consisting of tolerating the undertaken actions (Thomson & Boutilier, 2011). A social licence occurs when a mining project is perceived as having continuous approval and widespread acceptance of the public for conducting the given business activity (Prno & Slocombe, 2012).

This article discusses the consequences of existing business activity and the effects related to the basic activity of the company, which is mainly engaged in the mining, processing and treatment of copper ore. The article aims to diagnose social acceptance for the existence of post-mining facilities in the form of settling tanks (6 inactive and 1 operational mining waste treatment facility). The acceptance assessment was carried out by identifying objects, such as buildings or road and rail infrastructure in the immediate vicinity. The above-mentioned objects are used by people and created for their needs. Their existence, together with the diagnosis of the state of development as a result of an on-site inspection, testifies to the acceptance (or lack thereof) of settling tanks by the inhabitants. Thus, on the basis of the conducted analyses, the method of managing the immediate surroundings of post-flotation settling tanks in the context of social conditions will be subject to the assessment. The works performed with the use of the tools of geographic information systems, combined with a cartographic presentation, will allow to verify the coexistence between the facilities and the local communities, and can be used for future assessments of "social acceptance". The usefulness of GIS tools in dealing with social licencing issues has been confirmed in Craynon's work (Craynon, 2016). Social acceptance is a key indicator of the socio-political risk associated with a mining project (Que, et al., 2015). While interpreting

the above sentence in the context of the entire life cycle of the plant, and further the impact of the objects, the existence as associated with the conducted activity, it should be considered that such a risk also applies to post-flotation settlers. Goodland (2012) wrote about the hazards resulting from the existence of post-flotation settling tanks. They occupy the large area of land, contain the toxicity of deposited waste and provide problems resulting from their insufficient protection. All these issues may cause public opposition. Thus, they are socially and environmentally sensitive areas.

In the context of social acceptance, it is worth paying attention to the activities of the KGHM company adopting the "licence to operate" principle. Documents including the ethical standards Social Dialogue Policy are prepared taking into account the interests of the stakeholders (Sustainable Report of KGHM Polska Miedz S.A. 2018). And although the social licence is an important issue particularly at the investment stage, it is also relevant when attention must be paid to the social issues arising from mining activities, especially when these aspects were omitted in the operations conducted so far (Owen & Kemp, 2013). Issues regarding external stakeholders, such as local communities, and interactions between this interest group and the company are one of the aspects of social responsibility—a pillar of sustainable development (next to the environmental and economic issues) (Dubiński, 2013).

2 Literature review

Public opinion polls in the Flash Eurobarometer series (Flash Eurobarometer 363, 2013), which includes thematic ad hoc telephone interviews, show that more than half of Europeans (52%) assess the impact of enterprises on society (without distinguishing between sectors) as positive. Opinions about whether companies are paying more or less attention to their impact on society than ten years earlier are divided: 40% of Europeans see the greater commitment and 39% say the opposite. Enterprises from the mining and oil & gas industry companies are rated worse. In this case, 34% of respondents answered positively (yes) to the question: Do you think that the mining industry is making efforts to behave responsibly towards society? The remaining people strongly denied (total "No" 55%), answered "not applicable" (1%) or did not have an opinion (10%). Opinions on this subject vary between EU countries. Polish people are most favourable to the mining sector. As many as 48% of them consider companies to be responsible. The most critical in the study was the French (yes: 20%, no: 26%, not applicable: 1%, I have no opinion: 48%).

In the countries or regions where the opinion about the mining industry is critical, one should expect the greater social risk of future and current activities. Stakeholder acceptance is one of the conditions for recognising the mining industry as responsible and sustainable (Goodland, 2012). When sustainable extraction is assessed as unlikely or even impossible, companies should develop and implement more responsible environmental, economic and social practices (RESPONSIBLE MINING, 2012). In some regions, a crisis of reciprocity between stakeholders is diagnosed. The problems of local communities are ignored, and taxes and fees supporting the budgets are not used for investments that benefit the inhabitants (Muruviwa et al., 2020). There are also countries (including Poland, which may justify a positive opinion on mining) which allocate funds from companies to various types of investments and activities that bring benefits to all inhabitants of the mining region (Pactwa et al., 2018).

The emerging social opposition may be the result of the NIMBY phenomenon (Not In My Backyard), which is defined as the resistance of the inhabitants to the investment. This term appeared in the early 1980s (Schively, 2007). This syndrome means general acceptance regarding the social need of a given investment, but also resistance to its close location. It is one of the types of local conflicts, because it is related to the issue of space, both geographically and socially (Michałowska, 2008). Based on research by Guo et al. (2015), the social acceptance of investments (in the discussed case, the analyses concerned wind energy) is influenced by two factors: economic benefits and environmental costs. In such a case, it is important to provide information to the public in the above-mentioned scope. Increasing social acceptance will ensure the employment of local residents throughout the life cycle of the project. The NIMBY phenomenon also occurs in the case of mining investments (Badera, 2010; Pelekasi et al., 2012). This is an example of a unique and complicated situation as mines are not flexible in terms of location. Unfortunately, it is still difficult to explain what influences the acceptance or opposition of the residents (Menegaki & Kaliampakos, 2014). The issue of social resistance to mining activities is a complex and changing problem. It may go beyond the local context and establish contacts with non-governmental organisations, lawyers and scientists, which may lead to legal action and, consequently, to the formal rejection of mining projects (Conde, 2017). Due to the fact that these issues are ambiguous, the solution proposed in the article is justified.

