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Spatial and Quantitative Analysis of Waste from Rock Raw Minerals Mining: A Case Study of Lower Silesia Region in Poland

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Abstract: Mining of minerals is associated with waste that needs to be dealt with, e.g., safely deposited or, if possible, reused. From 2010 to 2016, 6,182,277 Mg of waste was deposited during mining of rock raw materials in the Lower Silesia region in Southwest Poland. Extraction activities were responsible for 46.95% of that waste, while mineral processing was responsible for 53.05% of that waste. This study analyzed the spatial and temporal distribution of waste resulting from mining rock raw minerals in Poland's Lower Silesia region. In the study, an inventory of waste deposited during rock raw mineral mining and processing was prepared. Then, a geographic information systems (GIS) database that included information on the quantity and quality of waste generated during rock raw mineral mining and processing during the 2010–2016 study period was created. It was used for assessment of the variation of waste distribution and density in time and space with GIS kernel density estimation (KDE) functions. Spatial context of mining waste production and distribution over a period of 7 years in Lower Silesia were analyzed and presented graphically. The study revealed increasing accumulation of mining waste and helped to identify spatial clusters of its deposition in the region. Based on a literature study and the identified main waste types, the potential of selected types of this waste for re-use was analyzed and prospective uses were proposed. The methodology of quantitative and spatial analysis used in this research can be applied to studies in other regions coping with the problem of a large amount of mining waste.

Keywords: rock raw minerals; mining waste; use of waste; spatial analysis; quantitative analysis; Poland

1. Introduction

In Poland and around the world, the mining regions are struggling with the increasing problem of the management of waste created during the extraction and processing of minerals. According to Eurostat [1], more than 632 million Mg of mining waste was generated in European Union (EU) countries in 2016. The biggest producers of mining waste included Romania, Sweden, Bulgaria, Finland, and Poland, where approx. 11.2% of this waste was produced (Figure 1). Such waste is usually stored in mining waste storage facilities and it is also a threat to the surrounding environment [2–8]. Mining companies seem to notice the need to adapt their development plans to the concept of a circular economy, perceiving it as an opportunity to minimize costs, but also to increase their competitiveness. The main challenge of a circular economy in the scope of rock mining is the improvement of the potential of waste use and its preparation for reuse [9–11]. The first step to implement this challenge is the preparation of an inventory of waste facilities, along with its spatial distribution. For this purpose, it is necessary to obtain reliable data concerning the amount and the places of occurrence of this waste. Moreover, the implementation of such an objective also requires knowledge regarding the existing technologies, which could be used in the management of this waste. The literature presents the results of studies concerning the use of waste, which originates from rock raw minerals extraction and processing [12–16]. However, its review still indicates problems associated with the use of waste created in the sector of rock mining. Thus, both quantitative spatial analysis and technological analysis concerning the possibility of using mining and processing waste from rock mining constitute the subject of this article. These analyses were carried out at the request of the Marshal Office of the Lower Silesia Voivodship [17–19] within the CircE project (European Regions Toward Circular Economy), co-financed from the European Regional Development Fund and the Interreg Europe Program. The purpose of this project is to develop a regional action plan for the circular economy, along with recommendations for regional authorities. These analyses were supposed to indicate the scale of the problem, as well as possibilities of improving the situation by discussing existing or new technologies of using waste created in the rock mining industry.

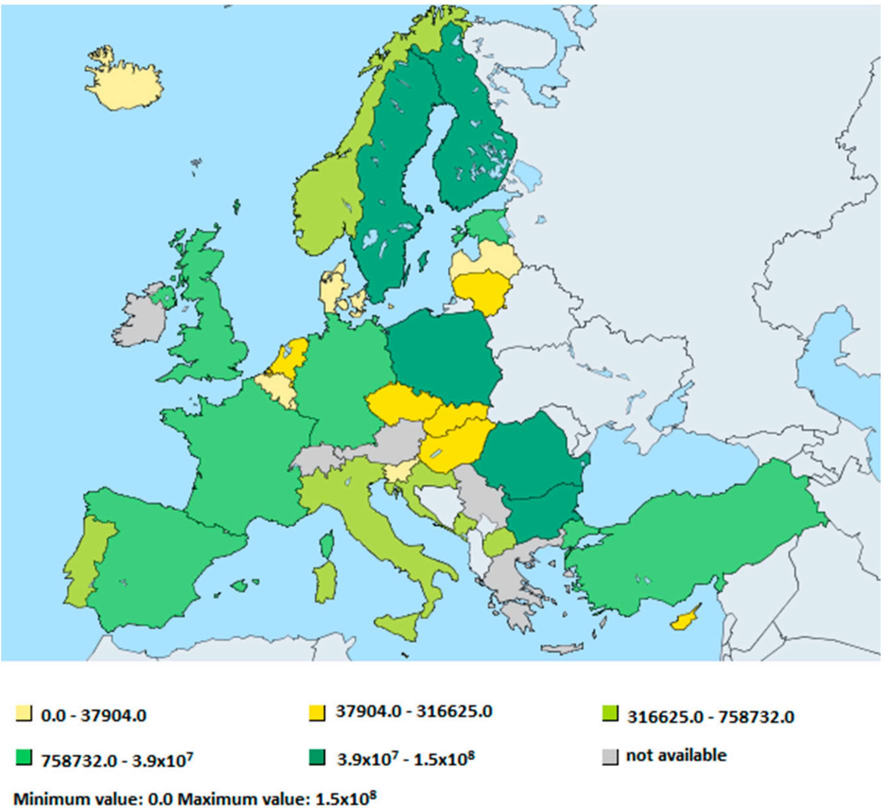


Figure 1. Waste created in EU countries in the mining sector in 2016 (source: Eurostat [1]).

According to the applicable legal norms [20–24], mining waste is understood as: "waste created in the course of searching, identifying, extracting, processing and storing minerals from deposits, while the processing waste is understood as waste in the solid form or in the form of sludge remaining after the processing of minerals carried out by mechanical, physical, biological, thermal or chemical processes, as well as in the case of combination of these processes (e.g., crushing, grinding, grain classification, flotation and other physicochemical processes), in order to separate useful minerals from less useful rocks." In the first place, the owner of such waste is obligated to subject it to a recovery process, and if it is impossible or unjustified for economic reasons, to neutralize it in accordance with environmental requirements in mining waste treatment facilities. These facilities include landfills for storing mining waste in the solid form, liquid form, in solution or suspension, including spoil tips and sedimentation ponds, which cover dams or other structures intended for containing, maintaining, limiting, or strengthening such a facility. Excavations or open-pits filled with mining waste for reclamation and technological purposes are not considered to be a mining waste treatment facility. Before starting the activity associated with the generation or management of mining waste, the waste owner has to obtain a decision approving the mining waste management program, which constitutes an annex for obtaining a permit to operate a mining waste treatment facility. Quantitative and qualitative analysis and records of waste are necessary to carry out by the owner on an ongoing basis, in accordance with the waste catalogue. The records of such waste are kept with the use of a waste record card. Moreover, the producer of the waste is obligated to keep the records of the waste and prepares an annual report on the generated wastes and the method of their management. This report is submitted by the producer by March 15 for the previous calendar year to the voivodship marshal [20–24].

To facilitate our research, we have applied geographic information systems (GIS), which are a powerful analytical environment for dealing with spatially referenced problems. Examples of GIS uses in environmental mining waste studies include the review of GIS-based modelling and assessment of mining-induced hazards that refer also to mining waste dumps and tailings ponds [25]. Dong et al. applied GIS geostatistical techniques for modelling distributions of some heavy metals and to determine the ecological safety of reclaimed land from subsided areas that had been filled with mining waste and fly [26]. Wasilewski and Skotniczny [27] suggested the application of GIS for modern monitoring of thermal and gas activities in coal waste piles in Poland, a similar study was conducted by Tang [28] with the application of remote sensing data and GIS processing for coal waste piles. Abdelaal applied GIS spatial analyses to derive heavy metal contamination risk assessment in the Hungarian quarry mine waste sites [29]. Stiels et al. suggested GIS-based support for environmental reporting on the environmental status for various fields of mining activity that include: dumps, waste, and hazardous waste in the case of the mining sector in Vietnam [30]. Maryati et al. [31] have also proposed the GIS database template for environmental management of mining for the example of Indonesia.

In our work, we have proposed the application of kernel density estimation (KDE) functions, with explanation and examples of implementations presented in Section 2.3: Density of Waste Production. The structure of this paper consists of the introduction section with the justification of the research problem and reference to legal acts regulating the waste management process. This is followed by statistical analysis of mining waste in the case study area of Lower Silesia and description of geodatabase development. Next, results of spatial analysis with density functions in GIS are described and followed by discussion of the results obtained as well as potential uses of the identified waste types.

2. Statistical and Spatial Analysis of Mining Waste

2.1. Description of the Research Area

The territorial scope of this research covered the area of Lower Silesia located in the south-west of Poland (Figure 2), where heterogeneous geological structure is conducive to mining activity. The complex and complicated geology of Lower Silesia is the result of polyphasic evolution that lasted from the Proterozoic to Quaternary periods. The first and second phases are represented by metamorphic and magmatic rocks subjected to subsequent deformations at different depths of the earth's crust. The third phase is connected with the Variscan orogenic processes. As a result, sedimentary flysch type rocks, granitoid, and volcanic rocks were formed. The fourth phase (Zechstein to Tertiary) was a typical period of platform sedimentation and block deformations. In the fifth phase (Quaternary), sedimentary rock was formed [32]. These processes caused formation of various and rich occurrences of rock minerals. These include: dimension and crushed rocks; magmatic rock such as basalts, gabbro, granites, granitoids, melaphyres, porphyres, and syenites; sedimentary rock such as dolomites, limestones, and quarzites; and metamorphic rock such as amphibolites, gneisses, marbles, and serpentinites. Many of these rocks occur or are mined only in Lower Silesia. Other rocks include: vein quartz, quartz and mica schists, magnesites, dolomites, ceramic and refractory clays, bentonites, gypsum and anhydrytes, sands, and gravels. An important role in mining activity is played in this area by the exploitation of these rock raw minerals. By the end of 2017, current licenses for the exploitation of rock raw minerals in the analyzed area amounted to around 400 (Polish Geological Institute, MIDAS database [33]). The result of conducted mining activity in the form of exploitation of rock raw minerals is the mining and processing waste, whose largest amount is created in the process of obtaining crushed road and construction aggregates, natural aggregates, carbonate raw materials for the cement and lime industry, and stone elements for construction and road engineering. Figure 3 presents data concerning mining and processing waste created in Poland and in Lower Silesia in 2010–2016 (Local Data Bank [34]). According to data from the Central Statistical Office, the mining activity the economic sector producing the largest amount of waste. Therefore, it is worth thinking about the management of this waste, particularly since this waste is usually stored in landfills in the form of spoil tips and sedimentation ponds within the enterprise premises (mining plants and mining waste treatment facilities), in which they are generated (Figure 4).

