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Aggregates production in Poland and other selected countries – an analysis of dependence on cement production

Introduction

Mineral aggregates are commonly used building and road construction materials. It is a basic raw materials in many applications, constituting even more than 90% of construction materials used (e.g. in road construction). In terms of quantity, aggregates are most commonly used to manufacture concretes, precast concrete, in the construction of roads, motorways, flats, houses, and many other transport and volumetric infrastructure objects. For instance, according to the UEPG report (UEPG 2009–2019), approx. 30,000 Mg of aggregates are needed to build one kilometer of a typical motorway, approx. 9,000 Mg/km to build one kilometer of high-speed railway line, approx. 400 Mg to construct a typical house, a approx. 3,000 Mg a school, and approx. 300,000 Mg a sports stadium. Without the use of natural aggregates or flours made of them, it would be impossible to manufacture asphalt, electricity in conventional firing plants (flue-gas desulfurization), the construction chemical

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products (glues, mortars) and agricultural chemicals (fertilizers), and some foodstuffs (such as sugar). It would also not be possible to build various ground structures (such as mounds, dikes, flood banks, etc.), to re-cultivate post-industrial areas, to create sports and recreation facilities (e.g. pitches, golf courses), and many other things. Sand is used in mining to extract hydrocarbons by the fracturing method, as well as in water conditioning and sewage treatment plants. High quality sand of special properties can also be used a basic component of creams, lotions, and other body care products. Therefore, it may be stated that mineral aggregates play a fundamental or important role in many sectors of human activity, beginning with construction and industry, through to cosmetics, which we often forget about.

The growth of the global population, urbanization as well as economic and industrial development influence the continuously increasing demand for aggregates. The current estimated consumption of mineral aggregates amounts to approx. 50 billion Mg/year (UNEP 2019; Kabziński 2019), which statistically approximates 6.5 Mg per an inhabitant of the globe. Hence, in terms of consumption volume, water is the only raw material ahead of aggregates. Both the production and consumption of aggregates vary depending on the country and continent. The consumption is the highest in North America (approx. 8.3 Mg/capita) and in Asia (7.9 Mg/capita); whereas it is the lowest in Oceania (0.8 Mg/year) and Africa (3.1 Mg/capita) (Kabziński 2019). According to the provided data (UEPG 2009–2019), in Europe (including Russia and CIS countries) the production amounts to 6.1 Mg/capita, including 5.8 Mg/capita in EU and EFTA countries. Estimated material balances show that the consumption of aggregates in the least developed regions of the world amounts to 3–4 Mg/capita, in countries with an average economic development, 4–8 Mg/capita, whereas in developing countries and regions, located in a difficult area, consume 8–16 Mg/capita (UNEP 2019).

In Europe, the greatest total production of aggregates (natural, artificial, and other) is in Russia – 706 million Mg/year, in Germany (591), Turkey (480), France (463), and in Poland (300) (UEPG 2009–2019). Therefore, in terms of aggregate production volume, Poland comes third in the EU. Per capita, the greatest amount is extracted and consumed by China, approx. 14.3 Mg/capita (an estimated amount). It is assessed that China, India, and other Asian countries consume a total of approx. two-thirds of the global production of mineral aggregates.

1. Social and environmental conditions of extraction and production of aggregates in some countries and regions of the World

The production and consumption of mineral aggregates are growing continuously, although the volumes are not exactly known, because in many countries the data concerning the extraction and production of aggregates are purely approximate (particularly concerning gravel and sand). The extraction is made by a great number of entities, mostly private, which often operate informally and without required licenses. This significantly increases the negative impact of exploitation on the natural and social environment, due to the destruction of

riverbeds and oxbows, coastal erosion, decreased water level, drying up cultivation areas, etc. (UNEP 2019). This particularly refers to countries and regions with unregulated sand and gravel aggregates economy (UNEP 2019), but to a certain degree, it also applies to European countries in which the volume of extraction and the production of natural aggregates is often provided on the basis of approximate data.

The dynamic development of urbanization and infrastructure in, among others, some countries of the Arab world and Asian continent as well as the fact that desert sand is not suitable to produce concrete, bring about a huge deficit of sand and other natural aggregates in these countries as well as the need to import them from distant regions, such as Australia, South-East Asia and recently also Europe. In some countries e.g. (the United Arab Emirates, Saudi Arabia, Singapore, etc.), sand is sometimes more expensive than crude oil (in 2003–2005 – 190 USD/Mg!), and its trade and illegal (unlicensed) extraction are handled by sand mafias (UNEP 2019; Kabziński 2019; Koziół and Baic 2018). It is assessed that in the countries with a deficit of aggregates the international aggregate trade grows at the rate of 5.5% annually (UNEP 2019), whereas a significant portion of these aggregates originate from illegal extraction. In many countries and regions, the extraction and production of aggregates belong to the least regulated sector of human activity. This refers to the countries of Asia, Africa, and South America, where both the resources and the extraction of aggregates, particularly of sand and gravels, are not monitored and registered, or the records are not very precise.

