

# Extraction, Production and Consumption of Gravel and Sand Aggregates in Poland – an Attempt to Assess National and Regional Balances

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## Abstract

Natural aggregates are the basic group of extracted minerals. In Poland, their share in the extraction of solid minerals over 30 years (1989–2018) increased from about 24% to 54%. Current aggregate production is about 300 million Mg and in 2019 it will probably exceed the record volume of 2011 – over 330 million Mg. In the extraction and production of aggregates in Poland, there is a decisive preponderance of gravel and sand aggregates – their share in the total production of natural aggregates amounts to 70–75%. The remaining part consists of crushed-stone aggregates produced from compact and moderately compact rocks of magma origin (basalts, granites, gabbro and diabases, melaphyres, porphyry, syenites, etc.), sedimentary rocks (dolomites, limestones, sandstones, etc.), and metamorphic rocks (amphibolites, migamatites, gneisses, serpentinites, etc.). A gradual deterioration in the quality of the raw material base of gravel and sands as well as a simultaneous increase in the demand of the construction industry for the best quality thick aggregate fractions (5/8mm, 8/11, etc.) has a significant impact on the rise in the amount of hard to sell and unsalable (waste) fractions of aggregates produced in Poland. This applies especially to gravel and sand aggregates in whose deposit the share of fine fractions (below 2 mm) is systematically increasing, while the demand for them in the construction sector is limited and they are often treated as useless (waste) material. Since it is practically unknown what is the production and consumption of these aggregates, an attempt was made to assess the amount of extracted and produced sand and gravel fractions of natural aggregates in Poland.

The deficit of natural aggregates in many countries and regions as well as the limited aggregate resources in Poland and increasing difficulties in obtaining licenses for their extraction indicate the need for selective storage of sand aggregate assortments instead of “melting” them in post-mining excavation pits. The presented research results should contribute to the development of more accurate market forecasts regarding the demand for and production of natural aggregates in Poland and in individual regions, especially when it comes to gravel and sand aggregates, including also fine fractions.

**Keywords:** sands, gravels, natural aggregates, national and regional balances

## Introduction

Natural aggregates are the basic group of extracted minerals. In Poland, their share in the extraction of solid minerals over the period of 30 years (1989–2018) increased from about 24 to 54%. Aggregate production amounts to approximately 300 million Mg and in 2019 it will probably exceed the record volume of 2011, i.e. over 330 million Mg. In the extraction and production of aggregates in Poland, there is a decisive preponderance of gravel and sand aggregates – their share in the total production of natural aggregates amounts to 70–75% (Kozioł et al., 2018d). The remaining part consists of crushed-stone aggregates produced from compact and moderately compact rocks of magma origin (basalts, granites, gabbro and diabases, melaphyres, porphyry, syenites, etc.), sedimentary rocks (dolomites, limestones, sandstones, etc.), and metamorphic rocks (amphibolites, migamatites, gneisses, serpentinites, etc.). In the European Union and other European countries, crushed-stone aggregates produced from magma and sedimentary rocks prevail (their share in the production amounts to about 55%), but there are countries in which, similarly to Poland, gravel and sand aggregates predominate (Holland, Latvia, Iceland, Switzerland, Israel). It

is dependent on the geological structure of the countries and documented, extractable particular types of rocks. In Poland, a gradual deterioration in the quality of the raw material base of gravel and sands as well as a simultaneous increase in the demand of the construction industry for the best quality thick aggregate fractions (5/8mm, 8/11, etc.) (PIG-PIB 2008–2018, Kozioł et al., 2018c, Kozioł et al., 2018d) has a significant impact on the rise in the amount of hard to sell and unsalable (waste) fractions of aggregates produced in Poland. This applies especially to gravel and sand aggregates in whose deposit the share of fine fractions (below 2 mm) is systematically increasing, while the demand for them in the construction sector is limited and they are often treated as useless (waste) material. Since it is practically unknown what is the production and consumption of these aggregates, an attempt was made to assess the amount of extracted and produced sand and gravel fractions of natural aggregates in Poland on a national and regional scale (voivodeships, regional zones).

**National resource base for gravel and sands as well as trends in changes**  
*Gravel and sand resources*

Tab. 1. Division of sand and gravel aggregate resources (PIG-PIB 2018, Kozioł et al., 2018d)

Tab. 1. Podział zasobów żwirów i piasków (PIG-PIB 2018, Kozioł et al., 2018d)

Type of mineral		Sand point <sup>a</sup> [%]	Basic grain fraction [mm]	Dust content (<0.063 mm) [%] <sup>a</sup>
<b>Sands</b>	sand	> 90	0.05-2.0	up to 10 (up to 5 in quartz ones)
	sand with gravel additions	75-90		up to 10
<b>Sands with gravel (all-in aggregate)</b>	sand and gravel mix	50-75	0.05-63	up to 15
	gravel and sand mix	30-50		
<b>Gravel</b>		< 30	2.0-63	
<b>Boulders</b>			over 63	

<sup>a</sup> according to balance criteria

Tab. 2. Percentage contribution of individual subgroups of deposits in the total resources of gravel and sands in 2007 and 2016 (Kozioł et al., 2018d)

Tab. 2. Udział procentowy poszczególnych podgrup złóż w łącznych zasobach żwirów i piasków w latach 2007 i 2016 (Kozioł...2018d)

Type of deposit	Balance resources		Industrial resources	
	2007	2016	2007	2016
<b>Sand</b>	27.8	37	25.7	42.5
<b>Gravel and sand</b>	65.5	58.1	65.5	55.4
<b>Gravel</b>	6.7	4.9	8.8	2.1
<b>Total</b>	100	100	100	100