3 Materials and methods

The methodology includes the following steps: preliminary research consisting in the selection of the research object, its inventory and assessment of the current state, and identification of social elements taken into account in further analyses, preparation of input data for analyses, i.e. development of a spatial-descriptive database for a post-industrial object along with the zones of its influence on social elements, and databases of environmental elements as well as appropriate research methodologies, including the analysis of the impact of a post-industrial object on selected social elements (Fig. 1). The result of the proposed methodology is to obtain an acceptance / non-acceptance assessment of the post-industrial object related to the mining industry under research. The research used the GIS system, which can be defined as a system for acquiring, collecting, verifying, analysing, transferring and sharing spatial data in a broader sense, also including methods, hardware, software, spatial databases, organisation, resources and people interested in its functioning (Heywood et al., 2006; Longley et al., 2005).

Fig. 1 The methodology of research concerning the social acceptance of post-industrial facilities related to the mining industry

Analyses performed in GIS systems allow to automate the process of assessing the studied phenomenon (e.g. social acceptance of a post-industrial facility) by overlaying layers with thematic data, performing spatial analyses (e.g. proximity analysis) and obtaining an impartial result (e.g. in the form of spatial identification of objects located in given distance from a post-industrial object) in a descriptive, tabular or graphic form (Smith et al., 2007). The GIS system was used in the research. More about the construction and application of GIS systems in mining can be found in (Górniak-Zimroz, 2019).

Based on the literature (World Economic Forum, 2012), the authors identified in the research the social infrastructure essential for the functioning of the local community living around post-industrial facilities. The authors concluded that the research will analyse the following social elements constituting the components of social infrastructure: built-up areas (including single-family and multi-family residential buildings, industrial, commercial and service buildings, farm buildings, historic buildings, objects related to religious worship, with cultural activities, buildings of schools and scientific institutions and other buildings), road infrastructure in the form of national, provincial, national, municipal, company and other roads, railway infrastructure in the form of active and inactive railway lines, railway sidings and route tracks, ways of supplying residents with water (including intakes, water supply and own wells) and soil permeability, i.e. the ability of the soil to penetrate water. For the identified social elements, a database was developed in the GIS system (Fig. 2). The data for the database were obtained from the state institutions dealing with the acquisition and sharing of spatial data.

Subsequently, five impact zones were determined for each object selected for analysis in the form of buffers, starting from the borders of the examined object, according to the key presented in Table 1. The buffer in spatial analysis is a polygon surrounding the object and it is defined by specifying the distance of its outline, from the objects' outline (Urbański, 2012). The size and number of zones were assumed arbitrarily.

After the zones were designated, social objects were identified (built-up areas, road and rail infrastructure, drinking water sources together with a water supply and soil permeability) located in these zones according to the key from Table 1, where Y means the occurrence of an element, and N means no social element in the buffer zone. After their identification, an analysis of the selected object in the context of social acceptance of the post-industrial facility was carried out, in order to find an answer to the

Fig. 2 Database of the social elements

Table 1 Identification in the social infrastructure zones

Zone name	Zone width [m]	T	Towns	Buildings	Residents	Built-up area	Road infrastructure	Railway infrastructure	Deep-water well	Very poor soil permeability	Diverse soil permeability	Vari-able soil permeability	Poor soil permeability	Average soil permeability	Easy soil permeability
				B	R	BA	RI	RwI	D-W	VP	D	V	P	A	E
Zone I	= < 1000	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Zone II	1000–2000	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Zone III	2000–3000	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Zone IV	3000–4000	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N
Zone V	4000–5000	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N

question of whether the post-industrial facility located in the vicinity is accepted by society. The tools used in the research for spatial analysis of mutual relations between objects, including a post-industrial object versus objects related to the life of the local community, allowed for impartial spatial identification of social elements in the buffer zones. The result was obtained by overlaying data layers in the GIS system, performing a proximity analysis on the data in given zones, enabling the search for elements in the vicinity of objects, around which the buffer zones were generated, and identification of social elements in the zones.

The methodology proposed in the paper is a general method that can be widely applied to the analysis of post-industrial objects in the context of their social acceptance or opposition to their coexistence in the immediate environment. Its application can be a major starting point towards developing the tools that allow to evaluate a sustainable social agenda. The tools in the form of databases and GIS systems used in the proposed methodology can be used to improve the public's access to reliable data and information. Thanks to the proposed methodology, various groups of stakeholders (including external ones) can obtain tools for the impartial assessment of social acceptance of post-industrial facilities, which will allow for the conscious formulation of opinions based on the facts. In order to illustrate the developed methodology, the copper ore post-flotation settling tanks located in south-western Poland were used (Fig. 3). The performed analysis was described as a case study.