The view that the resources of mineral aggregates are unlimited and inexhaustible is unjustified. Some specialists believe that regional shortages of natural aggregate resources, including sand, are beginning to resemble the shortages of water or decreasing resources of crude oil, and they are just as important. These problems were noticed by the United Nations, and one of the Organization's agendas in 2019 in Geneva published a report concerning the impact of extraction of mineral aggregates, particularly sand and gravel, uncontrolled in some countries and regions, on the natural and social environment (UNEP 2019). The fundamental conclusion of this Report is that "it is time to challenge the paradigm of infinite aggregate resources and increase awareness about the environmental and social consequences of exploitation, and the scale of the challenge inherent in sand and gravel extraction in many regions makes it one of the major sustainability challenges of the 21st century". The countries of Southeast Asia and some countries of North Africa serve as examples of sand and gravel exploitation, devastating to the environment and often illegal. In order to regulate the situation related to the natural aggregate resources management, "implementing a common requirement to plan and monitor the process of extraction of natural resources" is proposed (UNEP 2019). In Europe, including the EU, the situation is generally much better regulated (Galos and Smakowski 2008). Nonetheless, also here the data concerning the extraction and production of aggregates are in many cases approximate and imprecise (UEPG 2009–2019). In Poland, the balances regarding, among others, gravels and sand as well as rocks extraction for the production of crushed-stone aggregates, are annually published by PIG-PIB (The Balances of 2008–2019), whereas the volume of production of

gravel and sand aggregates by Statistics Poland (GUS) is underestimated, about 50% lower than shown in the balances regarding extraction. It is a consequence of the fact that the data provided by GUS does not take the data from manufacturing facilities employing less than 10 employees into consideration. In Poland, more than two-thirds of sand and gravel mines are small and very small facilities. Their extraction volume does not exceed 40,000 Mg/p.a. (concessions issued by the head of local administration – a starost) and the production from these mines is not taken into consideration in GUS balances (Kozioł and Galos 2013).

2. Forecasts of production and consumption of mineral aggregates

Missing or incomplete records of resources and volume of extraction of aggregates, particularly gravel and sand, a great number of exploitation sites, frequently informal or without adequate licenses, as well as the fluctuating demand (subject to the economic situation in the construction industry) make it difficult to prepare balances of domestic and worldwide volumes of production and the consumption of aggregates, as for many countries they take only estimated data into account. For these very reasons, indirect statistical methods are sought in order to determine the forecasts of production and consumption of aggregates in specific countries and regions. A variety of methods of forecasting used to predict the volume of production of mineral aggregates, including neural networks, are presented, for instance, in the works of (Kawalec 2007; Kozioł et al. 2014; Kozioł and Galos 2013). Such studies include, for example, the analyzed trends of the developmental tendency of production and

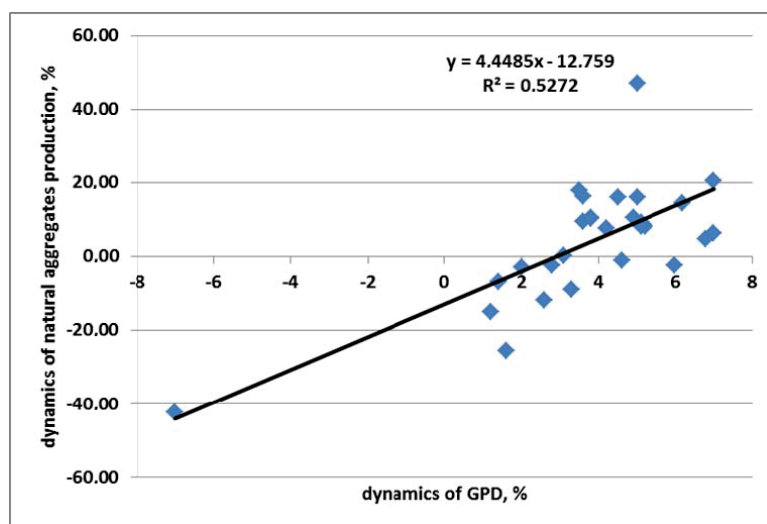


Fig. 1. Dependence of the dynamics of natural aggregates production on the dynamics of GDP changes in Poland in the years 1991–2018

Rys. 1. Zależność dynamiki produkcji kruszyw naturalnych od dynamiki wzrostu PKB w Polsce w latach 1991–2018

stochastic models of the dependence of aggregates production on GDP development ratios or other economic development indicators. Figure 1 presents a statistical dependence of the increase of natural aggregates production on the dynamics of GDP changes in Poland in the years 1991–2018. According to this model, on a national scale, the limit of the mineral aggregates demand and production is approx. 2.9% GDP growth, whereas the 1% GDP growth (above the limit of 2.9%) corresponded to approx. 4.4% growth of aggregates production. Figure 2 features a dependence of the production of aggregates per capita on GDP per capita (USD/inhabitant) in particular EU countries between 2008 and 2011 (UEPG 2009–2019; Koziol et al. 2014). The correlation coefficients R^2 obtained in both cases (0.47–0.70) indicate that these dependencies are on an average level; therefore, new models are sought, as well as more precise indicators than the description of correlation dependencies.

