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Infrastructure and Environment

Springer

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ISBN 978-3-030-16541-3 ISBN 978-3-030-16542-0 (eBook)
https://doi.org/10.1007/978-3-030-16542-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This volume presents refereed papers based on the oral and poster presentations at the 25th International Conference Infrastructure and Environment, which was held from June 18 to 20, 2018, in Dobczyce, Poland. The conference was organized by the University of Agriculture in Krakow, Polish Academy of Sciences—Committee of Technical Rural Infrastructure and Association Infrastructure and Ecology of Rural Areas.

The scope of the conference covers a variety of environmental issues in rural areas and how they could be solved through innovations in science and engineering. The development of agriculture and urbanization processes on the rural areas has raised the living standards on one hand (roads, sewage systems, water supply systems, etc.), but also the environmental degradation on the other. There is a need to intensify efforts to ensure the proper state of knowledge about these problems, particularly concerning rural areas.

The scientific community is, therefore, searching for ways toward ecologically sustainable rural development. Discussing all these issues, this book offers a useful guide for researchers, academicians, practicing engineers, local governments and managers dealing with diverse environmental and infrastructural problems related to rural areas.

This volume of proceedings from the conference provides an opportunity for readers to engage with a selection of refereed papers that were presented during the conference. It is divided into four sections: technical infrastructure, environmental protection, sustainable development, environment-friendly power generation; the 47 papers published here raise the multifaceted nature of infrastructure and ecology problems.

We would like to thank all participants for their contributions to the conference program and for their contributions to these proceedings. Special thanks go to all reviewers for their support and care of scientific level of the papers.

Many thanks go as well to the members of the organizing committee of the conference for their devoted assistance in the overall organization of the conference and help with the editorial process of this proceedings volume.

We hope you both enjoy and find valuable contributions and ideas in this book sustaining your professional development.

We are looking forward to the next conference on infrastructure and ecology.

December 2018

Anna Krakowiak-Bal
Magdalena Vaverkova

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Contents

Technical Infrastructure

Reliability of Sewage Treatment Process in SBR Reactor with the Use of Statistical Quality Control

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Abstract. The purpose of the work was to determine the reliability of the selected pollution indicators removal i.e. COD_{Cr}, ammonium nitrogen, total phosphorus and total suspension from the SBR- type collective sewage treatment plant. The level of operational reliability of sewage treatment plants was determined by means of quality control using control charts. Physical and chemical analyzes of raw and treated wastewater, were carried out in the period from 2008 to 2016. As a result of the control charts analysis, it was found that in the sewage treatment plant there was full stability of the process of total suspended solids reducing. In the case of COD_{Cr}, total phosphorus and ammonium nitrogen, there were noticed occasional samples groupings below the lower characteristic line, which could indicate a disturbance of process stability. However, they did not affect the efficiency of wastewater treatment in the tested treatment plant. Therefore, it is possible to confirm the thesis that the method of determining the reliability of the treatment plant operation by using control charts is an easy and effective tool for the operator to detect any disturbances and irregularities in the process occurring in the tested object and enables to take appropriate action to remove them.

Keywords: Reliability of the purifying process · Control charts · Sewage treatment plant

1 Introduction

In the case of the assessment of a sewage treatment plant operation, a commonly used method is to compare the values of pollutant indicators in treated wastewater, often expressed as an arithmetic mean, with the limit values given in the water-law permit. Another popular method is to calculate the percentage reduction of pollutants between raw sewage and effluent after treatment in sewage treatment plants [2, 4, 5, 8]. These are very simplified methods, which usually do not provide information on, among others, occurrences and duration of failures, stability of the wastewater treatment process or factors interfering with this course, or forecasts of the wastewater treatment system efficiency [13]. These types of simplified methods for assessing a treatment

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 3–8, 2019.
https://doi.org/10.1007/978-3-030-16542-0_1

plant operation do not allow a detailed comparison of the operational efficiency of other similar facilities due to too limited information. Therefore, it is important to develop a method of assessing the efficiency of a sewage treatment plant in order to be able to directly compare objects with different capacity, different concentration or pollutant load. The present research results and their analysis indicate that one of the methods that can be used to assess the level of sewage treatment plant reliability is the statistical quality control method using control charts [3, 14]. This method is an innovative method in assessing the stability and effectiveness of wastewater treatment plants [13].

2 Research Methodology

The analyzed sewage treatment plant in Sterkowiec-Zajazie town was designed for characteristic daily inflows: $Q_{av.d} = 600\ m^3 \cdot d^{-1}$ and $Q_{max.d} = 720\ m^3 \cdot d^{-1}$ and PE = 4000. The sewage treatment plant in the biological part has 3 SBR biological reactors. The facility is supplied with sewerage system from the Brzesko-Sterkowiec agglomeration, which includes the following villages: Jadowniki, Sterkowiec, and Wokowice. In addition, wastewater from some households that are not connected to a collective sewerage system is also delivered by a cesspool emptier to the sewage treatment plant. The research was carried out in the period from 2008 to 2016. In the analyzed period, totally 35 samples of raw and treated sewage were collected and analyzed physically and chemically. The sampling frequency was 4–5 a year. Impurities in wastewater were determined by such indicators as: COD_{Cr}, ammonium nitrogen, total phosphorus and total suspended solids.

Wastewater analysis was performed in accordance with the reference methods included in the Regulation of the Minister of the Environment, which were in force during the research period. The analysis of the reliability of wastewater treatment in the researched SBR reactor was made on the basis of control charts x, which were determined for the discussed pollution indicators in treated wastewater. The verification of the normal distribution of the studied variates was made using the Shapiro-Wilk test for the significance level $\alpha = 0.05$ [10, 12]. Due to the fact that the analyzed variates were not characterized by a normal distribution, they were normalized by means of logarithmication. The boundaries of helping lines, control lines and the central line were determined taking into account the rule of three sigmas for the normal distribution N (μ, σ) [6, 7, 11]:

Upper control line (UCL):

$$\text{UCL} = \mu + 3\sigma \tag{1}$$

Upper warning line (UWL):

$$\text{UWL} = \mu + 2\sigma \tag{2}$$

Upper helping line (UHL):

$$\text{UHL} = \mu + 1\sigma \tag{3}$$

Central line (CL):

$$CL = \mu \tag{4}$$

Lower helping line (LHL):

$$LHL = \mu - 1\sigma \tag{5}$$

Lower warning line (LWL):

$$LWL = \mu - 2\sigma \tag{6}$$

Lower control line (LCL):

$$LCL = \mu - 3\sigma \tag{7}$$

where:

μ – mean value of the analysed variable [$mg \cdot dm^{-3}$],

σ – standard deviation of the analysed variable [$mg \cdot dm^{-3}$].

According to the results obtained by Andraka [1], there are following observations confirming the disturbance or instability of the wastewater treatment process: eight consecutive points on one side of the central line, one point outside the control lines, two out of three points outside the warning lines ± 2σ and four out of five consecutive points beyond the helping lines ± 1σ.

3 Results and Discussion

Figure 1 shows the course of the control chart x for COD_{Cr} in treated wastewater, where it can be seen that during the research period there was one case of exceeding the lower control line and this occurred for the sample 25.

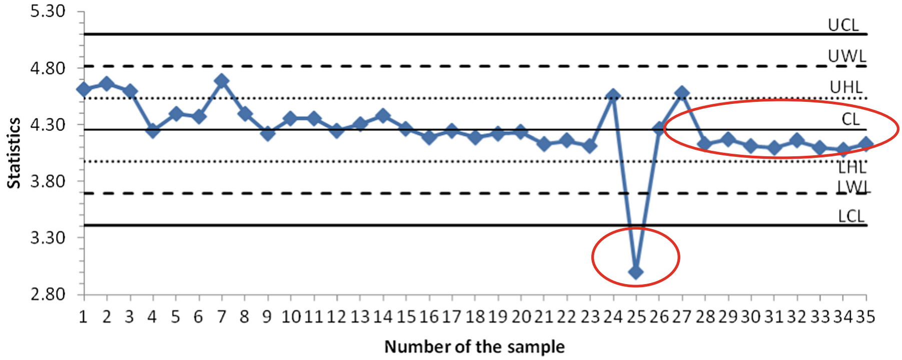

Fig. 1. Control chart x for COD_{Cr} in treated wastewater (source: own study).

Nevertheless, this situation is not worrying because it is related to the low value of the COD_{Cr} index in sewage flowing into the treatment plant (148.0 $mgO_2 \cdot dm^{-3}$), which also resulted in its low value in treated sewage (20.0 $mgO_2 \cdot dm^{-3}$). According to Bugajski and Wałęga [3], in such case, the task of each operator of the treatment plant should be to determine the process conditions that ensured such low values of the index and to keep this process level as long as possible. In addition, there was observed the occurrence of a temporary grouping of samples below the central line, which may indicate a certain periodic disturbance of the process stability, which, however, does not translate into the efficiency of COD_{Cr} reduction in the tested treatment plant. The research conducted by Młyński and Chmielowski [9] confirms the lack of influence of this type of stability disturbance on the effectiveness of the analyzed index reduction.

While analyzing the results presented in the Fig. 2 it was found that the values of ammonium nitrogen fluctuated around the mean value (central line), and none of the tested samples exceeded the upper or lower control line. Despite the grouping of four samples below the lower helping line, the stability of the process of ammonium nitrogen reduction in the tested treatment plant can be clearly seen. In the work of Młyński and Chmielowski [9], similar results were presented, where the exceedance of the lower helping lines also did not negatively affect the treated wastewater quality.

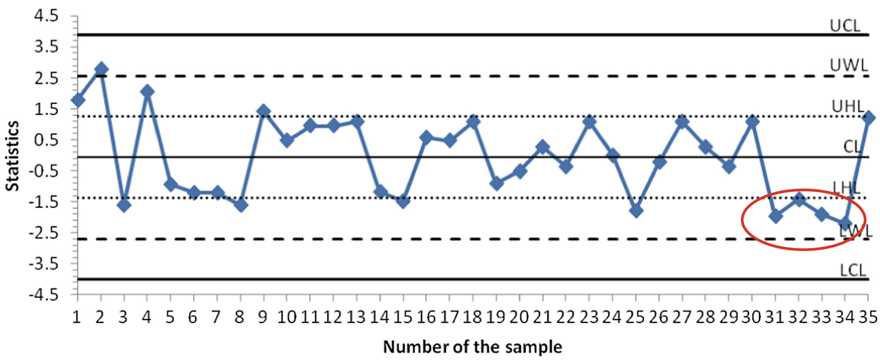

Fig. 2. Control chart x for ammonium nitrogen in treated wastewater (source: own study).

On the basis of the analysis of the Fig. 3, there was no case of exceeding the control lines by the values of total phosphorus, which would indicate the instability of the analyzed process. On the other hand, there was noted a one-off samples grouping (9 observations) below the central line, which could have had an impact on the temporary disruption of the observed stability, without affecting negatively the efficiency of the discussed indicator reduction.

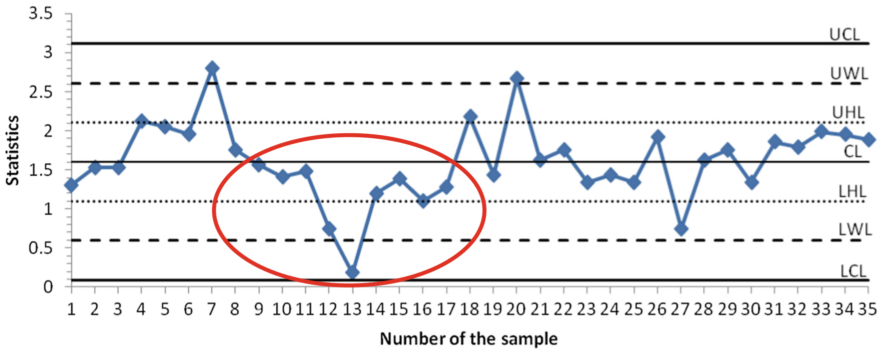

Fig. 3. Control chart x for total phosphorus in treated wastewater (source: own study).

After analyzing the results presented in the Fig. 4, there was found a stability of the process of total suspended solids removal in the tested sewage treatment plant. The concentrations of the discussed indicator oscillated around the central line, there were recorded no exceedance of the control lines and no samples grouping below or above the characteristic lines.

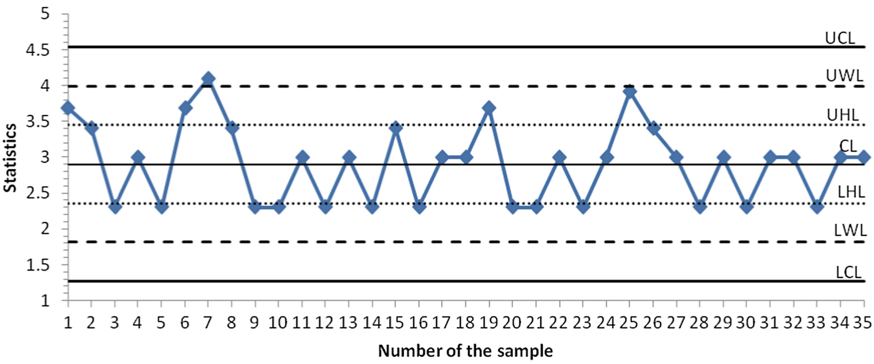

Fig. 4. Control chart x for total suspension solids in treated wastewater (source: own study).

4 Conclusions

1. Analysis of the control charts showed full stability of the process of total suspended solids removal in the tested wastewater treatment plant. In the case of COD_{Cr}, total phosphorus and ammonium nitrogen, there were noticed occasional samples groupings below the lower characteristic lines, which could indicate a disturbance of process stability.
2. In the analyzed period there were no factors that significantly influenced the quality of treated sewage, confirming the reliability of the SBR reactor operation.

3. Control charts are an easy and effective tool for the operator and they enable to detect any disturbances or irregularities in the process occurring in the tested object and to take appropriate actions to remove them.

Acknowledgement. Financed from the DS of the Department of Sanitary Engineering and Water Management of the University of Agriculture in Krakow and Department of Regional Economy Cracow University of Economics.

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Comparative Analysis of Environmental Impacts of Municipal Road Structures

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Abstract. The objective of the study is the environmental assessment of construction solutions for concrete paving. In the study, unit environmental indicators for selected road construction solutions for the KR1 traffic have been determined. The considerations include road constructions with substructures made of: lean concrete, cement bound soil and crush-stone aggregate. Seven key environmental indicators were adopted for the evaluation as recommended by the PN-EN 15643-2:2011 standard "Sustainability of construction works. Part 2: Framework for the assessment of environmental performance": global warming potential (GWP), ozone depletion potential (ODP), acid-generating potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP), abiotic depletion potential for nonfossil resources (ADPE), abiotic depletion potential for fossil resources (ADPF). The weights were adopted on the basis of the DTT method, assessing the distance of EU domestic impacts from the desired state set by EU binding policy targets.

Such evaluation enabled the prioritisation of concrete roads construction solutions from the point of view of environmental impact. The obtained measurements may be a part of the evaluation for the road investment projects. The presented approach disseminates sustainable design patterns in the area of engineering practice with the implementation of requests of the United Nations Framework Convention on climate change.

Keywords: Concrete pavements · LCA · ILCD · Impacts on the environment

1 Introduction

Concrete pavements have no established tradition in Poland despite that the first such surfaces appeared already in 1912. In Poland the vast majority of roads are still made of bitumen, despite the many benefits of concrete pavements, which include: high load rating and the load-carrying capacity ability, resistance to permanent deformations, bright colour (improving safety), good operating characteristics, low maintenance costs. A properly designed and constructed pavement usually reaches a 20-year, even a 30-year period has become a standard. The advantages of concrete pavements demonstrate that they should gain popularity and become a complement to the selection of available technologies next to bitumen surfaces, cobblestone surfaces and other,

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 9–14, 2019.
https://doi.org/10.1007/978-3-030-16542-0_2

especially for municipal roads, which account for around half of all roads in Poland. In addition, due to its technological simplicity, they can be constructed by small local companies [20].

Contemporary trends for the socio-economic development, however, require the consideration of social and environmental aspects next to the technological and design aspects during design process, hence the construction of concrete pavements should be covered by a new design approach that takes into account all the requirements of sustainable construction, i.e. integrated life cycle design (ILCD - integrated life - cycle design) [16, 22, 24].

The new approach combines the design at the material, construction element and the whole construction level and then considers the selected criteria from the areas relevant to sustainable development at each of these levels - including those that reflect the impact of the object on the environment. In practice, there is no finished template for the evaluation and raising the efficiency of the environmental design solutions. The study presents the variant analysis of the solutions with the use of basic environmental indicators which form the evaluation criteria.

2 Materials and Methods

The environmental impact assessment (EIA) is a structured way of conduct based on interdisciplinary identifying and assessing the impact of the planned measures and their alternatives on a specific area and its processes [1]. For an environmental assessment of construction works in accordance with PN-EN 15643-2:2011 [8], the recommended approach is the LCA method.

The subject of the analysis are the structures of concrete pavement with substructure made of:

- cement bound soil (cement-stabilised soil) (W1),
- mechanically stabilised crush-stone aggregate (W2),
- lean concrete (W3) (Fig. 1).

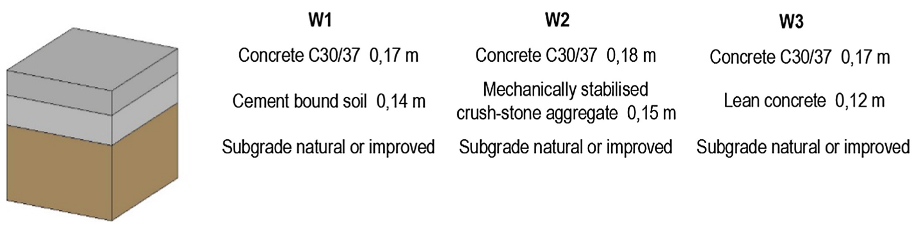

Fig. 1. Variants of the design solutions to be evaluated

In the study the unit indicators - listed on 1 km of road with a width of 5 m - were adopted. The presented evaluation has the *cradle to gate* character includes the production phase (modules A1–A3) [7]. 7 key environmental indicators (categories) were adopted for the evaluation of variants as recommended by the PN-EN 15643-2:2011 standard “Sustainability of construction works. Part 2: Framework for the assessment of environmental performance” shown in Table 1. The weights for the category (w_k) were adopted on the basis of the DTT method, assessing the distance of EU domestic impacts from the desired state set by EU binding policy targets. (Table 1) [3]. DTT method gives you the ability implement the requirements of the United Nations Framework Convention on Climate Change (UNFCCC), the objective of which is to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Table 1. Evaluation categories, normalization factors, weights

Category	Unit	Normalization factor	Weight
Global warming potential (GWP)	kg CO_2 eq.	1.23E+04	1.16
Ozone depletion potential (ODP)	kg CFC11 eq.	2.20E–01	1.05
Acid-generating potential (AP)	kg SO_2 eq.	7.12E+01	1.18
Eutrophication potential (EP)	kg $(PO_4)^3$ eq.	3.25E+01	1.14
Photochemical ozone creation potential (POCP)	kg ethene eq.	2.15E+01	1.28
Abiotic depletion potential for nonfossil resources (ADPE)	kg Sb eq.	3.91E+01	1
Abiotic depletion potential for fossil resources (ADPF)	MJ, (net)	2.73E+05	1

The measure of the assessment is ultimately the E_P value, which is the weighted sum of the standardised values of the environmental categories (N_K) :

$$E_p = \sum\nolimits_k^m N_k \cdot w_k \tag{1}$$

The data for the evaluation was adopted on the basis of the environmental product declarations (EPD) [1–5, 7–13, 16–24]. In view of the diversity of the raw materials extraction technologies (A1) and their processing (A3) and also of the differentiated transport distances in the A2 module, for the solutions ranking the average Ep values were adopted for several material suppliers to build the substructure. The evaluation variance were also analysed.

In the first variant the quantity of cement (c) in kg per 1 m^3 of the stabilised ground was calculated according to the formula [8]:

$$c = \rho_{ds} \cdot x \tag{1}$$

where ρ_{ds} is the soil bulk density (adopted: 1850 kg/m^3), x - percentage addition of cement (adopted: 0.03).

3 Results

3.1 Evaluation Results

The results of the design evaluations were presented in Fig. 2.

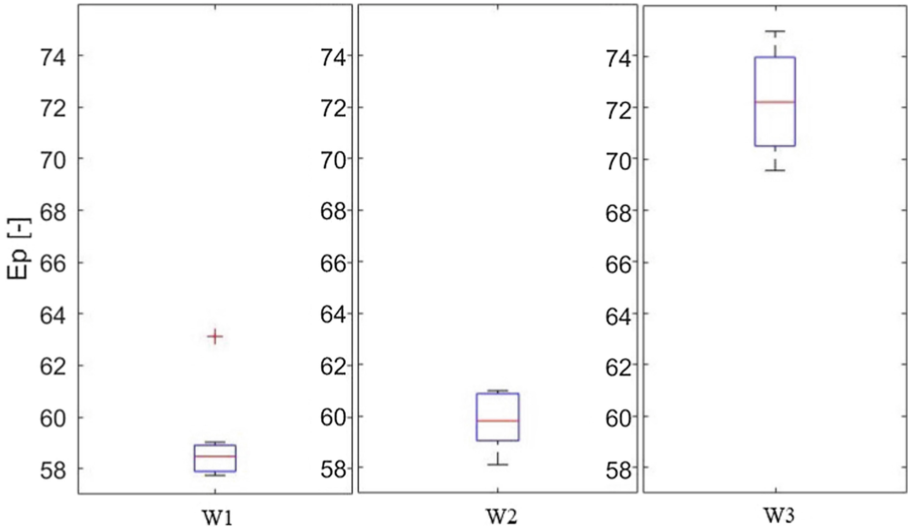

Fig. 2. Box plot for variants (a) w1; (b) w2; (c) w3

The most favourable variant of the solutions included in the analysis in the view of the selected environmental indicators and weighting is the concrete surface with cement-stabilised soil substructure (W1). The average Ep value in this option was 59. A comparable solution is the W2 variant (substructure made of crush-stone aggregate) for which the average Ep value is only 0.8 less. Typical variation ranges of W1 and W2 variant overlap, despite the small variation of coefficient W2 of 1.96%. So there is a collection of solutions in the W2 variant, which are characterised by lower impact on the environment - depending on the material supplier. The variant of substructure made of lean concrete (W3), is clearly a solution worse than the others. None of the analysed suppliers offered a competitive material in terms of environmental conditions, despite the largest coefficient of evaluation variation (3.17%).

The share of environmental categories in the evaluation structure also varies within the variants (Fig. 3). Therefore, the evaluation result will be sensitive to the weights of the evaluation indicators and therefore depends on the adopted methodology of weighing and the range of impact (other weights are adopted in local considerations that take into account the local environmental problems, and other for the global considerations).

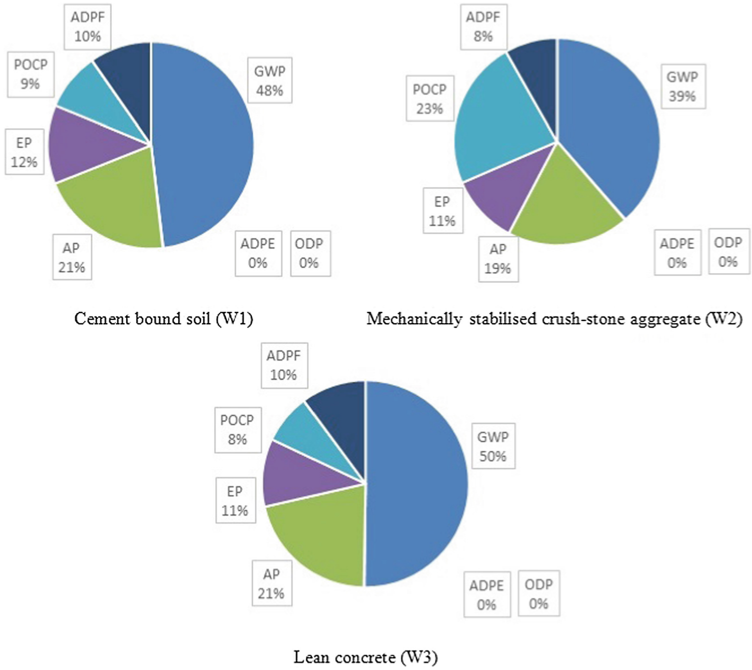

Fig. 3. Share of the environmental impacts in the evaluation structure

4 Conclusions

The evaluation enabled the prioritisation of concrete roads construction solutions from the point of view of environmental impact. Adopting the average value as the variant evaluation measure, the best solution is a substructure respectively made of cement-stabilised soil, crush-stone aggregate and the lean concrete. The obtained measurements may be a part of the sustainable evaluation for the road investment projects. The analyses show that the adopted methodology of weighing the environmental indicators can significantly affect the evaluation results Furthermore obtained results for the adopted methodology are not timeless - the change the current state of the environment and its impact on the ecosystem can result in a change in the environmental criteria weights in time and thus stimulate the evaluation result. A similar approach to environmental impact assessment is observed in other branches of industry. In the works [14, 15] LCA and multi-criteria analysis were also used using various methods. The process of integrated design now enters the engineering practice, which requires additional efforts to conduct associated analyses and studies. The evaluation of the impact on the environment is a complex and interdisciplinary process. It requires close cooperation of the design engineer and the environmental engineer or learning the additional methods and tools for the determination of the environmental impact indicators by the designer. The necessity to obtain information about the implications of the individual technological processes on the environment is also a problem - they are not widely available. Nevertheless, the workload allows for a complete evaluation of the selected material-construction solutions.

A favourable approach to design is the differentiation of material solutions and calculation of the overall impact of e.g. a planned road based on the knowledge of the material environmental profile and the characteristics of its use. In the course of further study it is planned to extend the number of variants for the concrete pavements involved in the assessment and the extension of the evaluation by successive stages of the life cycle of the structure.

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Role of Vertical Barrier Application in Protecting the Soil-Water Environment from Municipal Waste Landfill Contamination

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Abstract. Bentonite vertical barriers could be effectively applied as a one of the remedial solution limiting environmental hazards caused by landfills and waste management sites. The paper presents engineering methods aiming at remediation of an old municipal landfill located to the northeast side of Warsaw. The particular attention has been paid to the impact of application of groundwater protection system on the improvement of groundwater quality in the study area and its surroundings. Water quality assessment was performed on the basis of the 20 years data from monitoring network. The reduction of pollutant indicators, including chlorides concentration and electrical conductivity are presented on isoline maps. The results show that the implementation of the containment system has a significant impact on the improvement of the soil-water environment. The results of monitoring data presented in this paper clearly indicate efficiency of the vertical barrier application and its important role in protecting the soil-water environment from contamination.

Keywords: Landfill · Vertical barrier · Remediation

1 Introduction

Landfills are the main means of municipal solid waste (MSW) disposal in many countries worldwide. Primarily, they offer dumping high quantities of MSW at economical costs in comparison to other disposal methods such as incineration. Only in 2016, a total of 11.6 million tons of municipal solid wastes were collected in Poland, of which 36.5% were landfilled in 320 operating landfills [1, 2]. Unfortunately, landfills can cause environmental nuisances because of generating the leachate, what mainly depend on precipitation, hydrogeological conditions of the area, solid waste composition, concentration and chemical composition of the contaminants, degree of compaction, landfill biological and chemical activities, age of waste, and the direction of the groundwater flow [3–6]. Landfill leachate can be defined as a liquid that seeps through the solid waste in a landfill, producing extracted, suspended or dissolved materials.

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 15–22, 2019.
https://doi.org/10.1007/978-3-030-16542-0_3

Leachates contain high amounts of heavy metals, ammonium, organic matters and chlorinated organic and inorganic salts [7–10]. What is more, the landfill leachate is one of the major sources of the surface and groundwater pollution if it is not properly collected and safely disposed, and it can percolate through the soil profile reaching water aquifers [11, 12]. One of the ways of reducing the effects of such pollutants on the environment is the application of vertical barriers [13]. The aim of the study was to evaluate the efficiency of reclamation woks by analyzing long term monitoring results of groundwater samples collected from piezometer network. The result are presented as graphs of contaminants concentrations and pollution distribution maps.

1.1 Study Area

Radiowo landfill is located in the commune Stare Babice and partially in Warsaw. From the eastern and southern side, landfill is surrounded by Nature Reserves (peat lands Łosiowe Błota and Kalinowa Łąka) and “Bemowo” Forest Park (Fig. 1).

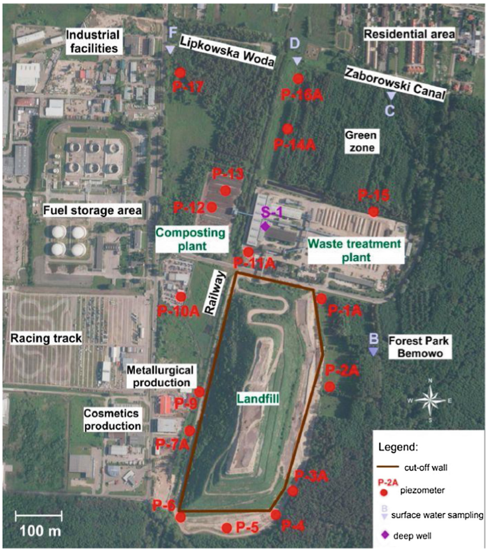

Fig. 1. Location of the Radiowo landfill and groundwater monitoring system [9].