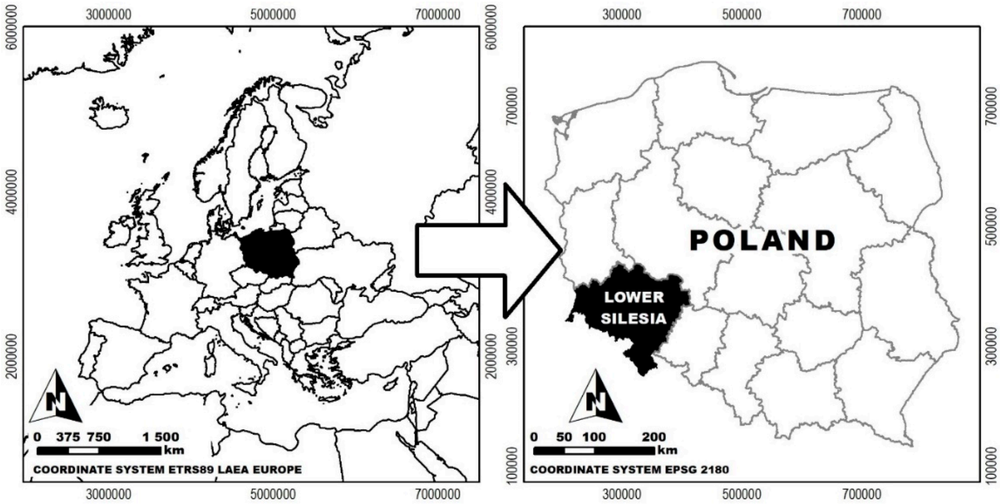
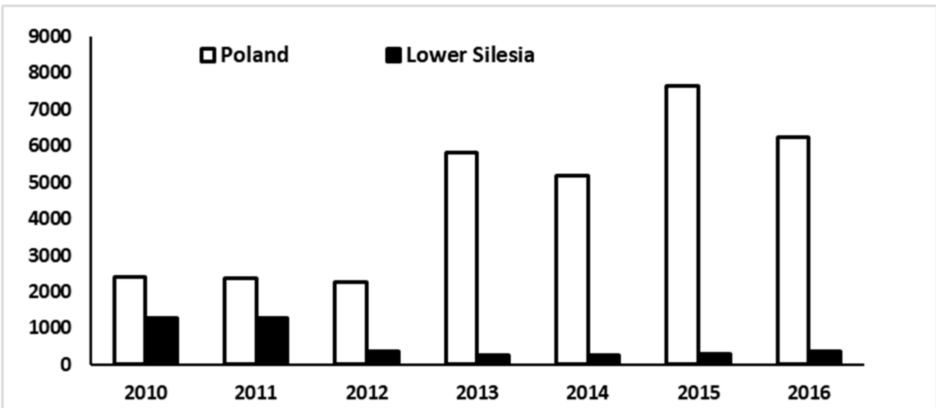
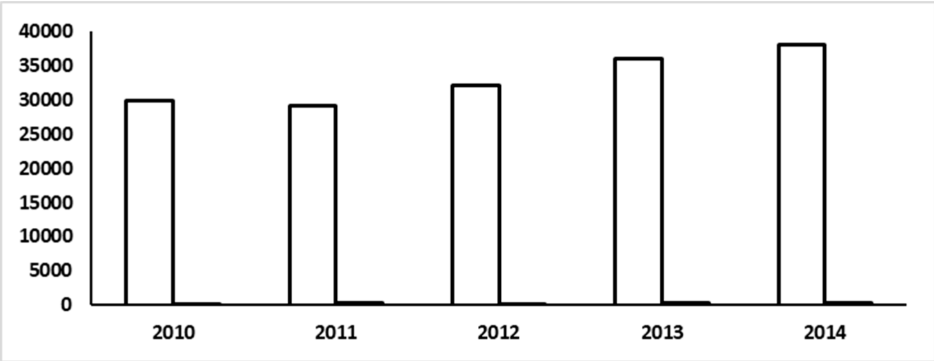


Figure 2. Location of study area.



(a)

Figure 3. *Cont.*



(**b**)

Figure 3. Mining waste (**a**) and processing waste (**b**) generated in Poland and in Lower Silesia in 2010–2016 and in 2010–2014 (amount in thousand Mg, based on Reference [34]).

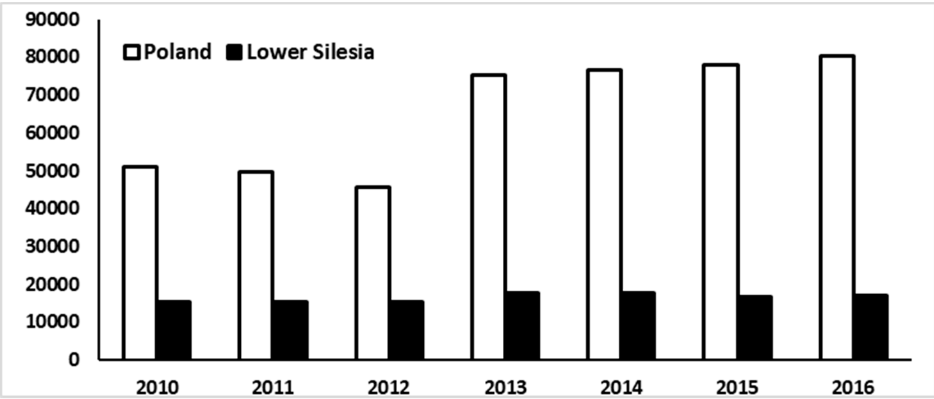


Figure 4. Mining waste previously stored in own landfills in Poland and in Lower Silesia in 2010–2016 (amount in thousand Mg, based on Reference [34]).

2.2. Analysis of Source Data

In order to collect and analyze the source data, the method of examining documents was used consisting of the collection, selection, description, and scientific interpretation of the facts contained in them, the so-called document content analysis technique [35,36]. The research included the determination of the management state of mining and processing waste of rock raw minerals in Lower Silesia in 2010–2016. Documents from state institutions were acquired for the research, which collect data concerning the management of mining and processing waste, i.e., mining waste management programs and annual reports submitted by the producers of this waste. Moreover, graphical data in the form of administrative boundaries and boundaries of deposits were acquired. Juxtaposition of the acquired data, along with their sources, is presented in Table 1.

After verification and analysis of the source data, a database structure was developed in order to standardize the information obtained for the needs of spatial analysis. The database contains records representing individual mining plants and mining waste treatment facilities in the GIS with attributes such as: deposit identifier, deposit name, type of mineral, name of the entity conducting activity in the deposit (mining plant), and amount of waste generated from 2010 to 2016, along with its division into types, management state of the deposit, and mineral production. The structure of descriptive data, along with examples of data, is presented in Appendix A. The data available in analogue form was entered manually (digitally coded). Due to the susceptibility of the method to typographical errors, the methods of checking attribute data errors were used, such as: verification in terms of impossible values (e.g., negative value of generated waste), verification in terms of outliers (too large or too small), examination of internal integrity of data by comparison of source data and GIS data. After preparing the descriptive data, the prepared files were combined with the class of point geometry features representing centroids of mining plants, obtained from the Polish Geological Institute from the MIDAS database, with the use of the spatial join function in GIS. The GIS database was used to carry out spatial analyses of the spatial distribution of created waste, and divided into mining waste, processing waste, and total waste, as well as the analysis of changes in spatial distribution over time.

Table 1. Collection and analysis of source data.

Institution	Data Description	Data Format	Number of Data
Marshal Office of the Lower Silesia Voivodship, Department of the Environment	Decisions approving MWMP [1]	Scans of documents	157 documents
	MWMP [1]	Scans of documents	51 documents
	Reports on MWMP [1]	MS Excel spreadsheet	341 entries
Marshal Office of the Lower Silesia Voivodship, Department of the Geology	List of active mining plants	MS Excel spreadsheet	293 records
District Mining Office in Wroclaw	List of active mining plants	MS Excel spreadsheet	412 records
Polish Geological Institute	Boundaries of deposits	File in shp format [2]	427 features
Provincial Centre for Geodesic and Cartographic Documentation	Administrative boundaries	File in shp format [3]	31 features

[1] MWMP—Mining Waste Management Programs; [2] Projected Coordinate System: EPSG:2176 (Poland CS2000 zone 5), and EPSG:2177 (Poland CS2000 zone 6); [3] Projected Coordinate System: EPSG:2180 (Poland CS1992). Scale of graphical data is 1:10,000.

2.3. Density of Waste Production

Density of waste production in Lower Silesia and its change in time was analyzed using the Epanechnikov quadratic kernel function described in Reference [37] available in ESRI ArcGIS geospatial software (ESRI, Redlands, CA, USA) [38]. Kernel is a weighting function used in non-parametric estimation, such as density estimation, to calculate a variable density function (in this case rock raw material production). The general function is given by the following formula [39]:

$$f_\lambda(x) = \frac{1}{n\lambda}\sum K_0\left(\frac{x - x_i}{\lambda}\right) \tag{1}$$

where,

K_0 is the chosen Kernel function, and
λ is the bandwidth (smoothing parameter), which determines the width of neighborhood and degree of smoothness.