In this article, due to the availability, consistency and repeatability, the primary source of data was Bilans Zasobów Złóż Kopalini i Wód w Polsce (The Balance of Mineral Resources and Waters in Poland) (PIG-PIB 2008-2018), published annually by the Polish Geological Institute – National Research Institute in Warsaw. The analysis took into account data from 2007–2017. The number of documented gravel and sand deposits in Poland is steadily growing and over the analysed years, it increased from 6029 in 2007 to 10117 in 2017, including the number of developed deposits which increased from 2278 to 4004. It seems that the main reason for the increase in the number of deposits results from the division of the documented deposits into smaller and often very small ones (up to 2 ha of land, which makes it possible to apply for the so-called koncesje starościńskie, i.e. Starost Concessions). In the years 2007–2015, starosts issued 3283 concessions (Baradziej, 2015), which accounted for about 2/3 of the total number of open-pit mining concessions in Poland, including concessions for the extraction of gravel and sand aggregates, which accounted for about 94%. As the number of deposits increases, so do the resources. In the years 2007–2017, the balance resources of gravel and sands increased by about 28% (to 19.3 billion Mg), and the industrial resources by as much as 80% (to 3.96 billion Mg). The increase in industrial resources contributed to an increase in the sufficiency rate of industrial resources from a low level of around 12 to 18 years. An alarming threat to the aggregate production is the deteriorating quality of gravel and sand deposits, which has an impact on the production volume of the gravel products sought and the increase in their costs. In the geological documentation of gravel and sand deposits and in the balance sheets of resources (PIG-PIB 2008-2018), three basic groups of gravel and sand aggregate are distinguished (Table 1), namely: sands, sands with gravel, and gravel. What constitutes the division criterion is the proportion of fine grains up to 2 mm in diameter. There is also a fourth group of resources, i.e. dusty clay sand, but these resources were excluded from the analysis due to a very small share (about 0.4%) and lack of economic significance. The analysis of changes in the size of deposits in the period of 10 years (2007–2016) (Kozioł et al.,

2018d) shows that we have quite a large increase in deposits despite exploitation, but it is disadvantageous that it is mainly the deposits of sand (SP>75) that are growing. The industrial resources of sand deposits have almost doubled (by 190%), while the resources of sand and gravel deposits have increased by about 50% and the resources of gravel deposits have decreased by almost 60%.

The change in the structure of deposits affects the share of particular subgroups of gravel and sand deposits in the total balance and industrial resources, as shown in Table 2.

The share of sands in industrial resources increases particularly fast from 25.7 to 42.5% (in 2017, there was a further increase to 46%) while the share of gravel and gravel-sand resources decreases.

#### **Trends in the share of sand fractions in gravel and sand resources**

The assessment of the number of fine fractions in the resources of gravel and sand aggregates can be approximated based on the calculation of medium sand points (fraction content below 2 mm) in the analysed deposits. Assuming the division of documented gravel and sand resources into three basic groups: sands, sands with gravel and gravel, and determining for each of these groups the medium sand points (SP), i.e. sands – 85%, sands with gravel – 60%, gravel – 25%, the medium sand points were then calculated in the balance and industrial resources and in the extracted mineral (resources) in the annual balance of minerals (Kozioł et al., 2018d). Sample calculations for individual voivodeships, zones and the whole country are presented in Table 3 (balance resources) and Figures 1–4 (balance, industrial and extracted resources). The analysis was conducted for the years 2007–2016, which allowed to determine the trend of changes in the content of fine fractions in resources and extracted mineral over a 10-year period. Table 3 and Figure 1 show that in 2016 the medium sand point in the country in terms of balance resources was 67.5% and over 10 years it increased by 4.5%.

The resources in the southern zone have the lowest SP (60.5%), including the małopolskie (50.5%) and opolskie

Tab. 3. Medium sand points in balance reserves of gravel and sand aggregate in the years 2007–2016 (PIG-PIB 2008-2018, Kozioł et al., 2018d)  
 Tab. 3. Średnie punkty piaskowe w zasobach bilansowych kruszyw żwirowo- piaskowych w latach 2007–2016 (PIG-PIB 2008-2018, Kozioł 2018d)

Description	Medium SP in balance resources in years, %										
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
<b>Poland</b>	64.6	64.7	65.2	65.8	66.1	66.5	66.7	66.9	67.4	67.5	
northern zone	62.3	62.6	63.4	63.9	64.3	65.1	65.2	65.5	66.0	66.4	
central zone	78.4	78.0	78.4	79.0	79.1	79.4	79.5	79.7	79.8	80.0	
southern zone	58.6	58.8	59.1	59.6	59.9	59.9	60.1	60.2	60.7	60.5	
<b>Voivodeships</b>											
dolnośląskie	60.4	60.2	60.5	61.3	61.5	61.6	61.8	62.2	63.9	62.8	
kujawsko-pomorskie	74.4	75.3	77.7	78.5	79.5	79.5	79.8	80.3	80.7	81.3	
lubelskie	83.9	83.7	83.7	83.7	83.8	83.9	84.0	84.0	84.1	84.1	
lubuskie	62.4	62.7	64.0	64.4	65.3	65.5	65.4	65.7	66.0	66.1	
łódzkie	72.8	73.7	75.0	77.8	78.1	77.7	77.8	77.9	77.7	77.8	
małopolskie	48.3	50.0	50.7	50.8	50.8	50.6	50.6	50.5	50.5	50.5	
mazowieckie	75.4	75.3	75.7	76.2	76.1	76.9	77.2	77.4	77.6	78.0	
opolskie	58.5	58.5	58.8	58.9	59.1	59.2	59.4	59.3	59.3	59.5	
podkarpackie	67.7	67.2	67.2	68.1	68.7	68.9	68.9	68.9	69.0	69.3	
podlaskie	60.6	60.7	60.8	61.1	61.2	61.3	61.3	61.2	61.2	61.3	
pomorskie	65.1	64.5	65.8	66.5	66.9	67.4	68.3	68.6	69.9	70.7	
śląskie	63.5	63.7	64.2	64.2	64.0	63.7	63.9	64.0	64.0	64.1	
świętokrzyskie	83.1	82.8	82.8	82.9	82.9	82.9	82.9	82.9	82.9	82.9	
warmińsko-mazurskie	60.6	61.7	62.2	62.9	63.4	63.7	63.8	64.1	64.2	64.5	
wielkopolskie	75.7	74.0	74.5	75.0	75.4	76.3	76.5	77.0	77.6	77.8	
zachodniopomorskie	64.1	64.4	65.3	66.2	66.0	68.7	68.7	69.9	71.0	71.2	