In the north, at the distance of about 350 m from the composting plant, there is a watercourse Zaborowski Canal, and on the west side in the vicinity of the landfill western slope, there are industrial facilities and a railway siding The Radiowo landfill was a disposal site for the municipal waste from Warsaw from 1962 to 1991. Since 1992, only non-composed wastes from the composting plant have been stored in the landfill and since 2012 only the waste from the installation of mechanical and biological treatment plant. At present, Radiowo landfill covers ca. 16 ha area, and its height is approximately 60 m. Remedial works have been carried out on the landfill site since 1994, including peripheral drainage, installation of a leachate re-circulation system, forming and planting slopes and clay mineral capping [13]. What is more, the 0.6 m wide vertical barrier (Table 1) was installed at the site in November 2000, to minimize the spread of contamination to the groundwater system.

Table 1. Parameters of the bentonite vertical barrier.

Parameter	Unit	Value
Length	m	1687.2
Thickness	m	0.6
Minimum depth	m	3.0
Maximum depth	m	22.0
Lateral surface area	m^2	14529.8
Permeability coefficient after 60 days	m/s	max. 1.0×10^{-9}
Compressive strength after 60 days	MPa	min. 0.90

2 Methods

For the chemical analyses the groundwater samples were collected 4 times each year since 1998 until present, using the immerse pump according to ISO 5667-11 [14] and stored at a temperature 1–5 °C in smoked glass bottles. Each pumping was also accompanied with simultaneous measurements of the temperature, pH and electrical conductivity. The chemical analysis of chlorides were conducted according the recommendations presented in PN-ISO 9297:1994 [15]. Additionally, the values of electrical conductivity (EC) were measured according PN-EN 27888:1999 [16]. Based on the data obtained for nearly 20 years of monitoring, before and after the closure of the vertical barrier, it was possible to compare the water quality in respect of chlorides content in groundwater. Chlorides are usually not attenuated by the soil and are very mobile, so they have a special significance as the tracer element of the leachate plume linking the groundwater [17–19]. Also EC was taken into account to rule out the influence of the precipitation and external pollution sources. The impact of the landfill on the groundwater pollution by chlorides was analysed for eleven piezometers located at the landfill site. Piezometers P-4 and P-6A were located in the inflow direction of the landfill and piezometers P-2A, P-7A, P-9, P-10A, P-11A, P-12A, P-14A, P-15 and P-17 were located in the groundwater outflow from the landfill. The levels of the groundwater table were recorded to estimate the pattern of possible migration paths. The location of the groundwater table is presented in Fig. 2.

3 Results and Discussion

Based on piezometric recordings the groundwater table changes have been monitored over the period of the landfill exploitation. Due to the various weather conditions and different levels of nearby waterways, the position of the groundwater table is continuously changing. However, the most significant impact on the groundwater flow direction and depth, had obviously the construction of the cut-off wall. It has modified entirely the hydrogeological conditions of the subsoil's permeability [13]. The most recent piezometers recordings showed that the groundwater flows towards the north, and does not reveal any significant disruption of spatial flow directions (Fig. 2). The significance of the precise and reliable determination of the groundwater flow is crucial when analyzing the spread and the transport paths of the potential plumes.

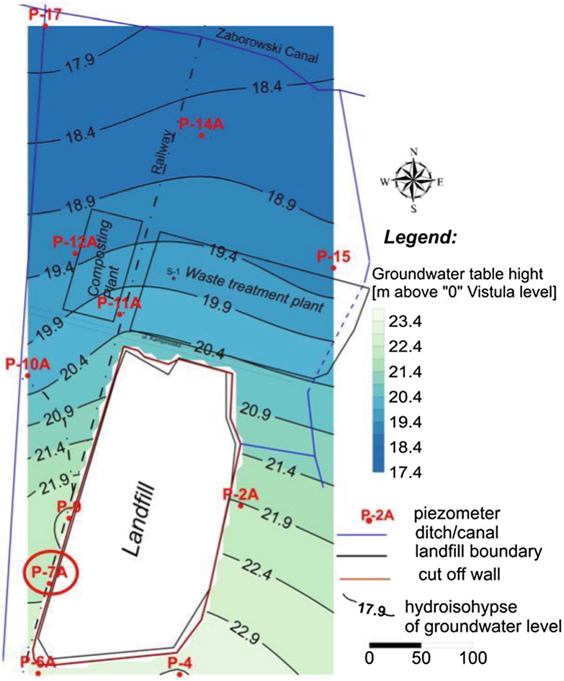

Fig. 2. Groundwater table levels and distribution of piezometers monitoring network.

The chemical laboratory tests of the groundwater samples comprise the analyses of 19 pollution indicators. However, for the present study only chloride concentrations and electrical conductivity (EC) tests were presented. They appear to be very much representative in terms of the soil-water environment quality assessment. The results of the exact chloride concentrations values changing over time (1998–2017), in every monitored piezometer are presented in Table 2. Additionally, for piezometer no 7A the graphical presentation of the dropping concentrations is presented in Fig. 3. From both, Table 2 and Fig. 3 it is clear that the drop of the chloride concentration in piezometers

2A-11A and 17 is significant, nevertheless for 4 remaining piezometers 12A-15, the recorded values are higher than in 1998. There are two explanations of such behavior.

Table 2. Changes of the chlorides level in piezometers.

Piez.	Chlorides [mgCl/l]						
	27.09.98	30.11.00	14.05.02	08.11.06	09.11.10	25.11.14	22.11.17
2A	1751	Closure of the vertical barrier	290	1595	243	246	116
4	64		39	40.7	40.3	57.1	59
6A	161		56	55.7	56.6	76.1	94
7A	**2180**		**470**	**202**	**63.1**	**32.8**	**27**
9	3739		n/a	1595	1137	518	217
10A	988		1034	584	617	213	100
11A	1384		754	1140	1360	1310	530
12A	31		31	320	250	756	990
14A	54		36	354	313	184	94
15	52		47	97.6	214	321	861
17	542		n/a	61	348	206	192

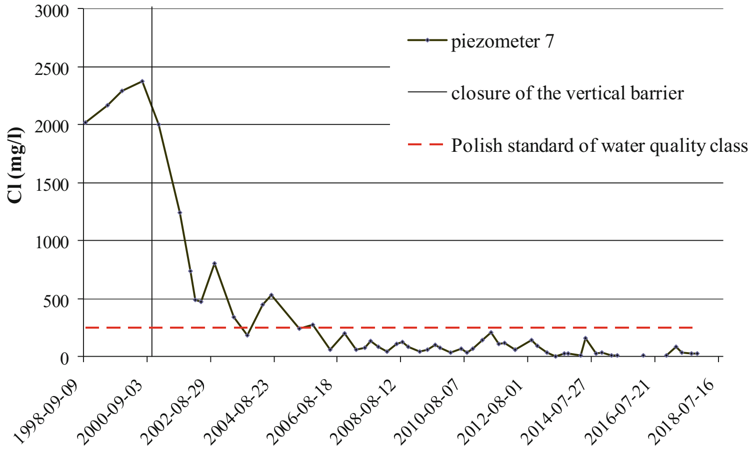

Fig. 3. Temporal changes of the chlorides concentrations in piezometer 7A.

First of all the plume movement is observed along the groundwater flow path, so the pollution is clearly moving away from the landfill, and during that process the environment self-purification phenomena takes place [20]. The second reason of increased values of the concentration is the close vicinity of the landfill facilities like waste treatment and composting plants that could be the external source of chloride pollution. To visualize the transport path of the chloride pollution and associated electrical conductivity the contamination spatial distribution maps are presented in Figs. 4 and 5.

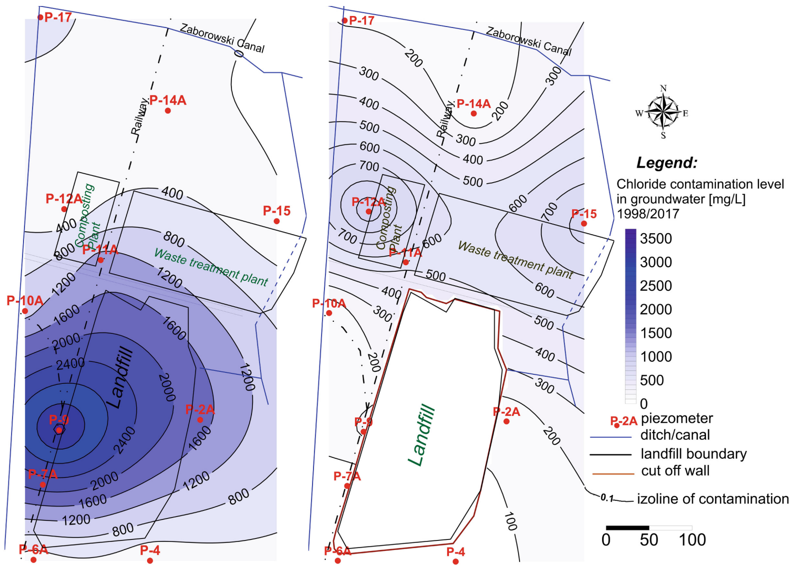

Fig. 4. Chloride concentration changes in 1998 and 2017 (before and after barrier construction).

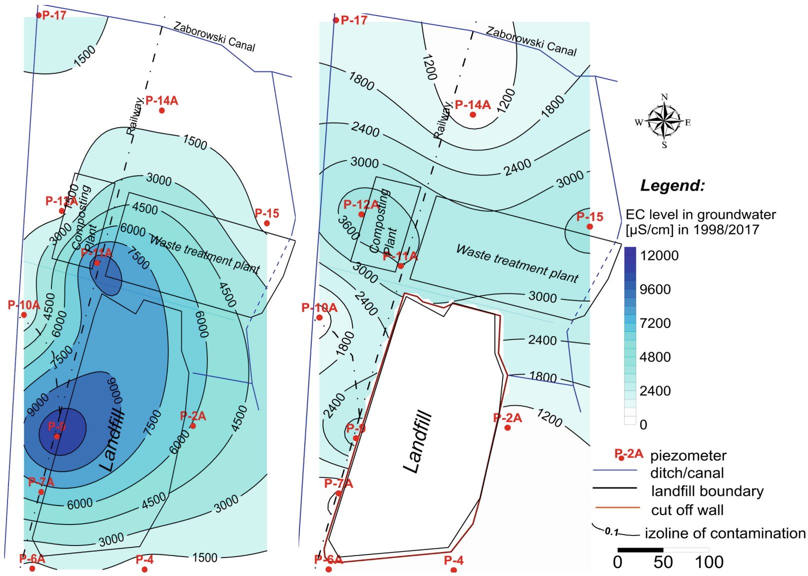

Fig. 5. EC level changes in 1998 and 2017 (before and after barrier construction).

The maps clearly indicate the pollution plume moves towards the north, where the discharge of the groundwater from the landfill is also observed. The chloride concentration and electrical conductivity (EC) are very much related to each other in the soil water environment, what was confirmed in this case as well. The observation of piezometers, for which the values of chloride content are high, is also reflected in raised values of EC. The concentrations are now moved, when compared to the values recorded before the vertical barrier was constructed (1998). Moreover, the concentration values have been progressively dropping, and they depend on changing groundwater levels, due to different weather events (precipitations, draughts). Nevertheless, all those observations prove the groundwater quality improving character.

4 Conclusions

There are numbers of conclusions deriving from the study. First of all the chlorides are the chemical elements that indicates sever pollution of the environment within the landfill site in 1998. The associated electrical conductivity is the result of such high concentration values caused by chlorides. Before the vertical barrier installation on the site, the concentrations of pollutants were very much exceeded (even 8 times in piezometer 7A acc. the Polish Standard [21]), in most of the sampling points. However, the records from 2017, show major improvement of the groundwater quality. There are still the locations where the chloride and EC concentration values are unacceptable, but the environment purification is progressing continuously. The plum is moving away from the landfill, however the records of piezometers 12A and 15 should raise the awareness whether the exceeded values are not the result of further contamination deriving from the facilities associated with the landfill. This zone needs particular attention in further observations. The novel approach of observational method has been introduced to optimize the reclamation works, and give a clear understanding of contamination concentration and flow, by presenting pollutants distribution maps.

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The Assessment of Thermal Insulation of Bioreactors for an Aerobic Biostabilization of Waste

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Abstract. The aim of the study was to analyze and assess the thermal insulation of three walls (the side wall, the front wall with a hook and the back wall – the door) of a bioreactor for an aerobic biostabilization of waste (built in accordance with the DIN 30722 standard) for 3 different variants of thermal insulation applied. It should be noted that currently there are no requirements in the literature regarding the design of a thermal insulating layer of bioreactors in municipal solid waste treatment installations in Poland. The side wall of the bioreactor and the front wall (with a hook) appeared to have the best thermal insulation while the back wall (the door of the bioreactor) showed the worst insulation. This was confirmed by photographs (thermograms) taken using a thermal imaging camera. The highest observed temperatures were recorded on the door of the bioreactor, on which many thermal bridges were also visible. The lowest mean temperatures on the surface of the bioreactor walls were obtained using foam insulation (variant 1), however, it was found that the differences between the temperatures of the analyzed elements in particular variants were not statistically significant.

Keywords: Aerobic biostabilization · Heat transfer · Thermography

1 Introduction

Installations for mechanical and biological treatment (MBT) of mixed municipal solid waste have been the basic form of municipal waste management in Poland since 1 July 2013. In the MBT plant, the oversize fraction with a grain size >80 mm (which can be used e.g. in cement plants as an alternative fuel) and undersize fraction with a grain size below 80 mm (directed to the biological part of the MBT plant for biological drying, aerobic stabilization or methane fermentation) are generated [5, 6, 9]. One of the most popular biological waste treatment methods in the MBT plant is aerobic biostabilization. This is a process of biological treatment of organic waste, carried out under

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 23–29, 2019.
https://doi.org/10.1007/978-3-030-16542-0_4

aerobic conditions [1, 7, 10]. The processes of aerobic biostabilization and bio-drying are the best way for decomposition of organic matter contained in the waste (as a result of the activity of various groups of microorganisms), which is accompanied by an increase in temperature [1, 4, 7, 8, 19]. High temperature kept in the range of 50–60 °C is advantageous for aerobic bacteria, the activity of which is then the highest. This causes the process to proceed dynamically and the product of the stabilization process, which is the stabilizer, can be obtained in a shorter time. Jędrczak [9] states that all biological waste treatment processes should be carried out in specially designed bioreactors, which allows controlling the process.

The aim of the study was to assess the thermal insulation of 3 different elements (walls) of bioreactors with container construction designed for aerobic biostabilization of waste. The research was carried out for three different construction variants of isolated bioreactors for aerobic stabilization of waste in real conditions in the MBT plant in Kraków (Poland). Proper selection of solutions for thermal insulation of bioreactors is indispensable to ensure the lowest possible heat loss through the bioreactor walls. The waste deposit cooling (inter alia due to the heat loss through the wall of the bioreactor) results in the process being slowed down.

So far no similar studies have been carried out for bioreactors for biostabilization of waste. This is a novelty of the tests carried out. Teleszewski and Żukowski [18] give the results of research on the thermal insulation of bioreactors for the production of biogas in Polish conditions.

2 Materials and Methods

The bioreactor for aerobic biostabilization of waste is a closing construction of working volume of 33 m^3 with a hook and special skids which enable its loading on a hook lift. The bioreactor was built in accordance with the DIN 30722 standard with a wall thickness of 4 mm. The walls, roof and bottom of the bioreactors were additionally insulated with a layer of polystyrene foam, insulating foam and external metal sheet depending on the type of construction (variant). The bioreactors have openings for delivery and removal of process air, as well as an opening for getting rid of leachate. The bioreactors are airtight, so that there is no possibility of uncontrolled contact of the process air with the atmosphere. The analysis covered three walls of bioreactors, i.e. the side wall, the front wall with a hook and the back wall (the door of the bioreactor). The research was carried out for three variants of insulation of bioreactor walls:

1. insulation with insulating foam (60 mm) and 1 mm external metal sheet;
2. insulation with polystyrene foam (40 mm) and 1 mm external metal sheet;
3. insulation with polystyrene foam (20 mm) and external metal sheet 2 mm.

In order to determine the substitute heat transfer coefficient, the thermal resistance of individual elements was calculated for the side wall, front wall with a hook and the back wall (door) of the bioreactor. The thermal insulation of the partitions depends on the size of the heat transfer coefficient through the partition. It is the reverse of the total thermal resistance, which consists of the thermal conductivity coefficient of the material from which the partition is made and the thickness of this partition, as well as resistance to heat penetration on both sides of the partition (internal and external).

Each construction material is characterized by a different heat conduction coefficient, therefore it is possible to determine whether a given material is a good thermal insulator or not. The lower the coefficient value, the better the insulation level. Heat transfer coefficient indicates the amount of heat that permeates within 1 h through 1 m^2 of a flat partition with the difference of air temperature on both sides of it equal to 1 °C (1 K). In order to determine the heat transfer coefficient of the bioreactor walls, the PN-EN ISO 6946 standard was used.

The assessment of thermal insulation of bioreactors for aerobic stabilization of waste was undertaken employing the FLIR ThermaCAM E300 thermal imaging camera. The images were digitally processed using the ThermaCAM ™ FLIR QuickReport 1.2 software. Thermography deals with the detection, recording, processing and visualization of infrared radiation, which is invisible to the human eye, emitted by each object, as a result of which it receives a digital image (thermogram) representing the temperature distribution on the surface of the object in question [11, 15, 17, 20]. All bodies that is solid, liquid and gas, whose temperature is higher than 0 K (−273.15 °C), emit thermal radiation called infrared radiation. The measured thermal energy of the object depends on the spectral, thermal and physical properties of the material [13, 14, 16, 18, 20].

Thermography is a method that enables to visualize the temperature distribution on the surface of a given element. The measurement takes into account the influence of the environment, which can distort the thermal image of the thermogram [2, 3, 12–14]. The execution of thermograms of the external walls of buildings and their analysis allows non-invasive identification of defects in the insulation layer, as well as the occurrence of manufacturing errors, mold or moisture [11].

The photos of bioreactors were taken between the 3rd and 4th day of the aerobic biostabilization process of waste. The tests were carried out from December 2017 to February 2018. The air temperature on the measurement days was 0 ± 3 °C and the temperature inside the bioreactors 60 ± 5 °C. Most often the sky was overcast, but with no rain, snow or wind. Solar radiation did not significantly affect measurement errors. The surfaces of bioreactors were carefully cleaned of all kinds of contaminants. 81 photos were taken during the measurements. For each variant, 27 thermograms illustrating bioreactors for aerobic biostabilization of waste were executed. In each variant, three different bioreactors were analyzed. The bioreactors were structurally new (production date: March 2016).

3 Results and Discussion

Table 1 presents the data that enabled calculation of a substitute heat transfer coefficient for individual construction elements of the bioreactor presented in Table 2. The calculations assumed heat transfer coefficients from the internal side of the bioreactor at the level of 0.066 (m^2 K) W^{-1} and from the external side of 0.04 (m^2 K) W^{-1} [17]. The lowest thermal resistance was demonstrated for variant 1 (foam insulation (60 mm) and external metal sheet (1 mm)). The highest thermal resistance was noted for the side wall for variant 1, the resistance amounted to 2.87 (m^2 K) W^{-1}, while the lowest resistance was observed for the back wall (variant 3): 0.8 (m^2 K) W^{-1}. The lowest heat transfer coefficient and hence the highest thermal insulation was discerned for the side wall of the bioreactor in variant 1 (Table 2), for which the heat transfer coefficient equaled to 0.35 W $(m^2\ K)^{-1}$, while the lowest thermal insulation was noted for the back wall (the door of the bioreactor) in variant 3: 1.25 W $(m^2\ K)^{-1}$.

Table 1. Heat transfer coefficients for individual types of layers forming the bioreactor structure

Type of material	Heat transfer coefficient W $(m^2\ K)^{-1}$	Layer thickness (m)
Metal sheet (construction steel)	58	0.001
Metal sheet (construction steel)	58	0.002
Polystyrene foam	0.043	0.02
Polystyrene foam	0.043	0.04
Insulating foam	0.025	0.06

Table 2. Heat transfer coefficients of individual structural elements of the bioreactor

Type of structure	Unit	Variant 1	Variant 2	Variant 3
Side wall	W $(m^2\ K)^{-1}$	0.35	0.48	0.79
Front wall with a hook	W $(m^2\ K)^{-1}$	0.38	0.55	0.97
Back wall (door)	W $(m^2\ K)^{-1}$	0.42	0.62	1.25

Figure 1 shows the temperature distribution on the side wall surface of one of the analyzed bioreactors (variant 1). The marked pixels Sp1 and Sp2 indicate the temperatures of the process air discharge conduit from the bioreactor. The Ar1 area indicates the range of temperature values on the side wall of the bioreactor. With the use of the Li1 and Li2 lines, the temperatures on the ribs (structure) of the bioreactor, whose temperature in the lower part was higher than the rest of the wall of the bioreactor, were visualized. A similar situation with a bioreactor ribbing which is well visible on the thermogram is shown in Fig. 2 (the thermogram of the bioreactor whose thermal insulation was made of polystyrene foam with a thickness of 20 mm and metal sheet thickness of 2 mm (variant 3). Figure 2 shows that the door of the bioreactor had a much higher temperature than the side wall, which was due to the very high value of the heat transfer coefficient (1.25 W $(m^2\ K)^{-1}$).

Table 3. Mean values of temperatures of analyzed structural elements of the bioreactor

Type of structure	Unit	Variant 1	Variant 2	Variant 3
Side wall	°C	16.3 ± 6.1	17.1 ± 5.4	17.2 ± 5.9
Front wall with a hook	°C	17.3 ± 5.6	17.9 ± 4.4	17.8 ± 7.1
Back wall (door)	°C	20.2 ± 4.2	21.1 ± 5.2	22.0 ± 5.4

Table 3 presents mean temperatures of individual structural elements of bioreactors calculated on the basis of the analysis of thermograms. The highest temperatures concern the door of the bioreactor, on which numerous thermal bridges were evident. The lowest mean temperatures were recorded on the surface of the bioreactor walls, the insulation of which was made of foam (variant 1), however, it was found that the differences between the temperatures of the analyzed elements in individual variants were not statistically significant. This means that when selecting insulation materials for the construction of a bioreactor, economic factor should be considered and the cheapest option chosen. In this work, thermal bridges were not assumed in the calculations.

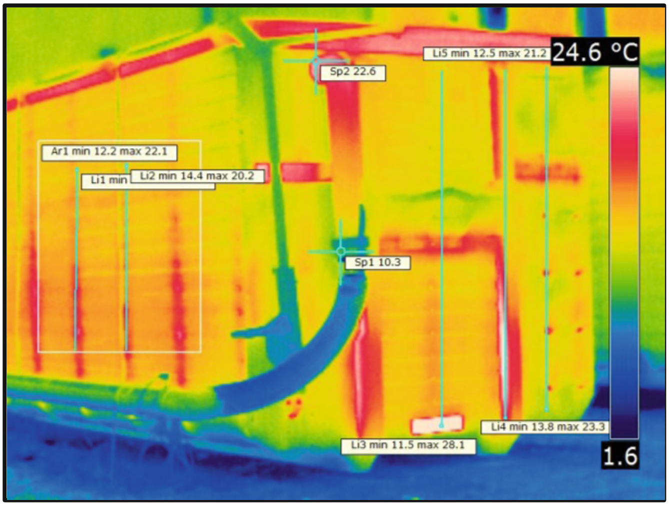

Fig. 1. Temperature distribution on the surface of the side wall and the front wall of the bioreactor (variant 1)

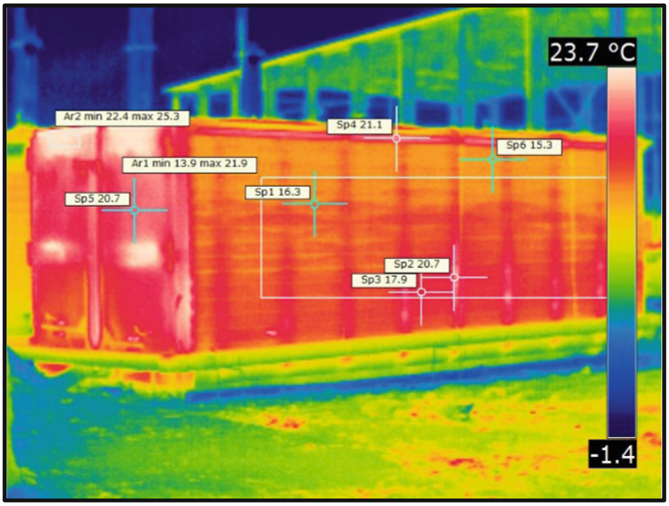

Fig. 2. Temperature distribution on the surface of the side and back walls of the bioreactor (variant 3)

Thermal bridges noticeable on thermograms were of structural and geometrical character. The main reason for the occurrence of thermal bridges involves the design or assembly errors. Structural thermal bridges are those that appear as a result of difficulties in executing the insulation due to structural solutions (in this case, the ribbing of the side walls of the bioreactors and the door of the bioreactors). In turn, geometric thermal bridges are connected with the shape of the external partitions of the bioreactor and occur in the corners of the bioreactors. In the place where the ladder was attached to the front wall, the occurrence of a point thermal bridge was noted, which had been the result of a puncture of the insulation layer by fixing bolts. The most common thermal bridges are caused by: breaking the continuity of the insulation layer, insufficient thickness of the thermal insulation layer and inhomogeneity of the partition structure, i.e. occurrence of elements that conduct heat better in the construction of the partition [18].

4 Conclusion

The paper presents an analysis of thermal insulation of walls of bioraector for a typical municipal solid waste treatment plant under the Polish climatic conditions. The simulations were made for an existing object. On the basis of the conducted research, the following conclusions were drawn:

1. Thermal insulation of bioreactors for aerobic biostabilization of waste is adequate for the process carried out in them.
2. All of the tested bioreactors had similar thermal insulation of side walls. The side wall of the bioreactor and the front wall with a hook appeared to have the best thermal insulation while the back wall (the door of the bioreactor) showed the worst insulation.
3. The analysis of the thermograms of individual structural elements of the bioreactor showed that there were thermal bridges on the surface of the walls (mainly the door of the bioreactor).

Acknowledgements. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland (means of Statutory Research No. DS 3600/WIPIE, University of Agriculture in Krakow).

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The New Construction of Heating Elements for Greenhouse Heating Systems

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Abstract. Power demand in a greenhouse's heating system is characterized by high diversity over time. The differences range from several to more than a dozen times and are a result of conditions changes between day and night as well as in longer periods of time. Improving greenhouse microclimate and reducing heat losses are nowadays the main research areas in greenhouse technology. New construction of heating pipes – hexagram-shaped pipes called "Walczak's pipes" – enable higher heat efficiency and quicker response to changes of external conditions. In this research Walczak's pipes made of polypropylene were tested. Specific heat efficiency was determined for three different heating medium flow rates. Moreover, thermal parameters of the tested pipes were compared to those of similar pipes made of steel. The conducted research allowed for stating that Walczak's pipes made of PP are suitable for low-temperature heating systems, e.g. in greenhouses, heat pumps, etc.

Keywords: Greenhouse · Walczak's pipes · Heating pipes · Heating system

1 Introduction

The development of modern horticulture technologies as well as pursuance towards more efficient and energy-saving greenhouse production force the producers to seek for new solutions in construction and equipment of a greenhouse. Achieving high quality crops is possible only if optimal conditions of growth are provided [1, 2]. In a modern greenhouse all the plant requirements need to be fulfilled, hence its construction and equipment has been changing rapidly in recent years [2–4]. For instance, in order to ensure optimal light access, the height of greenhouses increases. On the other hand, heat losses have to be minimized, which force the constructors of greenhouses to search for more advanced technologies. The recent research shows, however, that there are still some significant possibilities to improve greenhouse microclimate and reduce heat losses [5–7].

Power demand in a greenhouse's heating system is characterized by high diversity over time. The differences range from several to more than a dozen times and are a result of conditions changes between day and night as well as in longer periods of time. Research shows that greenhouses use on average 15–25% of peak power. Any change in the intensity of solar radiation (common in autumn or spring) results in an immediate

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 30–36, 2019.
https://doi.org/10.1007/978-3-030-16542-0_5

change in momentary heating power demand [8–13]. Considering a high amount of heating water used in installations (approx. 20 $dm^3 \cdot ha^{-1}$), the heating system requires a heat source characterized by optimal heating power and hot water accumulation capacity [11]. The factors mentioned above force the use of such solutions which, on the one hand, secure the power demand, and on the other, reduce the energy consumption.

A modern heating system in a greenhouse means not only maintaining proper temperatures but it also should ensure balanced air movement in the vegetation zone and quick response to sudden changes in external conditions [4, 11]. To meet these requirements the independent control of heating circuits with varied thermal inertia should be applied. Diversified thermal inertia of heating circuits is particularly important in periods of high variability of external conditions, when either overheating of a greenhouse or high heat losses are often noted. That is why a new generation of heating pipes – hexagram-shaped pipes referred to as “Walczak’s pipes” - have found application in modern construction of greenhouses. Such pipes have several times smaller volume compared to traditional heating pipes of the same outer diameter, they are more rigid as well. Much lower volume of heating medium needed in the system based on Walczak’s pipes enables quicker response to sudden changes in external conditions. The preliminary assessment of applying Walczak’s pipes in greenhouse production is highly positive [7]. Compared to traditional systems, such pipes allow for better heat management. The detailed research on thermal and physical parameters of greenhouse heating systems equipped with Walczak’s pipes has been conducted at the Faculty of Production and Power Engineering, University of Agriculture in Krakow, Poland.