The quadratic kernel function has the form:

$$K_0(t) = \left\{ \begin{array}{cc} 0.75\left(1 - t^2\right) & for\ |t| \le 1 \\ 0 & otherwise \end{array} \right\}, \tag{2}$$

As part of applying the kernel density function in GIS, a smoothly curved surface fitted over each point representing magnitude per unit area of the analyzed variable is generated. The methodology has been used for example in analysis and visualization of the spatial and temporal variation of rock raw minerals production [40]. Other uses include diverse environmental and socio-economic phenomena examples such as tornado mapping [41], road accident occurrence [42], crime maps [43], and air pollution [44].

The input parameters for this analysis include: spatial location, population field value, and the search radius. In the study point (X, Y) locations of all waste sites (67) and their annual reported waste deposition were used. The latter (total, mining, and processing waste values for the 2010–2016 period) was used as the population field value (in Mg). In addition, the total waste reported in particular years (2010, 2012, 2014, and 2016) was used to generate maps representing temporal changes in the spatial context. A search radius of 20,000 m was used, which is suitable for the area of the Lower Silesia [40].

The pixel size of the resulting raster maps was set to 500 × 500 m based on the distances between waste deposition sites.

3. Results

There were 67 sites declaring mining and/or processing waste during exploitation of rock raw mineral deposits in Lower Silesia. In this group, there were 41 dimension and crushed rock quarries, 16 sand and gravel (natural aggregates) pits, as well as 10 other sites mining clays (ceramic and refractory), dolomites, limestones, and marls for the lime industry. The total amount of waste deposited in 2010–2016 period was 6,182,277 Mg. Approximately 53.05% of the total waste was generated during the processing of rock raw materials, and not much less (approx. 46.95%) during the mining stage.

3.1. Results of Statistical Analysis

In the analyzed period (2010–2016), mining or processing waste from rock raw materials was deposited in 67 locations. The amount of generated waste varied from 9.5 Mg to 546,099 Mg. Average amount of waste deposited in this period for a location was 95,102 Mg. This gave 1441 Mg per year on average. Graphical representation of the spatial distribution of deposited waste using graduated symbols is shown in Figure 5. The amount of waste deposited was classified into seven intervals. A histogram of these classes is shown in Figure 6. To construct the classes, we have used the natural breaks classification method (Jenks method) and the normative interval classification method to present values (sites) important for the analyzed case study and dataset [45].

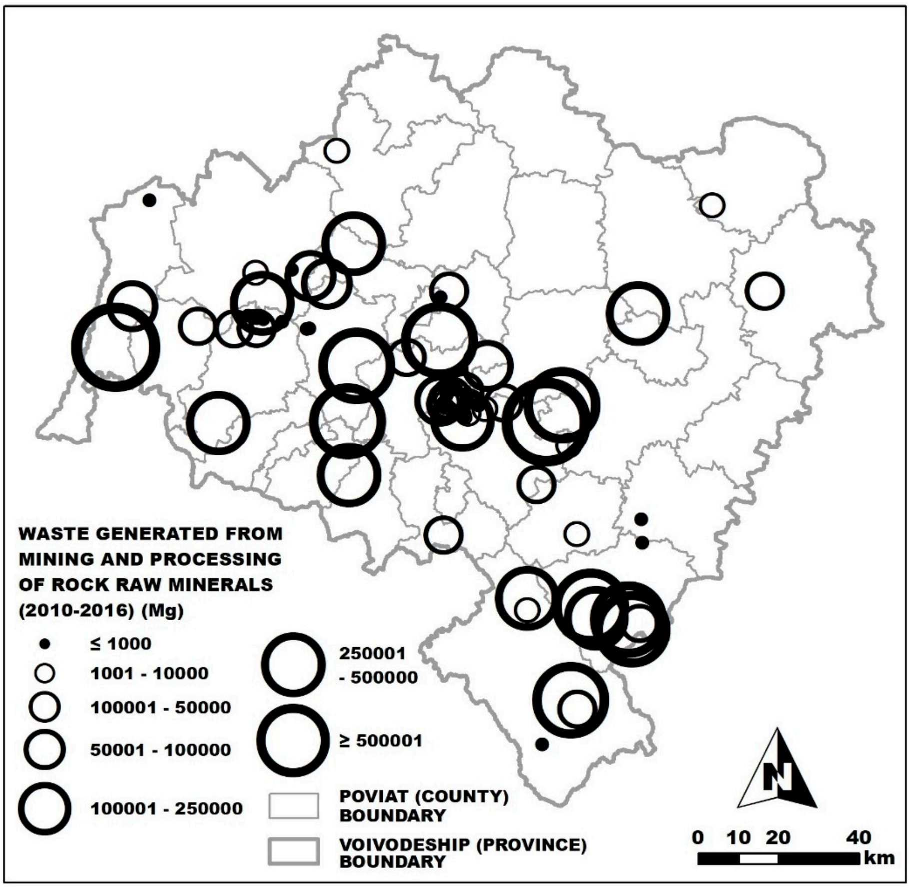


Figure 5. Location and amount of waste generated in 2010–2016 in rock raw minerals mining and processing plants in Lower Silesia.

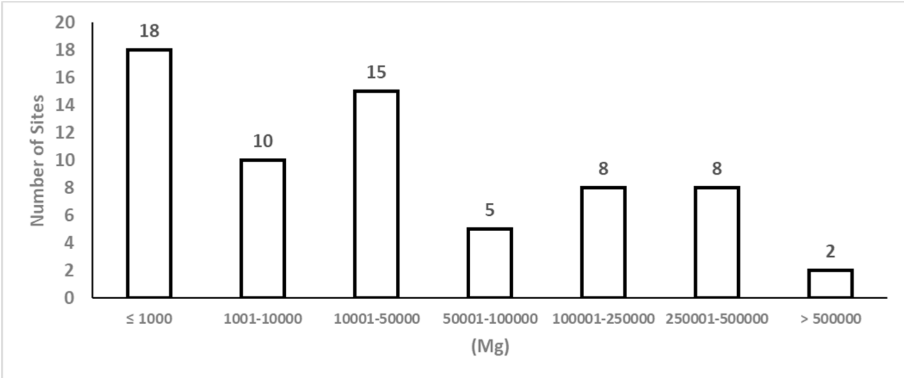


Figure 6. Histogram showing distribution of the amount of total waste deposited at each location in 2010–2016 (bars have been constructed with equal width).

Broken down into waste resulting from mining and processing of rock raw minerals, the results are as follows. The number of sites where waste was produced during the mining of minerals was deposited in 2010–2016 was 32 out of 67 plants that declared waste. The amount of generated waste varied from 48 Mg to 377,278 Mg. The average amount of waste deposited in this period for a location was 97,781 Mg. This gave 3056 Mg per year per site on average. Graphical representation of the spatial distribution of deposited waste using graduated symbols is shown in Figure 7. The amount of waste deposited was classified into seven uneven intervals. A histogram of these classes is shown in Figure 8.

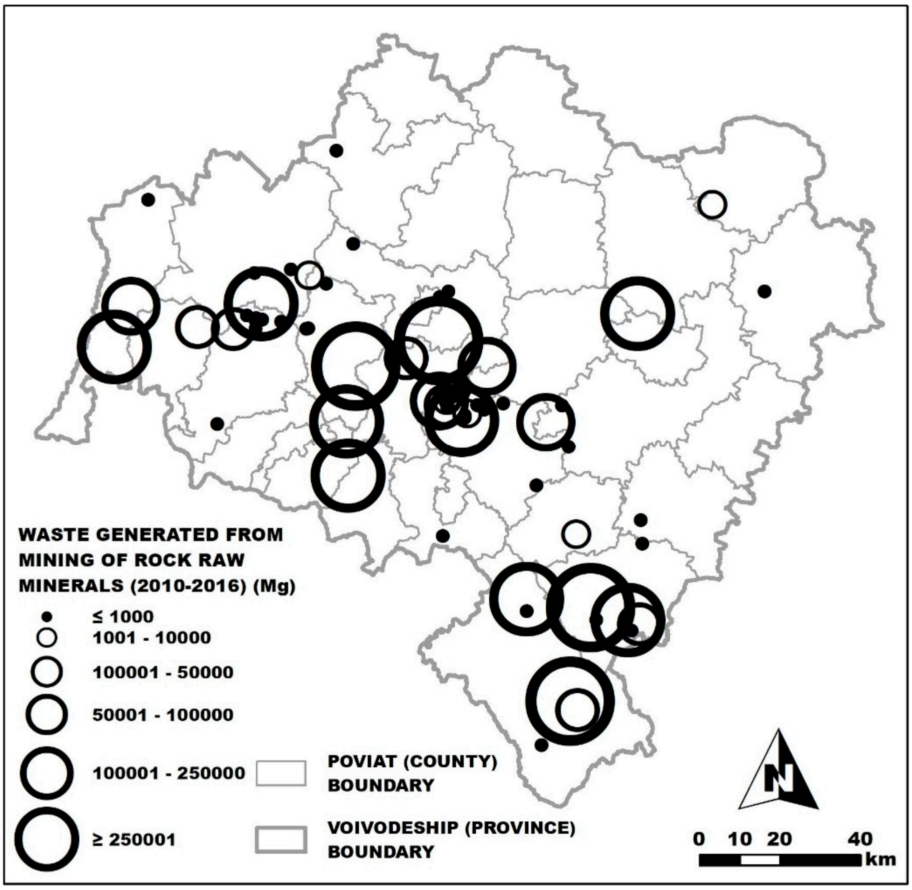


Figure 7. Location and amount of waste generated in 2010–2016 during mining of rock raw minerals in Lower Silesia.