Fig. 3 Location of the post-flotation settling tanks in Poland (own elaboration)

4 Results: case study

The first stage of works resulted in a decision regarding the selection of objects for research. The analyses were limited to the post-flotation settling tanks resulting from business activity of the company mainly engaged in mining, processing and treatment of copper ore. Figure 4 demonstrates the technological diagram of copper ore mining and processing, which is currently used at KGHM Polska Miedź S.A.

KGHM Polska Miedź S.A. is one of the leading mining companies in the region (Lower Silesia, S-W Poland). Due to the production size, the assessment of residues impact is significant, especially for the post-flotation waste management, as its neutralisation is carried out through storage (Statistics Poland, 2019; Woźniak & Pactwa, 2018). Seven post-flotation settling tanks were selected as research objects, including six inactive (Lena 1, Lena 2, Wartowice, Konrad 1, Konrad 2, Gilow) and one active (Zelazny Most), located in the Lower Silesia area (Fig. 3).

After the selection of objects, their inventory was carried out based on the literature analysis, as well as data from the Polish Geological Institute (“Mine heaps database”) and the Provincial Centre of Geodetic and Cartographic Documentation of the Lower Silesia Province Marshal’s Office (Orthophotomap). The results of this inventory are demonstrated in Table 2.

Recognition of the current state of post-flotation settling tanks was carried out through the analysis of the Study of Conditions and Directions of Spatial Development and the Local Spatial Development Plans of the municipality: Warta Bolesławiecka (Resolution No. XXVI/124/05), Lubin (Resolution No. LII/383/2014), Polkowice (Resolution No. XL/485/14, Resolution No. III/54/15), Grebocice (Resolution No. XLVII/191/2009), Złotoryja (Resolution No. XXXIV/383/2018), as well as the EPP of the following counties: Bolesławiec County (EPP for the Bolesławiec County for 2017–2020), Legnica County (EPP for the Legnica County), Lubin County (EPP for the Lubin County for 2017–2024), Lwówek Śląski County (EPP for the Lwówek Śląski County for 2018–2021), Polkowice County (EPP for the Polkowice County for 2012–2015) and for the Złotoryja Municipality (EPP for the Złotoryja Municipality).

Fig. 4 Diagram of the copper ore mining and processing (Own elaboration based on (<https://kgbm.com/pl>))

Description of the current state is presented in Table 1 in the “Object’s current status” column.

A site visit of the inactive post-flotation settling tanks was also carried out in September 2019, which resulted in photographic documentation of the studies. During the above-mentioned site visit, it was concluded that post-flotation settling tanks, created as a result of mining activity, have a negative impact on the landscape. These settling tanks occupy large areas, along with surrounding embankments, constituting a negative element of the landscape (Fig. 5a–b). After the completed mining activity, the waste contained in the settling tanks has been dehydrated and dried, therefore such waste is susceptible to dusting and leaching to groundwater and local surface waters. Several years after closing, the following settling tanks: Konrad 1 (1971), Konrad 2 (1968), Gilow (1980), Wartowice (1986) are partially covered with trees (Fig. 5 d, e) and self-sown low grassy-woody vegetation (Fig. 5c–f), which, however, does not provide full protection against dusting (Fig. 5c, e).

Fig. 5 View of the post-flotation settling tank: Wartowice (a–c), Gilow (d, e) and Konrad 2 (f) (own photographs).

In the seventies of XX century, the research works were performed on the settling tank Lena 1 and Lena 2, which resulted in the determination of a direction for the forest reclamation, with modification depending on soil–water relations, i.e. afforestation of the dry part and planting of the wet part of the reservoirs. The effects of this reclamation were initially not fully satisfactory, while the good results were obtained only during reclamation of the settling tank Lena 1 by selecting the appropriate varieties of vegetation and spreading the biologically active soil layer on the barren surface. From the time of object's formation to the present time, the frontal earth dam managed to biologically renew itself to a significant extent, mainly through self-sown plants. The crown and northern slope are covered with turf, bushes and low trees, mainly with birch and hazel. In 2002, in the area of the sedimentation pond Lena 1, the ecological use area Lena was created with an area of 12.82 ha, in the form of three mid-forest ponds, with a variety of plant communities and complexes, from water-reed and willow ones, along with mixed forests with numerous species of protected fauna and flora (General Directorate for Environmental Protection, 2019). The sedimentation pond Lena 2 was drained in the eastern part, while in the middle and west part it is filled using water with aquatic vegetation. This pond was filled with fish by fishermen, while in 2005 it was taken over by the Legnica District of the Polish Angling Association (Fig. 6a–d), which intensively stocked it with fish. This pond is also extensively visited by water birds (Dyda, 2009; Piątek & Piątek, 2019; Piątek et al., 2004).

Fig. 6 View of the post-flotation settling tank Lena 2 (Dyda, 2009).