2 Materials and Methods

The research was aimed at the assessment of heat efficiency of hexagram-shaped heating pipes, known as Walczak’s pipes. The pipes under examination were made of polypropylene and were manufactured by extrusion of circular PP pipes with a circumference of 40 mm. They have more than 2.5 times smaller capacity in comparison with typical greenhouse pipes, which allows for quick response of the heating system to sudden changes in external conditions (lower thermal inertia). Moreover, PP pipes are rust-proof and do not require maintenance, as well as they are lighter than steel pipes, which may lessen the load supported by the greenhouse structure.

The research was conducted in accordance with the standard guidelines for the measurements of thermal devices. In the first step the specific heat efficiency was determined at the ambient temperatures in the range of 15–22 °C. Such temperature range in the chamber, in which the tests were carried out, was chosen due to the potential application of the tested pipes in greenhouse tomato production. Water was used as a heating medium, its temperature reached up to 56 °C. The tests were carried out at steady state (after all the parameters of the system – including ambient temperature, heating medium temperature and flow rate – became stable). The values of power supplied to the system were assessed for discrete points on the basis of conducted tests in periods of 30 min.

The examined section of the pipe was 12 m long, with two loops enabling compensation of thermal expansions, which occurred due to changes in temperatures. The tested section was hung at the height of 0.5 m and was linked to the inlet and outlet connections located at the distance of 6 m from each other. The specific volume of the tested heating pipe was 0.5 dm^3, which, after calculations, gives hydraulic diameter of the pipe equal to 25.2 mm. It corresponds to the pipe 1” in series of types of hydraulic elements.

In Fig. 1 the key system elements are presented, i.e. the examined section of the pipe and the measuring system, in which DT9818 USB card with sixteen analog voltage inputs was an essential component. The measured values were recorded directly to a PC using DaisyLab 11.0 program, which controls the card operations. Sampling rate of 1 Hz was applied. Temperature measurements of the tested heating pipe at the inlet and outlet as well as of its surroundings were performed by Pt100 paired sensors (T_1, T_2, T_3, T_4 – Fig. 1). Such arrangements of sensors allowed for complete balancing of the heat fluxes in the heating system. The flow rate of the heating medium was measured using MTWH flowmeter. Relative humidity of the air inside and outside the measuring chamber was also recorded. For water circulation a DC pump with regulation of flow rate was used.

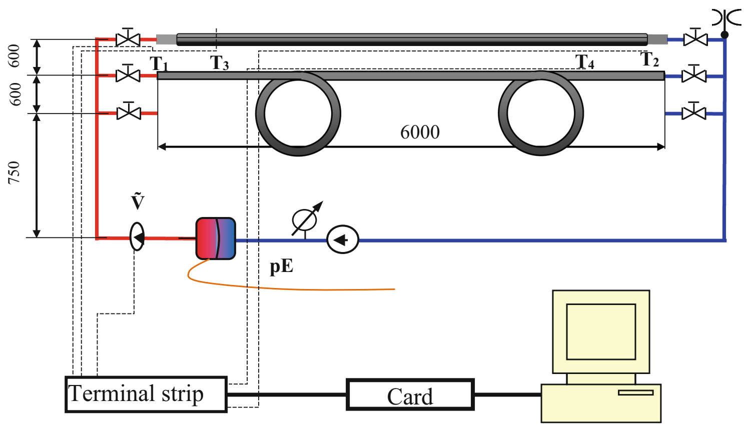

Fig. 1. Scheme of the stand for measuring heat efficiency of heating pipes.

3 Results and Discussion

The results of the conducted tests are presented on the diagram (Fig. 2). The tests were carried out for three different flow rates: 4.0, 2.1 and 1.1 $dm^3 \cdot min^{-1}$, which corresponds to the average theoretical speeds of heating medium equal 13.2, 7.0 and 3.6 $cm \cdot s^{-1}$, respectively. For those parameters the characteristics of specific heat efficiency (power per unit length of the heating pipe) in relation to the difference between heating medium and ambient temperatures. On the diagram it can be noticed that with an increase in flow rate the heat efficiency of the tested heating pipes also increases slightly. However, most noticeable is an increase in the heat efficiency resulting from a rise in temperature difference DT. An increase in DT equal 1 °C forces the specific heat efficiency increases of 0.865, 0.831 and 0.700 W · m^{-1} for flow rates 4.0, 2.1 and 1.1 dm^3 · min^{-1}, respectively. According to [14, 15], in the DT range between 10 and 40 °C traditional round steel heating pipes with a diameter of 26.4 mm and plastic pipes (made of PE) with a diameter of 25.0 mm are characterized by the average coefficients of 1.21 W · m^{-1} · °C $^{-1}$ and 0.97 W · m^{-1} · °C $^{-1}$, respectively. Comparison of the research and literature values allows for stating that in the case of the tested hexagram-shaped PP pipes for the flow rate 4.0 dm^3 · min^{-1}, the rate of heat efficiency increase with temperature is lower by 28.5% and 10.8% than for steel and plastic pipes of similar diameters, respectively.

On the basis of the presented relations (Fig. 2) it can be stated that at the flow rate 4.0 dm^3 · min^{-1} and the difference in temperatures of a pipe and its surrounding equaling to 30 °C, a 50 m long heating pipe is able to provide the heating power of approx. 1.25 kW. It is important to mention that this range of power is generated through heating the air by three mechanisms of heat-transfer: convection, conduction and radiation.

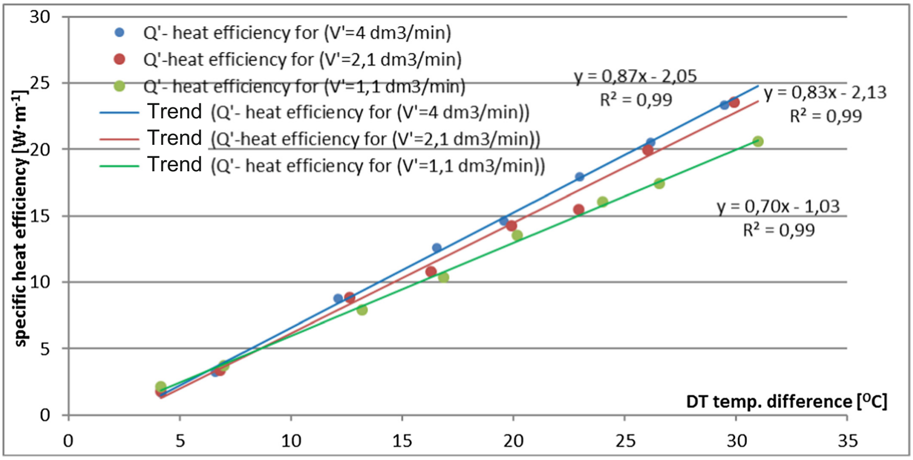

Fig. 2. Specific heat efficiency in relation to temperature difference DT for three examined flow rates.

Figure 3 presents a comparison between specific heat efficiency of Walczak's pipe made of PP and steel. Both heating elements were star-shaped in cross section, but the hydraulic diameter of the steel pipe was larger than that of the tested PP pipe (28.0 and 25.2 mm, respectively). It has also to be mentioned that the flow rate in the steel pipe was slightly higher (5.0 dm^3 · min^{-1}) than in the PP pipe. The presented characteristics (Fig. 3) reveal that for DT values lower than 15 °C the specific heat efficiency for both types of pipes are similar. However, for higher DT values (exceeding 15 °C) the characteristics begin to differ noticeably – more efficient are the steel pipes.

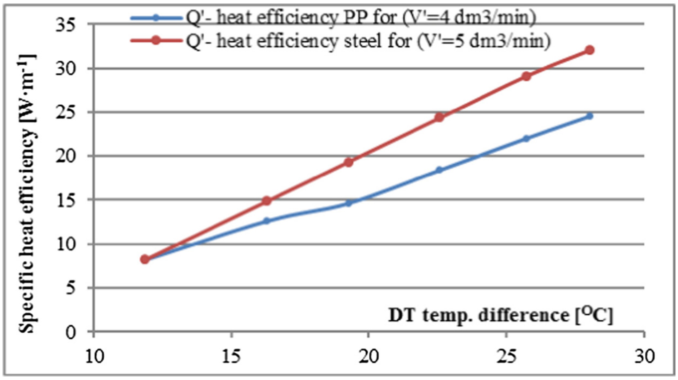

Fig. 3. Characteristics of specific heat efficiency for Walczak's pipes made of PP and steel.

For more detailed comparison of specific heat efficiency of both pipe types, percentage differences were calculated and shown on a diagram (Fig. 4). The diagram shows that in the DT range from 12 to 20 °C the difference of specific heat efficiency between steel and PP pipes is linear and increases from 1% to 20%. For DT higher than 20 °C it can be stated that the heating element made of PP reveals the specific heat efficiency lower by 24%. However, it has to be remarked that measurement conditions of both pipe types were not the same – the hydraulic diameter and the flow rate in the case of steel pipe tests were higher than in PP pipes tests by 11% and 20%, respectively.

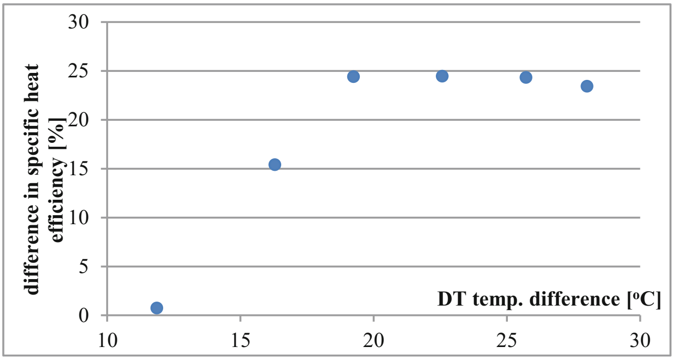

Fig. 4. Difference in specific heat efficiency between heating pipes made of PP and steel.

4 Conclusions

On the basis of the conducted research and analyses, the following conclusions concerning heating elements (Walczak's pipes) made of PP can be drawn:

1. A 1 °C increase in difference between the heating medium and ambient temperatures forces the specific heat efficiency increases of 0.865, 0.831 and 0.700 $W \cdot m^{-1}$ for flow rates 4.0, 2.1 and 1.1 $dm^3 \cdot min^{-1}$, respectively.
2. A 50 m long heating pipe made of PP is able to provide the heating power of approx. 1.25 kW if the value of DT reaches 30 °C.
3. Hexagram-shaped heating elements made of steel can be replaced by PP elements of similar dimensions provided that the circumference of their cross-section will be larger by at least 20%.
4. The researched heat elements made of PP are suitable for applications in low-temperature heating systems, e.g. in greenhouses, heat pumps, etc.

Acknowledgements. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland (statutory activities DS-3600/WIPiE/2018, Faculty of Production and Power Engineering, University of Agriculture in Krakow).

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The Influence of the Height of Foil Tunnels on the Formation of Thermal Conditions in the Plant Growing Zone

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Abstract. The paper attempts to determine the influence of the height of foil tunnels on the formation of thermal conditions in the plant growing zone. A diagnosis of the temperature distribution and the direction of heat flow in the ground under tunnels was made. Continuous recording of the temperature and relative humidity of the internal and external air, the intensity of solar radiation and the direction and speed of the wind was also carried out. There are periods and places where there are losses and heat gains from the ground. Studies on the formation of thermal conditions in the ground and selected parameters of the internal and external microclimate were carried out in two free-standing tunnels of different construction, in an agricultural holding located in the Świętokrzyskie Province. In the tunnels, seasonal cultivation of cucumbers was carried out from April to October. In the hot bottom, the internal temperature in the higher tunnel was 6.8 °C lower than in the lower tunnel. On the other hand, on cloudy days, the temperature in both tunnels was similar, and its differences were within the scope of measurement error of the sensors. The studies did not show the influence of height on the temperature distribution in the root zone of plants. Differences in the top soil layer (−0.1 m) reached 0.8 °C. At lower levels (−0.5 m and −1.0 m), ground temperature differences under the tunnels were around 0.2 °C. The results of the detailed analysis indicate that, when taking the varied surface of the tunnels into account, the energy gains from the soil in the low tunnel reached 44.3 kWh/m^2, whereas in the high one their value was higher and reached 46.4 kWh/m^2.

Keywords: Plastic tunnel · Temperature · Soil

1 Introduction

Intensive covered horticulture in countries with less favourable climatic conditions involves high costs in order to provide proper efficiency of crop growing. Poland is one of the states where average monthly temperatures and solar irradiance are significantly lower in the heating period when compared to the Mediterranean, but also to the south-western regions of Sweden or the Netherlands [6, 11, 14]. Regardless, Poland is a relevant European producer of vegetables and ornamental plants grown under

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 37–45, 2019.
https://doi.org/10.1007/978-3-030-16542-0_6

protective covering. Based on the data collected by the Central Statistical Office (Główny Urząd Statystyczny – GUS) for 2015, 55% of vegetables from under such covering come from polytunnels, 44.6% from greenhouses. The remaining 0.4% of crops are grown in cold frames [5].

The cultivation of vegetables under protective covering is strictly related to the provision of proper internal microclimate conditions, especially the indoor air temperature and relative humidity [6, 10]. This mainly entails providing the required internal temperature throughout the vegetation period. However, rapid temperature fluctuations in the tunnel may significantly affect the crop yield. The minimum temperature in this type of structures depends on what plants are cultivated and ranges from 5 to 10 °C, issues related to the high temperature start to affect the majority of crops when the temperature exceeds 30 °C [2, 7].

The optimisation of the microclimate in tunnel structures requires the adoption of proper material and structural solutions, as well as the provision of effective ventilation. Due to the fact that the most intensive period for vegetable production under protective covering is from spring to autumn, it is necessary to ensure suitable conditions for development within this period [4]. One option for improving thermal and humidity conditions in polytunnels is to ensure sufficient cubic volume of the structure, which decreases the impact of the high temperature of the outdoor air and high solar irradiance on the microclimate of the indoor environment [8, 12, 13]. Equally important is the role of the soil inside and around the tunnel structure. In the summer season, the soil serves as the main receiver of excess heat from inside the tunnel, whereas during transition periods, the flux of heat is directed inside the structure, therefore decreasing the maintenance costs [3, 9, 11]. The substrate may also impact temperature fluctuations in the cultivation area, which may directly affect the crop yield. Proper energy management in polytunnels may reduce the demand for energy in this type of structures.

The aim of the study was to examine fluctuations of the air temperature and relative humidity as well as soil temperature inside and around two tunnel structures of different heights.

2 Materials and Methods

The study was performed in two free-standing single-bay polytunnels of different designs and cubic volumes intended for the intense production of greenhouse cucumbers. Both structures are located at a horticultural farm southern Poland. They are part of a complex which consists of 28 polytunnels with the total area of 0.64 ha. In order to carry out the study, two tunnels were selected of various heights. One of the polytunnels, the lower one, with the dimensions of 30.0 × 3.5 × 7.0 m, had a wooden structure covered with year-round horticultural film of type UV-4. The second polytunnel, the higher one, with the dimensions of 30.0 × 5.0 × 9.0 m, had a steel structure and was also covered with the same type of film. The arrangement of the measuring points in the examined tunnels is presented in Fig. 1.

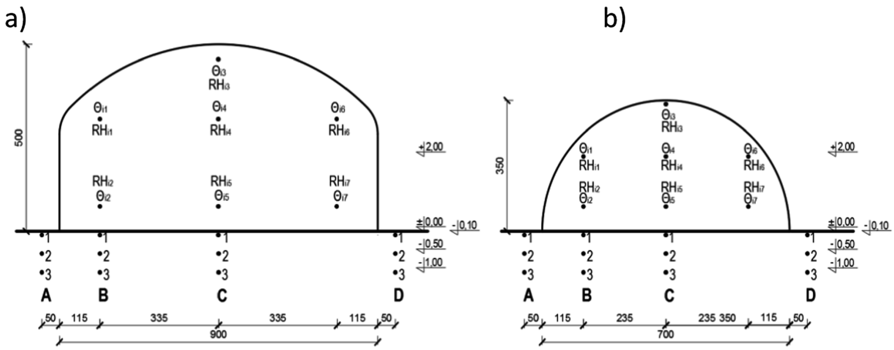

Fig. 1. Layout of the locations where the temperature and relative humidity of the indoor air (Θ_i, RH_i) and temperature in the soil were measured (A1–A3, B1–B3, C1–C3, D1–D3): (a) polytunnel with the dimensions of 30.0 × 5.0 × 9.0 m, (b) polytunnel with the dimensions of 30.0 × 3.5 × 7.0 m.

The research was carried out between 16.03.2016 and 16.10.2016. Within this period, the following microclimate parameters were measured continuously: indoor air temperature and relative humidity, outdoor air temperature and relative humidity, soil temperature in the tunnels, soil temperature around the tunnels, solar irradiance.

To measure the indoor air temperature and relative humidity, LB-710 hythero-graphs were used. The soil temperature measurements were conducted with PT-100 sensors. The solar irradiance measurements were performed with the LB-901 Kipp&Zonen CMP3 pyranometer. The collected data was saved in the computer memory by use of a measurement data logger as frequently as every 60 min.

The following equation was used to calculate the heat transfer to the ground:

$$q = \frac{\theta_i - \theta_g}{\left(\frac{0.1}{\lambda_s}\right) + R_{si}} \tag{1}$$

As θ_i, inner air temperature measured above the ground (θ_{i2}, θ_{i5}, θ_{i7}), θ_g, soil temperature interpolated between points B1 and C1, λ_s, thermal conductivity of soil (1,8 $W \cdot m^{-1} \cdot K^{-1}$ was assumed), R_{si}, resistance of heat transfer (0,17 $m^2 \cdot K \cdot W^{-1}$ was assumed). The vertical direction of the heat flow was assumed and the storage of heat by the ground was omitted, due to the small thickness of the soil layer, which was assumed at the level of 10 cm.

To determine the course of isolin, a simplified IDW (Inverse Distance Weighting) method was used. The smallest rectangle containing all the base points, including the value of the tested temperature, was determined. Then the rectangle was divided into cells with the same temperature value. Cells with the same temperature were then subjected to isolin.

3 Results and Analysis

To precisely analyse temperatures in the tunnels and temperature distribution in the soil around them, the period from 25 March to 16 October 2016 was selected, during which the cucumber (*Cucumis sativus L.)* was cultivated. The results yielded by the measurements of indoor and outdoor air temperatures and solar irradiance are presented in Fig. 2. The more favourable conditions for the cultivation of the cucumber were recorded in the higher tunnel (Θ_{iL}), where the indoor temperature exceeded the permissible temperature, 35 °C on very hot days only. On the other hand, on the first days of the October, the indoor air temperature dropped by approx. 8 °C below the required temperature of 18 °C. The temperatures in the tunnels were extreme due to solar irradiance (Fig. 2a) reaching as high as 1,145 W/m^2 in the summer season. In the spring and autumn, the mean solar irradiance varied between 260 and 360 W/m^2.

The largest soil temperature fluctuations under the tunnels occurred in the top layer, both at the walls and in the middle. In the summer season, the soil temperature under the tunnels decreased with depth (soil temperature difference at −0.1 m and −1.0 m was even 17 K). On 23 June 2016, when Θ_e rapidly increased, the soil temperature also increased on each measuring level, but with some delay. The increase was delayed from one day at −1.6 ft (−0.5 m) and by up to three days at (−1.0 m).

The periodic drop of Θ_e, from 11 to 19 July 2016, caused the average daily temperatures to equalise in the soil on each measuring level, which occurred on 18 July and lasted until 22 July 2016; then, the soil temperatures varied between 18 and 21 °C.

In the spring time, that is from 28 March, the temperature in the topsoil under the tunnels was observed to have increased faster than in the ground beyond them. It positively affected the conditions in the rhizosphere of the plants. Knowing the temperature curves for the soil under and around the examined tunnels, characteristic periods were selected for which temperature fields and heat flux directions corresponding to them were determined (Fig. 4), which illustrate the heat transfer between the tunnels and soil within the analysed study period.

What seems especially interesting are the temperature fields recorded on 26 March (Fig. 4a and b), when the soil under the tunnels, which had been cold after winter, received the heat from the top layer, in contact with the indoor air. In the summer season, the temperatures of the soil under and around the tunnels is equilibrated; at that time, the thermal soil conditions are beneficial to the crops being cultivated. Meanwhile in autumn, the soil in the tunnels, which is warm after the summer, transfers the heat to the layers located deeper and outside the tunnels.

The analysis of the study results shows thermal differences in the soil at −0.1 m under the surface of the ground between the area in the middle (warmer) and the one at the walls (cooler). A similar phenomenon as regards both areas was confirmed by Al-Kayssi [1].

The impact of the outdoor climate on the substrate in the examined polytunnels at the walls is greater and includes a strip as wide as 2 m. The research carried out by Al-Kayssi [1] and later by Nawalany et al. [10] shows that in greenhouse structures the temperature may be higher in the middle even by 3.6 °C in comparison to the area at the walls.

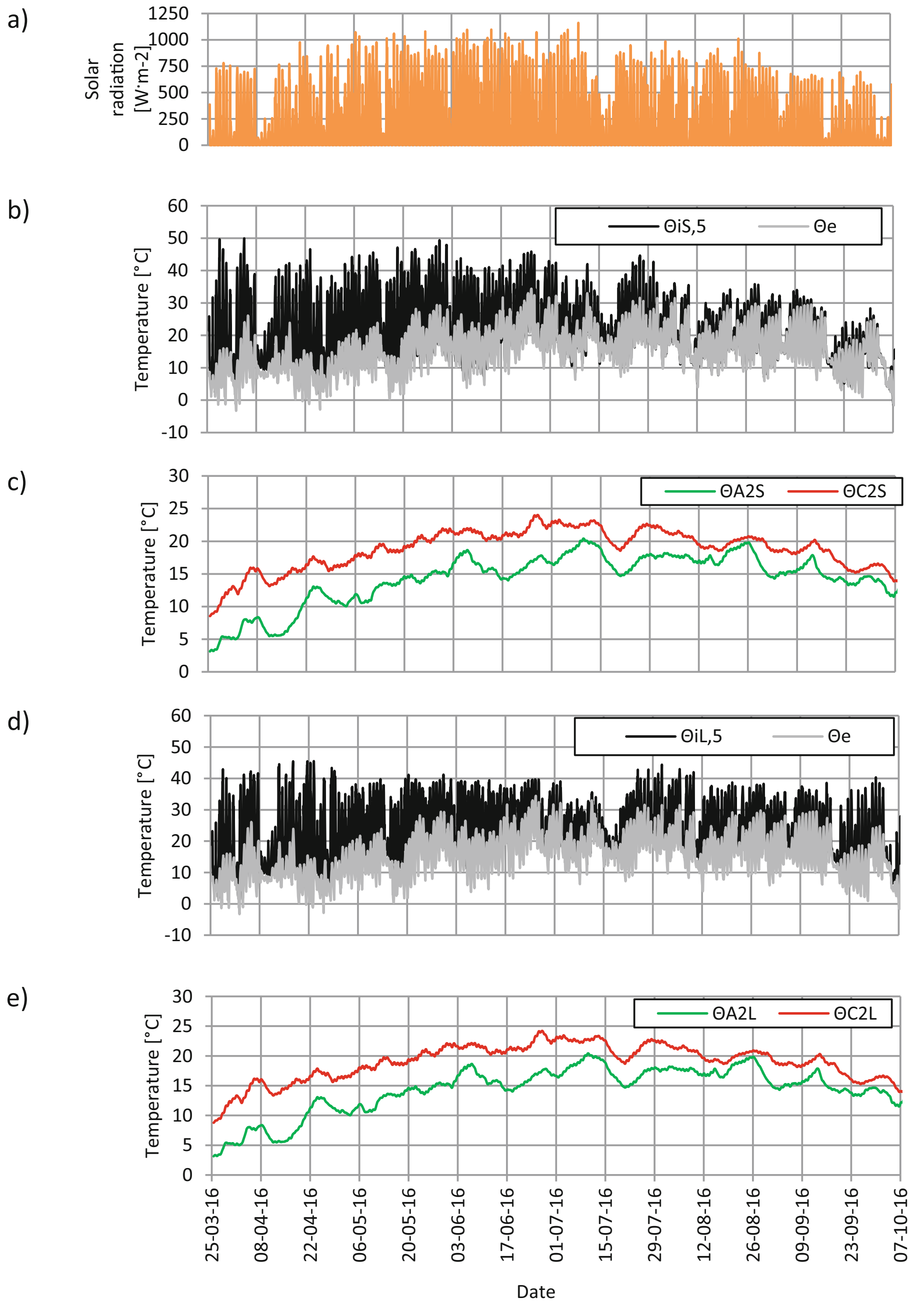

Fig. 2. Solar irradiance (a), ground temperature and outdoor/indoor temperature curve: b, c – in the lower tunnel (Θ_{iS5}), (3.5 m high), d, e – in the higher tunnel (Θ_{iL5}), (5.0 m high).

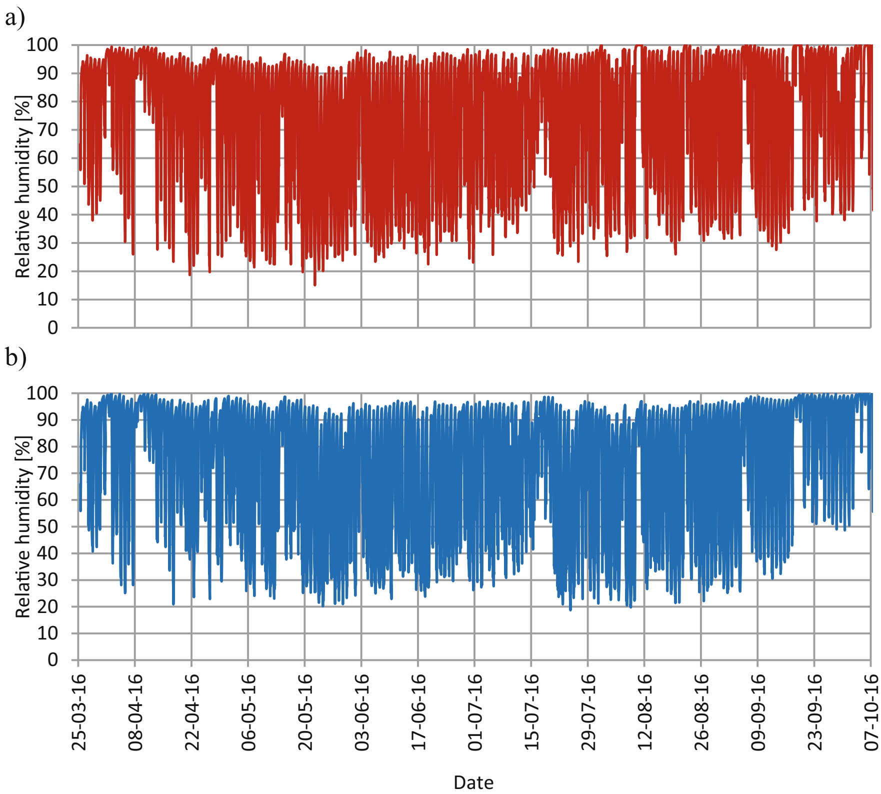

Fig. 3. Curve illustrating the relative humidity of the indoor air (RH): a - in the lower tunnel (3.5 m high), b - higher tunnel (5.0 m high).

The relative indoor air humidity in the small tunnel fell between 15% and 99% (Fig. 3a), whereas in the large one – from 19% to 99% (Fig. 3b). The exceedance of the permissible maximum relative air humidity (90%) was recorded within 21 days in the small tunnel and 17 days in the large one. These exceedances are attributable to the periodic closure of the tunnels in the evening, which significantly limited their ventilation.

The variability of thermal conditions of the soil under the tunnel is reflected in how the heat is transferred between the tunnels and soil. In the initial period of the production cycle (25.03–25.04), the heat exchange with the soil in the low tunnel varied between −34 kW to 7.6 kW. As for the high tunnel, the range of this parameter fell between −43.6 kW and 9.8 kW. The results of the detailed analysis indicate that, when taking the varied surface of the tunnels into account, the energy gains from the soil in the low tunnel reached 44.3 kWh/m^2, whereas in the high one their value was higher and reached 46.4 kWh/m^2.