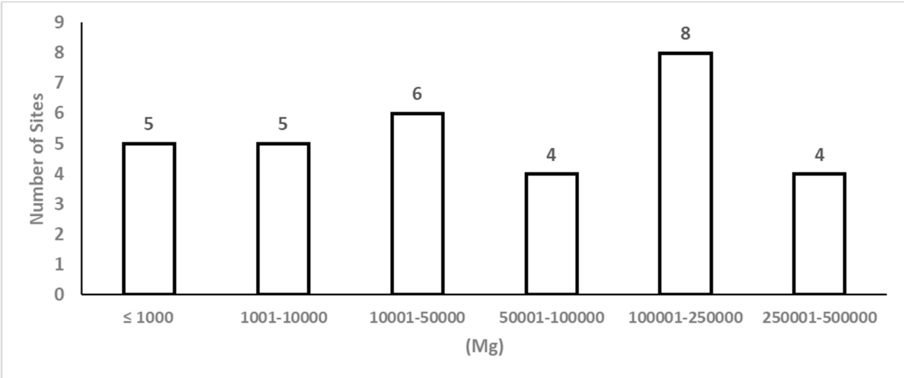


Figure 8. Histogram showing distribution of the amount of mining waste deposited at each location in 2010–2016 (bars have been constructed with equal width).

Meanwhile, the number of sites where waste was produced during the processing of minerals was deposited in 2010–2016 was 51 out of 67 plants that declared waste. The amount of generated waste varied from 9.5 Mg to 485,413 Mg. The average amount of waste deposited in this period for a location was 48,400.5 Mg. This giave 949 Mg per year per site on average. Graphical representation of the spatial distribution of deposited waste using graduated symbols is shown in Figure 9. The amount of waste deposited was classified into seven uneven intervals. A histogram of these classes is shown in Figure 10. The same number of sites (16) declaring mining waste deposited up to and above 50,000 Mg in the analyzed period (2010–2016). The sites (4) with the largest declared amount of mining waste, i.e., above 250,000 Mg were dimension and crushed rock quarries.

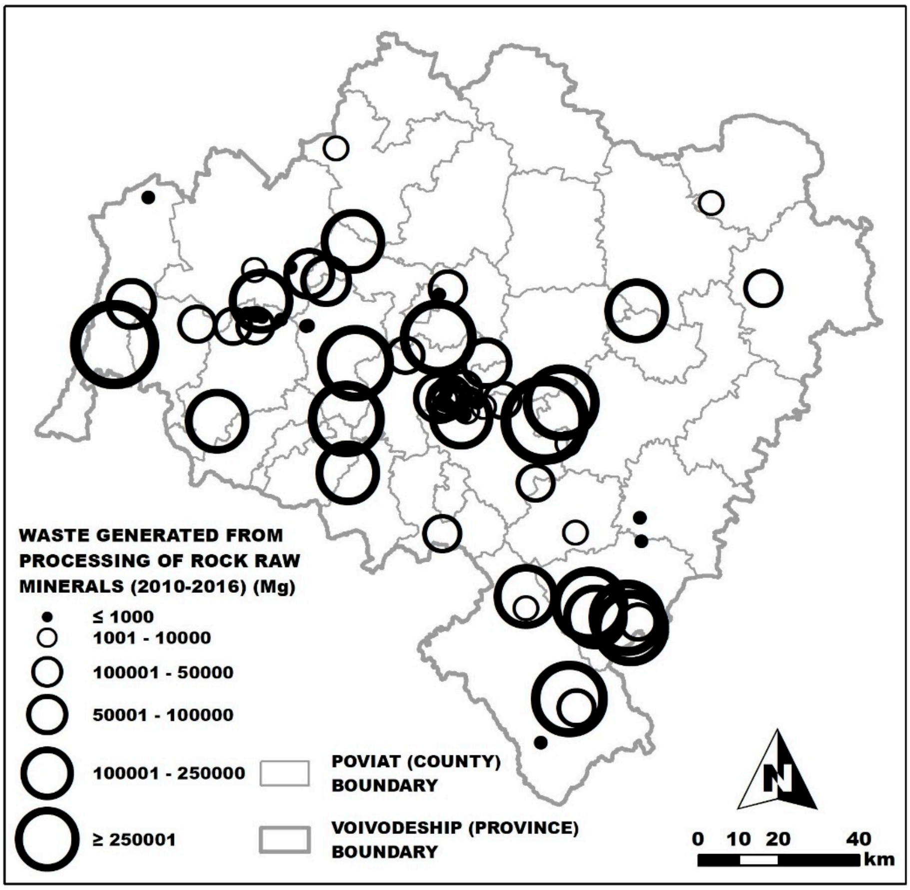


Figure 9. Location and amount of waste generated in 2010–2016 during the processing of rock raw minerals in Lower Silesia.

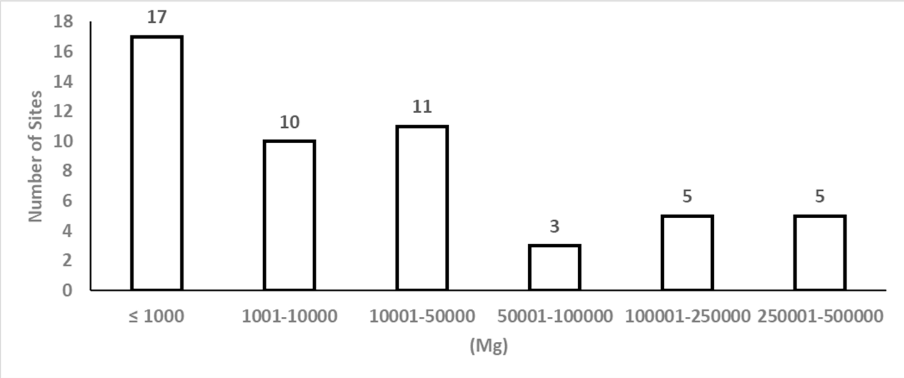


Figure 10. Histogram showing distribution of the amount of processing waste deposited at each location in 2010–2016 (bars have been constructed with equal width).

The majority of sites (38 out of 51) declaring processing waste deposited up to 50,000 Mg in the analyzed period with 1/3 of sites (17) depositing up to 1000 Mg. The sites (5) with the largest declared amount of processing waste, i.e., above 250,000 Mg were natural aggregate (sand and gravel) mines, as well as limestones and marls for lime industry quarry. The sites producing the smallest amount of processing waste (up to 1000 Mg) were dimension and crushed rock quarries. It should be noted that the number of sites producing waste during the mining and processing of rock raw materials was not even, 32 to 51 respectively. All the 32 sites producing waste from mining report waste from processing rock raw materials as well. Meanwhile, 29 sites report waste from the processing of rock raw minerals only.

The amount of total waste deposited per year was not even (Figure 11). Steady growth until 2012 was attributed to an increased demand for rock raw minerals in Poland because of preparation for Euro 2012 football championship (construction of new stadiums, roads, and associated infrastructure). Fall in demand for these materials after 2012 caused a drop in the amount of waste (especially from mining) generated in 2013. In the following years, subsequent growth in demand related to improving economic conditions (new housing and transport investments) again resulted in growth of the amount of waste produced, especially the amount of processing waste. The increase was less dynamic than observed until 2012. The cumulative amount of waste deposited between 2010 and 2016, divided into mining and processing waste, is shown in Figure 12.

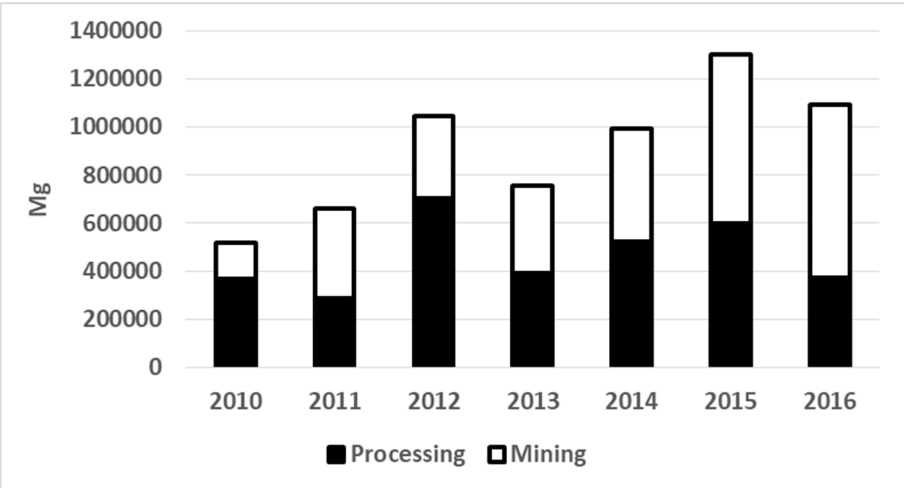


Figure 11. Amount of waste deposited each year (2010–2016) divided into mining and processing waste.

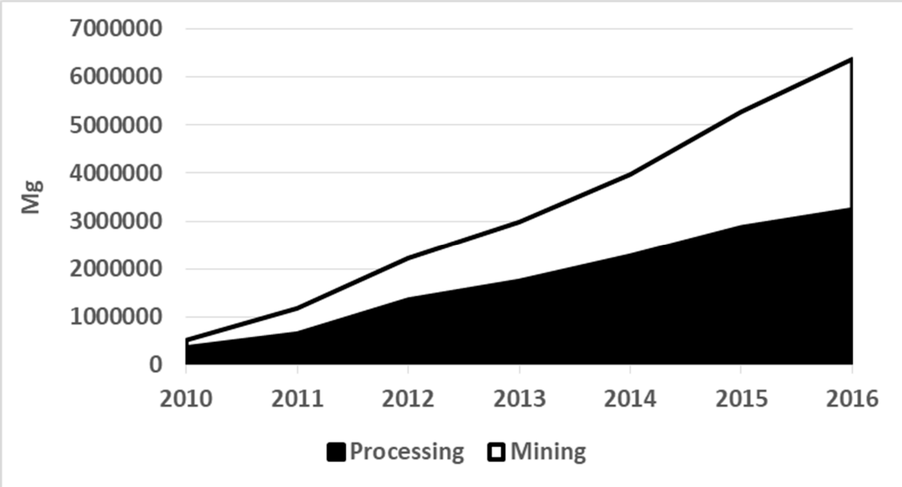


Figure 12. Cumulative amount of waste deposited between 2010 and 2016 divided into mining and processing waste.