The post-flotation settling tanks Gilow, Wartowice, Konrad 1 and Konrad 2 belong to KGHM Polska Miedz S.A. Oddzial Zaklad Hydrotechniczny. Biological stabilisation was implemented on the settling tank Gilow, which effectively protected the surface of this object against aeolian and water erosion. In order to generate an organic layer that enables the introduction of vegetation, the waste and overburden from the nearby Obora sandpit were used. In the years 1981–1986, the vegetation of stabilising nature was implemented on the surface of the object. Approx. 200 ha of water table, surrounded by reeds, was left in this object, to constitute a habitat for water birds and animals (Meinhardt et al., 2014). In the Local Spatial Development Plans of the Warta Boleslawiecka Municipality (Resolution No. XXVI/124/05), the settling tanks Wartowice, Konrad 1 and Konrad 2 are planned to be reclaimed in the forest direction. Currently, these settling tanks are covered with trees and grassy vegetation (Fig. 5).

Input data for the actual research were obtained in digital form from databases kept by: Provincial Centre of Geodetic and Cartographic Documentation of the Lower Silesia Province Marshal's Office (Topographic Objects Database, Hydrographic and Sozological Maps), the Polish Geological Institute-National Research Institute (Central Geological Database, Mine heaps database) and the General Directorate for Environmental Protection (Central Register of Nature Conservation Forms). The above-mentioned data were subjected to a qualitative analysis consisting of assessment of their suitability for research. Selected data were used in further works in order to prepare a database of post-flotation settling tanks and social elements.

A crucial element in the analysis of social responsibility of the copper ore mining is identifying which social elements are affected by the copper ore post-flotation settling tanks, left by KGHM PM S.A. after mining activity carried out in the years 1950–1986. The authors understand social elements as objects, infrastructure or other elements of the surroundings that are directly associated with people and that affect the quality, as well as the comfort of their lives. Moreover, the surroundings of the post-flotation settling tank Zelazny Most, which is currently used by KGHM PM S.A., were also analysed. This research consisted of assessing the settling tanks' impact on people's lives in the designated zones, i.e. built-up areas, road and rail infrastructure, drinking water sources along with water supply systems and soil permeability, were identified and analysed. The purpose of conducted works was to analyse the impact of these tanks on their immediate surroundings and to diagnose the social acceptance of the mining entrepreneur resulting from the existence of large-area objects.

In the first stage of research, the built-up areas along with road and rail infrastructure were identified in the impact zones. In order to identify these objects, the data from the Topographic Objects Database were used. Figure 7 presents built-up areas along with road and rail infrastructure.

After identification of built-up areas, their detailed analysis was carried out, which consisted of recognition of the names and types of built-up areas, along with the calculation of the number and area of buildings in the designated impact zones. Figure 8 presents the results of analyses and calculations performed for the designated zones.

In the impact zones of the settling tank Lena 1, there are 22 built-up areas inhabited by 12,892 residents, including approx. 50% of the urban area of Zlotoryja (NofR = 8558; where NofR means the number of residents) located N-E from the settling tank and 21 rural areas (NofR = 3107). Most of the residents live in the impact zone V (NofR = 9044). In the impact zones of the settling tank Lena 2, there are 24 built-up areas inhabited by 22,803 residents, including the area of the city of Zlotoryja (NofR = 16,147) located in each impact zone for this settling tank, 22 rural areas with NofR = 14,920. Most of the

Fig. 7 Location of buildings, road and rail infrastructure in the impact zones of the post-flotation settling tanks

Fig. 8 Analysis of built-up areas in the impact zones of the copper ore post-flotation settling tanks; where L1—Lena1, L2—Lena 2, W—Wartowice, K1—Konrad 1, K2—Konrad 2, G—Gilow, ZM—Zelazny Most

people live in the impact zone II (NofR=9363). In the impact zones of the settling tank Wartowice, there are 26 rural areas inhabited by 8174 residents. Most of the residents live in the impact zone V (NofR=2433). In the impact zones of the settling tank Konrad 1, there are 23 rural areas inhabited by 9419 residents. Most of the residents live in zone IV (NofR=4341). In the impact zones of the settling tank Konrad 2, there are 19 rural areas inhabited by 5575 residents. Most of the residents live in zone V (NofR=2155). In the impact zones of the settling tank Gilow, there are 29 built-up areas, including to the south from the settling tank in each impact zone there is approx. 50% of the city of Lubin NofR=39,152, to the north-west from the settling tank in the impact zone from III to V there is approx. 30% of the city of Polkowice (NofR=4641), while the remaining areas are rural buildings with NofR=9726. Most of the residents live in zone V (NofR=28,199). In the impact zones of the settling tank Zelazny Most, there are 38 areas inhabited by 8153 residents, including the urban area Polkowice with NofR=221 (zone V) and rural areas with NofR=7932. Most of the residents live in zone II (NofR=3902).

In the subsequent stage, a detailed analysis of the road and rail infrastructure in the designated impact zones was carried out. Figure 9 presents the results of identification of the rail and road infrastructure in the analysed area, which includes both rail and road infrastructure in the form of national, provincial, municipal, plant and other roads.

An inactive railway siding was identified in the impact zone I of the settling tank Lena 1, which is probably a remnant of the railway tracks used during the mining enterprise's activity in this area (1947–1974 (Piątek & Piątek, 2019)), while in the zones IV and V, the active freight railway lines in the form of a railway siding and ordinary mainline tracks were identified. In the impact zone II–V of the settling tank Lena 2, the active freight railway lines in the form of a railway siding and ordinary mainline tracks were identified, while in the zone III–V, inactive railway sidings and inactive ordinary mainline tracks were identified. In all zones of the settling tank Lena 1 and Lena 2, the county, municipal, plant and other roads were identified, while in the zone V (Lena 1) and II–V (Lena 2) the provincial roads (328, 363, 364) were identified.