(59.5%) voivodeships. In the central zone, the medium SP is the highest and amounts to 80%, including 84.1% in the lubelskie voivodeship and 82.9% in the świętokrzyskie voivodeship. In the industrial resources (Figure 2) in 2016, the medium SP in the country was higher in comparison with the balance resources, i.e. 69.9%, and – what is characteristic – within 10 years, it increased by as much as 10.4%, i.e. the medium annual growth of SP in industrial resources is over 1%. What is also characteristic as well as alarming is the fact that the highest increase was recorded in the southern zone (by 16.4%), i.e. in the region with the best gravel and sand deposits in terms of quality (grain size composition), which denotes the fastest deterioration. Industrial resources have the lowest SP values in the following voivodeships: opolskie (50.8%), małopolskie (58.4%), podlaskie (61.4%); while the highest values in the following ones: świętokrzyskie (85%), lubelskie (83%), wielkopolskie (81.2%), and kujawsko-pomorskie (81.1%) (Kozioł et al., 2018d). Higher SP values in industrial resources compared with balance resources indicate that some gravel and sand deposits with relatively favourable grading (lower SP values) are not currently being developed, probably for environmental reasons. Especially large differences in SP value occur in the southern zone (in 2016, balance resources – 60.5%, industrial resources – 64%), including the following voivodeships: dolnośląskie (62.8/69.3%) and małopolskie (50.5/58.4%). However, in the opolskie voivodeship, the opposite situation is true, i.e. it seems that in 2016, SP in industrial resources (50.8%) was much lower than SP in balance resources (59.5%). Relatively large differences in SP value were also noted in three voivodeships: lubuskie (in 2016, balance resources – 66.1, industrial resources – 73.4%), łódzkie (77.8/80.2%) and wielkopolskie (77.8/81.2%) (Kozioł et al., 2018d). In 2017 (the data for 2018 are still not available), there was a further increase of SP in industrial resources up to the medium value of 70.6% (PIG-PIB 2018). From the perspective of exploita-

tion, what matters significantly are SP values in the extracted mineral (resources) of gravel and sands. In 2016, the medium SP in extracted resources (Figure 3–4), similarly to industrial resources, amounted to 69.9% and within 10 years increased by 4.8% (Kozioł et al., 2018d). The lowest PP was in the southern zone (65.1% – increase by 8.7%) and the highest in the central zone (79.9%). On each individual voivodeship's scale (Figure 4), the lowest SPs were observed in the extracted resources in the following voivodeships: małopolskie (54.6% in 2016), opolskie (59.3% – increase over 10 years by 12.0%), podlaskie (62.5%) and podkarpackie (65.8%). In turn, the highest SPs in the extracted resources were recorded in the świętokrzyskie (85%), lubelskie (83.8%), wielkopolskie (81.2%) and łódzkie voivodeships (79.4%). These values are similar to SP values in industrial resources. The comparison of average SP values in extracted and industrial resources shows that on a national scale and in the three regional zones the values are the same (country, central zone) or very similar (northern and southern zones). Whereas on the regional scale, in 4 voivodeships the values are the same or very similar (lubelskie, łódzkie, świętokrzyskie, wielkopolskie), in 6 voivodeships they are higher (dolnośląskie, mazowieckie, opolskie, podlaskie, śląskie, warmińsko-mazurskie) and in 6 voivodeships lower (voivodeships: kujawsko-pomorskie, lubuskie, małopolskie, podkarpackie, pomorskie, zachodniopomorskie). The analysis of trends of SP changes in the extracted resources in the years 2007–2016 shows that these changes (the SP growth) are slower compared to the changes of medium SP in industrial resources, but also in balance resources. This means that priority is given to exploitation of better quality resources with lower SP values, which is obvious from an economic point of view. Summarizing the SP analysis of the documented and utilized aggregate resources, it should be stated that the medium sand points in the gravel and sand resources range from approximately 50 to 85%. In 2016, the medium SP in extracted resources was as

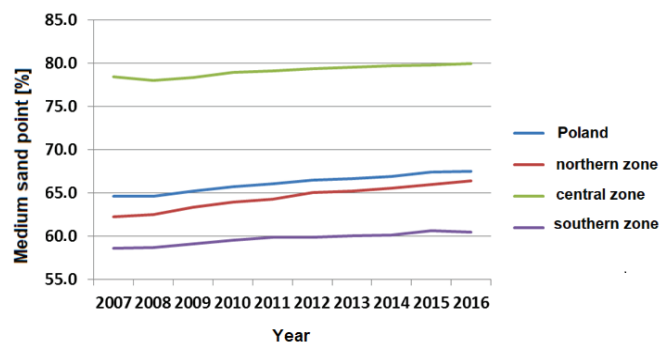


Fig. 1. Trends in changes of medium sand points for balance reserves in the years 2007–2016  
 Rys. 1. Tendencje zmian średnich punktów piaskowych zasobów bilansowych w latach 2007–2016