3.2. Spatial Analysis

The density function (kernel density estimation, KDE) in GIS was used to model the spatial distribution of mining and processing waste deposited in Lower Silesia between 2010 and 2016. The results of density modelling for the total amount of waste are presented in Figure 13. The map was prepared using a classified renderer with a defined 100 Mg/km^2 interval for grouping raster cells and red color ramp. The highest value obtained depicting the greatest concentration of waste production was 3180 Mg/km^2. The areas of greatest waste density were identified based on an analysis of mean raster values and an incremental mean threshold approach with four mean boundary values. There were four distinct regions of high waste density: A was associated with large sand and gravel (natural aggregates) and dimension and crushed rock mines, B and C with dimension and crushed rock quarries (predominately granite), and D with dimension and crushed rock quarries (basalts). There was also a region of increased density between regions B and D associated with a large number of sites producing small amounts of waste.

Figure 14a represents the density of mining waste deposited in Lower Silesia from 2010 to 2016, whereas Figure 14b represents density of processing waste deposited in the region in the same period. For the mining waste density map, the highest waste density value obtained was 1158 Mg/km^2. As previously, the map was prepared using the classified renderer with a defined 100 Mg/km^2 interval for grouping raster cells and red color ramp. There were three distinct regions of higher waste density: A was associated with large sand and gravel (natural aggregates) mines, as well as dimension and crushed rocks (i.e., marble mines, gabbro) in the southern part of this zone; B was associated with numerous dimension and crushed rock quarries (predominately granite); and C with dimension and crushed rock quarries (predominately basalt). There was also a region of increased waste density in the northeastern part of Lower Silesia associated with a large natural aggregate mine. For the processing waste density map, the highest value obtained was 2062 Mg/km^2. This map was prepared using a classified renderer with a defined 100 Mg/km^2 interval for grouping raster cells and red color ramp. There were two distinct regions (A, B) with a high density of deposited waste, and three other regions of increased density (“c,” “d,” “e”). Region A was associated with large sand and gravel (natural aggregates) mines, and B was associated with dimension and crushed rock quarries (predominately granite). Region “c” was associated with dimension and crushed rock quarries (predominately basalts); region “d” consisted of sand and gravel, as well as dimension and crushed rock (such as sandstones) sites; and region “e” mostly consisted of limestone and marl waste for the lime industry quarry. In general, the increased density was a result of a large number of sites depositing waste (not necessarily large amounts) and individual, large mines producing a high amount of waste.

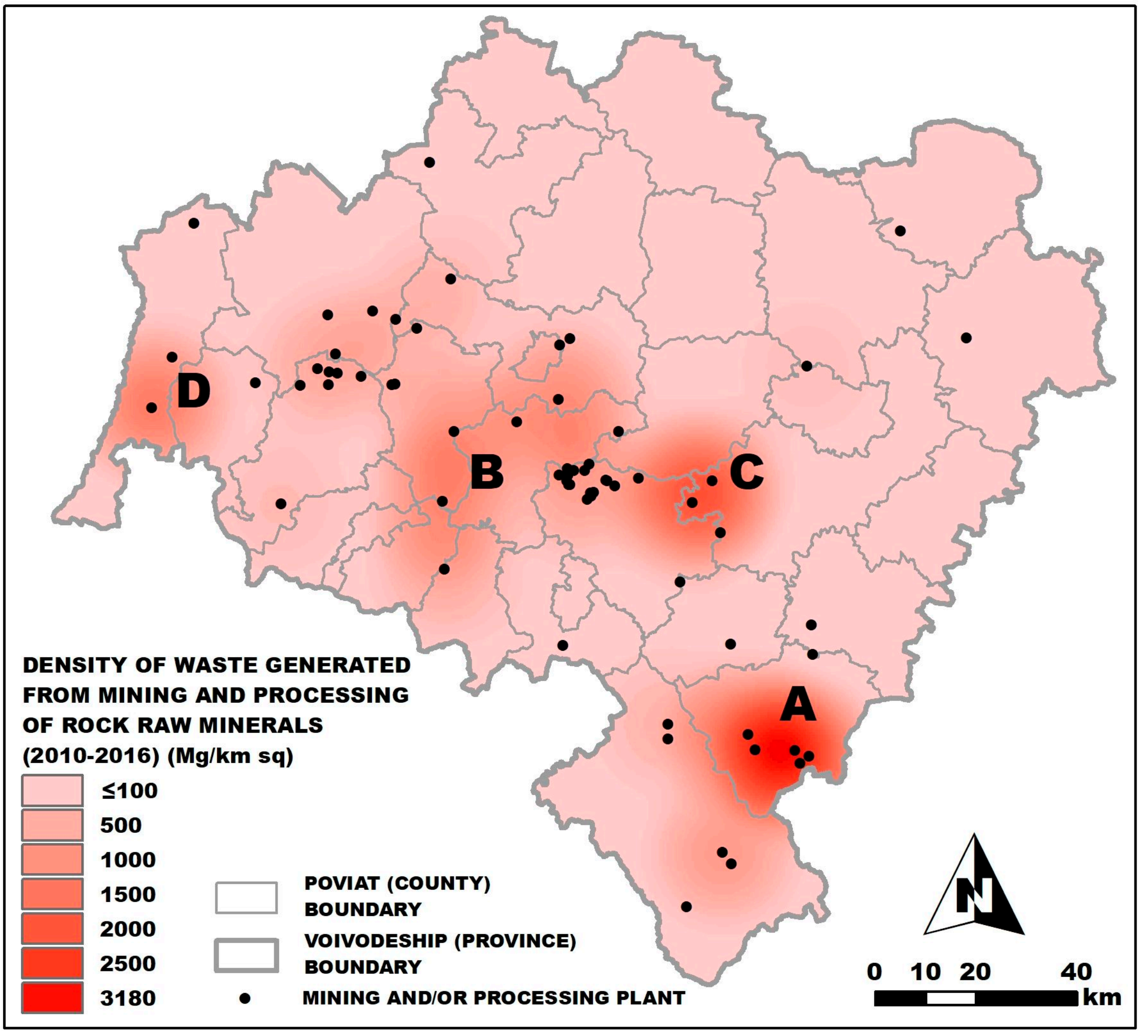


Figure 13. Density of waste generated in 2010–2016 during mining and processing of rock raw minerals in Lower Silesia.

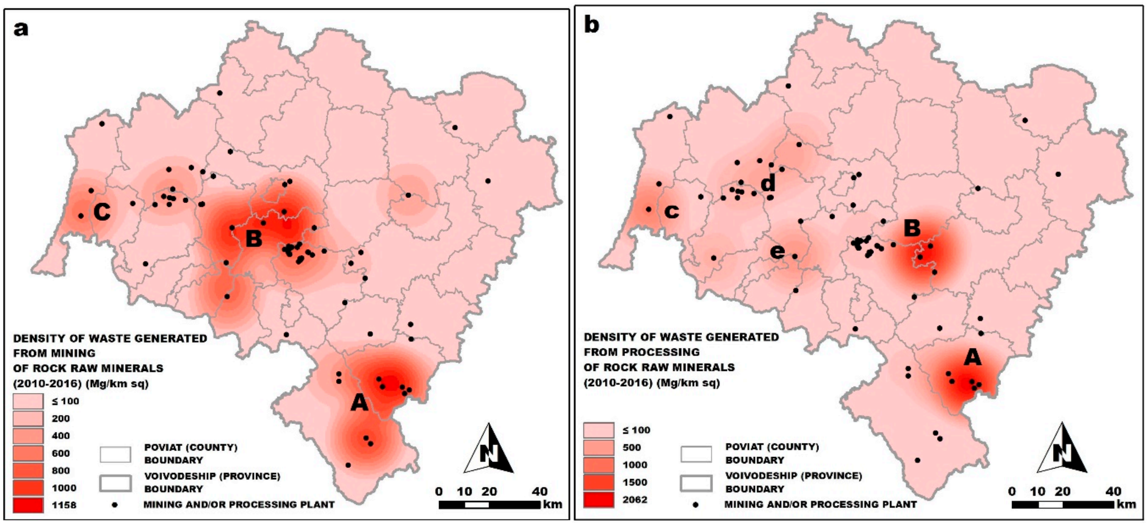


Figure 14. Density of waste generated in 2010–2016 during mining (**a**) and processing (**b**) of rock raw minerals in Lower Silesia.

The four maps included in Appendix B to the paper portray the temporal change of total (mining and processing) waste density in two-year intervals in Lower Silesia. The maps for years 2010, 2012, 2014, and 2016 show significant variation of spatial distribution of deposited waste and changing intensity of waste production in the mining regions of Lower Silesia. The maps indicate the irregular character of waste production in time and over a spatial context that should be taken into account when interpreting maps in Figures 13 and 14 and corresponds to the graph in Figure 11.

4. Discussion

As it can be seen from the conducted quantitative and spatial analyses, the amount of stored waste increased and it was unevenly distributed. The increase in waste production resulted from greater demand for rock raw minerals that was connected with improving economic conditions and the growth of building construction and road engineering. On the other hand, the analyses of spatial modelling of waste storage in treatment facilities exposed diversification of waste distribution, which was associated with the geological structure of the studied area, i.e., the occurrences of given raw materials and the legal possibility of exploiting the mineral in a given place (obtaining a decision on the environmental conditions of the undertaking and license for exploitation). Results of the quantitative analyses point to the problem of the growing amount of stored waste and its re-use. Four main clusters of mining waste deposition in the region of Lower Silesia were identified with GIS spatial analysis. Waste density maps were used to analyze the growth and change of waste concentrations over time.