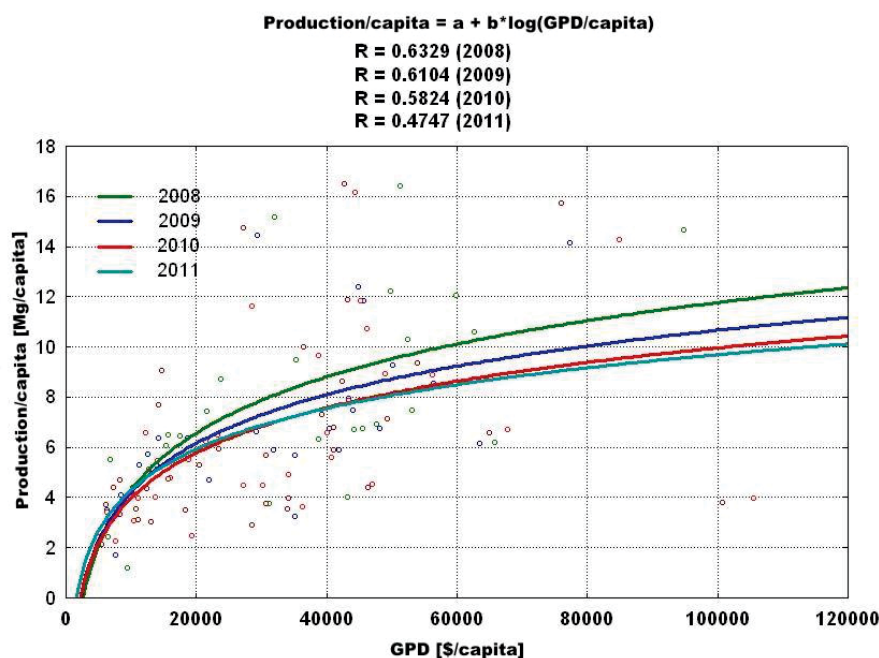


Fig. 2. Aggregates production in 2008–2011 in Europe, tons per capita vs. GDP USD per capita (Koziol et al. 2014)

Rys. 2. Zależność produkcja kruszyw na mieszkańca od PKB na mieszkańca w krajach UE w latach 2008–2011

3. An analysis of changes in the production of aggregates and cement in Poland and selected countries

The statistical studies of the dependence of the production of aggregates on various indicators of economic development performed so far confirmed that GDP relatively constitutes

the best indicator; however, the developed models of dependencies both for Poland and for other countries are not precise; therefore, new, more precise dependencies are still sought. One of such indicators is the production and use of cement as these spheres are generally more precisely identified in the statistics of economic development of particular countries. The sphere of production and consumption of cement in most countries worldwide is rapidly developing, and it doubled in the last two decades, to reach approx. 4.1 billion Mg/year. More than two-thirds of the worldwide cement production takes place in Asian countries, in China (58.5%) and India (6.6%). The production of cement in EU amounts to 175 million Mg (4.3%) and in the US – 88.5 million Mg (2.2%). The use of mineral aggregates to concrete and precast products is assessed to amount to between 28.7 and 32.8 billion Mg (UNEP 2019), which means that more than two-thirds of aggregates production are used with cement to produce concrete, precast concrete, etc. Subject to the class of concrete, its production consumes 5–7 Mg of aggregates per 1 Mg of cement, including 65% of coarse aggregate (gravel, grit) and 35% of sand (Cement 2019; Koziol and Galos 2013).

The production of aggregates and the consumption of cement in Poland, Germany, Great Britain, France, and Italy (The Balance... 2014; Cement 2019; UEPG 2009–2019) are presented in Figures 3–7. The production of aggregates took into account the division into gravel and sand aggregates and crushed-stone aggregates, and the total production of natural, artificial, and recycled aggregates (excluding Poland).

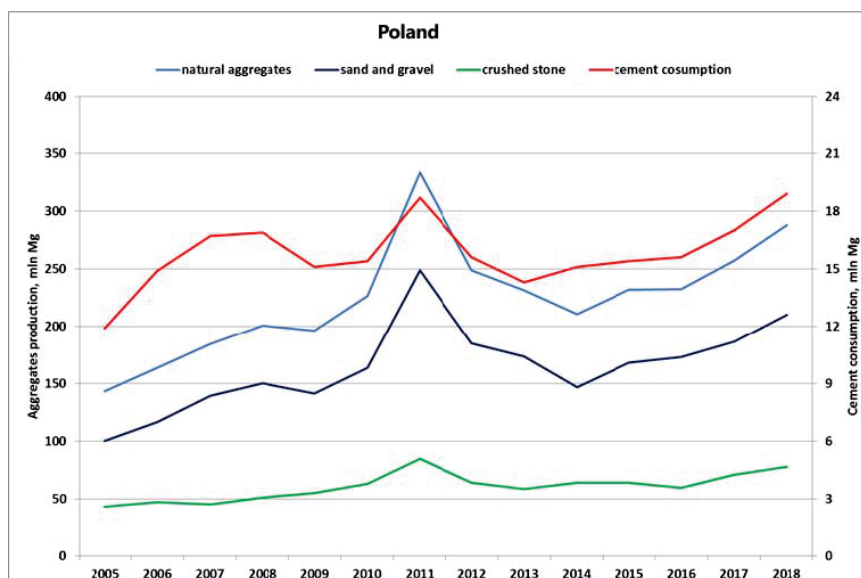


Fig. 3. The production of natural aggregates and the consumption of cement in Poland in the years 2005–2018

Rys. 3. Produkcja kruszyw naturalnych i zużycie cementu w Polsce w latach 2005–2018