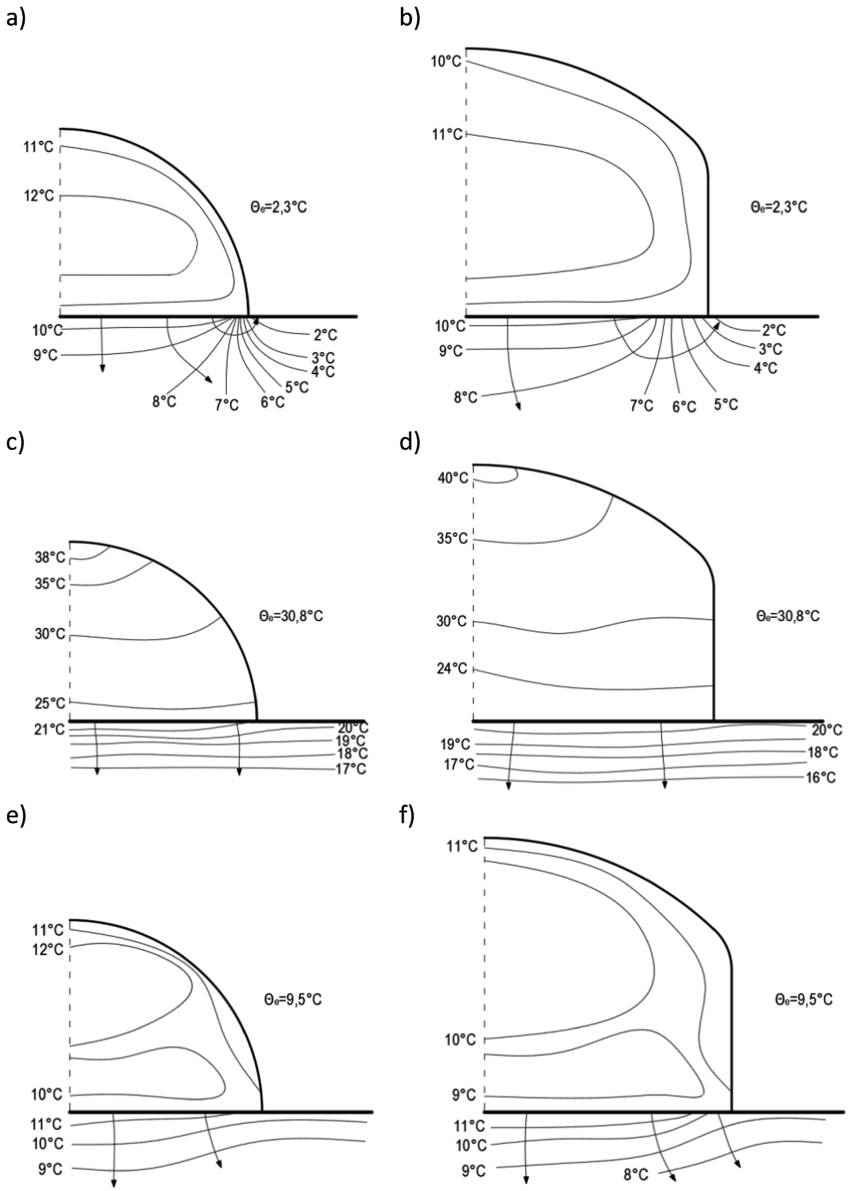

Fig. 4. Temperature distribution in the soil under and around the examined tunnels and heat flux directions: a (26.03), c (11.07), e (10.10) – under the lower tunnel, b (26.03), d (11.07), f (10.10) – under the higher tunnel.

The identified heat flux directions in the soil during the spring indicate that the heat flux outflow may be limited from under the tunnels outwards. This may be achieved by using vertical thermal insulation, which should reduce heat loss and, therefore, improve the efficiency of crop production. Only this solution will not hinder the transfer of excess heat to the soil in the summer season, which benefits the energy management of polytunnels.

4 Conclusion

The study has shown the impact of the tunnel height on fluctuations of temperatures inside polytunnels. On hot days, the temperature in the higher tunnel was 6.8 °C lower than in the lower one. However, on cloudy days, the temperatures in both tunnels were almost the same, whereas the difference between them was within the measurement error range.

The different heights of the tunnels did not materially affect the temperature distribution in the ground. The differences in the topsoil (−0.1 m) reached 0.8 °C. At the lower levels (−0.5 m and −1.0 m), the differences in the soil temperature under the small and large tunnels were on the order of 0.2 °C.

The impact of the outdoor climate on the substrate in the examined polytunnels at the walls is greater and includes a strip as wide as 2 m. In the summer season, the difference between the soil temperature fields disappears; therefore, the division of the substrate in the tunnels into the areas in the middle and at the walls is irrelevant.

Acknowledgments. The research was financed by statutory activity subsidy from the Ministry of Science and Higher Education of the Republic of Poland.

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Needs and Effects of Use Sprinkler Irrigation Systems in Crops Production in Central Poland on the Example of Spring Malting Barley (*Hordeum vulgare* L.)

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Abstract. The purpose of the paper was to determine the yielding and production needs and effects of sprinkler irrigated spring malting barley (*Hordeum vulgare* L.) depending on the intensity of droughts occurring during its period of high water needs spanning May and June. The paper was based on the results of field experiments with irrigated barley cultivars, carried out in 2006–2017 on Luvisol (LV) with fine sandy loam texture, in central Poland – the zone of the greatest need for supplementary irrigation in terms of climatic criterion. The results proved that the yield of non-irrigated crops depended significantly on meteorological parameters and was characterized by very high variability, while sprinkler irrigation contributed to a significant yield increase of 42% and yield stabilization in years. The coefficient of variation calculated for the yield of irrigated plants decreased from 29 to 17%. Irrigation water doses as well as grain yield increases caused by sprinkler irrigation depended significantly on weather conditions in the period of high water needs of barley. Formulas developed on the basis of this analysis enable the forecasts of needs and effects of irrigation based on rainfall totals or rainfall/evapotranspiration ratio.

Keywords: Drought · Rainfall · Evapotranspiration

1 Introduction

In the contrast to arid and semi-arid climatic zones, where irrigation is the essential treatment in crop production, in Poland irrigation has a supplementary character. The demands for the use of this treatment primarily occur during droughts, which in the central part of the country appear irregularly but at the approx. frequency of 30% [5, 15, 16]. It is noteworthy that surpluses of soil moisture, in short sections or even in the whole growing seasons, occur with the same frequency. But for this reason, inter alia, irrigation systems in Poland (according to data from National Statistical Office) [6] cover only about 73 thousand hectares, whereof sprinkler irrigation mainly used in horticultural crops accounts for 8.7 thousand ha. Research aimed at the development of irrigations in central Poland include mainly the issues concerning the advisability of its

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 46–52, 2019.
https://doi.org/10.1007/978-3-030-16542-0_7

use in the cultivation of different plant species by determination of production efficiency and economy and changes in quality of yield or optimization irrigation doses in relation to water needs of plant [3, 4, 8, 11, 13].

The purpose of the paper was to determine the yielding and production needs and effects of sprinkler irrigated spring malting barley (*Hordeum vulgare* L.) depending on the intensity of droughts occurrence during the period of the high demand for water of barley (May-June), determined on the basis of selected meteorological parameters.

2 Materials and Methods

The needs and effects of barley irrigated by sprinkler system were developed on the basis of the results of multi-annual field experiments with spring malting barley cultivars carried out in 2006–2017 (with the exception of 2014). The experiments were conducted in the research centre of the University of Science and Technology in Bydgoszcz (53°13′N, 17°51′E, 98.5 m.a.s.l.) within the zone of the greatest need for supplementary irrigation in Poland in terms of climatic criterion on a Luvisol (LV) with a fine sandy loam texture [17].

Spring malting barley was optimally irrigated, providing plants with readily available water in the root zone throughout the period of plant high water needs, spanning May and June. The irrigation schedule was established on a constant monitoring of moisture in the root zone by a counterbalance of the amount of readily available water. The procedure was based on meteorological parameters measurements and soil moisture measurements by the soil moisture meter Fieldscout TDR 300. Barley was irrigated by a portable sprinkler system with low-pressure Nelson-type sprinklers with the discharge of 200 $dm^3\ h^{-1}$. The amount of individual irrigation rates and the total seasonal rate of discharged water depended on the weather conditions, mainly on the rainfall volume and distribution. Detailed information on the factors and design of experiments as well as farming practice are presented in the papers of Żarski et al. [14] and Błażewicz et al. [1]. The average level of nitrogen fertilization was 45 kg ha^{-1} due to intended use of grains for malting purpose. In the research, results of meteorological measurements carried out in a traditional way in accordance to the World Meteorological Organisation procedures, at the measuring point in the vicinity of experimental field, were used. To examine the strength of the relationship between results of the 11-year field experiments with barley and meteorological data, an analysis of regression was applied. In the study were searched the most significant dependencies between yielding of barley cultivated without irrigation and the needs and production effects of irrigation treatment, and selected meteorological indicators in the period of plant high water needs, i.e. from May 1 to June 31. The following meteorological indicators were taken into account: absolute rainfall (P), relative precipitation index (RPI), standardized precipitation index (SPI) [5] and the rainfall/potential evapotranspiration ratio (ET) (evapotranspiration calculated by Grabarczyk formula:

$$\mathrm{ET} = 0.32(\mathrm{d} + 1/3\mathrm{t}) \tag{1}$$

where: d – average air saturation deficit (hPa), t – average air temperature (°C). According to the results of research by Grabarczyk and Żarski [2] this formula better represents plant water needs in the climatic conditions in Poland, compared to the reference model of Penman recommended by FAO. In addition, it does not require the use of plant's coefficients kr, which in the period of the plant high water needs and optimal soil moisture conditions amount to about 1.0.

3 Results and Discussion

Meteorological conditions in the period of plant high water needs, in subsequent seasons of the experiments with irrigated barley, differed greatly. The total rainfall was on average of 117.7 mm, varying from 27.0 mm in 2008 to 178.6 mm in 2007. The values of RPI ranged from 26 to 175%, SPI from −2.45 to 1.58, and the ET/P ratio from 0.11 to 0.92. Based on the results of the analysis, the following seasons were identified: 2 dry, 3 averages, 3 wet, 1 moderately wet and 3 very wet (Table 1). Irrigation was carried out in almost all years of experiments except 2009 – the wet one, when no demand for water supplementation occurred. In the remaining seasons referred to as wet and moisture, the need for sprinkler irrigation use resulted from the uneven rainfall distribution during the period of barley high water needs. Summarizing, the 11–year research period was wetter than the average multi-annual rainfall conditions in the region: RPI was 115%, and SPI 0.46.

Table 1. Meteorological indicators and the total irrigation rates over the period of high water needs in malting barley from May to June. (P – rainfall total, RPI – relative precipitation index, SPI – standardized precipitation index, P/ET – rainfall total to potential evapotranspiration ratio, D – total irrigation rate).

Year	Drought level acc. to SPI	P mm	RPI%	SPI	ET mm	P/ET	D mm
2006	Normal	81.7	80	−0.40	245	0.33	90
2007	Very wet	178.6	175	1.58	195	0.92	30
2008	Extremely dry	27.0	26	−2.45	235	0.11	180
2009	Wet	142.7	140	0.96	165	0.86	0
2010	Normal	110.7	108	0.31	161	0.69	105
2011	Wet	139.2	136	0.89	231	0.60	75
2012	Moderately wet	159.2	156	1.25	209	0.76	70
2013	Wet	141.0	138	0.92	193	0.73	60
2015	Moderately dry	54.6	53	−1.23	241	0.23	135
2016	Moderately wet	149.5	146	1.08	268	0.56	67
2017	Normal	110.6	108	0.31	223	0.50	55
Average	**Normal**	**117.7**	**115**	**0.46**	**215**	**0.55**	**79**

The analysis showed that grain yield of non-irrigated barley in the years of research was on average 4.09 t ha^{-1} (Table 2). In the individual seasons, barley yields were characterized by a high variability – from 1.98 to 5.90 t ha^{-1}; the coefficient of variation (CV) amounted to 29%. Regression analysis showed that the yield depended significantly on rainfall totals during the period of high water needs of spring malting barley, in the period spanning May and June. Among the analyzed indicators, stronger correlation with the non-irrigated barley grain yield revealed the P/ET ratio (Fig. 1), but also the absolute rainfall totals determined the yield in the similarly significant extent. In three May–June periods, in which the total rainfall in the period critical for plant, was less than 82 mm and the P/ET ratio did not exceed 0.33, the grain yield was lower than the multi-annual mean, by an average of 37%. The yield decrease resulting from the occurrence of meteorological and agricultural droughts during plant vegetation is a distinctive feature of crop production in central Poland. It affects all crops, but to a greater extent the spring cultivars compared to the winter ones; it is recorded at the frequency of about 30%. Therefore it means that it occurs on average once every 3 years [5, 15, 16].

Table 2. Seed yields and sprinkler irrigation effectiveness in malting barley depending on drought level (O – non-irrigated, W – irrigated).

Year	SPI	Drought level acc. to SPI	Yield 15% moisture content (t ha^{-1})		Yield increase under irrigation		
			O	W	t ha^{-1}	%	kg mm^{-1}
2006	−0.40	Normal	2.64	5.32	2.68	102	29.8
2007	1.58	Very wet	4.79	5.03	0.24	5	8.0
2008	−2.45	Extremely dry	1.98	5.37	3.39	171	18.8
2009	0.96	Wet	5.90	5.90	0.00	0	0.0
2010	0.31	Normal	3.76	5.17	1.41	38	13.4
2011	0.89	Wet	3.67	4.83	1.16	32	15.5
2012	1.25	Moderately wet	4.45	5.64	1.19	27	17.0
2013	0.92	Wet	4.95	5.64	0.69	14	11.5
2015	−1.23	Moderately dry	3.11	7.51	4.40	141	32.6
2016	1.08	Moderately wet	5.07	7.83	2.76	54	41.2
2017	0.31	Normal	4.69	5.70	1.01	22	18.4
Average	**0.46**	**Normal**	**4.09**	**5.81**	**1.72**	**42**	**21.8**

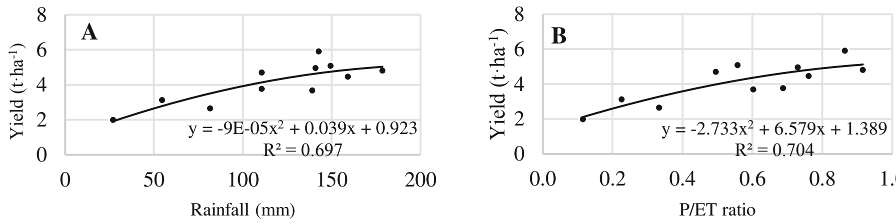

Fig. 1. Dependence of grain yield of non-irrigated spring malting barley (t ha^{-1}) and meteorological parameters in May-June; A – rainfall (mm), B – P/ET ratio.

The needs of sprinkler irrigation of spring malting barley determined by means of seasonal irrigation doses were on average 79 mm, ranging from 0 to 75 mm in moist and wet periods, to 135–180 mm in dry periods (Table 1). The needs significantly depended on both: the rainfall totals as well as the P/ET ratio (Fig. 2).

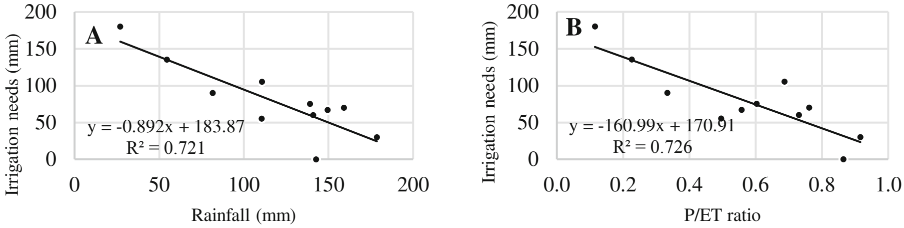

Fig. 2. Dependence of spring malting barley irrigation needs (mm) on meteorological parameters in May-June period; A – rainfall (mm), B – P/ET ratio.

The grain yield of irrigated barley averaged 5.81 t ha^{-1} in the years of study, varying in different growing seasons from 4.83 to 7.83 t ha^{-1} (Table 2). Irrigation contributed to the stabilization of the crop, since the coefficient of variation (CV) of the yield obtained from irrigated plots amounted 17%. Irrigation assured the correct rhythm of growth and development of plants and intensified their physiological processes.

As the result, the average long-term production effect of irrigation applied in spring barley, destined for malting, amounted to 1.72 t ha^{-1}, which determined an increase in the grain yield of 42%. One mm of water from the irrigation system made an average increase in grain yield of 21.8 kg mm^{-1} ha^{-1}. In the individual seasons, the production effects of irrigation depended significantly and linearly on meteorological parameters in the period spanning May and June (Fig. 3). The P/ET ratio (R^2 = 0.7921) was a better indicator of these effects compared to the absolute rainfall totals.

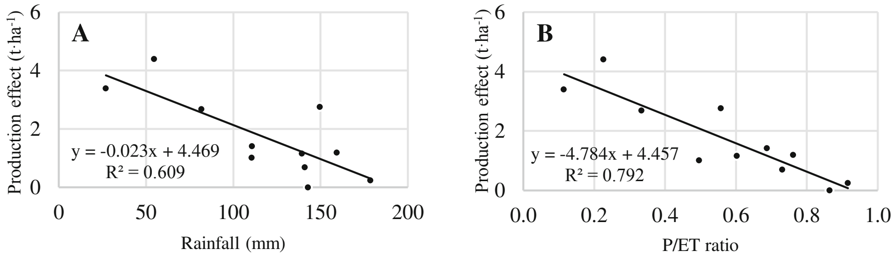

Fig. 3. Dependence of production effects of irrigated spring malting barley (t ha^{-1}) on meteorological parameters in in May-June period; A – rainfall (mm), B – P/ET ratio.

The production effects of sprinkler irrigation obtained in the studies indicate that there is a great potential for increasing crop production in central Poland, provided that the water factor is at the optimal level. Based on the obtained results, the introduction of available sprinkler irrigation systems to the cultivation technology of spring malting barley is a procedure that assures the growth and stabilization of grain production, whereas in dry vegetation periods – it prevents radical yields decreases. In practice, however, the popularisation of this system in the climatic conditions of central Poland will depend primarily on its economic efficiency, which depends on grain purchase price [3] as well as the infrastructural conditions, mainly including the access to water sources available for irrigation [13]. Regional character of the study showing the needs and effects of use sprinkler irrigation in the production of spring malting barley in Poland is justified by other results obtained in research carried out in different climate zones [7, 9, 10, 12].

4 Conclusions

The results of long-term (2006–2017) field experiments dealing with sprinkler irrigation in spring malting barley production in central Poland proved that the yield of non-irrigated crops depended significantly on meteorological parameters and was characterized by a high variability. Sprinkler irrigation contributed to a significant 42% increase in grain yield and its stabilization in years. The coefficient of variation calculated for the yields of irrigated plants decreased from 29 to 17%. Irrigation water rates as well as increases in grain yields caused by sprinkler irrigation depended significantly on meteorological parameters in the period of barley high water needs, spanning May and June. Formulas developed on the basis of this analysis enable the forecasts of needs and effects of irrigation based on rainfall totals or rainfall/evapotranspiration ratio.

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Irrigation Effects of Red Beet as Affected by Rainfall in Different Regions of Poland

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Abstract. The purpose of research was to determine the irrigation effects on the root yield of red beet grown on light soil in different regions of Poland, depending on rainfall amounts during the period July-August. Relationship between the increases of root yield and applying of irrigation was estimated using the Grabarczyk's formula. The amounts of rainfall in the average dry year, medium dry and very dry were determined by the Ostromęcki's method. Rainfall deficits in the cultivation of red beet were determined according to the difference between optimum and real precipitation in five meteorological stations. The highest precipitation deficiencies in the red beet crops in July-August were observed in the central Poland, where amounts 51–52, 98 and 118–124 mm, in average dry, medium dry and very dry years, respectively. The highest increases of the root yield obtained using irrigation were estimated also in the central Poland, where amounts 9.26 and 8.96 t ha^{-1}, 17.30 and 17.28 t ha^{-1}, and 20.92 and 22.00 t ha^{-1} in average dry, medium dry and very dry years, respectively. The increases of red beet yield obtained using irrigation showed the large possibilities of raising its productivity in the field cultivation under optimal water conditions.

Keywords: *Beta vulgaris* L. · Irrigation · Water needs · Regions of poland

1 Introduction

The water needs of red beet *Beta vulgaris* L. during the growing period were estimated at around 300 mm [5] or 300–400 mm [1–3]. According to [3] the optimum precipitation for red beet cultivated in the central region of Poland range from 400 to 450 mm

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 53–58, 2019.
https://doi.org/10.1007/978-3-030-16542-0_8

on heavy and medium soils and from 450 to 500 mm on light soils. The highest water needs during the vegetation period occurs in July and August, when the storage roots are growing rapidly [5].

The aim of presented study was to determine the expected effects of irrigation on the yield of the red beet grown on the light soil in different regions of Poland and depending on precipitation amounts during the period July-August (critical period).

2 Materials and Methods

In the present research, a straight line dependency between the red beet (*Beta vulgaris* L.) yield of roots increases obtained after using the irrigation and precipitation amounts during the period July-August was evaluated. The relationship between the increases of root yield and applying of the irrigation was estimated using the Grabarczyk's formula (1) [4]:

$$Q = \left(P_{opt} - P_{rz}\right) \times q \tag{1}$$

where:

Q – yield increases obtained after using the irrigation (kg ha^{-1}),
P_{opt} – optimal precipitation amounts in the period of increased water needs of the plants (mm),
P_{rz} – real precipitation amounts in the period of increased water needs of the plants (mm),
q – yield increases obtained after using the irrigation (kg ha^{-1} per 1 mm of precipitation deficiencies).

The determination of the red beet yield increases obtained after using the irrigation depending on precipitation amounts in the critical period (July-August) was performed according to [12] formula (2):

$$Q = (190 - P_{rz}) \times 177 \tag{2}$$

According to [5], it was assumed that the period of increased water needs of red beet plants lasts from July 1 to August 31.

The increases of the red beet root yield obtained after using irrigation were determined for five agro-climatic regions of Poland [10] with the representative meteorological stations located in Olsztyn, Bydgoszcz, Warszawa, Wrocław and Kraków (Fig. 1).

The amounts of precipitations in the average dry years (P50%), medium dry years (P25%) and very dry years (P10%) were determined by the Ostromęcki's method [14, 15], using Bp% coefficients that determine the variability of precipitation in the particular meteorological stations. The calculations were carried out for precipitations measured in the years 1981–2010. Precipitation deficiencies in the cultivation of red beet were determined based on the difference between optimum precipitation (Popt) and real precipitation (Prz) in the particular meteorological stations.

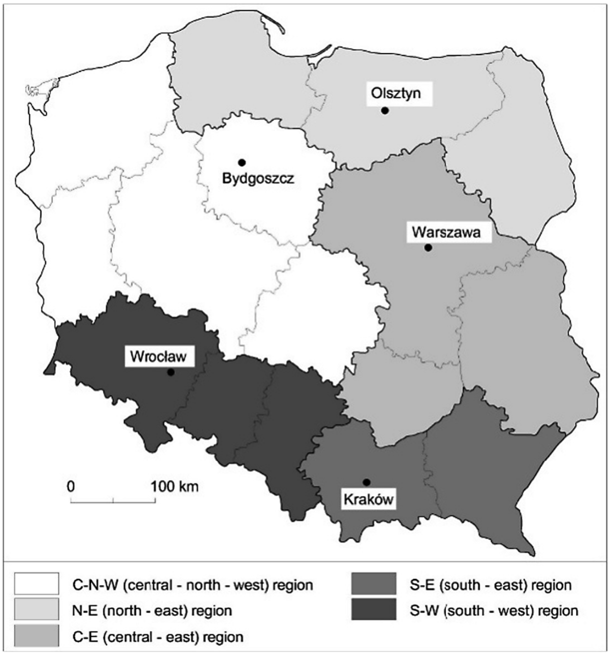

Fig. 1. Agro-climatic regions of Poland with the representative meteorological stations (according to [10]).

3 Results

In the average dry years, the highest precipitation deficiencies (51–52 mm) in the red beet cultivation were calculated in the C-N-W and N-E and C-E regions, and the lowest (25 mm) in the S-E region (Table 1). Subsequently, in the medium dry years, the highest precipitation deficiencies (98 mm) were measured in the C-N-W and C-E regions and the lowest (74 mm) in the S-W region. Finally, in the very dry years, the highest precipitation deficiencies (124 mm) were observed in the C-E region.

The expected increases of the red beet root yield obtained after irrigation applying, in the average dry years, amounted 8.96, 9.04 and 9.26 t ha^{-1} in the C-E, N E and C-N-W regions, respectively, (Table 2). Whereas, the lowest expected increases of the red beet root yield was noted in the S-E region. In the medium dry years, the root yield of red beet obtained after using irrigation was higher, ranging from about 17.3 t ha^{-1} in the C-N-W and C-E regions to 13.15 t ha^{-1} in the S-W region. Eventually, in the very dry years the applying of irrigation could increase the red beet root yield from 18.12 t ha^{-1} in the S-E region to 22.00 t ha^{-1} in the C-E region.

Table 1. Rainfall deficiencies (mm) in the red beet cultivation at the period July-August in the different regions of Poland.

Year in terms of the amount of rainfall	Probability (P) of occurrence % of years	Region of Poland				
		N-E	C-N-W	C-E	S-W	S-E
Average dry	50	51	52	51	41	25
Medium dry	25	85	98	98	74	80
Very dry	10	112	118	124	112	102

Table 2. Expected increase of red beet yield (t ha^{-1}) obtained after using irrigation in different regions of Poland.

Year in terms of the amount of rainfall	Probability (P) of occurrence % of years	Region of Poland				
		N-E	C-N-W	C-E	S-W	S-E
Average dry	50	9.04	9.26	8.96	7.34	4.38
Medium dry	25	15.09	17.30	17.28	13.15	14.12
Very dry	10	19.87	20.92	22.00	20.04	18.12

4 Discussion

The present studies basing on the relationship between the increases of the red beet root yield obtained after using irrigation treatment and the amounts of precipitation during the critical period (July-August) when, usually, increased the water needs of the plants [12]. The mathematical formula characterizing this dependence, showed the increases of red beet root yield observed as the effect of using irrigation technique, occurred in the period from July 1 to August 31, when the rainfalls were lower than 190 mm. The assessment of precipitation deficiencies in the critical period (July-August) in the cultivation of red beet that based on the comparison of the expected water needs and real precipitation in the particular regions of Poland ($P_{50\%}$, $P_{25\%}$ and $P_{10\%}$), showed the highest precipitation deficiencies in the central Poland (C-N-W and C-E regions). Similarly, [4, 13, 16, 17] also confirm the occurrence of the highest water requirements in the central regions of Poland.

The increase of red beet root yield obtained after irrigation treatment that was estimated in the presented study, indicate the large possibilities of raising the yield of red beet cultivated in the field under optimal water conditions. The prognostic formula, derived from the field experiments allow determining the effects of red beet plants irrigation on the root yield depending on the amounts of precipitations in the different regions of Poland. Similar estimates, including such species as root celery or cucumber, were performed by [17].

According to the reports presented by [6–9, 11], the expected in the near future climate changes, such as the raise of temperature, lead to the increase of water requirements of the plants, including vegetable field cultivation. The direction of climate changes compels the conception of a number of adaptation activities, such as irrigation treatments, whose role will be appropriately increased along with progressing weather modifying.

Additional factors that stimulate the development of irrigation techniques in the field cultivation of vegetables, regardless of the expected climate changes, are the necessitate to guarantee higher and stable, and good quality crops, as well as ensuring the modernity and competitiveness of agricultural and horticultural farms [16].

5 Conclusions

1. The highest precipitation deficiencies in the red beet crops during the period July-August were observed in the central Poland (C-N-W and C-E regions) where amounts 52 and 51 mm, respectively, in average dry years, 98 mm in medium dry years and 118 and 124 mm, respectively, in very dry years.
2. The highest increases of the red beet root yield obtained after using irrigation was estimated in the central Poland (C-N-W and C-E regions) where amounts 9.26 and 8.96 t ha^{-1}, respectively, in average dry years, 17.30 and 17.28 t ha^{-1}, respectively, in medium dry years, as well 20.92 and 22.00 t ha^{-1}, respectively, in very dry years.

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Application of the Triple Diagram Method in Medium-Term Water Consumption Forecasting

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Abstract. The paper discusses medium-term water consumption forecasting based on popular methods of time series analysis, indicating their limitation and strict requirements for the statistical properties of the time series, such as being stationary or linear. Therefore, a new approach in this area is proposed, based on the kriging method. This method is a geostatistical estimation method that provides unbiased linear estimates for the analyzed value. The study used the ordinary kriging method to provide input data for the preparation of a contour map. Coordinates have been replaced by water consumption values from earlier periods. The received "model" was tested against 24 months of historical data. For the triple diagram built using water consumption values from the two preceding months, the value of the assessment criterion for MAPE forecasting models was satisfactory (less than 13%).

Keywords: Triple diagram · Kriging model · Water consumption

1 Introduction

Urban water demand forecasting is an extensively researched subject. This results from the importance of providing high quality water in desired quantities to end-consumers, but also from the economic side of water municipality operation. Knowing water demand ahead not only facilitates its production but also ensures that the right quantity is provided. Water demand can be forecasted with different time horizons, although there is no consensus with regard to timeframes. Billings and Jones [1] define "long-term" as spanning for more than 2 years, "medium-term" as lasting from 3 months to 2 years and short-term as from 1 to 3 months. However, other authors [2] state that a "long-term" forecast should consider more than 10 years, "medium-term" ones from 1 to fewer than 10 years, and "short-term" ones from hour up to a year.

Over the years, a plethora of diverse forecasting methods and approaches has been applied to accurately forecast water demand. These include: moving average and exponential smoothing, stochastic process models, regression models, scenario-based approaches and decision support systems, artificial neural networks, composite/hybrid models. An extensive review of historically and currently used methods is presented by [3–6].