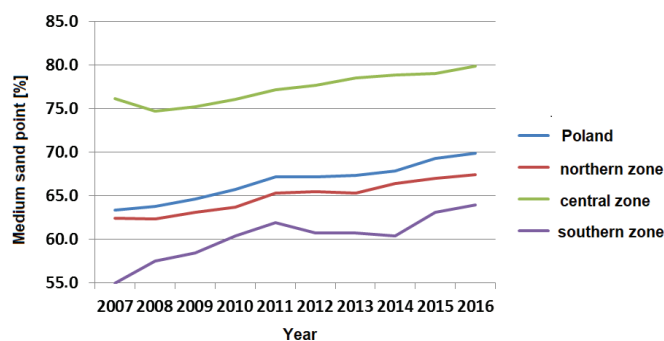


Fig. 2. Trends in changes of medium sand points for developed reserves in the years 2007–2016  
 Rys. 2. Tendencje zmian średnich punktów piaskowych zasobów przemysłowych w latach 2007–2016

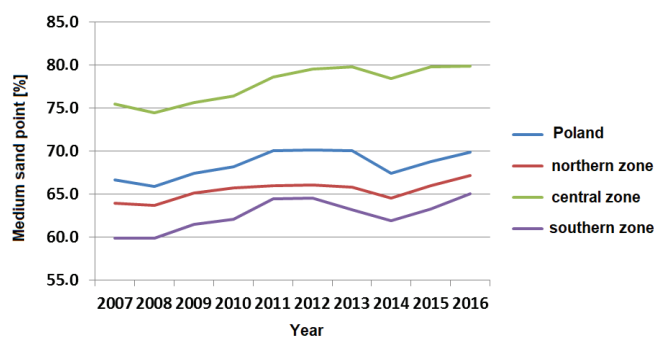


Fig. 3. Trends in changes of medium SP for resources extracted in the years 2007–2016  
 Rys. 3. Tendencje zmian średnich PP zasobów wydobytych w latach 2007–2016

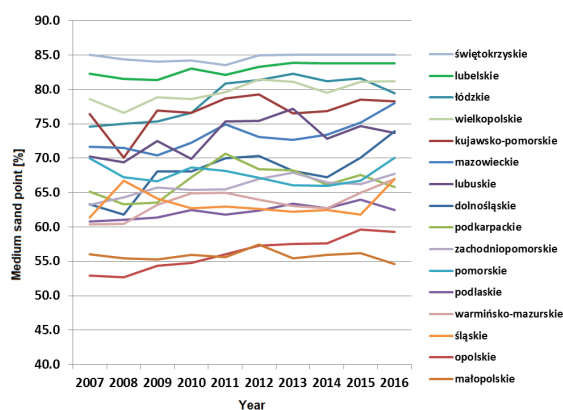


Fig. 4. Trends in changes of medium SP for resources extracted in voivodeships in the years 2007–2016  
 Rys. 4. Tendencje zmian średnich PP zasobów wydobytych w województwach w latach 2007–2016



Fig. 5. Extraction of gravel and sand aggregates with a suction dredger  
Rys. 5. Wydobycie kruszyw żwirowo-piaskowych pogłębiarką ssącą

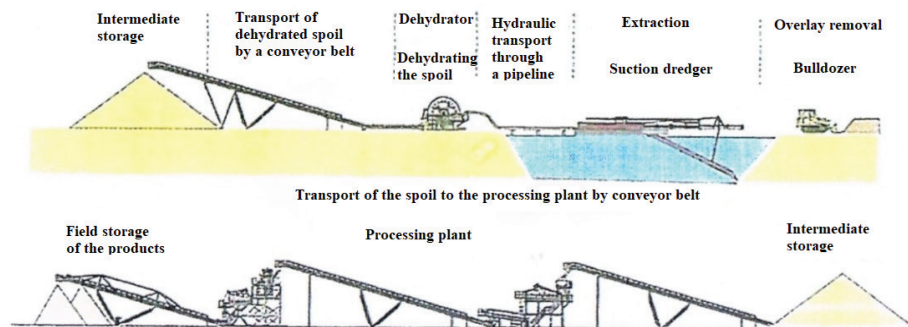


Fig. 6. The production scheme of sand and gravel aggregates (Witt, 2013)  
Rys. 6. Schemat produkcji kruszyw żwirowo-piaskowych (Witt, 2013)

follows: the country – 69.9%, northern zone – 67.2%, central zone – 79.9%, southern zone – 65.1%. On the individual voivodeship's scale in extracted resources, the medium SP ranged from 54.6% in małopolskie voivodeship to 85% in świętokrzyskie voivodeship (PIG-PIB 2008–2018, Kozioł et al., 2018d).

### Production of sands (0–2 mm) from extracted mineral resources

#### Separation of minerals in the extraction process

Knowing the content of sand fraction (0–2 mm) in the extracted mineral it is possible to determine the amount of recovery (production) of this fraction in the extraction and treatment process. However, in some of the gravel and sand extraction technologies used, part of the fine fractions are already lost during the extraction process. This applies in particular to the exploitation under the water surface, which is predominantly used in Poland (over 75% of gravel and sand extraction). As an example, below one can find separations of extracted minerals by means of dredgers that are most commonly used in Poland to extract sands and gravel.