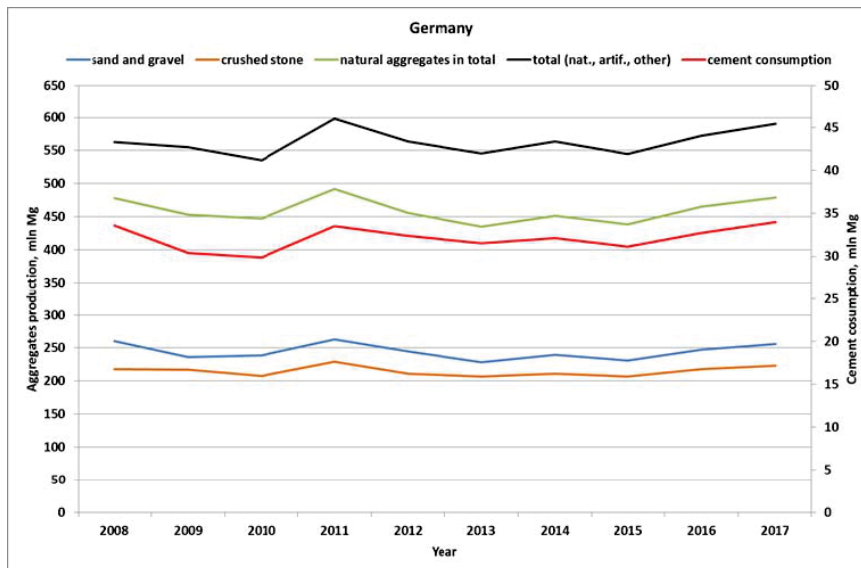


Fig. 4. The production of natural aggregates and the consumption of cement in Germany in the years 2008–2017

Rys. 4. Produkcja kruszyw i zużycie cementu w Niemczech w latach 2008–2017

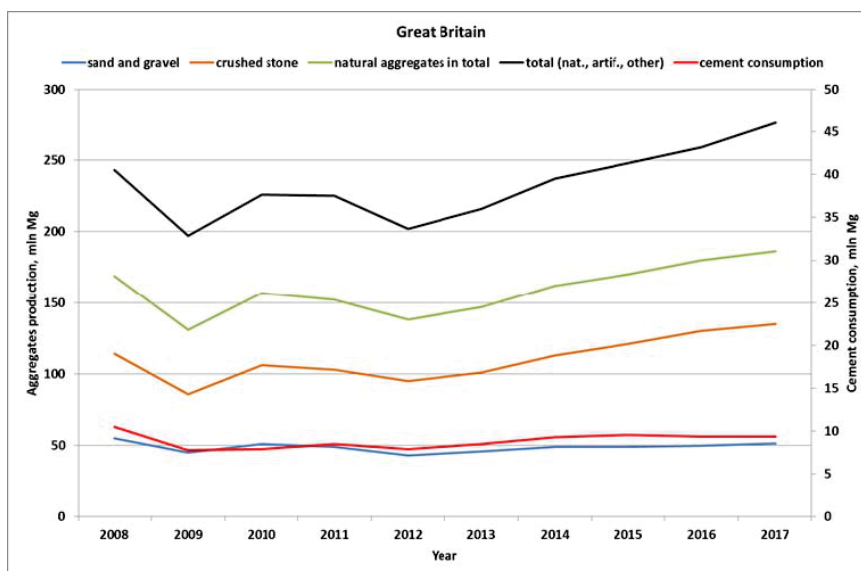


Fig. 5. The production of natural aggregates and the consumption of cement in Great Britain in the years 2008–2017

Rys. 5. Produkcja kruszyw i zużycie cementu w Wielkiej Brytanii w latach 2008–2017

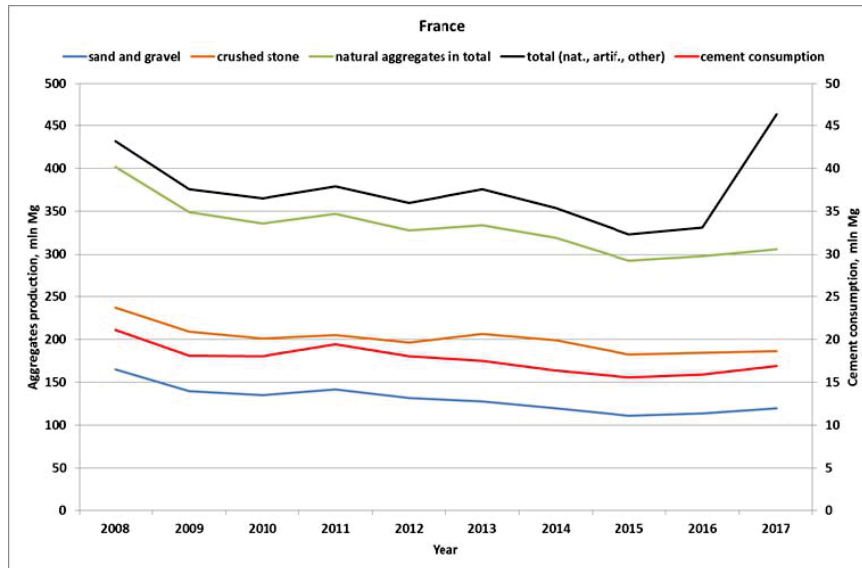


Fig. 6. The production of natural aggregates and the consumption of cement in France in the years 2008–2017