Rational management of waste raw materials in various groups of raw materials in Poland is quite diverse. There is no problem with waste characterized by high physicomechanical properties, which are used almost entirely. However, the management of waste with worse quality is a more complex issue. This results from the fact that such waste has to be subjected to additional refinement and processing [46]. Qualitative analysis of waste deposited in mining waste treatment facilities provided knowledge of the character and composition of the material stored (clay, gangue with overgrowths of weathered basalt, basalt, granite saprolite, and overburden). The main condition for the use of waste raw materials is knowledge about possible technologies of their application. This knowledge allows us to propose recommendations and guidelines for new applications of waste deposited in these objects. In the case of analyzed rock raw materials, it is possible to determine five general directions for the possible use of waste generated in rock mining based on a literature review. These include their use in environmental protection, agriculture, reclamation, fertilization, or the food industry. Analysis of waste located in mining waste treatment facilities resulted in the identification of six locations whose waste can be used for the above-mentioned applications. These are the Krzeniów, Lubień, Grabina Śląska, Gniewków, Boguszyce, and Romanowo Górne locations [47].

One of the most common wastes in rock mining consists of loamy raw materials (clays). Bentonites and bentonite clays occurring in this case distinguish themselves as a material swelling under the influence of water and they are characterized by a high sorption capacity. These properties make it possible to obtain a sorbent fertilizer from them, i.e., a sorbent fertilizer that is rich in fertilizing components and that optimally affects the water capacity of the sand. The use of such a fertilizer is possible for the reclamation of sands [48]. Bentonites can also be used for the production of a paraffin/bentonite composite enriching its heat exchange properties. This results from the fact that bentonites have the ability to store thermal energy in latent form [49]. Another manner of using bentonite is its use for soil fertilization due to the moisture retention and slow release of fertilizing elements. This ensures the continuity of dosing, regulates soil respiration, increases the heat exchange effect, and maintains the soil temperature longer during the night. In other words, bentonite in the surface layer of the soil does not allow for quick release and leaving nutritional components in the deeper layers. The use of bentonite provides greater flexibility and improved soil strength, as well as better water impermeability. Bentonite can also be used to store fruits and vegetables in households [50]. The conducted studies demonstrated that the bentonite clay storage system is a more effective method than storage in warehouses and cold stores. Thus, this clay could be used as the best ecological and cost-free mechanism.

Another solution for the management of clay waste raw materials is its application in the form of feed additive. Experiences in the scope of feeding broilers and laying hens indicate that adding aluminosilicates, such as kaolin of the FKW type or zeolite of the AA type, to the feed has a positive effect on production rates and on the quality of egg shells [51,52]. In addition, the use of clays and clay minerals in pesticide formulations is currently very popular. In order to increase the effectiveness of pesticides, it is proposed to reversibly bind pesticides on clay minerals. The literature also includes data on the use of kaolin in many different crops (mainly fruits) against various pests [53–55]. This material is chemically inert in a wide pH range, thus there is no direct toxicity to animals or plants.

Due to the fact that one of the important properties of clay is adsorption and the ability to interact with metal ions, it can be used as another method of removing heavy metal ions and purifying industrial and drinking water [49,56]. Serious environmental problems also result from the use of pesticides. In order to reduce the level of pesticides, it is proposed to implement leaching in such environments as air and water, while one of the possible solutions is the reversible binding of pesticides on clay minerals. Many studies have focussed on the adsorption of pesticides from clay minerals in order to remove them from water [57,58].

Another solution for managing the waste is their use as rock meal for soil fertilization. Of course, depending on the chemical composition of the rock from which they were produced, they are characterized by various contents of calcium, potassium, and magnesium. The idea of using basalt meals comes from the observation that alkaline and inert vulcanites are the basis for the formation of perfect, fertile soils (occurring, e.g., on the slopes of active and inactive volcanic cones). The supply of basalt to depleted soil, in an easy dusty form for chemical distribution, results in comprehensive "remineralisation" of the soil substrate.

In addition, basalt meals are often described as improving the soil properties due to their relatively low mineral content (main and trace mineral components). Clearly emphasized advantages of basalt meals include their non-toxicity, impossibility to overdose, non-leaching by groundwater, and not having a shelf-life or maximum storage period. It is worth to mention that dusty products generated from basalt rocks are considered to be microelement fertilizers due to the abundance of trace elements present in them, the most important of which include: Mn, Zn, Cu, Mo, B, Fe, and Se. The basic task of the so-called basalt meals is to enrich depleted soils with mineral components. These meals are also widely used in agriculture, gardening, animal husbandry, and garden design. Their application is recommended for growing cereals, vegetables (also in-house gardens), as well as ornamental plants, vines, flowers, and vegetables, in order to cultivate lawns, trees, and nursery-gardens.

Another use consists in an application for manure and slurry, which enriches these fertilizers with microelements and the binding of ammonia that limits its emission by approx. 27%. Moreover, the rock dusts show a purely mechanical insecticidal action, blocking the airflow in the spiracles, making it impossible for the insects to breathe [59–61]. Similar to basalt, the granite is a primary rock, therefore it has a desirable composition for cultivation of most plants that is unchanged by weathering (erosion). Granite meal is useful on heavy soils, as well as light and sandy soils, with low content of clay materials. In both cases, it increases the water capacity of soils, particularly in the humus layer. The most important advantage of this meal is the content of many necessary macro, micro, and ultra-micronutrients, which is necessary for the correct growth of plants. In addition, this meal plays a sanitary role, preventing the spread of diseases and pests. It also retains nitrogen in the soil. Granite meal is best suited for growing plants that like acidic soil (e.g., azaleas, bilberries, blueberries, cranberries, or rhododendrons), because it contains relatively small amounts (compared to basalt) of calcium and magnesium. If this deficiency is corrected with the use of calcium and/or dolomite, then the granite meal is a desired fertilizer for every cultivation. On the other hand, the serpentinite meal is rich in hydrated magnesium silicates, i.e., minerals from the serpentine group ($Mg_6[Si_4O_{10}](OH)_8$). In addition to magnesium, the serpentine meal can also provide soils with many microelements, including iron and phosphorus, among others [62]. Moreover, the effect of these rocks, whose main components are dolomite and products of its thermal decomposition or minerals from the serpentinite group, is incomparably slower than the effect of easily soluble potassium-magnesium salts [48].

Another very interesting possibility of application of the rock waste is the possibility of using granite waste for the production of light aggregates. The Institute of Mechanised Construction and Rock Mining in Poland has developed a technology for the application of granite waste for the production of light artificial aggregates [63]. In preliminary tests, waste from the process of cutting stone products using a circular saw and a wire saw, polishing stone products, waste mixed from the stated sources and from filtration work were used. It is a fine-grained waste with grains <0.063 mm. Only waste originating from the processes of cutting and polishing contained single grains >2 mm, and the amount of these grains amounted to half of the waste mass. In the developed technology, the previously used mineral raw materials have been replaced with granite waste. The degree of replacement ranged from 30% to 100%. The results of conducted studies turned out to be very beneficial because the strength of the obtained aggregates is approx. 1.5 times higher than aggregates manufactured only with the use of silica. Moreover, the use of granite waste allowed for total elimination of the flux, which significantly simplified the process of aggregate production. The conducted studies were preliminary studies and the authors of this technology inform that it is possible to achieve further improvement of the obtained values, e.g., by changing the parameters of the thermal process. In the scope of subsequent works, it is planned to create a prototype batch of artificial aggregate in order to carry out examination of the properties in accordance with the applicable standards. This provides the basis for the industrial production of such aggregates in the coming years.

5. Conclusions

Demand for rock raw minerals is constantly increasing and this means that more and more waste will be generated. Such waste is most often stored by occupying a space that could be used in other more socially and environment-friendly ways. Thus, there is a growing interest observed in the scope of possibilities of using rock raw materials, which are found in post-production spoil tips. This problem is significant taking into account 632 million Mg of waste was generated in 2016 in EU countries. Therefore, quantitative and spatial analyses of waste deposition were conducted in the region of Poland with the largest production of rock raw minerals (Lower Silesia).

Based on the obtained data, 67 mining waste treatment facilities were identified. In this group, there were 41 dimension and crushed rock quarries, 16 sand and gravel (natural aggregates) pits, as well as 10 other mineral sites for clays (ceramic and refractory), dolomites, and limestones and marls for the lime industry. Spatial analysis in GIS with KDE functions indicated an uneven distribution and uneven increase in the time of mining waste deposition within the area of Lower Silesia. Areas with the highest concentration of waste, including waste resulting from mining and processing of rock raw minerals, were identified. The four most important mining waste production regions, i.e., spatial clusters of deposited waste, and several subregions within them were identified and demonstrated on the maps of distribution and density of declared waste. The studies enabled us to determine the areas that are potentially the most susceptible to negative pressure on the environment and society exerted by the deposition of large and/or numerous mining waste sites. This pressure is most often related to the negative impact on human health, air pollution, and water quality or landscape changes, and thus with changes in flora and fauna [2–8]. The research results indicate the problem of diversifying the distribution and continuity of the waste source in the case of their economic re-use. Analysis of the potential of waste for re-use was based on the literature review, along with the determination of the main areas of application in environmental protection, agriculture, reclamation, fertilization, and the food industry. The largest group of waste from mining and processing of rock raw minerals consisted of clay raw materials. Taking into account the technical possibilities, their potential applications include the reclamation of sands, soil fertilization, and as a feed additive.

A very interesting solution is the use of clay raw materials as sorbents that eliminate odors, as well as for storing fruits and vegetables in households. The studies conducted in Poland regarding such application of clays focus on the development of modern technologies for the use of waste clay raw materials as an additive for feeds, mineral fertilizers, or sorbents eliminating odors. Meanwhile, the planned scientific effects include the determination of characteristics of the clay minerals useful in modern economy, covering the application of raw materials contained in waste.

In the case of remaining waste raw materials, the main possibilities for their management should be their use as rock meals for soil fertilization or as granulate supporting the cultivation of plants. These raw materials can also be managed in the scope of production of the aggregates characterized by inferior quality. Another important aspect, in this case granite waste, is the potential for their use in the production of light aggregates, and thus the studies concerning this manner of waste management should be supported.

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Appendix A

Table A1. Structure of the GIS database, along with the examples of data.