No railway infrastructure was identified in the impact zones of the settling tanks Wartowice, Konrad 1 and Konrad 2. Provincial road no. 363, as well as county, municipal, plant and other roads, was identified in each zone. National road no. 94 was identified in the zone V of the settling tank Wartowice. Active railway infrastructure in the form of ordinary mainline tracks was identified in all impact zones of the settling tank Gilow and Zelazny Most. In addition, a railway siding along with railway stations was identified in the zones

Fig. 9 Analysis of road and rail infrastructure in the impact zones of the post-flotation copper ore settling tanks

III-IV of the settling tank Zelazny Most, whereas in the case of the settling tank Gilow in the zone I, III and V, the railway stations were identified, as well as railway sidings in the zones I-V. In the scope of road infrastructure, the provincial (323, 331), county, municipal, plant and other roads were identified in all zones of both settling tanks, while in the case of zones I-V of the settling tank Gilow, expressway S3 and national road no. 3 were identified.

The most of railway infrastructure is located in the impact zones of the settling tank Gilow, with a total length of 98,184 m (most in zone V, track length 31,259 m) and the settling tank Lena 2, with a total length of 51,825 m (most in zone III, track length 17,071 m). While the most of road infrastructure is located in the impact zones of the settling tank Gilow, with a total length of 1,105,531 m (most in zone IV, road length 317,729 m) and for the settling tank Zelazny Most, with a total length of 1,075,134 m (most in zone V, road length 301,778 m).

In the second stage of research in the impact zones, the method of supplying residents with drinking water was analysed, i.e. water intakes were identified, as well as the method of supplying water in the form of a water supply system or own wells. Data for analyses were obtained from the Topographic Objects Database, from the Hydrographic and Sozological maps, as well as from the county and municipal environmental protection programmes, developed for the counties covered by the research. Figure 10 presents the location of analysed objects in the impact zones of the copper ore post-flotation settling tanks.

Drinking water for residents of towns located in the impact zones of the post-flotation settling tanks is supplied using water supply systems ensuring constant access to water for their users. However, the deep-water wells are located in the impact zones of

Fig. 10 Location of deep-water wells in the impact zones of the post-flotation settling tanks

the settling tanks, from which (among others) the water is collected for water supply systems. The number of wells in individual impact zones is presented in Fig. 11. Most of the deep-water wells are located in the impact zone IV of the settling tank Gilow (27 pieces), while in total most of the deep-water wells are located in the impact zones of the settling tank Zelazny Most (57 pieces). Drinking water for residents of towns located in the zones of influence of post-flotation settling tanks is supplied by water supply systems ensuring constant access to water for individual users from the local groundwater intakes. The counties where the research objects are located, together with the zones of their influence, are from 72 to 98% with water supply (data from Statistical Office, 2020). In the impact zones of the settlers, there are deep wells, which are local groundwater intakes, from which, inter alia, water is taken in order to supply the water networks. The water from these intakes is of good or very good quality (information from the county resolutions), i.e. post-flotation settling tanks did not affect the quality of groundwater.

In the third stage of research, soil permeability was identified, which determines the soil's ability to conduct water (Hydrogeological Dictionary, 2002). Data for the analysis were obtained from the Hydrographic map database. Figure 12 presents the types of soil permeability in the impact zones of the post-flotation settling tanks. Based on the available data, six types of soil permeability were identified: easily permeable soils made of debris, gravel, coarse-grained and even-grained sands, average permeable soils made of sands along with strongly sealed solid rocks, poorly permeable soils made of clay, silt, mudstones, sandy loams and dust, organic soils with variable permeability, anthropogenic soils with diverse permeability, as well as soils with very poor permeability that contain poorly sealed solid rocks.

Figure 13 presents the results of soil permeability analysis in the impact zones of individual post-flotation settling tanks. In all impact zones of the settling tanks: Lena 1, Lena 2, Wartowice, Konrad 1 and Konrad 2, the soils with poor permeability are the most common (Fig. 12—marked in brown). These soils are made of clays and dust. On the other hand, in the settling tanks Gilow and Zelazny Most, the soils with average permeability are the most common—consisting of sands with strongly sealed solid rocks (Fig. 12—marked in yellow). There are no easily permeable soils in the analysed area.