Rys. 6. Produkcja kruszyw i zużycie cementu we Francji w latach 2008–2017

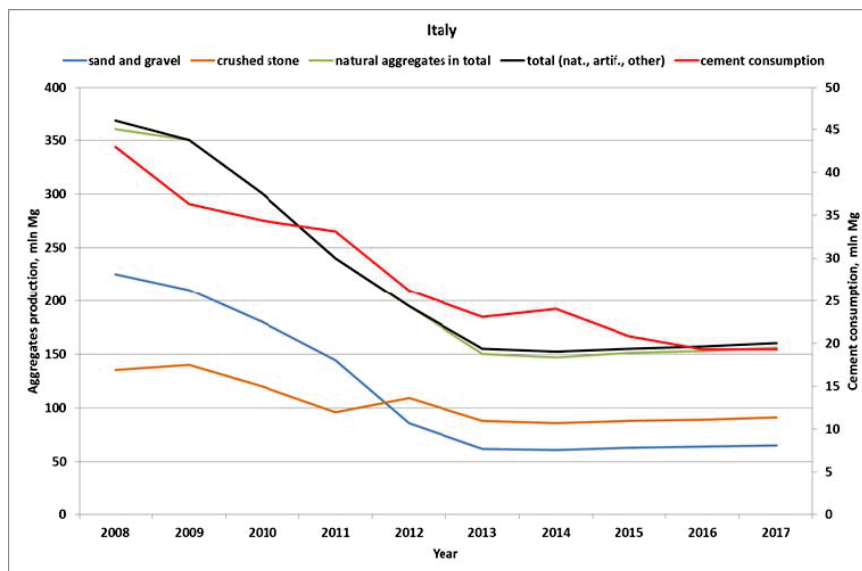


Fig. 7. The production of natural aggregates and the consumption of cement in Italy in the years 2008–2017

Rys. 7. Produkcja kruszyw i zużycie cementu we Włoszech latach 2008–2017

Despite a varying tendency of changes in the production of aggregates and the consumption of cement in the analyzed countries – growing in Poland and Great Britain, rather stable in Germany, and decreasing in Italy and France – the curves for aggregates and cement are similar, which points at an explicit correlation between the production of aggregates and the consumption of cement in all five analyzed countries. The large increase in aggregate production in France in 2017 (Figure 6) was caused by the increase in the share of recycled aggregates – from 4 to 84 million Mg, in the total aggregate production. The downward trend in aggregate production and cement consumption in Italy in 2008–2012 (Figure 7) was caused by the economic crisis and recession in the construction industry.

For these dependencies, the parameters of linear regression and the Pearson correlation coefficient, were calculated (Figures 8–12). The figures presented the models of linear regression for the dependence of gravel and sand aggregates production on cement consumption and the dependence of the production of sand and gravel and crushed stone mineral aggregates on cement consumption, and for Germany and Italy the dependence of the total production of aggregates (natural, artificial, etc.) on cement consumption, as for these dependencies the correlation coefficients were higher.

Table 1 provides the obtained correlation coefficients values and tabulated values of the Pearson correlation coefficients (Pearson's r) for the level of the materiality thresholds of 0.05, 0.01 and 0.001 (Statistics 2019). For the majority of cases, the calculated correlation coefficients are significant at the level of 0.01 and even 0.001, which indicates a high, or even

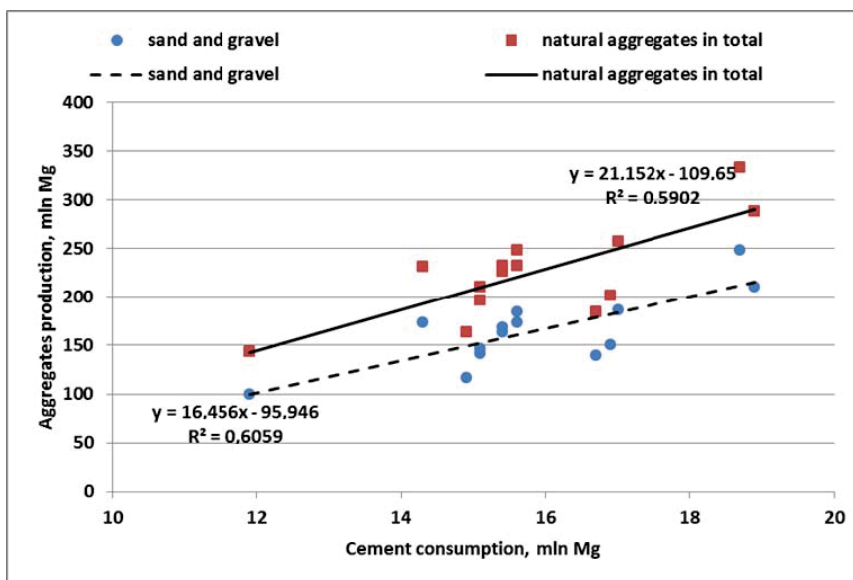


Fig. 8. The dependence of gravel and sand aggregates production on cement consumption in Poland

Rys. 8. Zależność produkcji kruszyw żwirowo-piaskowych od zużycia cementu w Polsce