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 59–65, 2019.
https://doi.org/10.1007/978-3-030-16542-0_9

In this study our objective was to apply a method proposed by Altunkaynak et al. [7]. Their approach is based on a triple diagram model (using various kriging techniques) and has so far only been applied to forecasting water-level fluctuations in Lake Van (Turkey). Accordingly to Altunkaynak et al. [1] this forecasting method is independent of autocorrelation, linearity, Gaussian distribution, homoscedasticity and stationarity, therefore it overcomes the majority of limitations usually encountered in conventional forecasting methods. In this study we used this method to predict monthly water demand in the Czerniewice district (located in Toruń). The application of this method to a new environment (case) provide evidence that this approach is accurate not only in case of forecasting water level in lakes but also in case of water demand. The major benefit of this method is the fact that once applied it does not require usage of sophisticated software and the forecasts can be made based on printed charts. The following sections briefly describe this method and the data used.

2 Study Area

Toruń is located in north central Poland on the Vistula River. The city currently covers 116 km^2 and has a population of 202,500. In the past dozen-or-so years, numerous investments have been made in water and sewage management in the city. They have resulted in, among others, a doubling of the length of the water supply network (to over 584 km), increased access to the water supply (almost 100% of residents are connected to the network) and an improvement in water quality. Currently, the city is being supplied by three water intakes, at Drwęca-Jedwabno (surface-infiltration), Mała Nieszawka (a well) and Czerniewice (a well). From the first two points, water is pumped into a common water supply system that supplies almost the entire city. In the south-east of the city (about 7 km from the centre), the Czerniewice district has a separate water supply system supplied by the aforementioned well intake (which is named after the district – Czerniewice). The quality of raw water extracted from it is so good that it does not require treatment [8]. The selection of Czerniewice district as the study area for a water consumption analysis was conditioned by several factors. It is a mainly residential area, with the dominant building type being single-family housing and service points. There are no industrial plants in the area, which eliminates this factor's ability to cause abrupt changes in water intake. The district is small and served by a closed water supply system, and this ensures that the influence of other external factors will be minimal (or will at least be experienced roughly equally across the whole district, e.g. weather conditions – precipitation and evaporation), and that any failures can be quickly identified.

3 Methods

The research employed a geostatistic kriging procedure to estimate average monthly water consumption. The increasing interest in this interpolator is a result of its advantages, such as its minimisation of interpolation errors and the possibility to assess the accuracy of the estimated quantities [9, 10]. A fundamental tool in geostatistical methods is the semivariance function, in the following form (1):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z_i - z_{i+h})^2 \tag{1}$$

where:

h – distance between observations
Nh – number of pairs at distance ‘h’
z_i, z_{i+h} – values of observations at distance ‘h’

The theoretical model is fitted into the empirical semivariogram chart as one of the analytical continuous functions. The theoretical function of semivariance expresses the geostatistical variability of the modelled phenomenon and allows kriging equations to be solved. For ordinary kriging, weights for observations and the Lagrange constant are determined. The idea of kriging is to minimise the difference between the estimated and true value of a parameter while accurately reflecting the expected value (which is known as the “best linear unbiased estimator”). The advantage of geostatistical kriging methods is their ability to estimate the modelling error, known as the “kriging error”. Meanwhile, their disadvantage is the phenomenon of “smoothing”, which leads to overestimation of low values of the parameter and underestimation of high values [9, 10].

The Kriging technique was used to create Triple Diagram (TD) [1]. This method requires three variables. Two of them (predictors) build a scatter diagram and refer to the third variable (prediction value). The equal value lines on TD are determined based on Kriging technique. Preparation of the Triple Diagram helps to predict the value, which is mapped in known variables.

4 Results

In the study, the empirical data set was divided into two subsets. The first included monthly observations from 2000–2010, and the second from 2011–2012. The first set was used to model the studied phenomenon. The second was used to check the effectiveness of the tool that had been made. Monthly water consumption (Lag-0) was described by two variables, an observation with a one-month delay (Lag-1) and one with a two-month delay (Lag-2). Those three variables (Lag-2, Lag-1, Lag-0) was used to build the Triple Diagram. The best match for the theoretical semivariogram was obtained for the Power model (Scale – 10, Length – 1, Power – 1.57) with the Nugget Effect (Variance – 2,600,000) – Fig. 1.

The resulting semivariogram allowed the distribution of average monthly water consumption to be determined using the Lag-1 and Lag-2 system in the form of a Triple Diagram model (Fig. 2) with information about the model’s estimation error in the form of the kriging standard deviation (Fig. 3).

For the triple diagram model (using water consumption from two previous months as the input) the observed MAPE value was 12.9%, which is a relatively good result

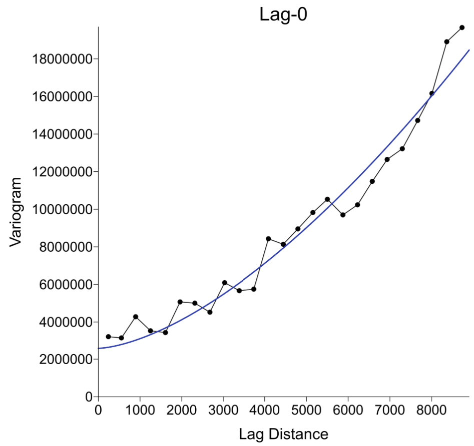

Fig. 1. Power semivariogram model based on empirical monthly water consumption.

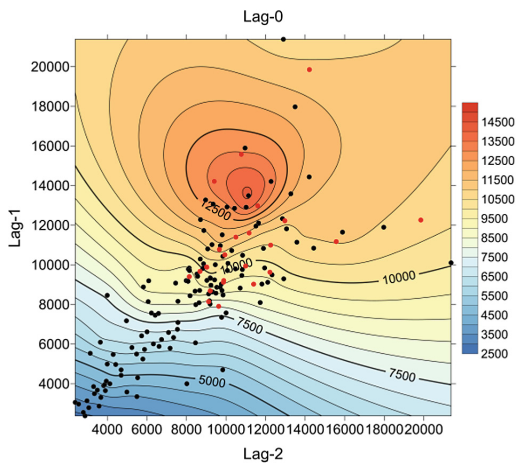

Fig. 2. Triple Diagram model of water consumption [m3/month]. The black dots represent observations from 2000–2010, which was used to construct TD. The red dots was used to evaluate the prediction model and represents the observation from 2011–2012.

considering the fact the more sophisticated Artificial Neural Network (ANN) method [8] gave forecasts with MAPE values slightly below 10%. It is important to note that the triple diagram model used only past water consumption values, whereas the ANN model was fed with additional exogenous variables such as: humidity, temperature, etc. The low value of R^2 indicates that the triple diagram model does not explain the whole variability of observed phenomena and there is still significant potential to improve it by considering additional variables.

The data from the period 2011–2012 was compared against the results of modelling in Fig. 4.

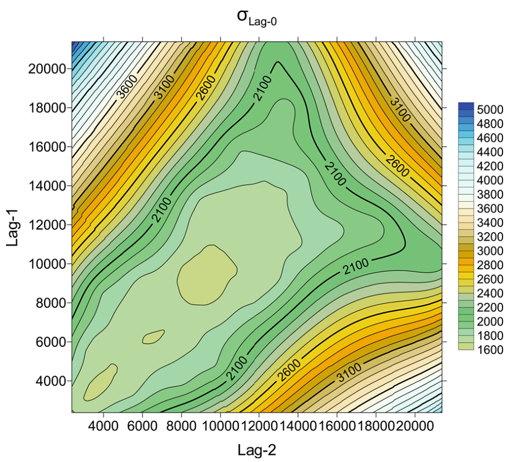

Fig. 3. Standard deviation of kriging technique.

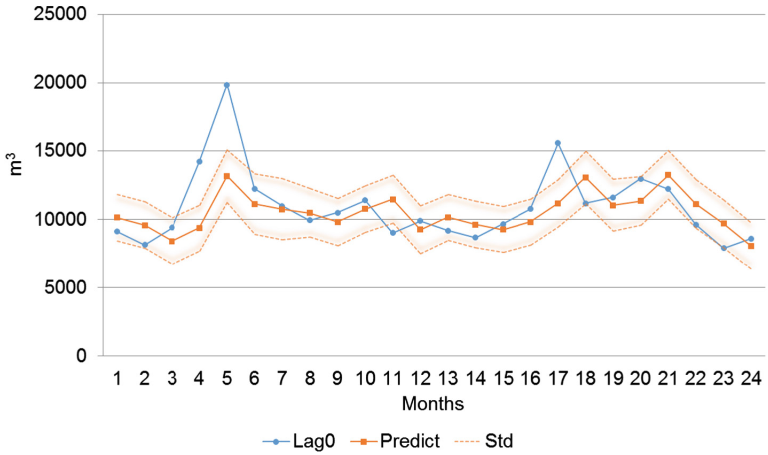

Fig. 4. Forecasted (based on kriging model) and observed water consumption.

5 Discussion and Summary

In the analyzed period (2000–2012) there was a significant increase in the amount of water used in the discussed district of Toruń. This is a tendency opposite to that observed in the rest of the city, as well as in other Polish cities. The reason for this is the relatively young age of the district and its attractiveness as a place of residence. This has resulted in a steady increase in the town's population in recent years. The inhabitants of this part of Toruń are largely affluent, so they do not necessarily limit water consumption in response to its rising cost.

The Triple Diagram water consumption forecasting method used in the work provided results that were satisfactory in the short-term (one-month) perspective. As has been shown, it may be a very good alternative to other advanced statistical methods, such as ANN. However, this method has some limitations that cause the overestimation low parameter values and the underestimation of high values. For forecasting water consumption this is of great importance because quite often there are sudden changes in values, which may be caused by weather conditions (wet or dry periods), infrastructure failures, industry, etc. As mentioned, in this example the possibility of these disturbances was minimised by the specific local conditions of the Czerniewice district. In spite of this, even in this case significant differences in values were found for several months (Fig. 4). The biggest differences were found in the spring months, and above all for May. This situation seems understandable when we take into account the specificity of Poland's prevailing climatic conditions (a moderate transitional climate). Here, spring is the most variable and unpredictable season of the year. In addition, due to globally observed climate changes, more and more years with periods of extremely different weather conditions (hot and dry or humid and cold) are also being recorded in Poland. Another symptom of climate change in Poland is the increase in average air temperature values from March to May, resulting in the accelerated vegetation of plants. This was the case in 2011–2012, when the largest deviations from the forecasted values occurred. The warmer spring months (March–May) resulted in accelerated vegetation in those years. In the analyzed district of Toruń, there are a lot of back gardens and lawns that required more water at that time.

Summing up, it should be recognised that the presented Triple Diagram method confirmed its usefulness in the study area and can be proposed as an alternative to the model currently used (in Torun Waterworks Company Ltd), which has an incremental time series and in which the MAPE error is over 16%. The method also has some limitations, which is why further works are planned on its use in other water supply systems.

Acknowledgement. This work was financed by a Dean's grant No. 15/11.200.363.

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Comparing the Retention of the Extensive Green Roofs with the Conventional Roof

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Abstract. The inevitable development of cities has necessitated of a searching for new alternative solutions that enable the retention of as much rainwater as possible and increase the biologically active surface in urbanized areas. Green roofs may be the solution to the mentioned problems. The work assessed how meteorological factors influence the retention on two types of green roof substrates. Another practical aspect of the study is determining the difference in retention of mineral-organic and mineral substrate based extensive green roofs. The monitoring of environmental factors and amount of runoff was carried out on two models of green roofs covered by extensive vegetation (moss-sedum-herbs) with substrates of an organic-mineral and mineral composition for 18 months in an urbanized area under moderate climate conditions. Higher values of runoff by approx. 5% were registered in the model with the mineral substrate, which indicates lower retention abilities. The analysis of two green roofs and references roof showed that the runoff coefficients ranged from 0.33 to 0.38 for GR 1 and GR 2, for RR runoff coefficients was 0.83. Rainwater entering the system of green roofs is the most important input factor in the conceptual model of the retention of a green roof system. The obtained results can provide us with information important to make decisions connected with designing green roofs as far as hydrological advantages are concerned.

Keywords: Extensive green roof · Stormwater retention · Sustainable urban stormwater management

1 Introduction

The progressing development of cities has made it necessary to seek out new alternative solutions which will facilitate the retention of rainwater as well as increase biologically active surfaces in urbanized areas [1, 2]. In many countries, the application of sustainable drainage systems (SUDS) is recommended for the management of rainwater runoff as opposed to traditional pipe drainage systems [3, 4]. Green roofs have the potential to meet these aims and, thanks to this, can work in collaboration with natural environmental processes, contributing to a sustainable urban environment [5–7]. Including green roofs in sustainable drainage systems in urbanized areas, it is

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 66–74, 2019.
https://doi.org/10.1007/978-3-030-16542-0_10

important to understand, at the design stage, how such roofs function, both in the case of extreme rainfall events (required in the case of flood protection), as well as under during normal rainfalls. Data provided in literature shows that the water retention abilities of extensive green roofs fall within the range of 40–80%, and intensive 80–90% of rainfall depth [8–12]. Retention of 100% for rainfalls of under 2 mm was noted by [13] in Sheffelds (Great Britain) for 9 models of green roofs characterized by different compositions of substrates. On the other hand, for rainfalls of over 10 mm the average retention ranged from 26.8% and 61.8% (depending on the configuration of the roofs). While interregional comparisons can be helpful, one ought to account for factors specific to a given location due to the information necessary for taking decisions regarding the designing of green roofs in terms of rainwater management in urbanized areas [14, 15]. In connection with this, in order to assess the efficiency of green roof systems in Poland, where every year the problem of flooding occurs, more studies in various regions of the country ought to be conducted. The present studies were conducted under conditions of a continental humid climate, where the influence of a large urban agglomeration on the climate is clearly marked. The main novelty of the research was to assess the retention of rainwater by extensive green roofs on the background of conventional roof. Studies on the influence of climate factors on retention on green roofs were also carried out. An extensive type of vegetation was selected because extensive green roofs are the kind of most often applied and require minimum maintenance. This type of green roof, which has the widest scope of application, is affordable and can be constructed on the majority of roofs (even with a slope of up to 45º [16, 17], has significant potential for application in Poland as, among others, a tool aiding the stormwater retention in urbanized areas. Another practical aspect of the studies is determining the difference in retention applying a mineral-organic and mineral substrate. A substrate with a mineral composition was originally prepared to limit P runoff from green roof [17, 18]. The substrate developed from widely available and cheap materials not only decreases P runoff, but allows for proper Sedum development and can be successfully applied in extensive green roofs.

2 Materials and Methods

In the article, results obtained from the vegetation period (IV–IX) in the years 2015–2017 at the area of the Water Centre of SGGW in the southern part of Warsaw were subject to analysis. Models of extensive green roofs were constructed in two cuvettes, one was developed as a reference unit. Each cuvette was drained using an 8 cm diameter drain pipe. All cuvettes have an internal dimension of 2 m/1 m/0.2 m (length/width/depth) and are inclined at an angle of 2%, their internal volume is 0.4 m^3 (Fig. 1). Two types of substrates were used in the green roofs constructions that were implemented in accordance with the [19] guidelines. The characteristics of the green roofs (GR 1–2) and reference (RR) model are shown in Table 1.

Table 1. Characteristics of test models.

Designation	GR 1	GR 2	RR
Extensive vegetation	Pre-cultivated vegetation mat XF317 moss-sedum-herbs; thickness of 2.5 cm (Sedum album, Sedum acre, Sedum kamtschaticum, Sedum spurium, Sedum reflexum, Sedum sexangulare, Dianthus deltoides, Dianthus carthusianorum, and Thymus vulgaris) (Xero Flor 2016)		None
Vegetation layer-an extensive substrate with a thickness of 15 cm	"SPG E-E" - mixture of washed sand, gravel, limestone, crushed red brick, broken fine lime, peat and compost	"SPG E-M - type 1" mixture of washed sand, gravel, limestone, crushed red brick	
Filter layer	Polyfelt TS 20 polypropylene geotextile with a GRK 2 strength class, weight 125 g/m^2		
Drainage layer	Terrafond Garden drainage mat 20L, height 2 cm		
Protective layer	Polyfelt TS 20 polypropylene geotextile with a GRK 2 strength class, weight 110 g/m^2		
Water insulation	Heat-sealable bitumen sheeting root resistant in accordance with PN-EN ISO 13948		
Underlay	OSB boards with thickness 16 mm with slots not exceeding 5 mm		

Rainfall measurements were carried out using a Hellmann rain gauge, placed next to the measuring stations. Outflows in the months April-September 2015 and April-October 2016 were measured by volumetric method after each rainfall. Since the beginning of November 2016, Odyssey appliances were installed and the outflows were recorded at 10 min intervals. Measurement vessels were calibrated at the Water Centre of Warsaw University of Life Sciences.

Fig. 1. Experimental object

On the basis of the obtained results of the runoff from the green roofs and the reference roof models, the flow coefficients and the amount of retained water were calculated. Measurements of the amounts of precipitation, air temperature carried out in a continuous manner at a weather station situated near the measurement stations. 24-h mean values of the weather parameters prior to the inception of each event were calculated. Based on a conventional approach relying on determining atmospheric precipitation suggested and assumed in other studies of the "green roof" type, rainfall events separated by six or more hours are classified as independent events [20, 21]. There were, however, situations when runoff from a previous event was still ongoing and another event occurred. In such situations, the two adjacent "events" were combined into one. Based on the measurements, a relative daily retention for each container was calculated using Eq. 1 [20]:

$$R = \frac{P - H}{P} \cdot 100\% \tag{1}$$

where:

R - retention [%],
P - precipitation [mm],
H - runoff [mm].

STATGRAPHICS Centurion XIV computer software was used for comparisons and statistical analyses.

3 Results and Discussion

3.1 Weather Profile of the Study Period

During the study period, 232 days of rainfall were noted, with total rainfall of 1106.30 mm (average 4.79 mm; min. 0.1 mm; max. 67.10 mm; median 2.10 mm). Rainfalls with P < 5 mm comprised 73.3% of all noted rainfalls, rainfalls with a 5–10 mm comprised 15.8%, those of 10–20 mm – 7.9%, rainfalls with 20–30 mm – 0.9%, while those of 30 mm – 2.1% (Fig. 2a).

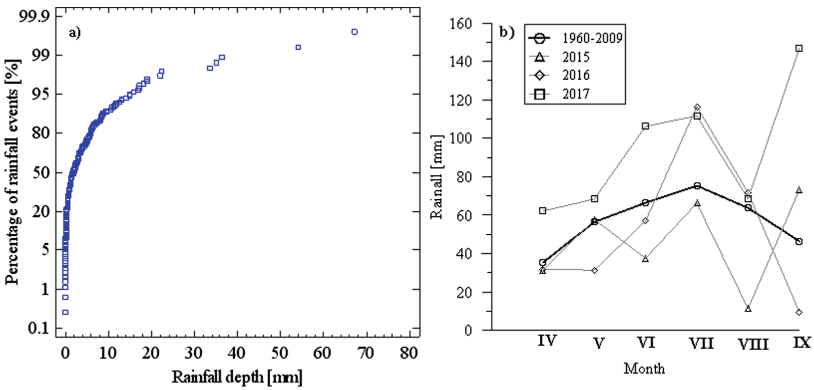

Fig. 2. Distribution of rainfall depths during the observation period (a), rainfall depth in 2015–2017 on the background of multi-year period (b).

In 2015, in the months of June – September, rainfalls differed significantly from the average observed in the multi-year period 1960–2009 (Fig. 2b). The month with the highest total rainfall was September (wet month) – the rainfall total equalled 73.1 mm. The month with the lowest total rainfall was August (extremely dry), when the total rainfall equalled 11.3 mm. In 2016, rainfalls differed significantly from the average from the 1960–2009 period in July and September [22]. The month with the highest rainfall was July 2016, with the monthly total equal to 115.1 mm (average rainfall from the multi-year period of 75.3 mm), while the highest daily rainfall occurred on July 12, 2016 and amounted to 67.10 mm. Similarly to 2015, the month with the lowest rainfall was September, when the total rainfall was 9.3 mm. In 2017, rainfalls were higher in all the analyzed months than the average from the multi-year period. The month which differed significantly from the average from the multi-year period was September 2017 – when the total rainfall amounted to 146.8 mm (average from the multi-year period of 46.4 mm). The maximum recorded rainfall was observed on 17 September 2017 and amounted to 54.10 mm.

3.2 Relationship Between Meteorological Parameters and Retention

In the year 2015, during the period IV-IX, the total rainfall amounted to 277.2 mm (19% less than average from the multi-year period), retention was 90% 84% for GR1 and for GR2 respectively. For the same period in 2016, total rainfall amounted to 317.9 mm (7% less of the average form the multi-year period), retention was 68% for GR1, and 64% for GR2. In 2017, in the period IV–IX, the total rainfall significantly exceeded rainfalls from the multi-year period and amounted to 663.3 mm (64% more than average from the multi-year period), retention amounted to 56% and 50% for GR1 and GR2 respectively. Over the course 3 years of in the vegetation period (IV–IX) on the model with the mineral-organic substrate (GR1), 5% higher retention than in the model with the mineral substrate (GR2) was observed. The Mann-Whitney W-test which was carried out additionally did not reveal any statistically significant differences between the GR 1 and GR2, $p > 0.05$. The linear relationship between rainfall depth and the retention, for both the GR1 as well as GR2 model, showed a negative correlation for $r(232) = -0.45$, $p < 0.05$, and $r(232) = -0.46$ (Table 2). The obtained negative values of correlation showed that, along with an increase in depth, the retention ability of green roofs decreases. The analysis of two green roofs and references roof showed that the runoff coefficients ranged from 0.33 to 0.38 for GR 1 and GR 2, for RR runoff coefficients was 0.83.

The research covering the three vegetation periods conducted on green roofs models and reference model proved, that green roofs are efficient SUDS measure in the scope of runoff volume reduction. Rainfall-runoff relation for both green roof models showed, that observed retention amounted 67% and 62% and was higher compared to reference model (17%). Obtained values were similar to reported by other Authors base on research run in different regions all over the world, where average retention was in the range of 40–90% [12, 21, 23–28]. [23] obtained 64% of runoff reduction for the sedum-moss roofs with a thickness of 3 cm influenced by natural and simulated precipitation. [21] base on 19 rainfall-runoff events for green roof located in Chongqing in China, concluded that average retention amounted 77.2%. Similar results were reported by [27] for the intensive green roof in Manchester, GB. The noted retention was 65,7% for 69 rainfall-runoff events.

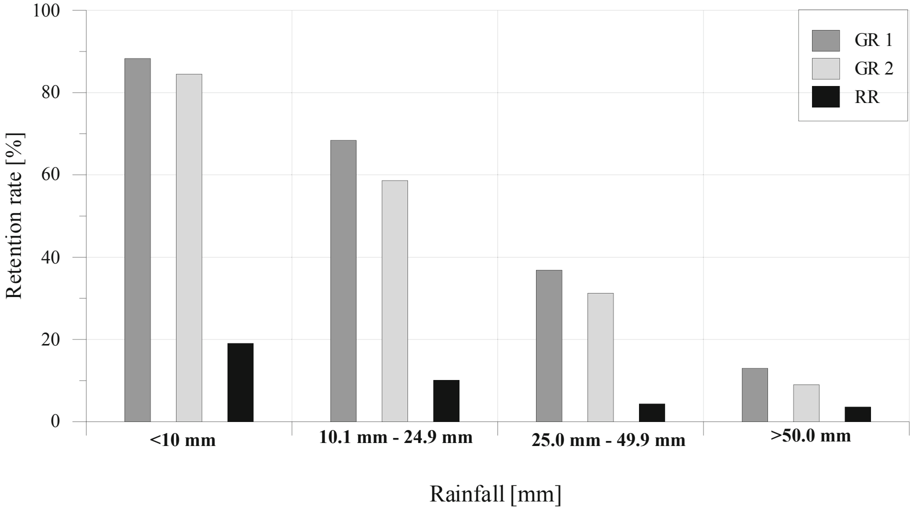

Fig. 3. The relationships between runoff retention in green roofs and outflow with conventional roof.

As shown on Fig. 3, green roofs retained nearly 88–84% of rainwater from small rainfall events (<10.0 mm), 58–68% in from of medium rainfall events (10–24.9 mm), 31–36% from large rainfall events (25.0–49.9 mm), and nearly 9–13% from storm events (>50 mm). [29] carrying out studies on an extensive roof, observed that water retention decreased from 90% for a rainfall depth of 13 mm to 39% with rainfall of 54 mm. Studies on the retention abilities of green roofs carried out by [30] in three Canadian cities showed that, for rainfall events of under 3 mm, retention ranged from 94.5% to 89.6%, and for rainfalls of over 15 mm from 58.5% to 36.4%, depending on the city. Table 2 shows the matrix of correlation for average values calculated for four metrological parameters preceding a rainfall (occurred 24 h prior to the rainfall). Connections between radiation (SR) and air temperature (T) as well as humidity (H) were found, as well as between air temperature (T) and wind speed (W). Additionally, a significant correlation between individual average input meteorological factors – air temperature, radiation and air humidity, and retention was obtained.

Some Authors suggest, that regional climatic conditions are significant factors influencing green roof retention [20, 31, 32]. At the local scale microclimatic conditions may differ between the roofs due to specific site condition. The results shoved, that volume of precipitation, humidity, radiation and air temperature have a significant effect on green roof retention. The obtained data show that the value of retention decreases with increasing rainfall and air humidity, while the increase in radiation and air temperature increases the green roofs retention ability. Performed statistical analysis confirmed that rainfall depth is strongly correlated with retention. Similar results are also reported by [5, 33–35]. [35] additionally stated, that radiation and wind speed are important factors influencing retention. In our study it was not confirmed in case of wind speed. Summing up, the results suggest that the interaction between meteorological factors and the percentage retention are probably complex and indirect. It is expected that some or all of these weather factors will work together with others resulting the influence of the retention of green roofs [35].

Table 2. Pearson correlation coefficient r and probability p (in brackets) of mean antecedent (24 h) meteorological parameters used in the multiple regression analyses. T - air temperature [°C], SR solar radiation [W m^{-2}], W - mean wind speed [m s^{-1}], H - mean relative humidity [%], P - rainfall depth [mm].

	SR	T	W	H	P
GR1	0.33 **(0.0000)**	0.22 **(0.0047)**	0.04 (0.5853)	−0.37 **(0.0000)**	−0.45 **(0.0000)**
GR2	0.24 **(0.0025)**	0.24 **(0.0024)**	0.08 (0.3110)	−0.29 **(0.0002)**	−0.46 **(0.0000)**

p-values below 0.05 indicate statistically significant non-zero correlations at the 95.0% confidence level.

4 Conclusions

In the article, the role of key environmental factors on rainwater retention on green roofs under the conditions of a continental wet climate was assessed. Subject to assessment was the difference in the amount of green roofs retention with a substrate characterized by a mineral-organic as well as mineral composition. Results from the statistical test suggest that rainfall depth, temperature and solar radiation are important factors which have the greatest influence on explaining percentage retention. These results support earlier studies that the total rainfall depth may have a strong influence on retention. Rainwater entering the system of green roofs is an input factor in the conceptual model of the retention of a green roof system. The retention ability of green roofs is, by nature, finite, thus the amount of retention depends largely on the number of rainfalls. Both models of extensive green roofs type were found to have a similar construction, though the model with the addition of low moor peat and compost revealed higher moisture content, both in the substrate as well as vegetation mat as compared to the model with the substrate of mineral composition (as confirmed by retention curves), signifying increased retention abilities. The analysis of two green roofs and references roof showed that the runoff coefficients ranged from 0.33 to 0.38 for GR 1 and GR 2, for RR runoff coefficients was 0.83. Over three years of observations during the vegetation period, the model with the mineral-organic substrate retained 5% more rainwater as compared to the model with mineral substrate. In addition to retention abilities, the mineral substrate reduces runoff of P and allows proper growth of Sedum and is a more practical solution than using the mineral-organic substrate.

Acknowledgment. The publication and research was conducted in the frame of cooperation project: "Testing of extensive green roof runoff for volume quantity and phosphate concentration" (1/KKŚ/2016).

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Energy Assessment of Organic Production

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Abstract. The paper presents efficiency of material and energy inputs and energy consumption of global and commodity production in organic farms with a varied production trend. These indices were expressed in traditional energy units. The results were obtained during a 3-year research conducted in 50 organic farms located in the southern Poland. The investigated facilities were divided into groups specialising in plant, animal and mixed production. Energy consumption was determined by division of the sum of energy streams i.e. direct energy carriers, raw materials and materials, investment means and repairs as well as live work by the sum of plant, animal production and other services. Efficiency of inputs was calculated as an inverse of energy consumption. The best result both with regard to energy consumption and energy efficiency were obtained by animal production farms.

Keywords: Organic farms · Production trend · Energy effectiveness · Energy consumption

1 Introduction

Organic farming due to its versatile aims is favoured by farmers both in Poland and around the world. It is proved by constantly raising number of organic producers [3, 4, 8, 19] However, we should remember that principles of organic farming differ from the ones used in the traditional farming. These differences affect the size, structure of incurred material and energy inputs and these, on the other hand, affect production efficiency [5, 6, 9]. Analysis of energy consumption of production is one of the methods of assessment of production effectiveness. It is described as co-dependence expressed in traditional energy units between the inputs incurred on production and their size [1, 11, 18]. The production size results, on the other hand, from the production potential, the use of which is varied. Since, it depends on the soil and climatic conditions which decisively influence the production trend [7]. This, on the other hand, will influence the improvement of indices of material and energy efficiency of its production. Agricultural producers wish to pass on the future generation an agricultural and rural environment, which is in a better condition than it has been so far, taking into consideration the decreasing area of agricultural land and changing structure of material and energy inputs and production services, they must intensify with a good quality of plant and animal production [2, 13, 20].