Fig. 11 Analysis of the water supply method in the impact zones of the copper ore post-flotation settling tanks (number of deep-water wells)

Fig. 12 Soil permeability in the impact zones of the post-flotation settling tanks

5 Discussion

The issue of mining waste constitutes a current and important topic (Driussi & Jansz, 2006; Kaźmierczak et al., 2019; Lottermoser, 2010). Recently, it is also raised in the context of the circular economy and sustainable development concept (Kulczycka et al., 2019; Zhaoa et al., 2012). Waste can be generated in three main stages of production: mining, processing and treatment. Waste management is affected by three factors (Lèbre et al., 2017): time (what is a waste today may turn out to be an ore tomorrow), mining strategy and economic issues. These factors are more diverse than the clear physical properties of the material and they affect the final classification in terms of waste and ore. A chance to change the classification, and consequently the use of waste, also occurs in the case of the discussed objects – post-flotation settling tanks (Łuszczkiewicz, 2000; Mining Waste Management ... 2013). However, it is a matter of new technologies, cost-effectiveness or legislation. KGHM PM S.A. ensures that it takes into account the circular economy issues at every stage of the value chain. Unfortunately, it is very difficult in the case of a waste disposal facility. There is a plan to expand Żelazny Most (a permit for this was obtained in March 2018), which will allow to deposit additional waste in the amount of approx. 170 million m³ (Sustainable Report of KGHM Polska Miedź S.A. 2018).

Flotation sedimentation tanks are objects that have a significant impact on the environment, and the health and life of people living in their surroundings. This happens during their operation and after they are closed, especially when their failure occurs. It is important to know the causes of the failure. The work (Rico et al., 2007, 2008) collected

Fig. 13 Soil permeability analysis in the impact zones of the copper ore post-flotation settling tanks, where VP very poor soil permeability, D diverse soil permeability, V variable soil permeability, P poor soil permeability, A average soil permeability, E easy soil permeability

and analysed the causes of 147 dam failures in active and inactive post-flotation settlers in the USA and Europe. Data for the analysis were collected from the databases of the International Commission on Large Dams (ICOLD), the US Large Dams Commission (USCOLD), the US Environmental Protection Agency (EPA) and the United Nations Environment Programme (UNEP) and from the analysis of articles published in scientific journals, conference materials, reports, published and unpublished dissertations, and websites. As part of the e-EcoRisk project—A Regional Enterprise Network Decision-Support

System for Environmental Risk and Disaster Management of Large-Scale Industrial Spills, a database was developed containing the basic parameters of the settling tank and failure, including the area of influence of the settler along with socio-economic and environmental consequences resulting from the failure. As part of the research, a preliminary statistical analysis was carried out in order to gain knowledge about the causes of the accident, the geometry of settling tanks sensitive to flotation waste, and the geographical distribution of the accident. 15 different causes of accidents resulting from meteorological causes (e.g. abnormal rainfall, hurricanes, rapid snow melting, ice accumulation in a sediment dam, etc.) have been identified, from poor management and inadequate human activity (e.g. poor management of the settler beach, poor maintenance of the dam drainage structures, improper operations on dams, the rapid growth of dams, etc.) and for technical reasons (e.g. overflow, leakage, foundation failure, land subsidence, improper stability, etc.). The authors of the research concluded that dams in post-flotation settlers should last forever, but the collected data show that smaller and larger settler failures pose a serious threat to the environment. Several special features make the post-flotation sedimentation tanks more sensitive than other types of structures, e.g. retention dams, they are (1) embankments formed by locally harvested materials (soil, coarse tailings, mining overburden and flotation tailings); (2) dams then raised as solid material coupled with a significant increase in wastewater (plus runoff from precipitation); (3) lack of provisions on detailed design criteria; (4) lack of dam stability requirements for the continuous monitoring and control during erection, construction and operation; (5) high costs of maintenance works on post-flotation sedimentation tanks after the end of mining activities.

The report of the United Nations Environment Programme UNEP (Roche et al. 2017) describes the catastrophes of post-flotation settlers in 2007–2017. It describes growing global concerns about the safety, management and impact of the storage and management of large amounts of mine tailings in the settling tanks. It has been found that the growing number and size of post-flotation settlers around the world increase the potential environmental, social and economic costs of the consequences of catastrophic accidents, as well as the risks and costs of their continuous management. This risk is a challenge for this generation, and if not resolved now, it will remain in the form of a debt that we will leave for the future generations.

The publication of the research results and reports described above provides the society with knowledge about the dangers of active and inactive post-flotation settlers in public space. In this context, as part of the research, the factors determining the quality of life around the post-flotation settlers were identified and it was analysed whether these factors occur in the vicinity of the settlers, and what impact the location of the analysed settlers has on them. The tools available in the GIS systems were selected for the analysis, allowing to identify objects in a given space and to define their spatial relations. The proposed methodology made it possible to identify in five impact zones the degree of exclusion of areas in the close vicinity of settlers from residential buildings, road and rail infrastructure or the location of deep wells.