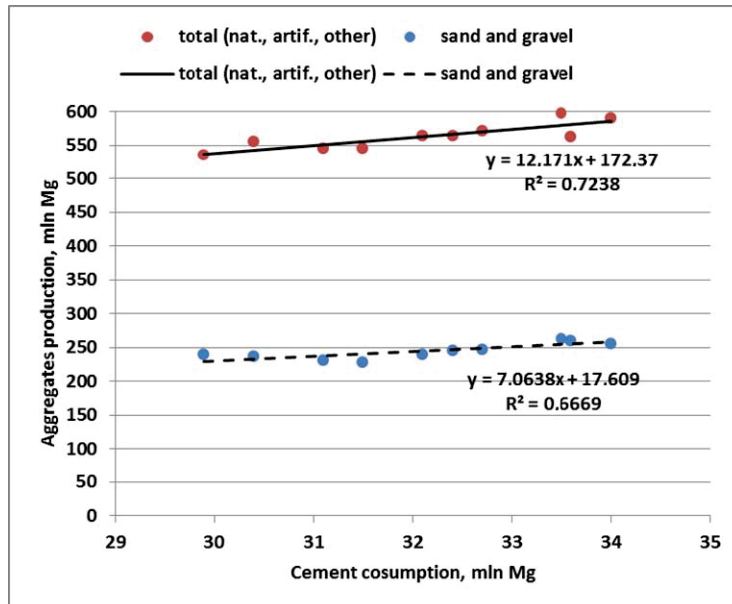


Fig. 9. The dependence of gravel and sand aggregates production on cement consumption in Germany

Rys. 9. Zależność produkcji kruszyw żwirowo-piaskowych od zużycia cementu w Niemczech

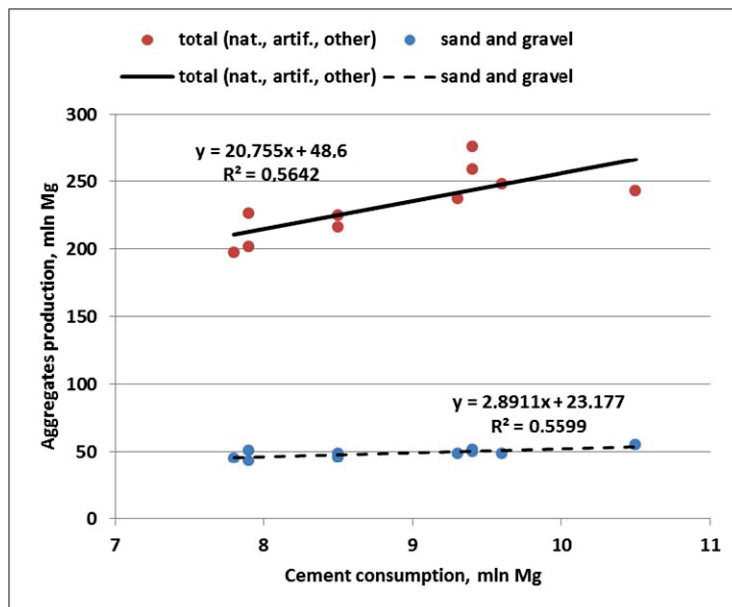


Fig. 10. The dependence of gravel and sand aggregates production on cement consumption in Great Britain

Rys. 10. Zależność produkcji kruszyw żwirowo-piaskowych od zużycia cementu w Wielkiej Brytanii

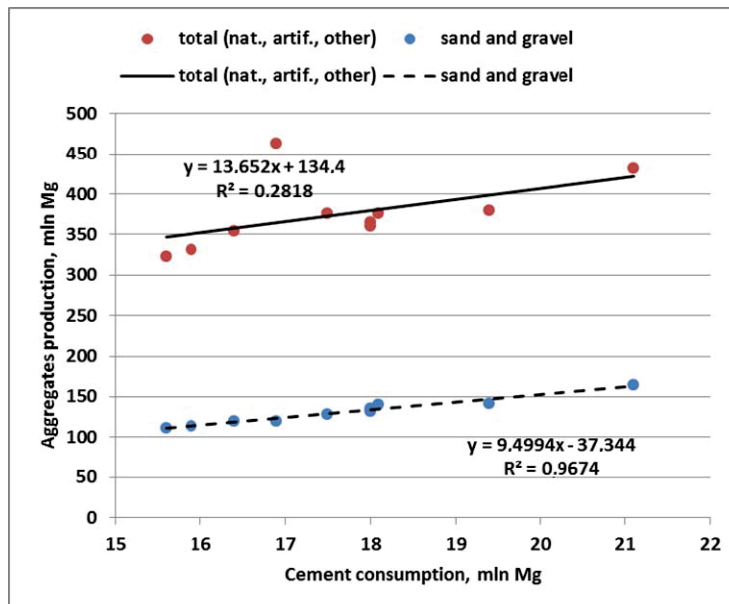


Fig. 11. The dependence of gravel and sand aggregates production on cement consumption in France

Rys. 11. Zależność produkcji kruszyw żwirowo-piaskowych od zużycia cementu we Francji