Id_MIDAS	Name	Mineral	Entity Name	County	Waste	Mass [1] (Thousand Mg)	Management State [2]	Extraction [3] (Thousand Mg)
983	Słupiec-Dębówka	dimension and crushed stones	Kopalnie Surowców Skalnych w Bartnicy	kłodzki	010102	100,507.8	E	1335
10084	Janina I	whiteware ceramic clays	EKOCERAMIKA Sp. z o.o.	bolesławiecki	010102	25,700.0	E	160
10084	Janina I	whiteware ceramic clays	EKOCERAMIKA Sp. z o.o.	bolesławiecki	0104	10,491.0	E	160
941	Jawor-Męcinka	dimension and crushed stones	Kopalnie Surowców Skalnych	jaworski	010102	11,850.0	E	589
941	Jawor-Męcinka	dimension and crushed stones	Kopalnie Surowców Skalnych	jaworski	0104	0	E	589
1755	Topola Zbiornik	natural aggregates	EUROVIA Kruszywa S.A.	ząbkowicki	0104	148,398	E	676

[1] Mass—amount of waste generated in the analyzed the years 2010–2016 (thousand Mg); [2] Mass—development state of the deposit in the years 2010–2016; [3] Extraction—amount of exploited mineral in the analyzed years 2010–2016 (thousand Mg).

Appendix B

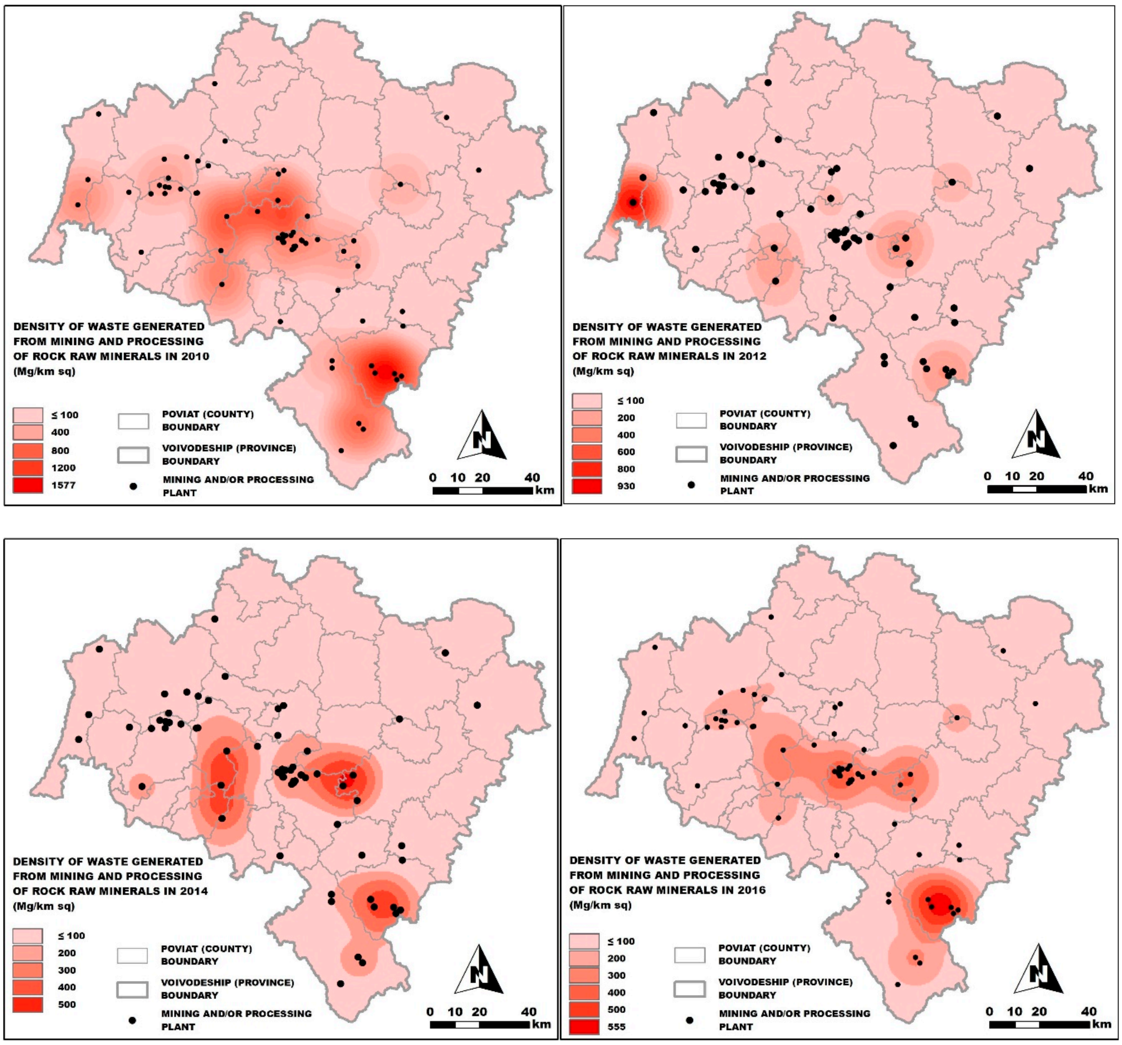

Figure A1. Density of waste generated during mining and processing of rock raw minerals in Lower Silesia in 2010 (**upper left**), 2012 (**upper right**), 2014 (**lower left**), and in 2016 (**lower right**).

References

1. Generation of Waste by Economic Activity. Mining and Quarrying. EUROSTAT. Available online: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=ten00106 (accessed on 11 October 2018).
2. Fourie, A.; Brent, A.C. A project-based Mine Closure Model (MCM) for sustainable asset Life Cycle Management. *J. Clean. Prod.* **2006**, *14*, 1085–1095. [CrossRef]
3. Hustrulid, W.; Kuchta, M. *Open Pit Mine Planning & Design. Volume 1. Fundamentals*; Taylor&Francis: London, UK; Leiden, The Netherlands; New York, NY, USA; Philadelphia, PA, USA; Singapore, 2006; pp. 1–735.
4. Lapcik, V.; Lapcikova, M. Environmental Impact Assessment of Surface Mining. *Inż. Miner. J. Pol. Miner. Eng. Soc.* **2011**, *12*, 1–10.
5. Mkpuma, R.O.; Okeke, O.C.; Abraham, E.M. Environmental Problems of Surface and Underground Mining: A review. *Int. J. Eng. Sci. (IJES)* **2015**, *4*, 12–20.
6. Dalmora, A.C.; Ramos, C.G.; Querol, X.; Kautzmann, R.M.; Oliveira, M.L.S.; Taffarel, S.R.; Moreno, T.; Silva, L.F.O. Nanoparticulate Mineral Matter from Basalt Dust Wastes. *Chemosphere* **2016**, *144*, 2013–2017. [CrossRef] [PubMed]

7. Dalmora, A.C.; Ramos, C.G.; Oliveira, M.L.S.; Teixeira, E.C.; Kautzmann, R.M.; Taffarel, S.R.; de Brum, I.A.S.; Silva, L.F.O. Chemical Characterization, Nano-Particle Mineralogy and Particle Size Distribution of Basalt Dust Wastes. *Sci. Total Environ.* **2016**, *359*, 560–565. [CrossRef] [PubMed]
8. Kalda, G.; Wilk, M. Analyssis of industril waste managements in Podcarpacie. *J. Civ. Eng. Environ. Archit. (JCEFA)* **2014**, *61*, 109–123.
9. Lebre, E.; Corder, G.; Golev, A. The Role of the Mining Industry in a Circular Economy A Framework for Resource Management at the Mine Site Level. *J. Ind. Ecol.* **2017**, *21*, 662–672. [CrossRef]
10. Neugebauer, S.; Traverso, M.; Blengini, G.A.; Mathieux, F.; Peiter, C.C. Social Life Cycle Assessment of Niobium Mining in Brazil in a Circular Economy context. In Proceedings of the 6th Social LCA Conference, Pescara, Italy, 10–12 September 2018; pp. 194–196.
11. Pactwa, K.; Woźniak, J. Overview of Polish Mining Wastes with Circular Economy Model and Its Comparison with Other Wastes. *Sustainability* **2018**, *10*, 3994. [CrossRef]
12. Hudson-Edwards, K.A.; Jamieson, H.E.; Lottermoser, B.G. Mine wastes: Past, present, future. *Elements* **2011**, *7*, 375–380. [CrossRef]
13. Gorakhki, M.H.; Barether, C.A. Sustainable reuse of mine tailing and waste rock as water-balance cover. *Minerals* **2017**, *7*, 128. [CrossRef]
14. Lottemorser, B.G. Recycling, reuse and rehabilitation of mine wastes. *Elements* **2011**, *7*, 405–410. [CrossRef]
15. Jamieson, H.E.; Walker, S.R.; Parsons, M.B. Mineralogical characterization of mine waste. *Appl. Geochem.* **2015**, *57*, 85–105. [CrossRef]
16. Santibañez, C.; Fuente, M.; Bustamente, E.; Silva, S.; León-Libos, R.; Ginocchio, R. Potential use of organic-and hard-rock mine wastes on aided phytostabilization of large-scale mine tailings under semiarid mediterranean climatic conditions: Short-term field study. *Appl. Environ. Soil Sci.* **2012**, *2012*, 895817. [CrossRef]
17. Blachowski, J.; Górniak-Zimroz, J.; Kaźmierczak, U.; Wirth, H. *Inventory of the Amount of Deposited Mining Waste Generated during Mining and Processing of Rock Raw Materials in the Province Lower Silesia in 2010–2016 in Active Mining Plants*; Unpublished Report; The Faculty of Geoengineering, Mining and Geology of the Wroclaw University of Science and Technology: Wroclaw, Poland, 2018; p. 21.
18. Website of the Project CircE European Regions towards Circular Economy. Available online: https://www.interregeurope.eu/circe/ (accessed on 13 November 2018).
19. Project Partner Website CircE European Regions towards Circular Economy. The Marshal Office of the Lower Silesia Voivodship. Available online: http://www.umwd.dolnyslask.pl/gospodarka/projekt-circe-european-regions-toward-circular-economy/ (accessed on 13 November 2018).
20. Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the Management of Waste from Extractive Industries. Official Journal of the EU L 102 of 11.04.2006, as Amended. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32006L0021 (accessed on 11 October 2018).
21. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste. Official Journal of the EU L 312 of 22. 11. 2008. Available online: https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=CELEX:32008L0098 (accessed on 11 October 2018).
22. Dz.U.2008.138.865 the Act of 10 July 2008 of on Mining Waste. Available online: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20081380865 (accessed on 11 October 2018).
23. Dz.U.2013.21 the Act of 14 December 2012 on Waste. Available online: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20130000021 (accessed on 11 October 2018).
24. Dz.U.2014.1923 Regulation of the Minister of the Environment of December 9 2014 on the Waste Catalogue. Available online: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20140001923 (accessed on 11 October 2018).
25. Suh, J.; Kim, S.; Yi, H.; Choi, Y. An Overview of GIS-Based Modeling and Assessment of Mining-Induced Hazards: Soil, Water, and Forest. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1463. [CrossRef] [PubMed]
26. Dong, J.; Yu, M.; Bian, Z.; Wang, Y.; Di, C. Geostatistical analyses of heavy metal distribution in reclaimed mine land in Xuzhou, China. *Environ. Earth Sci.* **2011**, *62*, 127–137. [CrossRef]
27. Wasilewski, S.; Skotniczny, P. Mining waste dumps—Modern monitoring of thermal and gas activities. *Miner. Resour. Manag.* **2015**, *31*, 155–182. [CrossRef]
28. Tang, S. Using remote sensing and GIS techniques in spatial information monitoring of coal refuse disposal piles. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2008**, *XXXVII*, 177–182.