#### A. Sand and gravel extraction with suction dredgers

In Poland, suction dredgers (dredger cutters) (Figure 5) are currently used most frequently and are usually used to extract sand and gravel aggregate deposits with an SP point of more than 35%. The mineral separation process during the extraction of the minerals is as follows (Figure 6)

- oversized solids that may be in the deposit are not mined; the suction pipe of the dredger is secured with an appropriate strainer to prevent blocking with oversized grains;

- the spoil, which is extracted by the suction pipe of the dredger in the form of a hydromixture, is dewatered directly on the dredger or on land; separation of water from the mineral is carried out in a dehydrator or on a dewatering screen;
- what is also drained along with the water are dusty and clay particles as well as occasional grains of sand;
- the extracted spoil remaining after dehydration is usually fed by a system of belt conveyors to the processing plant.

#### B. Sand and gravel extraction with single-bucket grapple, scoop or scraper dredges

Out of single-bucket dredgers, the most common types of dredgers are those with a scoop (Figure 7). At present, they are mainly used for extracting deposits with relatively low sand points. The separation of dredging spoil on the dredger is carried out as follows:

- oversized solids (determined depending on the operating parameters of the processing plant and the type of technological transport used) are separated on the initial grate and discharged directly to the excavation pit;
- from a 2 mm sifting screen placed on the dredger's deck, the fraction is directed onto the transport equipment and fed into the processing plant;
- the undersize grain from the sifting screen is discharged into the water tank below the dredger deck (useless fraction).



Fig. 7. Extraction of gravel and sand aggregates with a grab dredger  
Rys. 7. Wydobycie kruszyw żwirowo-piaskowych pogłębiarką chwytakową

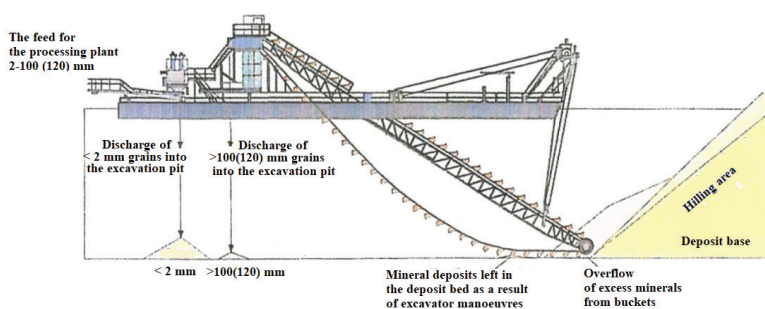


Fig. 8. Example separation of sand and gravel aggregates with a multi-bucket chain dredger  
Rys. 8. Przykładowy rozdział eksploatowanych kruszyw żwirowo-piaskowych wieloczerpakową pogłębiarką łańcuchową [Witt.2013]

In the processing plant, silty ( $< 0.063$ ), clay and sand grains as well as part of sand grains are discharged as processing waste to an excavation pit or a settler.

### C. Sand and gravel extraction with bucket-ladder dredgers (Figure 8)

The distribution of minerals mined by a ladder (chain) dredger is generally as follows (Witt, 2013):

- the oversized fraction (above 100 mm) is discharged from the dredger into an excavation tank;
- from a 2 mm sifting screen, the fraction is fed with belt conveyors or vessels to the processing plant;
- the fraction which is below 2 mm is usually discharged directly from the excavator to the excavation pit (useless fraction).

Further separation of the extracted material (feed) takes place in the processing plant with a division into commercial products and processing waste consisting mainly of the remaining silty ( $< 0.063$ ) and clay fractions, which usually constitute about 10% of the feed.

### Production of aggregates of gravel and sand fractions – quantitative assessment

The analysis presented in section 3.1 shows that practically only the use of suction dredgers enables full recovery of fine sand fractions from the extracted mineral, whereas in the case of single- and multi-bucket dredgers, sand fractions are often directly melted in the post-extraction pit. The construction industry is mainly looking for coarse aggregates (both gravel and crushed-stone), while the demand for fine

aggregates (sand) is changeable and largely depends on the demand for road construction. In the years 2013–2016, this demand was much lower than the volume of sand production and mines had great problems with their sale (aggregates that are difficult to sell and unsellable). The application of scrubbers and hydrocyclones to classify and enrich these fractions for most small plants is too expensive. Unsellable and hard to sell sand fractions of aggregates are often used in mines for reclamation of post-extraction pits. Recently, due to the implementation of the national road construction programme, their consumption has increased significantly.

In order to determine the estimated amounts of recovery (production) of small (sandy) fractions, the following assumptions have been made (Kozioł et al., 2018d):

- the basis for assessing the size of the recovered fraction of 0–2 mm is the value of SP in the extracted resources of sand and gravel (in the extracted mineral);
- approx. 75% of gravel and sand is extracted from underwater in Poland (with a growing tendency), including over 50% by means of suction dredgers with recovery of fine fractions; suction dredgers are used in mines with higher extraction volume (usually over 100 thousand Mg/year);
- small plants with the output of up to 40 thousand Mg (Starost Concessions for the extraction), predominant in terms of quantity (over 75% of the number of exploited gravel and sand mines), from which over 17% of domestic extraction is obtained (Kozioł, Baic 2018a; Kozioł et al., 2018 d), apply technologies of dry or underwater extraction with exploitation from the land and mainly use single-bucket excavators

(bucket, grab, scraper) or rope scrapers, etc.;

- the onshore (dry) exploitation (approx. 25% of extraction) in larger mines equipped with processing and flushing installations also recovers fine sand.