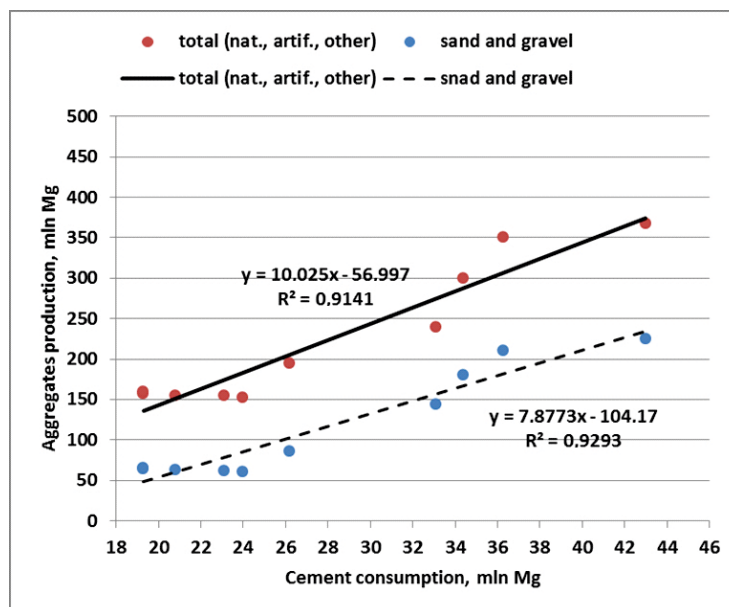


Fig. 12. The dependence of gravel and sand aggregates production on cement consumption in Italy

Rys. 12. Zależność produkcji kruszyw żwirowo-piaskowych od zużycia cementu we Włoszech

Table 1. Pearson linear correlation coefficients of the dependence of the aggregates production on cement consumption in Poland and selected EU countries

Tabela 1. Współczynniki korelacji liniowej Pearsona zależności produkcji kruszyw od zużycia cementu w Polsce i wybranych krajach UE

Type of aggregates	Country/Pearson's r coefficient				
	Poland	Germany	Great Britain	France	Italy
1. Sand and gravel	0.778	0.817	0.748	0.983	0.964
2. Crushed-stone	0.693	0.701	0.724	0.899	0.867
3. Natural in total	0.768	0.801	0.770	0.955	0.954
4. Aggregates in total natural, artificial, and other	-----	0.851	0.751	0.531	0.956
Number of data	14	10	10	10	10
Test t , $P = 0.05$	0.532	0.632	0.632	0.632	0.632
Test t , $P = 0.01$	0.661	0.765	0.765	0.765	0.765
Test t , $P = 0.001$	0.780	0.872	0.872	0.872	0.872

almost complete correlation. This refers particularly to the dependence of the production of gravel and sand on the total production of natural aggregates and the cement consumption. For Great Britain only, the obtained materiality threshold ($P = 0.05$) for the production of gravel and sand aggregates was lower. In one case, for the total production of aggregates (natural, artificial, and other) in France, the low linear correlation coefficient points to the lack of significant statistical dependence.

Similar dependencies of the production of aggregates on the consumption (production) of cement can also be seen in other countries. A good example is the United States, where the dependence of the production of gravel and sand aggregates on cement production is almost complete (Figure 13). In the US, in the years 1990–2017, approx. 10 tons of produced (consumed) gravel and sand aggregates (Figure 13) was present per each ton of produced (consumed) cement (UNEP 2019).

For Poland, the indicator of production of sand and gravel aggregates per cement production in recent years is at the level of 9.5 in 2014 and 11.0 in the years 2016–2017. The values of this indicator vary for particular countries, particularly subject to the share of specific kinds of aggregates (sand and gravel, crushed-stone, from recycling, artificial, etc.) in the total production of aggregates. For EU countries, this coefficient amounts to approx. 6.3 (2017), (UEPG 2009–2019, own calculations). For the countries in which the share of gravel and sand aggregates is relatively insignificant in the total production of aggregates, a much better (more stable) indicator is the dependence of the total production of gravel and sand aggregates and crushed-stone aggregates on the production (consumption) of cement. In the

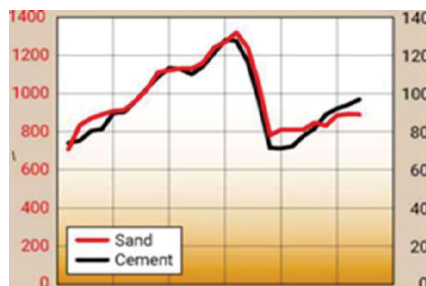


Fig. 13. The production of sand and gravel aggregates vs. cement production in the US in the years 1990–2017 acc. to (UNEP 2019)

Rys. 13. Produkcja kruszyw piaskowo-żwirowych i cementu w USA w latach 1990–2017 według UNEP 2019

years 2016–2017, for Poland this indicator amounted to approx. 16, whereas for EU countries – approx. 14. (UEPG 2009–2019, own calculations). Despite the different values of the analyzed coefficient of aggregates production per unit of consumed cement, its advantage is the fact that the production of cement is identified and taken into account in the material of industrial production of the majority of countries (more than 150), unlike the lack of identification or imprecise records for aggregates production.

Conclusions

Mineral aggregates, including primarily sands and gravels, despite very high production and consumption, in many countries and regions of the world are among the least regulated sectors of human activity. This has a large adverse impact on the natural environment, and its effects are a problem of regional and global importance.