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 75–83, 2019.
https://doi.org/10.1007/978-3-030-16542-0_11

2 Aim, Research Area and Methods

The aim of the paper was to define the efficiency of material and energy inputs and organic energy consumption of global and commodity production in farms which differ with a production trend. The calculations were made based on the information collected during a guided survey with owners of 50 farms located on the territory of the southern Poland. All facilities had a certificate confirming an organic nature of the activity which was carried out.

In order to carry out a comparative analysis, a division of farms into groups specialising in plant, animal and mixed production was made. The production trend was determined based on the participation of particular activities in forming a general value of standard gross margin in a farm. Farms, in which participation of this type of activity exceeded 2/3 of the total value of the standard gross margin was called one-trend (specialists). While, farms, where any type of activity did not exceed 1/3 of the value of this gross margin were included into mixed farms [IGŻiE]. From among the investigated farms, 21 plant production farms were distinguished including a vegetable, horticultural and generally plant farm, 24 animal farms, mainly milk production and 5 with mixed production.

Calculations were made based on Wójciski's method [21]. Energy consumption was determined by division of the sum of energy streams i.e. direct energy carriers, raw materials and materials, investment means and repairs as well as live work by the sum of plant, animal production and other services. Particular elements were expressed in energy units using conversion factors of those traditional units [20]. Efficiency of inputs was calculated as an inverse of energy consumption.

3 Research Results and Discussion

The average area of agricultural land in the investigated farm was 12.61 ha. In the use the structure of land 51.3% consisted of permanent grassland, arable land constituted 41.7% of agricultural land and orchards and perennial plantations - 4.0% (Table 1). With regard to the size of acreage, animal production farms, with almost twofold higher production differed from the objects with the plant and mixed production. It resulted from a bigger area of grasslands, which at the average was 9.93 ha, while in case of the plant and mixed production farms it was respectively 3.90 and 2.43 ha. Research conducted by other specialists also indicates that organic farms that keep ruminants are characterized by a much larger share of permanent grassland than traditional farms [16]. The area of arable land was on the other hand comparable (Table 1).

Table 1. Organization of agricultural production

Specification	Number of farms	Area [ha]				Livestock	
		Agricultural land	Arable land	Permanent grassland	Orchards and perennial plantations	Large conversion unit [LSU]	[LSU ha^{-1}]
	Production trend						
Plant production	21	9.92	5.37	3.90	0.65	11.56	0.87
Animal production	24	15.70	5.43	9.93	0.33	13.58	0.88
Mixed production	5	7.79	4.63	2.43	0.74	3.99	0.77
Average	50	12.61	5.27	6.47	0.51	11.55	0.92

With regard to the size of the herd, farms with the mixed production differed, where it was 3.99 LSU while in the objects with plant and animal production trend it was respectively - 11.56 and 13.58 LSU. Livestock, on the other hand, in all three trends was comparable and was within 0.77 LSU ha^{-1} in the mixed farms to 0.88 LSU ha^{-1} in objects which deal with animal production (Table 1).

Table 2. Consumption of energy carrier [GJ]

Specification	Electric energy	Diesel oil	Leaded patrol	Fuel oil	Hard coal
	Production trend				
Plant production	31.789	36.880	0.649	0.728	0.002
Animal production	27.407	41.201	1.718	–	0.001
Mixed production	23.465	21.195	2.390	–	–
Average	28.853	37.386	1.336	0.306	0.001

Energy inputs in trend groups were similar and were within 23.456 GJ in the farms with the mixed production to 31.789 GJ in the plant production farms. Rationalization of farms with energy is favourably influenced by raising the level of production through improvement of soil fertility, the use of highly efficient plant species, correct crop rotation or reduction of losses. Moreover, it is important to improve the production processes of particular produces, improvement of technical condition of the agricultural equipment and other energy receivers and good organization of production processes [10, 12, 14]. Diesel oil was used in the biggest amount in animal production farms - 41.201 GJ. It was twofold more than in the mixed production plants with the lowest consumption (Table 2).

Table 3. Consumption of agricultural raw materials [GJ]

Specification	Sowing material	Seed potato	Concentrate	Volumetric fodders	Others
	Production trend				
Plant production	4.92	1.26	40.76	79.63	9.25
Animal production	12.40	2.47	57.25	86.07	16.11
Mixed production	4.283	0.550	36.608	52.600	5.200
Average	8.444	1.771	48.259	80.020	12.138

Analysis of the agricultural expenditures led us to a conclusion that farms specialising in animal breeding incurred explicitly higher inputs than the two remaining trend groups (Table 3). It should be mentioned that agricultural raw materials decisively came from own farm.

Table 4. Consumption of non-agricultural raw materials [GJ]

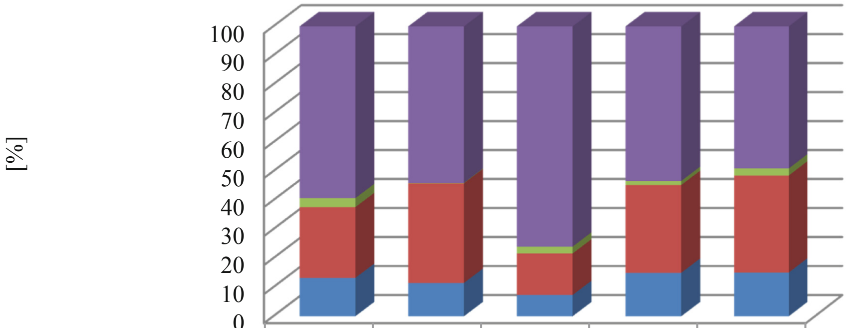
Specification	Fertilizers	Crop protection substances	Concentrate, vitamins, fodder additives	Supplementary materials	Cleaning agents
	Production trend				
Plant production	19.458	0.583	0.572	0.004	0.001
Animal production	2.150	–	1.362	0.008	0.003
Mixed production	–	2.760	0.221	0.005	0.001
Average	9.469	0.535	0.921	0.006	0.002

On the other hand, farms with the plant production trend incurred considerably higher non-agricultural inputs, Consumption of fertilizers in plant farms was 9-times higher than in animal production farms. On the other hand, mixed production farms did not apply fertilizers, and used the highest number of crop protection substances. Auxiliary materials, namely, foil, rope, packaging and cleaning substances constituted a small percent of consumption (Table 4).

Among the trend groups, the highest diversity was reported in case of repair of buildings, which burdened the animal farms the most. While, services and work inputs were decisively higher in farms with mixed production. Consumption of the remaining inputs in the trend groups was similar (Table 5).

Table 5. Remaining non - agricultural expenditures [GJ]

Specification	Water	Repair of machines	Renovation of buildings	Technical services	Replacement investments	Work expenditures
	Production trend					
Plant production	3.716	23.244	7.299	20.705	40.001	68.385
Animal production	7.986	37.059	67.354	9.406	44.099	89.323
Mixed production	7.680	57.540	3.800	70.440	26.956	124.480
Average	6.171	33.247	35.677	20.460	40.844	84.350



	up to 5 ha	5,01 - 10,00 ha	10,01 - 20,00 ha	above 20 ha	average
inputs other	59	54	76	53	49
inputs non-agricultural	3	0	2	1	2
inputs agricultural	24	34	14	30	33
inputs energy	13	11	7	15	15

Fig. 1. Structure of inputs in production trends

Participation of particular categories of inputs in the trend groups was similar. Energy inputs constituted from 18% in the plant production objects to 11% in the mixed ones. Participation of agricultural raw materials was 35% both in objects set on the plant production as well as on the animal production and 23% - on the mixed one. The highest participation of non-agricultural inputs was reported in the plant production objects [5%] and in the remaining groups it was only 1% (Fig. 1).

The highest global production calculated into gigajoules was obtained by farms which specialize in livestock breeding - 1307.819 GJ (Table 6). In all trend groups, the global animal production prevailed which constituted from 63.8%, in the plant production farms to 90.2% in the animal production farms. Commodity production constituted, on the other hand, at the average 20.5% of the global production. In the commodity production also a bigger participation in all trend groups was in case of animal production except for farms which specialize in plant production.

Table 6. Global and commodity production [GJ]

Specification	Global production			Commodity production		
	Plant	Animal	Total	Plant	Animal	Total
	Production trend					
Plant production	214.077	377.241	591.319	28.064	23.556	51.620
Animal production	128.559	1179.260	1307.819	6.641	314.815	321.456
Mixed production	125.162	321.756	446.918	14.218	112.582	126.800
Average	164.137	756.662	920.798	16.397	172.263	188.659

Energy efficiency indicates which inputs should be incurred to obtain one production unit. Production activity in the investigated organic farms may be generally considered as efficient since from each unit of incurred energy inputs [GJ] at the average 2 units of global production in GJ was obtained (Fig. 2).

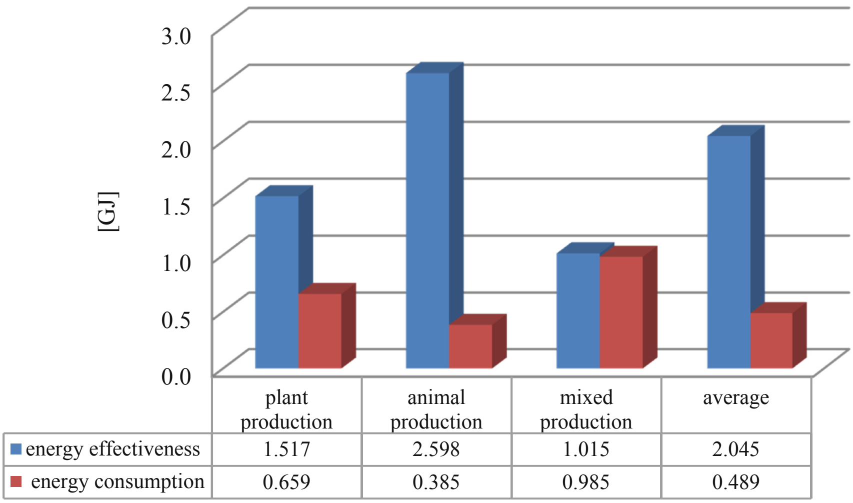


Fig. 2. Effectiveness and energy consumption of global production in production trends

While, in each trend group, positive effectiveness was obtained. The most advantageous activity with regard to energy effectiveness was obtained by farms specializing in animal production, since, from each unit of the incurred energy input [GJ] 2.598 production unit was obtained (Fig. 2). The least advantageous were mixed production farms, in which the obtained production balanced the incurred input. Moreover, in all groups, an advantageous index of energy consumption was obtained. It is proved by the fact that in order to obtain the global production with the value of 1 GJ, inputs from 0.385 GJ in the animal production farms to 0.985 GJ in the mixed production farms should be incurred.

While, energy efficiency of commodity production indicates that at the average out of 1 GJ of the input only 0.419 GJ of commodity production was obtained (Fig. 3).

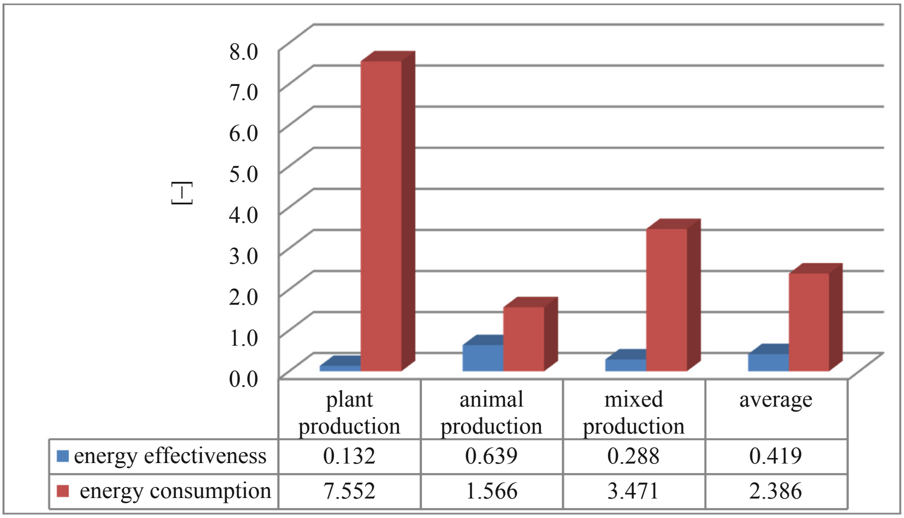


Fig. 3. Effectiveness and energy consumption of commodity production in trend groups.

In the trend groups, a negative effect with regard to effectiveness was obtained. Since, from 1 GJ of input, from 0.132 through 0.288 to 0.639 GJ of commodity production was obtained, respectively for farms which specialize in the plant, mixed and animal production (Fig. 3). While, the least favourable with regard to energy consumption were objects with the plant production trend because for the commodity production with the value of 1 GJ the input of 7.5552 GJ had to be incurred. In the remaining groups, energy consumption index was 3.471 and 1.566 respectively in the objects with the mixed and plant production trend. According to Sørensen et al. [17], in plant production, a 26% reduction of energy inputs can be obtained, through the use of minimum crops and as much as 41% in the case of a non-cutting system [17].

Energy intensity of agricultural production decreases along with changes in the agrarian structure and intensification of production in commercial farms. Nevertheless, energy consumption per unit of decreasing farmland and LSU stocking density will slowly increase along with the increase in the technical condition of agricultural equipment [15, 22].

4 Conclusion

At the average, in all trend groups a positive effect on account of energy efficiency of global production was obtained. However, the best index was reported in farms specializing in animal production [2.598] and the lowest in the mixed production farms [1.015].

However, commodity production efficiency was negative both at the average for all farms [0.419] and in all trend groups. Here, also animal production farms, where efficiency index at the level of 0.639 was twofold higher than in the remaining groups, distinguished.

With regard to energy consumption, both of global production and commodity production farms with animal production trend had the best results with the index at the level of respectively 0.385 and 1.566. While, in order to obtain 1 GJ of the global production, the highest input is incurred by farms which carry out mixed production [0.985] and commodity production – plant production facilities [7.552].

Reducing energy intensity of production, including in agriculture, it fosters respect for the natural environment. Research conducted using energy intensity assessment methods show the current state of energy economy in agriculture as well as ways and possibilities its improvement.

Transformations in agriculture cause, among others changes in the level of energy inputs and costs. The analysis of these changes over time is indispensable for forecasting their level in the future, because energy has a significant share in agricultural production outlays.

Acknowledgments. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland (statutory activities DS-3600/WIPiE/2017, Faculty of Production and Power Engineering, University of Agriculture in Krakow).

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Environmental Protection

The Influence of Long-Term Application of Organic Manures and NPK on Barley Grain and Straw Yields and Soil Properties

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Abstract. We evaluated how sixty years of regular application of mineral fertilizers (NPK), farmyard manure (FYM), poultry slurries (PS) and combination of FYM+NPK and PS+NPK influenced grain and straw yield of spring barley (*Hordeum vulgare* L.). The effect of fertilizer treatments on soil's pH, soil organic carbon (Cox) and total nitrogen content (Nt) in two decades of the long-term experiment (1983–1992 and 2001–2010) was also analyzed. Long-term application of FYM and PS increased grain yield by 19 and 35%, respectively, while application of NPK, FYM+NPK and PS+NPK increased grain yield by averagely 66%. Straw yield was not affected by organic manures, only NPK, FYM+NPK and PS+NPK treatments provided significantly higher yields compared to the unfertilized Control treatment. The soil's pH was comparable between fertilizer treatments between the years 1983–1992 and significantly differed between the years 2001–2010, especially in FYM+NPK and PS+NPK treatments. Generally, the mean pH significantly decreased from 6.42 (1983–1992) to 5.95 (2001–2010). Cox was not significantly affected by fertilizer treatment in both analyzed decades, but significantly increased from 1.44% (1983–1992) to 2.2% (2001–2010). Nt concentration was not affected by fertilizer treatment in both decades and did not change during the time. Application of NPK with or without organic manures is the best way how to achieve high production of barley grain and straw, but with organic manures and well-composed crop rotation is, according to the results, sustainable even without fertilizer inputs.

Keywords: Spring barley · Grain and straw yields · Soil organic carbon · Soil pH · Soil nutrient content

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 87–93, 2019.
https://doi.org/10.1007/978-3-030-16542-0_12

1 Introduction

Application of animal excreta slurry and farmyard manure is an old practice on how to support plants with nutrients they need to grow strong and healthy. Organic manure applied on arable land undergoes mineralization, a process of releasing of its nutrients to the soil. This process is controlled by several factors, such as temperature, soil humidity or soil microbial biomass and its activity. The amount of nutrients, mainly N, released to the environment is also strongly influenced by the manure origin since the inorganic and organic fractions and complexity of organic N compounds varies between manure types. Greater N mineralization is estimated in manures with lower C: N ratio (pig slurries and poultry manures) compared to cattle slurries, composted and straw-based farmyard manures, which have higher C: N ratios [1, 4]. Organic manures not only support and affect arable crops with released nutrients but can also influence soil chemical and physical properties and shape soil microorganism communities. Increasing the soil organic carbon content is one of the proclaimed attributes of organic manures. [5] found the significantly higher content of organic carbon, Nt, microbial and enzymatic activities in the arable soil after 15 years of FYM application. In the view of the above information, we decided to analyze the effect of mineral fertilizer (NPK), farmyard manure (FYM), poultry manure (PS), the combination of NPK with FYM (FYM+NPK) and PS (PS+NPK) on (i) spring barley grain yield, (ii) spring barley straw yield and on (iii) soil properties (the value of pH, soil organic carbon, total nitrogen content, concentration of P, K and Mg) over the sixty year long-term fertilizer experiment in Prague, Czech Republic, Central Europe.

2 Scope of Research and Study Methods

2.1 Site Description

The detailed description of the experimental site and soil and data analysis are available in [2].

2.2 Experimental Design

The long-term experiment is made up of five fields (marked as I, II, III, IV, and B), where different crop rotations and fertilizer treatments are analyzed. Each field comprises 96 plots (12 $\times$ 12 m), where we study 24 different fertilizer treatments. Each treatment is replicated four times and arranged in a completely randomized design. The subject of this study is field number II. Its crop rotation consists of alfalfa, alfalfa, winter wheat, sugar beet, spring barley, potatoes, winter wheat, sugar beet and spring barley (45% cereals, 33% root crops, 22% legumes). Eight spring barley varieties have been used from the beginning of the experiment: Hanácký Kargyn (1956, 1961), Branišovický (1965), Diamant (1970, 1974), Favorit (1979, 1983), Bonus (1988), Perun (1992), Akcent (1997, 2001) and Sebastian (2006, 2010 and 2015), therefore this paper covers 14 seasons of barley's cultivation in the long-term experiment. Out of 24 fertilizer treatments, we analyzed 6 treatments for the purpose of this paper, including organic manures and mineral fertilizers. The treatments were: unfertilized control (Control), mineral NPK (NPK), cattle farmyard manure (FYM), cattle farmyard manure with NPK (FYM+NPK), poultry manure (PS) and poultry manure with NPK (PS +NPK). Mineral nitrogen, phosphorus, and potassium in NPK treatments were applied as calcium ammonium nitrate (27% N) at rate 70 kg ha^{-1}, superphosphate (8.3% P) at rate 60 kg ha^{-1} and potassium chloride (49.8% K) at rate 100 kg ha^{-1}. Organic manures were applied in the autumn to the barley preceding crop (sugar beet) at the rates 21 t ha^{-1} (FYM) and 15 t ha^{-1} (PS). The pH value and mean concentrations of main nutrients in manures shows Table 1. Crop management practices, such as fertilizers rates, tillage, seed bed preparation and seeding depth have been constant from the experiment's establishment. Pesticides were used only if necessary, and growth regulators have never been used.

Table 1. Weights of factors and contributions of the given factor to the community in periods 1983–1992 (I) and 2001–2010 (II).

Attribute	Weights of factors		Contributions of the given factor to the community		
	Factor I	Factor II	Factor I	Factor II	R^2
pH	−0.120327	−0.144108	0.413785	0.703577	0.769137
P	−0.097037	0.382571	0.014452	0.816530	0.919118
K	0.031517	0.282479	0.232325	0.861867	0.856987
Mg	0.310025	−0.206716	0.840715	0.864409	0.939584
Corg	0.247970	−0.005415	0.880309	0.972254	0.990452
Nt	−0.152491	0.359987	0.014421	0.598640	0.449325
Grain yield (t ha^{-1})	0.170893	0.103396	0.614418	0.859014	0.966579
Straw yield (t ha^{-1})	0.279159	−0.131871	0.801267	0.801304	0.930642

3 Results and Discussion

3.1 Grain Yield

Grain yield was statistically significantly affected by fertilizer treatment (d.f. = 5, F = 16.97, $p < 0.001$, Fig. 1a). The average grain yields in the Control, NPK, FYM, FYM+NPK, PS and PS+NPK treatments were 3.36, 5.66, 4.01, 5.58, 4.52 and 5.50 t ha^{-1}, respectively (Fig. 1a).

3.2 Straw Yield

Straw yield was statistically significantly affected by fertilizer treatment (d.f. = 5, F = 9.70, $p < 0.001$, Fig. 1b). The average grain yields in the Control, NPK, FYM, FYM+NPK, PS and PS+NPK treatments were 3.00, 4.13, 3.32, 4.22, 3.51 and 4.06 t ha^{-1}, respectively (Fig. 1b). Means with standard errors of the mean (SE) followed by the same letter were not significantly different at 0.05 probability level.

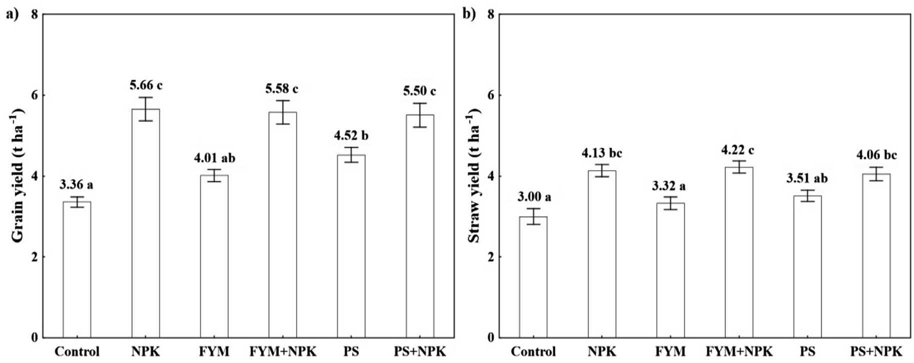

Fig. 1. The effect of fertilizer treatments on spring barley's (a) grain and (b) straw yields (t ha^{-1}) during the entire duration of the experiment (14 seasons)

3.3 Soil Properties

Due to incomplete data of soil properties from the long-term experiment we analysed and compared the effect of organic manures and mineral fertilizers on soil properties in two decades (1983–1992; 2001–2010), in which data were complete. Means followed by a different letter (A, B) were significantly different at 0.05 probability level. Means followed by no letter were not significantly different. The depth of the sampling was 30 cm of the top layer.

pH

The average pH value in 1983–1992 (respectively in 2001–2010) was in the Control 6.53A (6.07B), NPK 6.69 (6.30), FYM 6.78A (6.37B), FYM+NPK 6.14A (5.60B), PS 6.29 (5.97) and 6.10A (5.43B) in the PS+NPK treatment. Comparing two decades of the long-term experiment 1983–1992 and 2001–2010, the mean pH value decreased significantly (d.f. = 1, F = 13.04, $p < 0.001$) from 6.42 (1983–1992) to 5.95 (2001–2010).

Cox (%)

The average Cox content in 1983–1992 (respectively in 2001–2010) was in the Control 1.30 (1.76), NPK 1.38A (2.32B), FYM 1.39 (2.05), FYM+NPK 1.59A (2.50B), PS 1.46 (2.29) and 1.49 (2.30) % in the PS+NPK treatment. Comparing two decades of the long-term experiment 1983–1992 and 2001–2010, the mean Cox concentration increased significantly (d.f. = 1, F = 20.14, $p < 0.001$) from 1.44% (1983–1992) to 2.2% (2001–2010).

Nt (%)

The average Nt content in 1983–1992 (respectively in 2001–2010) was in the Control 0.14 (0.13), NPK 0.15 (0.14), FYM 0.14 (0.14), FYM+NPK 0.15 (0.15), PS 0.14 (0.14) and 0.15 (0.14) % in the PS+NPK treatment. Comparing two decades of the long-term experiment 1983–1992 and 2001–2010, the mean Nt concentration was not significantly affected (d.f. = 1, F = 0.42, p = 0.52) by fertilizer treatment and was 0.14% in both decades.

P (mg kg^{-1})
The average P content in 1983–1992 (respectively in 2001–2010) was in the Control 21.33 (9.73), NPK 66.00A (44.83B), FYM 34.67 (25.00), FYM+NPK 75.00 (79.33), PS 35.33A (73.67B) and 87.00A (134.50B) mg kg-1 in the PS+NPK treatment.

K (mg kg^{-1})
The average K content in 1983–1992 (respectively in 2001–2010) was in the Control 79.33 (124.00), NPK 169.33 (204.00), FYM 106.67A (168.00B), FYM+NPK 230.00 (281.50), PS 74.67A (145.50B) and 184.00A (233.00B) mg kg-1 in the PS+NPK treatment.

Mg (mg kg^{-1})
The average Mg content in 1983–1992 (respectively in 2001–2010) was in the Control 103.67A (145.83B), NPK 73.67A (127.83B), FYM 114.33A (165.33B), FYM+NPK 103.00A (157.67B), PS 103.33A (152.50B) and 90.33A (143.17B) mg kg-1 in the PS +NPK treatment.

Long-term and regular application of mineral fertilizers and organic manures has a positive and significant effect on productivity of arable crops, such as spring barley, and soil's organic carbon content [3, 6, 7]. The most positive effect was connected with application of mineral NPK, but sustainable production was related with all fertilizer treatments. Due to the soil's naturally high fertility and crop rotation including legumes, the production of spring barley was sustainable and increasing even without fertilizer inputs. This is very important information for farmers interested in now-a-days more popular organic farming. While soil organic carbon content increased in all treatments during the time, the value of the pH decreased significantly over the time and fluctuated significantly, especially in the treatments combining mineral NPK and organic manures. The concentration of nitrogen stayed unchanged during the time of the long-term experiment.

The Fig. 2 shows only the first two axes, which together explain approximately 80% of variability (PC1 and PC2 in the period 1983–1992, variants I, and 2001–2010, variants II). The Fig. 2 on the left compares the differences between the variables (if the characters are close together, they correlate strongly if they are far apart, then they do not correlate). The scales inform about the relationship between the original characters (parameters) and the main components. The PC1 axis in the graph (PC1 × PC2) characterizes Grain yields, K and Corg contents, which go directly along that axis and are correlated over 0.72–0.82 and partially correlated with P (0.5–0.6). Furthermore, the PC1 axis clearly characterizes soil reaction (pH). There is no pronounced correlation on the PC2 axis in the graph (PC1 × PC2), but the directions for Nt (the highest content in FYM+NPK, Ps+NPK) fertilization in both periods are different. The scatter plot of the component score (Fig. 2 on the right) shows the component score or the values of the first two major components. You can find clusters of objects similar to each other and objects that are remote and strongly different from other objects (objects close to each other are similar, far from each other they are dissimilar).

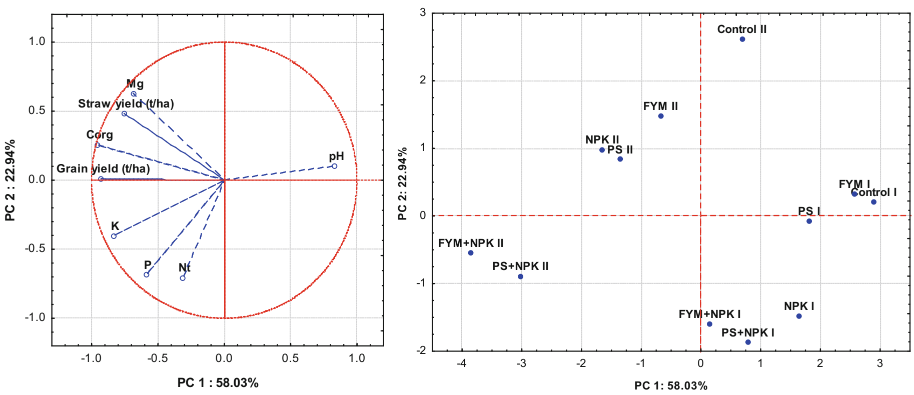

Fig. 2. PCA of parameters (pH, Cox, Nt, P, K, Mg, Grain yield, Straw yield) in period 1983–1992 (I) and 2001–2010 (II) in long-term application of different fertilizers treatment.