The adopted assumptions show that in Poland, depending on the extraction technology, the demand (which is changeable) and the region, the recovery (production) of small fractions is in the range of 60 to 80% of the content of this fraction in the extracted mineral. For an illustrative determination of the production volume of fine sand assortments in 2016, the medium recovery rate of 70% was assumed (Table 4). Based on the assumed assumptions, it follows that in 2016, when approx. 173.2 million Mg of gravel and sand were mined, it was practically possible to obtain approximately 51.8 million Mg of gravel aggregates and 84.6 million Mg of sand assortments (0–2 mm), i.e. the estimated total production of gravel and sand aggregates was probably approximately 136.4 million Mg, i.e. approximately 78.7% of the total annual production of gravel and sand (Kozioł et al., 2018 d). The remaining part (21.3%) is made up of losses (useless fractions). The amount of fine fractions recovery is changeable because part of the extracted sand and gravel mineral is used in the form of mixes (sand and gravel mixture) and sand with admixture of gravel. The share of these fractions in the production and consumption of aggregates varies depending on the quality and volume of resources and the fluctuating demand of the construction industry. In some years and voivodeships, a higher share of the consumption of mixes and sands results mainly from the implementation of road construction engineering works (mainly for road foundation). An example of such a period are the years 2011–2012, when approximately 50% of gravel and sand extraction was consumed by road construction in the form of raw sands (Kozioł, Galos 2013), also now (2017–2019) there has been an increase in demand for these aggregates due to the relatively large scale implementation of infrastructure investments. This favourable period is likely to continue over the next few years.

Table 4 presents the results of calculations of production (recovery) of small sand assortments (0–2 mm) in particular voivodeships and regional zones in 2016. The comparison shows that the highest volume of sand recovery was recorded in the following voivodeships: mazowieckie (9.1 million Mg), podlaskie (8.8 million Mg), dolnośląskie (8.7 million Mg), pomorskie (8.7 million Mg) and warmińsko-mazurskie (8.2 million Mg), while the lowest volume of sand was recorded in the świętokrzyskie (1.2 million Mg) and lubelskie (2.5 million Mg) voivodeships. In the regional zones, the estimated production of the 0–2 mm fraction sands was as follows:

- northern zone (region) – 33.9 million Mg,
- central zone (region) – 26.1 million Mg,
- southern zone (region) – 24.6 million Mg.

#### **Assessment of the production and consumption balances of gravel and sand**

Fine assortments of gravel, sand and crushed-stone aggregates are used both in the construction industry and in other various branches of the economy. Quantitatively, however, the basic demand concerns the construction industry, includ-

ing primarily concrete and concrete products (prefabricated products, etc.). In the structure of production of concrete and concrete products, the dominating factor is concrete mix (ready-mixed concrete), used both by the volumetric construction (residential, industrial, services) and road infrastructure (transport) – about 50–60% of consumption (Kozioł, Galos 2013). The second position is occupied by concrete slabs and cubes for transport infrastructure engineering about 17–20%, further prefabricated structural elements about 8–10%, mortars and dry mixtures about 7–10%, wall elements, concrete pipes – about 3%, other consumption – about 5–8%. Until recently, the production of concrete and concrete products was traditionally based on mixtures and all-in aggregates (unclassified sands), but the need to manufacture increasingly high quality products results in a steadily developing use of gravel and complementary classified sands with little use of all-in aggregates, i.e. unclassified mixes, for these purposes. The production of concrete and concrete products on individual construction sites is currently used for a very small number of applications. The above shares concern medium values and fluctuate in particular years depending on the size and structure of the executed volumetric construction and infrastructure engineering (Kozioł, Galos 2013).

Assuming typical proportions of the three main components of concrete products (Kozioł et al., 2018 d), i.e. cement approx. 18%, gravel-sand aggregates and crushed-stone aggregates (for higher classes of concrete) – approx. 61%, classified and unclassified sands – approx. 21%, the estimated consumption of classified and partially unclassified sands for concrete mix was determined on the example of 2016 (Table 4). On the national scale, it amounted to approx. 29.0 million Mg, and in particular zones (regions) it was the following:

- northern region – 6.5 million Mg,
- central region – 13.0 million Mg,
- southern region – 9.5 million Mg.

As for the voivodeships, the highest demand was specified for the following ones: mazowieckie along with the agglomeration of Warsaw (4.2 million Mg), wielkopolskie (3.1 million Mg), dolnośląskie (2.5 million Mg) and śląskie (2.5 million Mg), while the lowest for the following voivodeships: opolskie (0.4 million Mg), lubuskie (0.9 million Mg) and zachodniopomorskie (0.9 million Mg).

Sand consumption apart from concrete mix in 2016 was estimated at approx. 36.0 million Mg (increase in consumption in the road engineering). Since there are no data concerning both the national volume and the territorial distribution of this consumption, it was assumed that it is similar to the consumption of sand for concrete, and on that basis the consumption for individual voivodeships and regions was determined (Table 4).