29. Abdelaal, A. Preliminary contamination risk assessment of mining waste Using spatial analysis and geochemical characterization of rock formations. Case study in Hungary. *J. Environ. Geogr.* **2014**, *7*, 1–12. [CrossRef]
30. Stiels, C.; Brömme, K.; Stolpe, H. GIS-Applications for Environmental Reporting in the Mining Sector. Institute of Environmental Engineering and Ecology, Ruhr University of Bochum. Available online: http://www.ruhr-uni-bochum.de/ecology/mam/content/rame/paper_cstiels_final.pdfstart (accessed on 12 November 2018).
31. Maryati, S.; Shimada, H.; Sasaoka, T.; Hamanaka, A.; Matsui, K.; Nagawa, H. GIS Database Template for Environmental Management of Mining in Indonesia. *J. Geogr. Inf. Syst.* **2012**, *4*, 62–70. [CrossRef]
32. Cwojdziński, S.; Badura, J.; Przybylski, B. Characteristics of the Geological Structure of Lower Silesia. Available online: https://www.pgi.gov.pl/wroclaw/oddzial-dolnoslaski/opracowania/geologia-dolnego-slaska/charakterystyka-budowy-geologicznej-dolnego-slaska.html (accessed on 14 November 2018).
33. The System of Management and Protection of Mineral Resources in Poland MIDAS. Polish Geological Institute. Available online: http://geoportal.pgi.gov.pl/portal/page/portal/midas (accessed on June 2018).
34. Statistics Poland. Local Data Bank. Available online: https://bdl.stat.gov.pl/BDL/start (accessed on September 2018).
35. Apanowicz, J. General Methodology. In *Gdynia "Bernardinum"*; Publishing House: Pelplin, Poland, 2002. (In Polish)
36. Walliman, N. *Research Methods the Basics*; Routlege Taylor & Francis Group: London, UK; New York, NY, USA, 2011; pp. 1–190.
37. McCoy, J.; Johnston, K.; Knopp, S.; Borup, B.; Willison, J. *ArcGIS Spatial Analyst*; ESRI: Redlands, CA, USA, 2004.
38. ESRI. ArcGIS Desktop. Available online: http://desktop.arcgis.com/en/arcmap/ (accessed on 10 November 2018).
39. Epanechnikov, V.A. Non-parametric estimation of a multivariate probability density. *Theory Probab. Appl.* **1969**, *14*, 153–158. [CrossRef]
40. Blachowski, J. Spatial analysis of the mining and transport of rock minerals (aggregates) in the context of regional development. *Environ. Earth Sci.* **2014**, *71*, 1327–1338. [CrossRef]
41. Deng, Y.; Wallace, B.; Maassen, D.; Werner, J.A. Few GIS Clarifications on Tornado Density Mapping. *J. Appl. Meteorol. Climatol.* **2016**, *55*, 283–296. [CrossRef]
42. Anderson, K. Kernel density estimation and K-means clustering to profile road accident hotspots. *Acc. Anal. Prev.* **2009**, *41*, 359–364. [CrossRef] [PubMed]
43. Hart, T.; Zandbergen, P. Kernel density estimation and hotspot mapping: Examining the influence of interpolation method, grid cell size, and bandwidth on crime forecasting. *Polic. Int. J. Police Strategies Manag.* **2014**, *37*, 305–323. [CrossRef]
44. Vienneau, D.; de Hoogh, K.; Briggs, D. A GIS-based method for modelling air pollution exposures across Europe. *Sci. Total Environ.* **2009**, *408*, 255–266. [CrossRef] [PubMed]
45. Pieniążek, M.; Szejgiec, B.; Zych, M.; Ajdyn, A.; Nowakowska, G. *Graphical Presentation of Statistical Data*; Graphs, Maps, GIS; Central Statistical Office: Warsaw, Poland, 2014.
46. Stankiewicz, J. Technology of wastes development from rock mining in hydraulically bound mixtures. *Min. Sci.* **2013**, *136*, 205–211. (In Polish)
47. Kaźmierczak, U.; Blachowski, J.; Górniak-Zimroz, J.; Wirth, H. Quantitative and qualitative research on the waste from the mining of rock raw materials in Lower Silesia. *Minerals* **2018**, *8*, 375. [CrossRef]
48. Bolewski, A.; Skawina, T. *An Attempt to Use Montmorillonite Rocks for the Reclamation of Sands*; Polish Academy of Sciences Branch in Krakow, Commission of Mineralogical Sciences, Geological Publishers: Warszawa, Poland, 1972; pp. 1–68. (In Polish)
49. Savic, I.; Stojiljkovic, S.; Savic, S.; Gajic, D. Industrial application of clays and clay minerals. In *Clays and Clay Minerals: Geological Origin, Mechanical Properties and Industrial Applications*; Wesley, L.R., Ed.; Nova Science Publishers: Hauppauge, NY, USA, 2014; pp. 379–402.
50. Al-Arfaj, A.A.; Murugan, A.M.; Chinnathambi, A.; Al-Hazmi, M.I. Cost-effective bentonite clayed pyramid technologies for household fruits and vegetables siorage. *J. Food Agric. Environ.* **2013**, *11*, 175–180.
51. Dobrzański, Z.; Górecki, H.; Kołacz, R.; Górecka, H.; Rudzik, R. *Application of Certain Aluminosilicates in the Feed and Bedding in the Scope of Poultry Farming*; Scientific Works; The Institute of Inorganic Technologies and Mineral Fertilizers, Wrocław University of Technology: Wrocław, Poland, 1994; Volume 10/149, pp. 143–148. (In Polish)

52. Górecki, H. Small-volume production of a new type of agrochemicals. *Przemysł Chemiczny* **1995**, *74*, 243–246. (In Polish)
53. Abd El-Aziz, S.E. Evaluation of particle films as a physical control method for controlling melon ladybird, Epilachna chrysomelina (F.) (Coleoptera: Coccinellidae) on cantaloupe plants. *Bull. Ent. Soc. Egypt.* **2003**, *29*, 21–34.
54. Abd El-Aziz, S.E. Kaolin&Bentonite clays particle films as a new trend for suppression of chewing and sucking insects of cotton plants. *Arab. Univ. J. Agric. Sci.* **2003**, *11*, 373–385.
55. Abd El-Aziz, S.E. Laboratory and field Evaluation of Kaolin and Bentonite particle films against onion thrips, Thrips tabaci (Lind.) (Thysanoptera: Thripidae) on onion plants. *J. Appl. Sci. Res.* **2013**, *9*, 3141–3145.
56. Kłapyta, Z. Montmorillonite rocks of the upper silesian coal basin. In *Mineral Polish Sorbents*; Kłapyła, Z., Żabiński, W., Eds.; Uczelnianie Wydawnictwa Naukowo-Dydaktyczne: Kraków, Poland, 2008; pp. 20–30, ISBN 9788374641074. (In Polish)
57. Donia, A.M.; Atia, A.A.; Hussien, R.A.; Rashad, R.T. Comparative study on the adsorption of malathion pesticide by different adsorbents from aqueous solution. *Desalin. Water Treat.* **2012**, *47*, 300–309. [CrossRef]
58. Chevillard, A.; Angellier-Coussy, H.; Peyron, S.; Gontard, N.; Gastaldi, E. Investigating ethofumesate—Clay interactions for pesticide controlled release. *Soil Sci. Soc. Am. J.* **2012**, *76*, 420–431. [CrossRef]
59. Zagożdżon, P.P. Basalt powder in agricultural use. *Min. Sci.* **2008**, *123*, 133–142. (In Polish)
60. Mierzejewski, M.P. Basalt fertilizing meals in agricultural application, Polish Ecological Club. Lower Silesia District. 2008. Available online: http://www.ekoklub.wroclaw.pl (accessed on 10 November 2018). (In Polish)
61. Tryburski, J. *Fertilization and Fertility of Soil in an Organic Farm—Materials for Farmers*; National Center for Organic Agriculture—Regional Center for Advisory Services for Agriculture and Rural Development in Radom: Radom, Poland, 2004; pp. 4–5. (In Polish)
62. Heflik, W. On the possibilities of using serpentinites. *Pol. Stone Mag.* **2015**, *4*, 66–67. (In Polish)
63. Kukielska, D.; Cebra, P. Development of granite waste. *Miner. Aggreg.* **2018**, *2*, 93–97. (In Polish)