Conducted analyses allowed to conclude that the largest number of people live in the impact zones of the post-flotation settling tank Gilow (NofR=53,519), while the lowest number of people in the impact zones of the settling tank Konrad 2 (NofR=5575). In the case of Lena1 and Gilow reservoirs, it can be seen that while moving away from the object, we can observe a larger number of buildings and residents. However, this cannot be regarded as regularity (Fig. 8). At the same time, while analysing the number of residents in the subsequent zones, taking into account all reservoirs together, it was not found that the number of inhabitants increases as the distance increases (Table 3). New

Table 2 Copper ore post-flotation settling tanks

Object name	Period of operation	Capacity [mln m ³]	Area [ha]	Amount of waste [mln Mg]	User	Object's current status ¹	View of object's current state
Lena 1	1950–1958	4,2	42,08	7,0	Lena Mine	Forests, agricultural areas of the lowest classes V–VI, surface waters. Ecological use area Lena	
Konrad 1	1953–1971	16,40	119,56	18,0	Konrad Mine, Lubiechow	Partially reclaimed area, intended for further reclamation in the forest direction. This area belongs to KGHM Polska Miedź S.A., Oddział Zakład Hydrotechniczny	

Table 2 (continued)

Object name	Period of operation	Capacity [mln m ³]	Area [ha]	Amount of waste [mln Mg]	User	Object's current status ¹	View of object's current state
Lena 2	1959–1973	7.8	86.40	15.0	Lena Mine	Reclaimed area Forests, agricultural areas of the lowest classes V–VI, surface waters Artificial water reservoir was created	
Gilow	1967–1980	65.00	623.22	92.0	Mine: Rudna, Polkowice, Lubin	Partially reclaimed area, intended for further reclamation in the direction of green land-use (covering with grass, with the acceptance of shrubs and trees), along with the reclamation based on further automatic succession of vegetation. This area belongs to KGHM Polska Miedź S.A., Oddział Zakład Hydrotechniczny	

Table 2 (continued)

Object name	Period of operation	Capacity [mln m ³]	Area [ha]	Amount of waste [mln Mg]	User	Object's current status ¹	View of object's current state
Konrad 2	1967–1968	0,12	13,15	1,2	Konrad Mine, Lubiechow	Partially reclaimed area, intended for further reclamation in the forest direction. This area belongs to KGHM Polska Miedź S.A., Oddział Zakład Hydrotechniczny	
Wartowice	1971–1986	19,40	190,93	32,5	Konrad Mine, Lubiechow	Partially reclaimed area, intended for further reclamation in the forest direction. This area belongs to KGHM Polska Miedź S.A., Oddział Zakład Hydrotechniczny	

Table 2 (continued)

Object name	Period of operation	Capacity [mln m ³]	Area [ha]	Amount of waste [mln Mg]	User	Object's current status ¹	View of object's current state
Zelazny Most ²	1977	634,00	1522,68	630,0	Mine: Rudna, Polkowice, Lubin	Active post-flotation waste tank. This area belongs to KGHM Polska Miedź S.A., Oddział Zakład Hydrotechniczny	
In total:		746,92	2598,02	795,7			

Inventory results prepared based on own research and literature (Resolution No. XXVI/124/05; Resolution No. LII/383/2014; Resolution No. XL/485/14; Resolution No. III/54/15; Resolution No. XLV/II/191/2009; Resolution No. XXXIV/383/2018; EPP for the Bolesławiec County for 2017–2020; EPP for the Legnica County; EPP for the Lubin County for 2017–2024; EPP for the Lwówek Śląski County for 2018–2021; EPP for the Polkowice County for 2012–2015; EPP for the Złotoryja Municipality; Fajfer et al., 2010; Bar, 1973; Paździóra, 1996, 1999, 2008; Stolarczyk et al., 2015; Werno, 1996; <https://cbdgpportal.pgi.gov.pl/haldy/>, Haldy Geobase; <http://www.dymarkikaczawskie.pl/>; <https://www.geoportal.gov.pl>)

According to the Local Spatial Development Plans, Study of Conditions and Directions of Spatial Development (SUjKZP) and Environmental Protection Programmes Data from 2018 (<https://kgbm.com/pl>)

Table 3 Results of the impact of post-flotation settling tanks in the context of social responsibility

Zone name	Zone width [m]	NofT [pieces]	NofB [pieces]	NofR [pieces]	BA [m ²]	RI [m]	RwI [m]	D-W [pieces]	VP [m ²]	D [m ²]	V [m ²]	P [m ²]	A [m ²]	E [m ²]
Zone I	< 1000	42	1373	35,554	366,188	525,862	15,497	18	1,448,822	9,077,774	3,516,710	38,380,412	29,450,659	0
Zone II	1000–2000	59	5275	18,942	813,668	893,989	21,212	10	3,278,744	5,671,405	1,321,222	60,714,647	39,167,759	0
Zone III	2000–3000	91	6603	18,379	1,017,744	1,210,532	39,298	34	3,590,614	8,023,444	1,910,623	87,218,579	51,905,322	0
Zone IV	3000–4000	113	6631	34,468	1,196,825	1,524,644	57,242	46	4,020,701	8,242,308	2,200,065	116,119,604	65,386,748	0
Zone V	4000–5000	148	9220	45,192	1,794,703	1,711,848	66,531	44	5,688,290	10,780,905	2,919,058	155,196,374	66,522,788	0
In total:		453	29,102	120,534	5,189,129	5,866,877	199,780	152	18,027,171	41,795,837	11,867,678	457,629,616	252,433,276	0

Where NofT, number of towns; NofB, number of buildings; NofR, number of residents; BA, built-up area; RI, road infrastructure; RwI, railway infrastructure; D-W, deep-water well; VP, very poor soil permeability; D, diverse soil permeability; V, variable soil permeability; P, poor soil permeability; A, average soil permeability; E, easy soil permeability

housing investments are planned in the analysed region. According to the latest data including permits granted for the construction and registrations (Local Data Bank), in the regions located within defined buffers, there will be primarily single-family houses in the Bolesławiec county (Warta Bolesławiecka), Lubin county (Lubin and Rudna), Polkowice county (Polkowice, Prusice) and Złotoryja county (Złotoryja, Stanisławów, Rokietnica and Komorniki).