The comparison of the territorial distribution of the predicted total sand consumption with the estimated potential (probable) amount of production (recovery) of fine aggregate fractions resulted in the territorial distribution of the production balance – sand consumption of the 0–2 mm fraction (Table 4). It shows that in 2016, the estimated production (recovery) of sands in Poland exceeded their consumption by 19.6 million Mg. The highest positive balance was determined for the northern voivodeships: podlaskie (5.7 million Mg),

Tab. 4. Balance of production and consumption of fine assortments of gravel and sand aggregates in 2016 (Kozioł et al., 2018d)

Tab. 4. Bilans produkcji i zużycia drobnych asortymentów kruszyw żwirowo-piaskowych w 2016 r. (Kozioł, 2018d)

Description	Extraction, thousand Mg	Fraction's share in the mineral, thousand Mg		Recovery of 0–2 mm fraction, million Mg	Predicted consumption for concrete, million Mg	Other consumption, million Mg	Balance (recovery - consumption), million Mg
		0 - 2 mm	>2 mm				
<b>Poland</b>	<b>173239</b>	<b>120764</b>	<b>51825</b>	<b>84.6</b>	<b>29.0</b>	<b>36.0</b>	<b>19.6</b>
northern zone	72039	48410	23629	33.9	6.5	8.0	19.4
central zone	46596	37230	9366	26.1	13.0	16.1	- 3.0
southern zone	53954	35124	18830	24.6	9.5	11.9	3.2
<b>Voivodeships:</b>							
dolnośląskie	16895	12485	4410	8.7	2.5	3.1	3.1
kujawsko-pomorskie	5124	4012	1112	2.8	1.2	1.5	0.1
lubelskie	4308	3610	698	2.5	1.3	1.6	-0.3
lubuskie	5954	4388	1566	3.1	0.9	1.1	1.1
łódzkie	6011	4773	1238	3.3	2.0	2.5	1.2
małopolskie	12084	6598	5486	4.6	2.2	2.7	-0.3
mazowieckie	16580	12932	3648	9.1	4.2	5.3	- 0.4
opolskie	7653	4561	3092	3.2	0.4	0.5	2.3
podkarpackie	6750	4442	2309	3.1	1.9	2.5	-0.3
podlaskie	20073	12546	7527	8.8	1.4	1.7	5.7
pomorskie	17791	12471	5320	8.7	1.5	1.9	5.3
śląskie	10572	7083	3489	5.0	2.5	3.1	-0.6
świętokrzyskie	2052	1744	308	1.2	1.1	1.4	-1.3
warmińsko-mazurskie	17588	11784	5804	8.2	1.8	2.2	4.2
wielkopolskie	12521	10167	2354	7.1	3.1	3.8	1.2
zachodniopomorskie	10633	7199	3434	5.0	0.9	1.1	3.0

pomorskie (5.3 million Mg) and warmińsko-mazurskie (4.2 million Mg), while the deficit voivodeships were: śląskie, mazowieckie, świętokrzyskie (in this voivodeship crushed-stone aggregate sands are used as a substitute) and małopolskie. The zone division of extraction and production of gravel and sands shows that the positive balance of sand production is mainly in the northern region (+19.4 million Mg), while the southern region (+3.2 million Mg) is in balance with the deficit in the central region (-3.0 million Mg). The negative balance in the central region is affected by the high demand for gravel (4.2 million Mg) and sands (5.3 million Mg) in the Warsaw agglomeration. In the central zone in the years 2012–2013, the calculated production of sands amounted to approx. 35 million Mg, i.e. much more than in 2016.

In the estimated sand consumption reported herein, the use of fine sand fractions has not been specified as a separate group outside the construction industry. Compared to the values given above, however, this use is not significant, and in addition, the share in the consumption of sand from the production of crushed-stone aggregates and from the regulation of rivers and water reservoirs (extraction of aggregates not subject to mining activities) has not been taken into account. The share of sand from crushed-stone aggregates and from the regulation of rivers and water reservoirs certainly exceeds the volume of sand fractions use from gravel and sand deposits outside the construction industry.

The presented estimates of both production and consumption of fine sand fractions should be treated as approximations for several reasons. Firstly, there is no precise information on the contribution of various technologies to the extraction of gravel and sand, either underwater or on land. Moreover, not all mines using suction dredgers for extraction are equipped with appropriate classification nodes and dehydration prod-

ucts (dehydrators, hydrocyclones, presses, etc.) (Naziemiec, 2013). The consumption of fine sand is also approximated and varies depending on whether it is estimated on the national or local scale. However, it is a fact that fine sands are often not used industrially and are deposited in excavation voids, which entails their loss. Current and new directions and technologies of fine assortments application (Kozioł et al., 2018d) justify the need for their selection and separate storage. These landfills, as so-called anthropogenic deposits, should in the future become the basis for the extraction of aggregates used in industrial applications.

### Final conclusions

1. An analysis of the databases of gravel and sand deposits shows that with the growth of documented resources, the share of resources classified as sands increases. A particularly large increase in sand fractions is observed in the industrial resources in the years 2007–2017, i.e. from 25.7 to 45.3%.

2. What constitutes a measurable indicator of the deterioration in the quality of resources is the tendency towards change in the medium sand point (the percentage content of fine fraction of 0-2 mm) in the documented resources. In 2016, the average sand point in the balance resources was 67.5% and over 10 years (2007–2016) it increased by 4.5%. The resources in the southern region (zone) (60.5%), including the małopolskie (50.5%) and opolskie (59.5%) voivodeships, have the lowest SP. Whereas in the central region, the average SP reaches 80%, including 84.1% in the lubelskie voivodeship and 82.9% in the świętokrzyskie voivodeship.

3. In 2016, the medium SP in the industrial resources in Poland was higher compared with the balance resources, i.e. 69.9% and, what is characteristic, within the period of 10 years, it increased by as much as 10.4%, i.e. the aver-



age annual growth of SP in industrial resources is over 1%. The highest growth was recorded in the southern region (by 16.4%), i.e. the region with the best deposits in terms of quality (grain size); it is there that the fastest deterioration can be observed. The lowest SP values were observed in industrial resources in two voivodeships, i.e. opolskie (50.8%) and małopolskie (58.4%), while the highest values were noted in the following voivodeships: świętokrzyskie (85%), lubelskie (83%), wielkopolskie (81.2%) and kujawsko-pomorskie (81.1%). In 2017 (data for 2018 are not yet available), there was a further increase of SP in industrial resources to a medium value of over 70.0%.