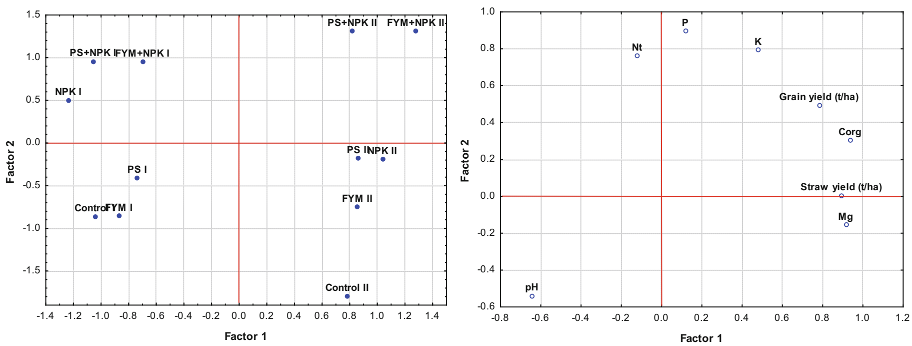

Fig. 3. FA of parameters (pH, Cox, Nt, P, K, Mg, Grain yield, Straw yield) in periods 1983–1992 (I) and 2001–2010 (II) as affected by the long-term application of different fertilizers treatment.

In the scattering diagram of the component score, variations of fertilization in both monitored seasons are unequally distributed along the PC1 axis. There are two clusters in the period 1983–1992 (Control I, FYM I, PS I and NPK I, FYM + NPK I, PS+NPK I). The fertilization treatments within the clusters are very similar, but the fertilization with organic manures and combinations of organic manures + mineral fertilizers is significantly different. In the period 2001–2010, there is already a significant differentiation (the distances between the clusters are large) and the variants of fertilization inside the clusters are very similar. The Control variation also differed significantly. This was confirmed by the Factor Analysis (FA) (Fig. 3), which differed similarly to the PCA method of the group of fertilization species. Factor 1 describes Grain yield, Grain yield, Corg content and Mg content, and Factor 2 describes the nutrient content (Nt, P, K). The community represents the proportion of the variability of the emblem expressed by the factors involved. It is similar to the R2 value we get when explaining the original characters by regression by selected factors. From the contribution of Factor 1 and Factor 2 to the Community, it is clear how the Communality is high, and the values of the values are very well offset by the proposed factor model (Table 1). Multi-dimensional analysis of PCA, FA significantly distinguished two categories of fertilizer variants in the current second period (2001–2010): pH, Cox, Nt, P, K, Mg, Grain yield, Straw yield.

4 Conclusions

1. The application of organic manures, such as farmyard manure and pig slurries, and application of mineral fertilizers (NPK) can achieve long-term stable yields of grain and straw while maintaining soil at optimal quality.
2. Application of organic manures together with mineral forms of fertilizers can significantly affect soil chemical properties (reduction of pH) and increase the levels of P and K, but already impaired plant availability and other negative effects on the natural environment (nitrogen spillage, etc.) at the expense of high grain and straw yields.

Acknowledgements. The writing of the paper was supported by the Ministry of Agriculture of the Czech Republic (MZe RO419).

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Time Domain Reflectometry Usage to Moisture Content Estimation in Electrically Conductive Mineral Wastes

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Abstract. The article presents the possibilities of using domain-time reflectometry (TDR) to determine the moisture content of waste. The TDR method consists in measuring the time of electromagnetic pulse transmission and reflection from the obstacle back to the source point. The impulse is a step signal of voltage. The reflected signal contains information about the dielectric properties of the material being tested. Therefore, qualitative and quantitative properties of the material can be detected. The tests were carried out using a stationary reflectometric device and an electronic temperature and humidity meter. The obtained results were validated using the traditional weight method, obtaining 94% convergence of results in the measurement cycle. On the basis of the obtained results, the usefulness of reflectometric methods in the study of the moisture content of wastes was determined.

Keywords: Reflectometry · TDR · Moisture · Waste

1 Introduction

Studies on municipal solid waste (MSW) require constant control of many physical parameters that determine the degree of their processing. Currently, many scientific centers are working on changing traditional measurement technologies to modern systems that allow to control biodegradation processes in an automated manner. The commonly used trend in humidity monitoring is its simultaneous measurement with temperature and pH conditions [7, 8].

The most popular technique for determining moisture content in waste is thermogravimetry (oven drying). This method requires appropriate measurement conditions and belongs to a group of destructive and local measurements. In order to avoid measurement errors, they are increasingly replaced with methods known from agriculture, which belong to fast and non-destructive measurement groups [7, 11].

The classic technique for determining moisture content is the gravimetric method. The principle of this measurement method is to determine the water content, which

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 94–99, 2019.
https://doi.org/10.1007/978-3-030-16542-0_13

evaporates from the sample during drying at 105 °C. The disadvantage of this method is the use of material samples of relatively low weight (up to 1 kg), which are collected in a selected batch of waste. According to this research method, it often leads to erroneous inference resulting from the evaporation of water during the transport of waste from the place of their collection to the laboratory [4, 10].

Due to the problem of changes in moisture content of waste samples during transport, for many years work has been underway on the use of electrical and electro-magnetic properties of waste for the study of humidity. These methods have been known for many years in soil research techniques [5, 8].

Time-domain reflectometry is an electro-magnetic measurement technique used to determine the electrical conductivity of materials - dielectric and spectroscopic properties of materials; qualitative and quantitative control of liquids; examinations of vegetable oils; cable fault detection; and measurement of soil moisture [1, 2].

The method uses special measuring probes that measure the electric pulse flow time in the aqueous solution around the waste between the probe electrodes. The probe consists of two electrically connected waveguides: concentric and parallel (formed by two parallel metal rods). An initial voltage spike with a fixed rise and fall time runs from the generator towards the sensor. The recorder register its course as it passes the splitter. The measurement results are recorded in the form of a waveform, showing the relationship between the time of electrical impulse flow and the length and distance of the electrodes in the probe (Fig. 1). On this basis, the dielectric constant (bulk electrical permittivity) is determined [8, 9].

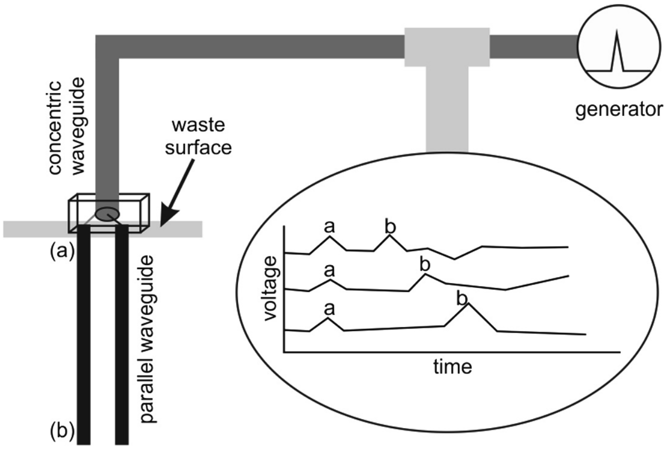

Fig. 1. TDR measurement method scheme

A comparison of the presented methods for determining moisture in waste is presented in Table 1.

Table 1. Advantages and disadvantages of gravimetric, thermogravimetric, and TDR measurements [5, 10]

Method	Advantages	Disadvantages
Gravimetric	Accurate absolute measure Medium sampling volume Very simple calculation	Questionable sampling locations (heterogeneous material) Destructive Time-consuming preparations
Thermogravimetric	Accurate absolute measure Very simple calculation	Questionable sampling locations (heterogeneous material) Small sampling volume Destructive Time-consuming preparations
Time-domain reflectometry	Inexpensive method Automation possible Non-destructive Possibility of constant measurement	Measurements may be material-sensitive Small measurement volume Needs correction of disturbance material Hard to average measurements

The aim of this article is to use two parallel indirect methods, gravimetric and time-domain reflectometry (TDR). The purpose of the presented paper is to validate and to clarify the limits of gravimetric and TDR for long-term moisture measurements in semi-technological laboratory containers.

2 Materials and Methods

The test installation consisted of a system of 6 rectangular containers with the dimensions of the 2 × 3 m base and a height of 1.5 m. Each container was filled with MSW. The main components of the MSW were ashes (58%), construction waste (17%), paper (15%), plastics (10%). In 2 containers, 3 TDR measurement probes were placed at a depth of 1 m. Samples for comparative tests were taken from the same depth at 6 h intervals in the form of cores with a diameter of 25 mm, from which moisture content was analyzed in the lowest batch of material (Fig. 2). Prior to the measurements, the probes were conditioned in a thermostat, in 0.1 KCl solution and 30°C.

The TDR measurement set consisted of three-rod type probes connected to a coaxial cable with an automatic data acquisition system and a coaxial multiplexer. All set components were manufactured by Campbell Scientific (Logan, UT, USA).

Humidity determined by the gravimetric method was carried out according to PN-Z-15008/02: 1993, using the Memmert UN55 dryer and the Radwag AS.310 analytical balance [3, 7].

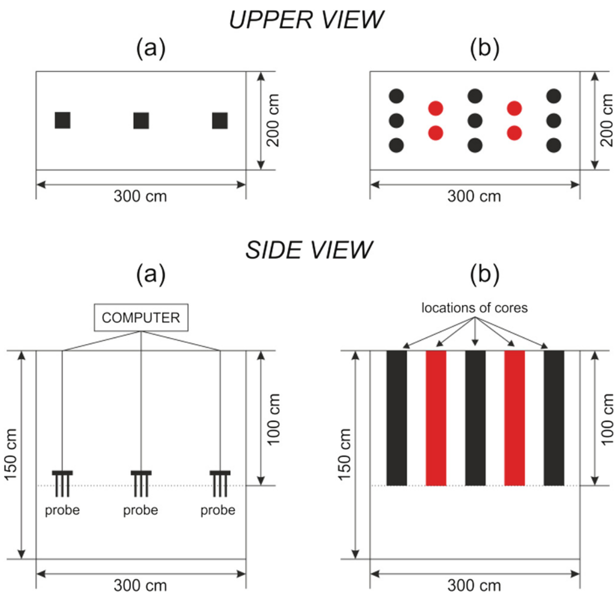

Fig. 2. Scheme of the experimental station - (a) container for TDR measurement, (b) container for humidity measurement by gravimetric method

3 Results

The results of conducted measurements are presented in Figs. 3 and 4. The measurements carried out using TDR probes and the gravimetric method show similar reaction. Analyzing the variability of humidity over time, both methods registered its decrease, but in the case of the TDR method it is clearly non-linear. The resulting differences between the methods can be partly explained by the inhomogeneity of the material or the periodic occurrence of air around the measurement probes. The gravimetric method allows for very accurate determination of humidity, while TDR measures local moisture in the so-called effective volume around the sensor.

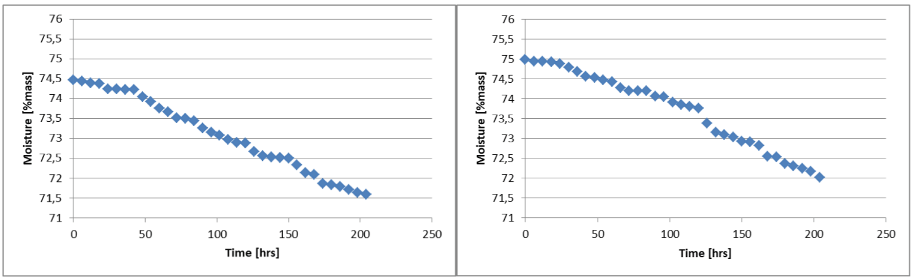

Fig. 3. The results of TDR moisture measurements - container 1 (left), container 2 (right)

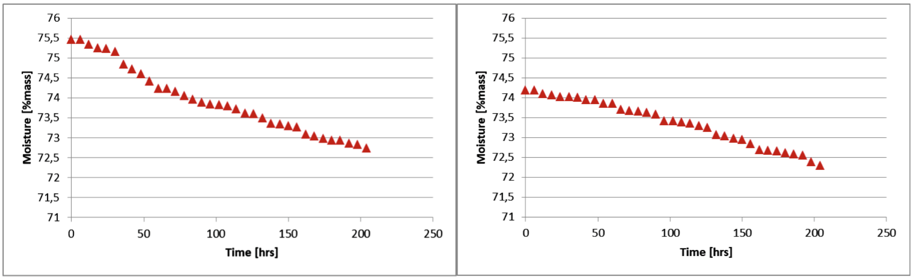

Fig. 4. The results of moisture measurements by weight method - containers 3–4 (left), containers 5–6 (right)

This phenomenon is the cause of undervaluation of the measurement results obtained in the TDR method. This effect has an impact on the slope of the moisture profile seen in Figs. 3 and 4. The standard error of the TDR measurements made was 1.6% with a standard deviation of 0.094%. Gravimetric measurements are characterized by significantly higher accuracy (standard error 0.4% and standard deviation 0.008%).

Comparison of the average values of the obtained results allows to state that the determination of moisture in waste by TDR method can partially replace the gravimetric method. The experiments carried out showed that during the first 100 h of measurement, the obtained values are within the 5% limit of quantification of the gravimetric method. Monitoring of humidity in the next 100 h showed discrepancies between the analyzed methods. It can be seen from Figs. 3 and 4 that the probes, along with the progressing drying of the waste mass, indicated a lower moisture content of the material than the gravimetric method. The cause of this phenomenon is the mentioned inhomogeneity of the material. The TDR method, when measuring the surface moisture of the material, does not show the moisture accumulated in the molecular structure of the waste, which is a source of error in the presented measurements.

4 Summary

The article presents long-lasting moisture measurements of the MSW using the TDR method and gravimetric analysis. The proposed measuring techniques during the tests demonstrated no signs of unreliability or technical problems. Measurements conducted with the use of TDR probes showed a higher measurement difficulty due to the need to place them inside the waste container. In the proposed semi-technical scale, both methods of humidity testing show significant similarity of the obtained results. The use of TDR also allowed to avoid the destruction of the tested position, in contrast to the gravimetric method, which used a total of 10 kg of waste.

Acknowledgment. Publication was financed by the Ministry of Science and Higher Education of the Republic of Poland.

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Passive Biomonitoring of Selected Water Ecosystems with *Lemna Minor* L. of Kuyavia-Pomerania Province in Poland

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Abstract. The aim of the study has been to evaluate the content of trace elements in the plant samples of common duckweed *Lemna minor* L. from five reservoirs or watercourses of Kuyavia-Pomerania province: A – Rynarzewo (ditch), B – Bydgoszcz (pond), C – Małe Rudy (the Noteć Canal), D –Drzewce (pond), E – Bydgoszcz (the Bydgoszcz Canal). The plant material was sampled in June 2016. In dried and mineralized plant material the total content of Zn, Cu, Mn, Fe, Pb, Ni, Cd was assayed with Atomic Absorption Spectrometry (AAS) with the use of spectrometer PHILIPS PU 9100X, while the content of sulphur – with the turbidimetric method developed by Bardsley–Lancaster. The content of carbon and nitrogen was determined with analyser Vario Max CN, made by Elementar. The results point to a varied level of metals accumulation in the common duckweed sampled from respective reservoirs and the watercourse. This research confirms the bioaccumulative properties of *Lemna minor* L. in terms of trace elements, including heavy metals. The greatest concentrations of manganese were assayed in the samples of plants from measurement points A and B, whereas most zinc – in the tissues of common duckweed from measurement points D and E and iron – from A and E. A low content of Cu and Ni, Cd, Pb below the quantification threshold of the analytic method applied points to a low pollution of the water ecosystems with those analytes. In *L. minor* tissues in the case of Zn and Cu, the large coefficients of variation was noted, whereas for Mn and Fe, there was a very large coefficients of variation, respectively 38.6% (Zn) and 25.7% (Cu), and 89.4% (Mn) and 76.1% (Fe).

Keywords: Trace elements · Bioaccumulation · *Lemna minor* L. · Biomonitoring

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 100–107, 2019.
https://doi.org/10.1007/978-3-030-16542-0_14

1 Introduction

The development of industry and urbanization have resulted in a serious pollution of waters with trace elements, including heavy metals [17]. The elements can be toxic to living organisms even in trace amounts and it is difficult to clean the water reservoirs and to eliminate them. Heavy metals harmfulness is mostly due to their capacity for bioaccumulation. They accumulate in water, soil, bottom sediments and in living organisms [7]. Water plants growing in polluted water uptake heavy metals which enter the trophic chains and pose a serious threat to the human health and life, most of them are carcinogenic [21]. They are also harmful for the physiological processes of plants, e.g. photosynthesis and enzymatic activity [15, 20].

One of the common water plants occurring in Poland is common duckweed *Lemna minor* L.. The plant is resistant to municipal pollution and, due to high concentrations of heavy metals, it can be used for waters phytoremediation [10]. Biomonitoring is becoming a more and more popular method to evaluate the pollution of various ecosystems. Due to the capacity for bioaccumulation of trace elements in tissues, common duckweed can be used for water ecosystem pollution evaluation biomonitoring [12, 19].

The aim of this research was has been to evaluate the content of trace elements in common duckweed plants from selected water ecosystems of Kuyavia-Pomerania province.

2 Materials and Methods

The preliminary research covered the plants of *Lemna minor* L. sampled during their intensive growth in June 2016 from four locations of five different water reservoirs and watercourses: A – Rynarzewo (drainage ditch), B – Bydgoszcz (pond), C – Małe Rudy (the Noteć Canal), D – Drzewce (a pond close to allotment gardens), E – Bydgoszcz (the Bydgoszcz Canal). Table 1 presents the location and the characteristics of measurement points in Kuyavia-Pomerania province.

Table 1. Location of measurement points.

Measurement point marking	Measurement point and its characteristics	GPS coordinates
A	Drainage ditch at Rynarzewo, 100 m away from county road 1950	53°3′55.42″N 17°49′3.25″E
B	Pond in Bydgoszcz in Babia Wieś residential district in the vicinity of public transport routes	53°07′10.8″N 18°01′31.8″E
C	Noteć Canal in at Małe Rudy surrounded by meadows away from routes	53°3′37.67″N 17°51′42.37″E
D	Pond in the allotment gardens at Drzewce	53°06′22.9″N 17°51′41.8″E
E	Bydgoszcz Canal in Bydgoszcz in the Miedzyń residential single-family-houses district	53°08′02.3″N 17°56′40.7″E

From each location of 4 healthy colonies of *Lemna minor* L., about 200 plants were sampled by hand. The plant material was packed into polyethylene bags, marked and transferred to the laboratory as fast as possible. To assay the trace elements, the plants were rinsed with distilled water and the whole lot was dried (40 °C) to become air-dry. The plant material was crushed in the agate mortar. The homogenized material of 300 mg was exposed to microwave digestion using mineralizer Speedwave Two (Berghof) applying the wet mineralization method (5 ml 65% HNO_3, 1 ml 30% H_2O_2).

In the plant material the total content of Zn, Cu, Mn, Fe, Pb, Cd, Ni was assayed with Atomic Absorption Spectrometry (AAS) with the use of spectrometer PHILIPS PU 9100X. The content of total sulphur was determined with the turbidimetric method following Bardsley–Lancaster [2]. The content of carbon and nitrogen was assayed with analyser Vario Max CN, made by Elementar.

To compare a variation of trace elements (Zn, Cu, Mn, Fe) in plant *Lemna minor* L., the coefficient of variation (CV%) was determined. The coefficient of variation is a measure of relative variability the ratio of the standard deviation to the average. For the interpretation of coefficients of of variation was used on the scale proposed by Bogucki scale [3].

3 Results and Discussion

In the experiment the content of carbon in the dry matter of *Lemna minor* L. plants ranged from 321.3 to 378.4 g kg^{-1} d.m., the highest N content was recorded for the common duckweed plants from location C (39.70 g kg^{-1} d.m.). The total sulphur content in the material analysed from five different watercourses was similar and it ranged from 1.7 to 1.8 g kg^{-1} d.m. (Table 2).

Table 2. The average content of carbon, nitrogen and sulphur total in dry matter *Lemna minor* L. (g kg^{-1} d.m.).

Place sampling[a]	C_{org}	N_t	S_t
A	338.10	26.50	1.80
B	321.30	31.04	1.80
C	373.10	39.70	1.70
D	378.40	36.40	1.80
E	364.30	36.12	1.80
Mean	355.04	33.95	1.78

[a]place sampling: A – Rynarzewo (ditch), B – Bydgoszcz (pond), C – Mełe Rudy (the Noteć Canal), D – Drzewce (pond) E – Bydgoszcz (the Bydgoszcz Canal)

The results point to a varied level of trace elements accumulation in common duckweed sampled from respective water reservoirs and watercourses. Their content in common duckweed plant tissues varied across the sampling locations. The trace elements ions can be ordered according to their decreasing mobility: Mn > Fe > Zn > Cu > Pb = Ni = Cd.

In this experiment manganese showed a much higher capacity for bioaccumulation, as compared with the other elements in *L. minor* biome. The content of manganese in the plants analysed from five stands varied and it ranged from 583 mg Mn kg^{-1} of d.m. in the plants of common duckweed from the pond at Drzewce to 8585 mg kg^{-1} of d.m. in the plants growing in the watercourse in the vicinity of Rynarzewo (on average Mn kg^{-1} of d.m.) (Figure 1). The highest manganese concentration was reported in the plants sampled from measurement point A (8585 mg Mn kg^{-1} of d.m.) and B (6692 mg Mn kg^{-1} of d.m.). Iram et al. [21] in the tissues of *L. minor* assayed on average 1055 mg Mn kg^{-1} of d.m., and Branković et al. [5] – 1740 mg Mn kg^{-1} of d.m.. Kastratović et al. [12] recorded the average Mn content in the root – 3427 mg Mn kg^{-1} of d.m. and 2225 mg Mn kg^{-1} of d.m. in the common duckweed leaves from Skadar Lake. Manganese is a trace element which commonly occurs in the surface waters and its content depends mostly on leaching from the ground and, less considerably, on the supply from wastewater [14]. Heal [6] claims that a more intensified migration of manganese from the ground occurs under soil acidification, whereas Baran et al. [1] stress that more intensive leaching of manganese and iron is reported in the soils with organic rather than mineral fertilisation.

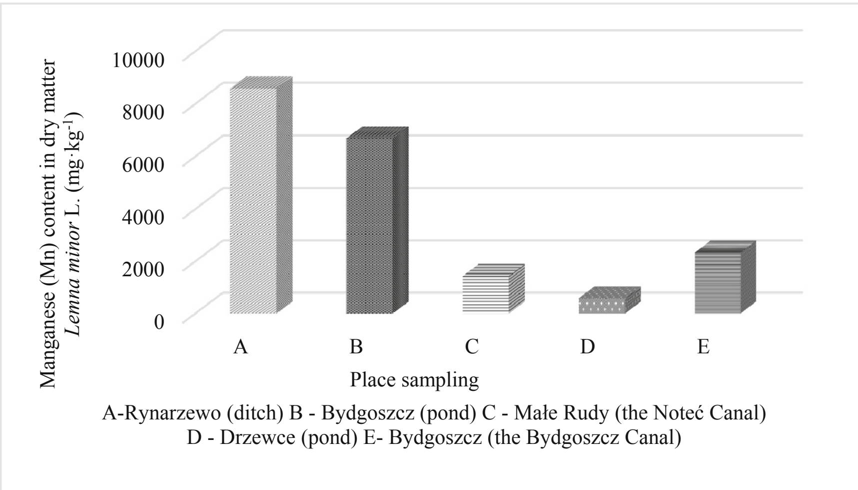

Fig. 1. The content of manganese (Mn) in dry matter *Lemma minor* L. (mg kg^{-1} d.m.).

In this experiment iron is a trace element which occurs in *L. minor* tissues at the concentration second highest after manganese, which is due to the fact that metals indispensable for metabolism can be more easily uptaken by roots from the environment and transported to green parts of the plants [13]. The highest Fe concentration was noted in the common duckweed from location A (3083 mg Fe kg^{-1} of d.m.) and E (2375 mg Fe kg^{-1} of d.m.) (Figure 2). Iron occurs in surface waters in a natural way at the amounts which depend on the structure and the mineral composition of the ground. A high Fe concentration in surface waters can be due to the discharge of waters from

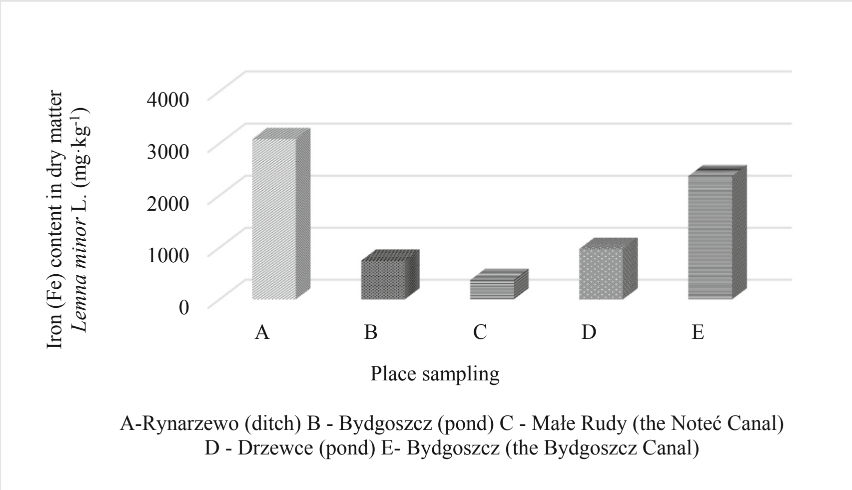

Fig. 2. The content of iron (Fe) in dry matter *Lemma minor* L. (mg kg^{-1} d.m.).

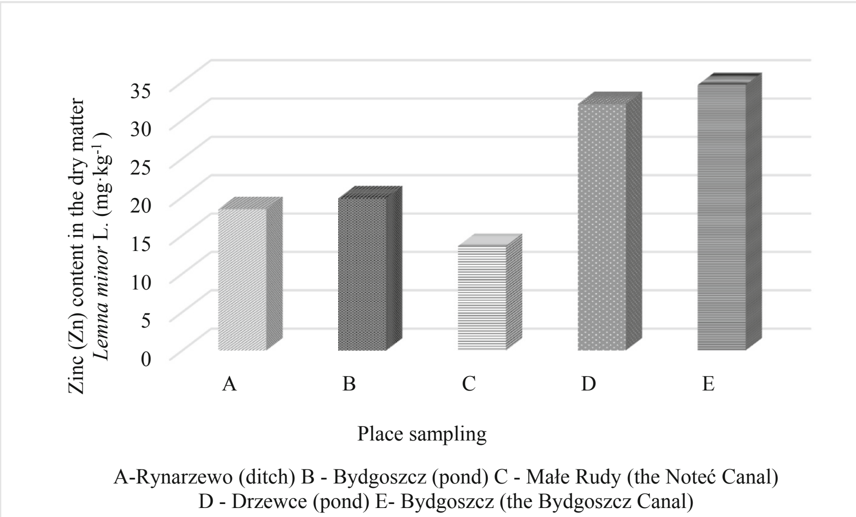

Fig. 3. The content of zinc (Zn) in dry matter *Lemma minor* L. (mg kg^{-1} d.m.).

urbanized areas and arable fields. Bojar [4] reports that iron can occur at high amounts in mid forest brooks, in wetland soils and peatland as it bonds with humus substances. A higher iron concentration in the tissues of *Lemma minor* L. from the Bydgoszcz Canal can be due to municipal pollutions [11].

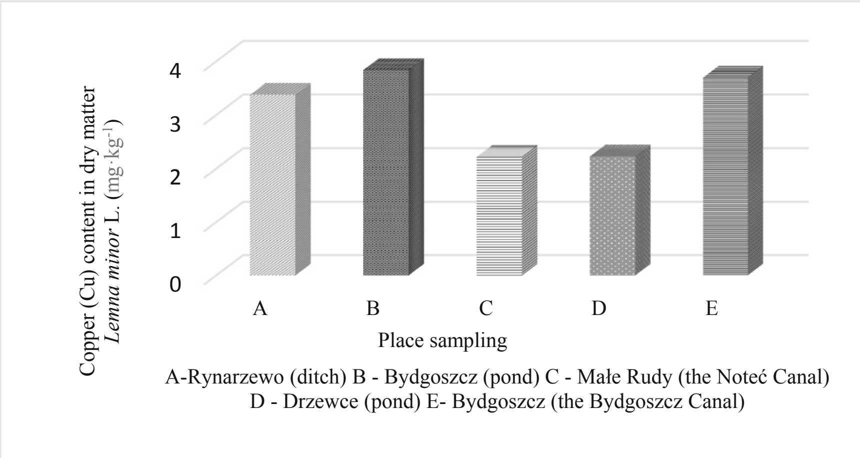

Fig. 4. The content of copper (Cu) in dry matter *Lemma minor* L. (mg kg^{-1} d.m.).

The content of zinc in this experiment varied and it was, on average, 23.7 mg Zn kg^{-1} of d.m. (Figure 3). The greatest concentration of that element was assayed in the samples of the plants derived from measurement point D (32.1 mg Zn kg^{-1} of d. m.) and E (34.6 mg Zn kg^{-1} of d.m.). Higher Zn contents were found in the plants of *L. minor* from the pond at Drzewce, in the area covered by allotment gardens. The key source of the natural emissions of zinc to surface waters is the erosion of its minerals. Also, e.g., the plant protection agents or mineral fertilizers can contribute to the anthropogenic emissions of zinc [18, 22], whereas a higher Zn content in the tissues of common duckweed in the Bydgoszcz Canal can be due to municipal pollution [11]. In another biomonitoring study Jamnička et al. [9] recorded the value of Zn in *L. minor* tissues of 14.68 mg Zn kg^{-1} of d.m., which was close to the lowest value in this study (measurement point C). Iram et al. [8] and Kastratović et al. [12] on the other hand, in common duckweed tissues assayed, on average, 106 mg Zn kg^{-1} of d.m. and 79.5 mg Zn kg^{-1} of d.m., respectively.