This allows to notice that the existence of these facilities has gained public acceptance. In particular, it is interesting due to the events of 1967, when at one of the landfills belonging to KGHM PM S.A., the embankments were broken, and this resulted in a rapid outflow of water with sediments. The Bobrzyca River valley and several villages were flooded. Many years after the above-mentioned catastrophe, the surface layers of soils still contain very high amounts of Cu and Pb, however, at the same time, there is no serious threat associated with the collection of Cu and Pb by crop plants intended for consumption or forage purposes (Karczewska & Lizurek, 2004). Based on the conducted analyses, it should be concluded that it is also not a strong obstacle that the mining waste disposal facilities, resulting from copper ore processing, are characterised by a burden to the environment, due to contaminating underground waters and soil as a result of infiltration of oversedimentary water into the ground, air pollution with dust or flooding of neighbouring areas due to rising of the level of groundwater (Fajfer et al., 2010).

Road and rail infrastructure is located in the vicinity of each of the facilities in all zones (Table 3). Part of the existing network is associated with earlier transport applications for the purposes of mining entrepreneur (remains in the form of a railway siding). Moreover, various categories of roads were identified, including municipal, county and provincial roads. Most railway sections are located near the settling tank Gilow (total length 98 184 m). Also, the largest road network (total length 1 105 531 m) was identified around this settling tank. While analysing the road infrastructure along with the increase in distance from the settling tanks (Fig. 9), it can be observed that in most cases, the increase in distance is accompanied by the expansion (development) of the road network. This is confirmed by the summary list (Table 3). It must be emphasised that road infrastructure also includes sidewalks and bike paths. A good example in this scope is a bike path near the settling tank Konrad 2 (Fig. 14), which is used by the residents.

It was concluded that deep-water wells occur in the impact zones defined by the authors. In accordance with the Polish legislation, i.e. the Regulation of the Minister of Environment

Fig. 14 View of the bike path located in the vicinity of the post-flotation settling tank Konrad

of May 29, 2014, on the monitoring of mining waste disposal facilities (2014), the monitoring of mining waste facility includes in its scope the operating phase of mining waste facility, as well as the phase after the closing of such mining waste facility for 30 years. In the case of discussed facilities, the regulations apply to the reservoir Zelazny Most, around which the local monitoring is implemented in a dense measuring network. The other settling tanks have several regional monitoring points in their vicinity. The greatest threat to the environment is posed by post-flotation waste, due to its quantity and contents of heavy metals. In the case of absence of the appropriate safeguards, these metals can also get into the water. In the case of copper ore mining, the pollution of underground waters includes the presence of copper, lead and zinc. Environmental threat assessment for inactive facilities concluded that for underground waters, they are insignificant in the case of Cu and Pb, i.e. they include slight exceeding of the highest permissible values, and they are potential in the case of Zn, which means that there is a probability of pollution occurrence in the absence of information concerning the impact (Fajfer et al., 2010). It was also concluded that soils in the vicinity of mining waste disposal facilities are characterised by poor permeability, which in the context of deposited waste is beneficial for the society.

6 Conclusion

The result of this study is a methodology that can be used in the assessment of public acceptance of the industrial facilities. The solution proposed by the authors of this study indicates the path of proceeding from the stage of selecting and recognising the object, obtaining the necessary data and creating a geodatabase, to conducting analyses and presenting the effects.

The obtained results can be the basis for further research on the impartial and automatic identification of social objects, due to demonstration of the analysis of social acceptance trends for post-industrial objects. These studies can be used for a comparative analysis of social elements identified in the buffer zones of the post-industrial facility due to their repeatability. The authors of the research intended to carry out comparative studies—from the end of the operation of post-flotation settlers (1960–1980 of the twentieth century) to the present state (2020). Due to the lack of access to data from the last century, it was decided to treat the current research as preliminary research on the comparison of the current state (2020) to the state in a few years (e.g. in ten-year time intervals).

The results obtained on the example of post-flotation settling tanks prove the method's usefulness. To sum up, post-flotation settling tanks, although they cannot be considered desirable in the social space, do not exclude the development of land in their vicinity for housing development or infrastructure related to the functioning of the inhabitants. The research in designated zones around the settlers identified social infrastructure that proves the functioning of the local community, i.e. residential buildings, road infrastructure, railway infrastructure, water intakes, water supply network and land with low and medium water penetration capacity.

In the authors' opinion, databases and GIS tools are a useful tool for communication between a company or investor and society, in compliance with the idea of corporate social responsibility and in accordance with the principles of sustainable development. As a tool for the decision-makers, it offers solutions based on a spatial analysis.

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Conflicts of interest The authors declare no conflict of interest.

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