4. The medium SP values in the extracted mineral are similar to those in the industrial resources (the national average is 69.9%), not big differences can be noticed for regional zones and voivodeships (Kozioł et al., 2018d).

5. After the sand point in the extracted mineral was estimated, an attempt was made to assess the amount of recovery (production) of this fraction in the extraction and treatment processes. Based on the adopted assumptions, it follows that in 2016, when approximately 173.2 million Mg of gravel and sand were mined, it was actually possible to obtain approximately 51.8 million Mg of gravel aggregates and 84.6 million Mg of sand assortments (0–2 mm); thus, the estimated total production of gravel and sand aggregates probably amounted to ca. 136.4 million Mg, i.e. about 78.7% of the annual production of gravel and sand according to PGI. The remaining part (21.3%) represents losses (useless fractions).

6. The volume of fine fractions recovery is changeable because part of the extracted sand and gravel mineral is used in the form of all-in aggregates (sand and gravel mixture) and sand with admixture of gravel. The share of these fractions in the production and consumption of aggregates differs depending on the quality and size of resources and the alternating demand of the construction industry. A higher share in the consumption of all-in aggregates and sand in some years and voivodeships results mainly from the implementation of road infrastructure engineering works (mainly for road

foundation). An example of such a period are the years 2011–2012, when approximately 50% of gravel and sand extraction in the form of raw sands was consumed by road construction, and there has also been an increase in demand for sands due to the good economic situation in road infrastructure and volumetric construction.

7. Deterioration of the quality of the raw material base and, at the same time, the increase in the building industry demand for thick aggregate fractions (5/8, 8/11, etc.) contribute to an increase in the extraction of gravel and sand aggregates with a simultaneous increase in the production of fine, hardly marketable assortments of aggregates.

8. Since it is practically unknown what is the production and consumption of fine (sand) fractions of aggregates, the present article constitutes an attempt to determine the balance of their production and consumption (demand), both at the national and regional level.

9. The estimated calculations show that, for example, in 2016 the production of sands was presumably about 20 million Mg higher than their consumption. For this reason, the sands from this period belonged to such categories of aggregates that were difficult to sell or unsellable. Large production surpluses (balances) were recorded in the northern region (three voivodeships: podlaskie, pomorskie, and warmińsko-mazurskie).

10. The deficit of natural aggregates in many countries and regions as well as the limited aggregate resources in Poland and increasing difficulties in obtaining licenses for their extraction indicate the need for selective storage of sand aggregate assortments instead of “melting” them in post-mining excavation pits.

11. In the future, the presented research results should contribute to the development of more accurate market forecasts regarding the demand for and production of natural aggregates in Poland and in individual regions, especially when it comes to gravel and sand aggregates, including also fine fractions.

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## *Wydobycie, produkcja i zużycie kruszyw żwirowo-piaskowych w Polsce – próba oceny bilansów krajowych i regionalnych*

*Kruszywa naturalne są podstawową grupą wydobywanych kopalin. W Polsce ich udział w wydobywaniu kopalin stałych w ciągu 30 lat (1989–2018) zwiększył się z ok. 24 do 54%. Obecne wydobycie kruszyw wynosi około 300 mln Mg i w 2019 r prawdopodobnie przekroczy rekordową wielkość z roku 2011 – ponad 330 mln Mg. W wydobywaniu i produkcji kruszyw w Polsce zdecydowana przewaga mają kruszywa żwirowo-piaskowe, ich udział w produkcji kruszyw naturalnych ogółem stanowi 70–75%. Pozostałą część stanowią kruszywa łamane produkowane ze skał zwięzłych i średnio zwięzłych pochodzenia magmowego (bazalty, granity, gabra-diabazy, melafiry, porfiry, sjenity i in.), osadowego (dolomity, wapienie, piaskowce i in.) i metamorficznego (amfibolity, migmatyty, gnejsy, serpentynity i in.). Stopniowe pogarszanie się jakości bazy surowcowej żwirów i piasków i równocześnie wzrost zapotrzebowania budownictwa na najlepsze jakościowo grube frakcje kruszyw (5/8mm, 8/11, itd.), ma duży wpływ na wzrost frakcji trudno zbywalnych i niezbywalnych (odpadowych) produkowanych kruszyw. Dotyczy to szczególnie kruszyw żwirowo-piaskowych w zasobach których systematycznie wzrasta udział frakcji drobnych (poniżej 2 mm), na które jest ograniczone zapotrzebowanie budownictwa i często traktowane są jako materiał nieużyteczny (odpadowy). Ponieważ praktycznie nie wiadomo jaka jest produkcja i zużycie tych kruszyw podjęto próbę oceny w skali kraju i poszczególnych regionów (województw, stref regionalnych) ilości wydobywanych i produkowanych frakcji piaskowych i żwirowych kruszyw naturalnych w Polsce.*

*Deficyt kruszyw naturalnych w wielu krajach i regionach oraz ograniczone zasoby kruszyw w Polsce i coraz większe trudności z uzyskaniem koncesji na ich wydobywanie wskazują na potrzebę selektywnego składowania piaskowych asortymentów kruszyw zamiast ich „topienia” w wyrobiskach poeksploatacyjnych. Wyniki badań powinny przyczynić się do opracowania w następnych latach dokładniejszych prognoz rynkowych zapotrzebowania i produkcji w Polsce i w poszczególnych regionach kruszyw naturalnych w tym szczególnie kruszyw żwirowo-piaskowych z uwzględnieniem również frakcji drobnych.*

*Słowa kluczowe: piaski, żwiry, kruszywa naturalne, bilans krajowy i regionalny*