One of the problems is the lack of information in many countries about resources, places and volumes of aggregate exploitation and production. Often, aggregate production and trading are carried out without appropriate permits and monitoring, which contributes to large-scale environmental devastation.

For these reasons, global information on the production of mineral aggregates is generally incomplete and difficult to compare and study. To regulate this unfavorable situation, the Report of one of the UN agencies (UNEP 2019) published in 2019 states the urgent need for the widespread planning and monitoring of the process of acquiring natural aggregates and seeking ways to reduce their consumption.

In order to more accurately and quickly estimate the volume of mineral aggregate production, the paper presents stochastic relationships between the volume of mineral aggregate production and cement production and consumption.

For Poland, the sand-gravel aggregate production index per ton of cement production in 2015–2018 was around 11.0. For EU countries, the average index in 2017 was about 6.3. Its lower value compared to Poland results from the high share of broken aggregates in most EU countries. In the United States, in the years 1990–2017, about 10 tons of gravel-sand aggregates were produced (used) for every ton of cement produced (used)

For countries where the share of gravel and sand aggregates is relatively small in total aggregate production, a much better (more stable) indicator is the dependence of the total production of gravel and sand aggregates to the production of cement, as presented in the paper.

Despite the differences in the value of the analyzed indicator for individual countries, the advantage of the proposed indicator is that cement production is identified and included in the industrial production balances of most countries, as opposed to the lack of such identification or inaccurate records for aggregates.

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**AGGREGATES PRODUCTION IN POLAND AND OTHER SELECTED COUNTRIES –
AN ANALYSIS OF DEPENDENCE ON CEMENT PRODUCTION****Key words**

mineral aggregates, extraction monitoring, production forecasts, cement production

Abstract

The growth of the global population, urbanization as well as economic and industrial development, affect the continuously increasing demand for mineral aggregates. The current assessed global production of mineral aggregates amounts to 50 billion Mg/year, which statistically approximates 6.5 Mg per an inhabitant of the globe. In terms of consumption volume, water is the only raw material ahead of aggregates. Despite such a great scale, in many countries and regions the extraction and production of aggregates belong to the least regulated sector of human activity. This refers particularly to the countries of Asia, Africa, and North America, where both the resources and the extraction of aggregates, particularly of sand and gravels, are either not monitored and registered. It significantly increases the negative impact on the natural environment, due to the destruction of riverbeds and oxbows, coastal erosion, drying up cultivation areas, etc. In the reports, local terminology of aggregates often functions, which makes it difficult to compare them and prepare appropriate balances. In order to regulate the unfavorable situation, one of the main conclusions of the Report (UNEP 2019) is the need of implementing a common requirement to plan and monitor the process of extraction of natural resources. The paper presents the possibility of forecasting the extraction and producing aggregates based on the consumption of cement, i.e. the basic building material. Although the analyzed coefficient of mineral aggregate production per unit of cement consumption (production) varies, its advantage is the fact that the production of cement is identified and taken into account in balances of industrial production of the majority of countries, whereas such identification for mineral aggregate production are still lacking.

**PRODUKCJA KRUSZYW W POLSCE I WYBRANYCH KRAJACH –
ANALIZA ZALEŻNOŚCI OD PRODUKCJI CEMENTU****Słowa kluczowe**

kruszywa mineralne, monitorowanie wydobycia, prognozy produkcji, produkcja cementu

Streszczenie

Wzrost ludności świata, urbanizacja oraz rozwój gospodarczy i przemysłowy przyczyniają się do ciągłego wzrostu zapotrzebowania na kruszywa mineralne. Szacuje się, że obecna światowa produkcja kruszyw mineralnych wynosi około 50 mld Mg, co stanowi około 6,5 Mg na statystycznego mieszkańca. Pomimo tak dużej skali, w wielu krajach i regionach świata produkcja kruszyw należy do najmniej uregulowanych sektorów działalności człowieka. Dotyczy to szczególnie krajów Azji,

Afryki i Ameryki Północnej, w których zarówno zasoby, jak i wydobycie kruszyw, szczególnie piasków i żwirów, nie są monitorowane i ewidencjonowane. Ma to duży wpływ na niekorzystne oddziaływanie na środowisko przyrodnicze w postaci niszczenia koryt rzek i starorzeczy, erozji wybrzeży morskich, wysychania obszarów uprawnych, itp. Często w sprawozdawczości oraz ewidencji funkcjonują lokalne nomenklatury nazewnictwa kruszyw, co utrudnia porównywanie i opracowywanie odpowiednich bilansów. W celu uregulowania niekorzystnej sytuacji, jeden z głównych wniosków Raportu UNEP 2019 stwierdza konieczność powszechnego wprowadzenia planowania i monitorowania procesu pozyskiwania kruszyw naturalnych. W pracy przedstawiono możliwość prognozowania wydobycia i produkcji kruszyw na podstawie zużycia cementu, podstawowego materiału budowlanego. Pomimo zróżnicowania wartości wskaźnika produkcji kruszyw mineralnych na jednostkę zużycia (produkcji) cementu, zaletą tego wskaźnika jest to, że produkcja cementu jest identyfikowana i uwzględniana w bilansach produkcji przemysłowej większości krajów (ponad 150), w odróżnieniu od braku takiej identyfikacji lub niedokładnej ewidencji dla produkcji kruszyw mineralnych.