In the common duckweed plants from five different locations, the content of Cu was low and it ranged from 2.22 mg Cu kg^{-1} of d.m. in the plants sampled from the Noteć Canal to 3.84 mg Cu kg^{-1} of d.m. from the pond in Bydgoszcz (Fig. 4). In earlier research reported by other authors, the content of Cu in common duckweed plants was reported to be 20.4 mg Cu kg^{-1} of d.m. [12], 29.9 mg Cu kg^{-1} of d.m. and 10.9 mg Cu kg^{-1} of d.m. [16], 112 mg Cu kg^{-1} of d.m. [19].

The plants under study were not polluted with Ni, Cd, Pb. In the tissues of the common duckweed plants the content of those elements was below the detection threshold of the analytical method applied (< 0.2 mg kg^{-1} of d.m.).

The average content of trace elements of Zn, Cu, Mn, Fe in *L. minor* tissues was respectively 23.7 ± 9.15, 3.07 ± 0.79, 3926.40 ± 3509.50, 1159.16 ± 1511.60. In the case of Zn and Cu, the large coefficients of variation was noted, whereas for Mn and Fe, there was a very large coefficients of variation, respectively 38.6% (Zn) and 25.7% (Cu), and 89.4% (Mn) and 76.1% (Fe) (3).

4 Summary

This research confirms the bioaccumulation properties of *Lemma minor* L. in terms of trace elements, including heavy metals. The content of trace elements in *Lemma minor* L in the water reservoirs and watercourses of Kuyavia-Pomerania provincewas varied. The municipal pollutions and the application of plant protection agents and mineral fertilisers were demonstrated to have affected the concentration of some of the trace elements analysed in common duckweed found in the water reservoirs and watercourses. In *Lemma minor* L tissues in the case of Zn and Cu, the large coefficients of variation was noted, whereas for Mn and Fe, there was a very large coefficients of variation, respectively 38.6% (Zn) and 25.7% (Cu), and 89.4% (Mn) and 76.1% (Fe). A low content of Cu and Ni, Cd, Pb below the detection threshold of the analytical method applied points to a low pollution of the water ecosystems studied with those analytes. The results indicate that the *Lemma minor* L. could be a bioindicator used to monitor the changes occurring in surface waters. Therefore, it is advisable to re-analyze the trace elements in a few years.

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A Pilot Study on Food Waste Amount and Origin in a Small Shop

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Abstract. On the basis of the annual monitoring, the situation in the selected food shop of the Coop retail chain was evaluated. More than half of the food waste was made up of fruits and vegetables (258 kg). The most often cause of its discard was the rot of fruits and vegetables (98%). Surprising findings were data on baked goods. Although baked goods are considered to be the most wasting food after fruits and vegetables, the opposite was found in the shop. For the whole year only 2 kg of baked goods were thrown away. The second most frequently food waste were dairy products (223 kg). Expired date of consumption has been identified as the most common cause of waste production for dairy products and dry goods (94%). According to the information, about 459 Mg of foodstuff was purchased in total in 2017 but only 483 kg of food was thrown away. Compared to the total cost of purchased food, the costs of the loss were minimal.

1 Introduction

Food loss and waste are often used in scientific literature to identify materials intended for human consumption that are subsequently discharged, lost, degraded or contaminated. The Food and Agriculture Organisation of the United Nations (FAO) defined food loss as any change in the availability, edibility, wholesomeness or quality of edible material that prevents it from being consumed by people. This definition was provided for the post-harvest period of food ending when it comes into the possession of the final consumer [6].

In 2011 the FAO estimated that one third of the worldwide food production is wasted or gets lost on the way from farm to fork [7]. In fact it means that while 870 million people are reported as being chronically undernourished, approximately 1.3 billion Mg per year is wasted [11]. In United States nearly 61 million Mg of food waste are generated every year [9]. Dee [2] reported a food waste generation rate of 4 million Mg per year in Australia. Other food waste generation data regards South Korea with 6.24 million Mg per year [10], China with 92.4 million Mg per year [12] and Japan where about 21 million Mg of food waste were generated in 2010 [11]. In Europe, food waste generation is estimated at 90 million Mg annually [3].

Food waste generation, happening throughout the entire food supply chain around the globe, is dominated by different dynamics, ultimately associated by the same unsustainable paradigm. Wasting food contributes to environmental pollution as well

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 108–113, 2019.
https://doi.org/10.1007/978-3-030-16542-0_15

as to natural resources degradation and depletion, threatening food security [5]. Wasted food is associated with an unnecessary use of energy and water, and emissions of greenhouse gases generated by production and delivery operations [13, 17]; it is also contradictory to the increased amount of food demanded by a growing population [8].

Although food is wasted at all supply chain (SC) stages, the cause of food waste does not necessarily arise at the same stage as the waste itself [16]. In developed countries, food waste is mainly associated to consumers, and because of their perception of product quality food waste also originates from farmers, processors, or retailers who sort out items that they expect to be undesired [1]. In developing countries, food waste mainly comes from poor technology and infrastructure, and rapid spoilage because of difficult climatic conditions [7].

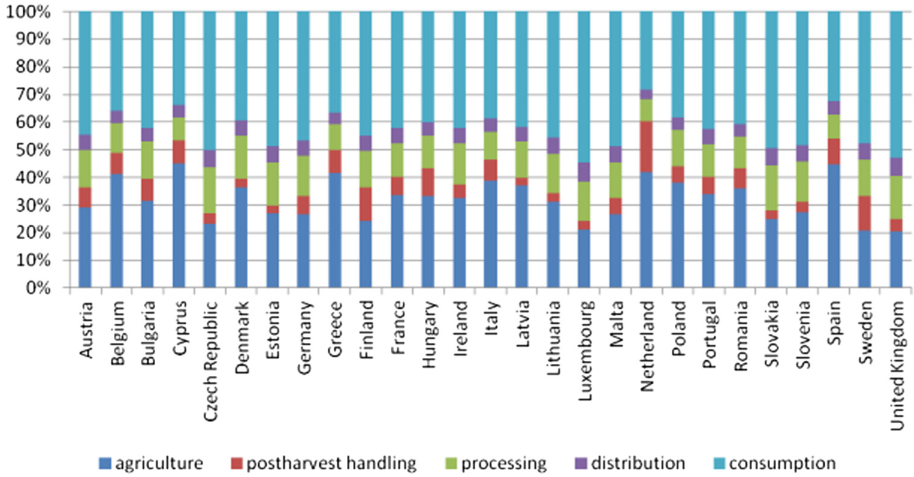

Fig. 1. Ratio of particular supply chain stages on the total food waste amount (based on: [14])

Therefore, food waste is one of the targets of both environmental and food security policies at different scales. According to the United Nations Sustainable Development Goal (SDG) 12.3, per-capita FW at retail and consumer levels should be halved and FW along the entire food supply chain should be reduced by 2030 [18]. The European Commission, beyond having committed to the SDG 12.3 reduction target on FW, has included FW among the priority areas of the Circular Economy Action Plan, and is committed to define a common EU methodology for FW accounting and to propose relevant indicators [4].

For effective food waste reduction it is necessary to know the ratio of particular supply chain stages on food waste production. Figure 1 shows required data of EU 27.

According to Bio Intelligence Service and other studies, most food waste is generated in households (42%) and in foodstuff production (39%). In public catering, food waste generation is significantly lower (14%), and in the sale stage, food waste is the lowest (5%) in the EU [14, 19]. On the other hand, there is not much empirical data in the area of sale stage.

The amount of food waste and associated economic losses are among the strictly guarded secrets of almost all the retail chains. Tesco was the only retail chain that published the date of the food waste generated for 2016/17 and 2017/18 in Central Europe and the Czech Republic. The composition of food waste in Central Europe was also published (Table 1):

Table 1. Tesco food waste in central Europe/in the Czech Republic. Based on [15].

Period	Total amount of sold foodstuff [Mg]	Total amount of food waste [Mg]	Ratio of sold foodstuff/food waste [%]
2016/17	3,352,675/654,249	54,102/13,925	1.6/2.1
2017/18	3,227,655/651,575	38,054/10,227	1.2/1.6

In 2017/18, in the Tesco chain of stores in Central Europe were mostly wasted fruit and vegetables (34%), baked goods (26%), finished meals (10%), dairy products (8%), meat and fish (7%), products in the cash register (7%), durable food (5%) and alcoholic beverages (2%) [15].

For the reason of missing data, the aim of this paper is to determine the most frequent cause of food waste generation, the amount of food waste and associated economic losses at a selected food shop.

2 Materials and Methods

In order to monitor the amount of generated food waste, the causes of the waste origin and the relevant financial losses of the shop, it was agreed the cooperation with a shop of Coop retail chain in village of Rohatec in the South Moravian Region (the Czech Republic). About 3500 inhabitans live in Rohatec.

The monitoring took place from 1 January 2017 until 31 December 2017. The foodstuffs offered by the shop was divided into (a) fruits and vegetables, (b) meat products, (c) baked goods, (d) dairy products, and (e) dry goods.

Due to the recording practice of the shop, some data were kept for several shop departments together. Depending on the shop departments, the data were collected at monthly intervals, with the exception of the department of fruits and vegetables, where data was provided for the entire year of 2017 only.

For the internal reasons of the shop, the costs of purchased goods in the department of fruit and vegetables, as well as of meat products was kept secret. For this reason, the total financial loss of the shop could not be evaluated.

3 Results

Table 2 shows the weight of food waste in departments of diary products, meat products, baked goods and dry goods in each month. As can be seen, the amount of food waste is around 20 kg per month. October is the only month when more than

30 kg of waste was produced. On the other hand, less than 9 kg of food waste were produced in March and June. These differences in waste production do not indicate any specific problem during the recorded period.

The main reason of food waste origin (of baked goods, milk goods and dry goods) was expired date of consumption (94%), than damaged package (4%) and unsatisfactory storage conditions (2%).

Table 2. Weight of food waste (diary products, meat products, baked goods and dry goods).

Date [mm/yy]	Food waste amount [g]	Date [mm/yy]	Food waste amount [g]
01/17	20,422	07/17	19,324
02/17	21,200	08/17	26,837
03/17	8,520	09/17	16,817
04/17	19,495	10/17	30,590
05/17	15,481	11/17	20,266
06/17	8,998	12/17	17,060
Total	225,010		

258 kg of fruits and vegetable was wasted during recorded period of one year. The main reason of food waste origin (of fruits and vegetable) was rotting goods (98%) and damaged transport package (2%). It seems that there is a bad handling of fruits and vegetables, especially during goods transport when fruits and vegetables are transported in very small boxes, causing pressing and subsequent rotting of the goods. The same damage occurs in the shop itself when sellers want to have a full shopping area and thus the goods are squeezed.

Table 3 shows summarized amount of purchased and discarded foodstuff goods depending on the shop department. Costs of purchased and discarded goods were provided just from baked goods, milk foodstuffs and dry goods.

The ratio of food waste in monitored shop is really very small. Compared to the available data, the Tesco retail chain shows more 10 times greater ratio of foodstuff waste in Central Europe; the ratio is even worst in the Czech Republic. By Preifer et al. [14] the foodstuff waste ratio is approximatelly 4–5%, on an average.

These small numbers indicate well worked-out management system of goods ordering, combined with timely discounting of goods near the expired date of consumption. Low food waste production also corresponds to low cost losses.

A small amount of food waste is achieved even without any ordering system by customers; nevertheless the almost monopoly position of the shop in the village and a perfect knowledge of the citizens' requirements of the offered goods greatly help the management of the shop.

Table 3. Amount of purchased and discarded foodstuff goods depending on the shop department.

Goods	Purchased goods amount [kg]	Discarded goods amount [kg]	Waste ratio [%]	Purchased goods costs [€]	Discarded goods costs [€]
Fruits and vegetables	53,766	258	0.48	No available	No available
Meat goods	22,563	0	0	No available	0
Baked goods	19,962	2	0,01	83,040	8.32
Milk and dry goods	362,880	223	0.06	460,800	549.32
Total	459,171	483	0.11	No available	No available

4 Conclusion

Food waste is generated at all stages of the supply chain. In worldwide total, around one third of all food, i.e. about 1.3 billion Mg per year is wasted. According to available information, about 5% of food waste is generated at the point of sale. Tesco is the only one retail chain that published relevant data for the Czech Republic and Central Europe. Therefore, the given values (1.6% and 1.2% respectively) are 3–4 times lower than the officially reported average values. However, relevant data on shop waste production are very rare.

Therefore, cooperation with the Coop retail chain was agreed. For one year, the amount of food purchased and the amount of food waste that was produced in the shop were monitored. The finding was very surprising: about 459 Mg of food was purchased in the shop, but only 483 kg of food was thrown away. Thus, the quantity of waste was only 0.11% compared to the quantity of purchased food. More than half of the waste was made up of fruits and vegetables. In particular, the handling of fruit and vegetables during transport and warehousing would help to reduce the amount of discarded food, as 98% of the fruit and vegetables were thrown out of rotting (very probably caused by pressing). The second half of the waste was generated in the dairy products and dry goods department. The main reason for this food waste origin was the expired date of consumption (94%). In this case it is possible to timely discount the goods near the expired date of consumption.

Overall, the management system of goods ordering is almost perfectly worked-out in the recorded shop.

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Biological Stability Assessment of Selected Types of Separately Collected Kitchen Waste

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Abstract. According to the Regulation on the Minister of Environment of 29 December 2016, four fractions of municipal solid waste has to be collected separately in Poland, including bio-waste. Since such waste has not been considered in currently applied waste collection systems, there is a need to rearrange those systems and provide for infrastructure for bio-waste collection and processing. The paper describes the results of the research on determining selected properties of some types of waste commonly present in kitchen waste generated in households. Such waste is biologically unstable, which means it is prone to fast biological decomposition. The analyzed fruit and vegetable peels are characterized by high values of moisture content (up to 87.97 ± 0.41%), loss of ignition (up to 98.0 ± 0.05%) and four-day respiration activity AT4 (up to 144.4 ± 11.9 $mgO_2 \cdot g^{-1}$ d.m.). Moreover, it was found that respiration activity in mixtures of different types of peels is determined by also other factors than only individual properties of components.

Keywords: Biological stability · Kitchen waste · Bio-waste · Respiration activity

1 Introduction

On 1st July 2017 the Regulation of the Minister of Environment came into force in Poland, which introduced an obligation of separate collection of selected waste types [1]. According to the Regulation, following 4 fractions of municipal solid waste have to be collected separately: (1) paper, (2) glass, (3) metals and plastics, (4) biodegradable waste (with special regard to bio-waste). Municipalities, which, according to other law acts [2], have been obliged to provide a waste management system on their territories, are bound to introduce the new collection system until 30th June 2021. This means a significant change in waste management mostly due to the obligation of separate collection of bio-waste. Prior to this Regulation, municipalities themselves decided which types of waste were collected separately which not. The majority introduced systems including separate collection of such waste as paper, glass, metals or plastics (often as so called "dry fraction"), but with bio-waste going into mixed municipal waste.

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 114–120, 2019.
https://doi.org/10.1007/978-3-030-16542-0_16

Directive 2008/98/EC defines bio-waste as “biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants” [3]. Article 22 of the Directive states that measures must be taken “to encourage the separate collection of bio-waste with a view to the composting and digestion of bio-waste and the treatment of bio-waste in a way that fulfils a high level of environmental protection” [3]. Introduction of the abovementioned Regulation in Poland responds to the requirements imposed by the Directive.

Food and kitchen waste from households consists mainly of left-over food waste, fruit and vegetable peels, egg shells, used coffee grounds and tea bags, withered flowers etc. [4, 5]. Such waste is biologically unstable, which means it is prone to fast biological decomposition. Its presence in mixed municipal solid waste (MMSW) increases moisture content and organic matter content and contributes to development of pathogens [4, 6]. Kitchen waste constitutes the organic fraction of MMSW, the share of which, according to the research by Malinowski *et al*., is in the range of ca. 20–35%, depending on the area of waste collection (rural, urban) and the season of the year [7, 8]. During MMSW separation on a drum screen in a MBT plant organics (i.e. kitchen waste) goes mainly to the undersize fraction ($\Phi < 80$ mm), which may contain up to 40% of organics [9, 10]. A large share of organics and other biodegradable waste in MMSW subjected to processing in MBT plants negatively influences the properties of produced alternative fuels (higher moisture content, lower heat of combustion) [7]. A share of organics in alternative fuel derived from MMSW may reach up to 3–4% [11].

Existing systems of waste collection in Poland allow for separate collection of kitchen waste from bigger subjects, such as restaurants, shopping centers, grocery markets, etc. Waste collected in such places are managed in a composting plant or an MBT plant, where kitchen waste can be added to undersize fraction during the biostabilization process. The new law [1] obliges every household to collect separately kitchen waste into a separate, brown bin or bag (marked “BIO”), which requires significant changes in logistics of waste management (more bins are needed, changes in waste collection routes and frequency are to be established, more specialized trucks are necessary, etc.). The change will affect also waste processing technologies – presumably a more emphasis will be laid on bio-waste composting (more supply of waste) and MMSW will change some of its properties (less organic matter). It has to be noted however, that many residents living in detached houses, are already using some of kitchen waste in backyard composters [12]. Of great importance is attitude of residents towards new obligations – how much kitchen waste will be collected and what the quality of such waste will be [13]. The pilot program of bio-waste separate collection launched in Krakow at the beginning of 2018 has not brought expected effects – the majority of Krakow residents taking part in the program are reluctant to collect kitchen waste separately [14]. The obligatory separate collection of bio-waste in Krakow is planned to start on 1st April 2019 [5].

One of the crucial feature of bio-waste treatment, e.g. during composting, is its biological stabilization. There are different methods of determining the rate of biological stability [15] – in Polish regulations the measurement of four-day respiration activity AT4 is recommended [16]. E.g. for compost derived from waste respiration activity has to be less than 10 $mgO_2 \cdot g^{-1}$ d.m [17]. It is of importance to know the properties of waste before submitting it to processing in order to apply proper process conditions. The aim of this study was to investigate the selected properties (moisture content, loss on ignition, AT4) of several types of kitchen waste often present in households as well as to attempt to assess the range of changes in those properties in different waste mixtures. There are no reports of such research scope in the literature, especially concerning AT4 measurements.

2 Materials and Methods

In the research four different types of fruit and vegetable peels were examined, namely apple, carrot, orange and potato peels. They are common components of kitchen waste generated in households in Poland. Each kind of peels was examined separately and in mixtures. Three mixtures were prepared: apple and carrot peels (weight ratio 1:1), orange and potato peels (weight ratio 1:1), and all four kinds of peels (weight ratio 1:1:1:1).

Moisture content in investigated materials was determined by oven drying of material samples at 105 °C till constant weight (according to PN-EN ISO 18134-3:2015-11). Dry matter content was calculated on the basis of moisture content. Loss on ignition was determined by igniting ca. 1–2 g dried material samples in a muffle furnace at 550 °C for 2 h (according to PN-EN 15169:2011). Tests for each type of material were repeated three times.

Respiration activity (AT4) was determined using OxiTop® System according to the procedure described in the Austrian standard *Richtlinie für die mechanisch-biologische Behandlung von Abfällen* (*Guidelines for biological-mechanical treatment of waste*) [18]. The method consists in placing 40 g of the analyzed sample in an air-tight vessel (volume 2.5 dm^3) equipped with a pressure sensor. Inside the vessel there is a small container hung under the lid with CO_2 absorber. Biological processes taking place in the vessel use oxygen and generate CO_2. Since CO_2 is immediately absorbed, the changes in pressure are related to loss of oxygen. A wireless controller allows for reading pressure changes in each vessel. The analysis lasts for 5 days (in constant temperature 20 °C), as the result a 4-day period is taken into account (without so called “lag phase”, which can occur at the beginning of the analysis) to determine AT4. The relation between pressure changes and respiration activity is described by the formula [15]:

$$AT4 = \frac{Mo_2}{R \cdot T} \cdot \frac{V_g}{m_s} \cdot |\Delta p| \tag{1}$$

where:

AT4 – respiration activity [$mgO_2 \cdot g^{-1}$ d.m.],

M_{O_2} – molar mass of oxygen, M_{O_2} = 31 988 $mg \cdot mol^{-1}$,

R – universal gas constant, R = 83,14 $dm^3 \cdot hPa \cdot (K \cdot mol)^{-1}$,

T – temperature, T = 293 K,

V_g – volume of gas in the vessel, V_g = 2.5 dm^3,

m_s – sample dry mass [g d.m.],
$|\Delta p|$ – pressure changes [hPa].
Respiration activity tests were repeated three times for each type of material.

3 Results and Discussion

The results of conducted analyses are shown in Table 1 (for separate types of waste) and in Table 2 (for waste mixtures). The presented values are averages from the results of three individual tests for each type of material, the standard deviation is given after the value.

Table 1. Results of physicochemical tests for different types of kitchen waste.

	Apple peels	Carrot peels	Orange peels	Potato peels
Moisture content [%]	81.70 ± 0.51	87.97 ± 0.41	70.56 ± 1.61	84.80 ± 1.14
Dry matter [%]	18.30 ± 0.51	12.03 ± 0.41	29.44 ± 1.61	15.20 ± 1.14
Loss on ignition [%]	98.02 ± 0.05	91.78 ± 0.57	97.06 ± 0.08	76.86 ± 1.41
AT4 [$mgO_2 \cdot g^{-1}$ d.m.]	56.80 ± 5.37	144.44 ± 11.85	54.10 ± 3.63	59.95 ± 2.60

The content of water and dry matter in peels from apples, carrots and potatoes are in the range between 81.70 ± 0.51% and 87.97 ± 0.41%. In orange peels there is more dry matter (29.44 ± 1.61%) and less water (70.56 ± 1.61%) than in other types of peels. Peels from analyzed fruits (apples and oranges) are characterized by very high values of loss of ignition (98.02 ± 0.05% and 97.06 ± 0.08%, respectively), whereas a significantly lower value was noted for potato peels (76.86 ± 1.41%). It indicates that there is a relatively high content of inorganic matter in potato peels (ca. one quarter). Results of respiration activity AT4 for analyzed peels show that apple, orange and potato peels undergo aerobic biodegradation processes at a similar pace (AT4 values in the range of ca. 55–60 $mgO_2 \cdot g^{-1}$ d.m.), while carrot peels are much more biologically active – AT4 reached 144.44 ± 11.85 $mgO_2 \cdot g^{-1}$ d.m.

The results of respiration activity tests indicate that the analyzed materials are biologically unstable, especially carrot peels. For comparison – typical AT4 values for such waste as untreated sewage sludge is ca. 60–70 $mgO_2 \cdot g^{-1}$ d.m. [19] and for fresh digestate form biogas production vary from ca. 50 to 80 $mgO_2 \cdot g^{-1}$ d.m. [15], wheras waste from composting or MBT processing are characterized by lower values (up to ca. 50 $mgO_2 \cdot g^{-1}$ d.m. [15].

Table 2. Results of physicochemical tests for mixtures of kitchen waste.

	Apple + carrot peels		Orange + potato peels		Mixture of 4 types of peels	
	Measured	Mean (calculated)	Measured	Mean (calculated)	Measured	Mean (calculated)
Moisture content [%]	83.26 ± 1.17	84.83 ± 0.33	79.08 ± 1.56	77.68 ± 0.99	82.40 ± 1.93	81.26 ± 0.52
Dry matter [%]	16.74 ± 1.17	15.17 ± 0.33	20.98 ± 1.56	22.32 ± 0.99	17.60 ± 1.93	18.74 ± 0.52
Loss on ignition [%]	94.27 ± 0.46	94.90 ± 0.29	87.85 ± 1.32	86.96 ± 0.71	90.68 ± 0.96	90.93 ± 0.38
AT4 [$mgO_2 \cdot g^{-1}$ d.m.]	109.87 ± 1.38	100.62 ± 6.51	72.10 ± 3.89	57.03 ± 2.23	96.39 ± 5.11	78.82 ± 3.44

Table 2 shows the measured values of analyzed properties of peels mixtures as well as outcomes of arithmetic mean calculations conducted on the basis of individual results for each type of peels (presented in Table 1) and weight ratios. Regarding moisture content, dry matter content and loss on ignition, in all cases for all the analyzed mixtures the measured results are very close to the calculated arithmetic means – the differences between respective values are within the range of standard deviation intervals. It indicates that those parameters are dependent only on actual content of water or organic matter (in the case of loss on ignition) of individual components and during mixing of such materials no processes occur which would change that state. A different situation is observed in the case of respiration activity – for each mixture the measured value is significantly higher than the calculated mean. The differences are in the range between ca. 9 $mgO_2 \cdot g^{-1}$ d.m. (for the apple + carrot peels mixture) and ca. 18 $mgO_2 \cdot g^{-1}$ d.m. (for the mixture of all four types of peels). It indicates that biological stability of bio-waste mixture is not a simple average of susceptibly to biodegradation of each components but other phenomena, such as synergic effects, may take place.

4 Conclusions

Fruit and vegetable peels used in the research are components of typical bio-waste from households. They are characterized by high values of moisture content (up to 87.97 ± 0.41% – carrot peels), loss of ignition (up to 98.02 ± 0.05% – apple peels) and AT4 (up to 144.44 ± 11.85 $mgO_2 \cdot g^{-1}$ d.m. – carrot peels). The research revealed that whereas such properties as moisture content or loss of ignition do not change in mixtures of different types of peels (the parameters of mixtures depend on properties of components and their weight ratio), biological stability (measured using AT4 index) can change due to natural processes and interactions occurring in mixed materials. In the case of examined mixtures the AT4 values rose significantly compared to the values calculated on the basis of arithmetic means of pure components. The fact that there are other factors determining biological stability of bio-waste than just individual properties of each component has to be taken into consideration during processing of such waste.

Acknowledgements. The publication and research was financed by the Ministry of Science and Higher Education of the Republic of Poland (BM 4638/2017, Faculty of Production and Power Engineering, University of Agriculture in Krakow). The author would like to thank Eng. Aleksandra Gałązka for help in conducting the research.

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The Effect of a Biopreparation Intended for Improvement of Biowaste Processing Efficiency on the Quality of Obtained Stabilized Waste

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Abstract. The aim of the paper was an assessment of the effect of a commercial biopreparation, a liquid bacteria composite intended for improvement of biowaste processing efficiency, on the course of aerobic biostabilization process of the undersize fraction (waste separated from mixed municipal solid waste) mixed with municipal sewage sludge, as well as an assessment of the quality of initially obtained stabilized waste. Presented research comprised analyses of raw materials and mixtures used in the process and the waste obtained after 2 stage process (2 week intensive phase in a bioreactor and 6 week second phase - maturation in the compost pile). Moisture content, organic matter, C and N contents, C/N ratio and pH were analysed. Moreover, the number of parasites and microorganisms in waste was estimated. The process temperature was monitored. On the basis of conducted analyses it was stated that the biopreparation tested does not fulfil its basic role, so it should not be used in sewage sludge and municipal solid waste hygienization process. Physicochemical analysis indicated an insufficient progress in the properties of treatment waste. The number of all investigated microorganisms increased considerably after aerobic biostabilization process, despite the added biopreparation, which according to its manufacturer's declaration was supposed to reveal antimicrobial effect. Moreover, presence of a large number of live parasite eggs was found in all analysed samples, which makes environmental application of the tested biowaste impossible.

Keywords: Biowaste · Biopreparation · Aerobic biostabilization · Microbiocenotic composition · Parasites

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 121–128, 2019.
https://doi.org/10.1007/978-3-030-16542-0_17

1 Introduction

The search for new methods which would enable shortening the duration of waste biological treatment and, at the same time, would ensure obtaining a final product of full value (e.g. compost) or waste meeting legal requirements (e.g. stabilized waste), has been currently one of the most important challenges of ecological engineering. Research conducted in this field focuses on decreasing the harmfulness of this process to the environment [5] and shortening biowaste processing time. Therefore, changes are made in construction of bioreactors [3] waste processing technologies, e.g. concerning lecheate recirculation [21], initial substrate transformation [10, 11, 30, 31], adding solid and liquid [9, 15, 17, 19, 20, 23] or gaseous substances [4]. Usefulness of these additives has been permanently discussed among experts and non-professionals [8].

Several works were published that studied both positive and negative effects on the course of the composting process and on the quality of the resulting compost [7]. Koivula et al. [12] studied the effect of bottom ash on the composting of source-separated catering waste and found that a 10% and 20% ash addition improved the temperature regime, mineralization and humification rates, and decreased loss of total nitrogen. Kollárová [13] experimented with two commercial additives for the composted waste. In this experiment, a positive effect was demonstrated on the reduced production of NH_3, CO_2, CH_4 and H_2S emissions. Out of three lime addition rates to sewage sludge (0.63%, 1%, and 1.63%) tested by Wong and Fang [29] the most efficient was 0.63%. This amount had a positive effect on composting by increasing temperature and CO_2 production without any negative effects on the microbial community. Bereza-Boruta et al. [2] investigated the effect of bacteria composite on odour emission and dynamics of bacterial microflora development.

Presented research analysed the efficiency of a liquid biopreparation (intended for sewage sludge composting plants and developed on the basis of various microorganisms mixture), whose main task is decreasing the odour nuisance of the process, shortening its duration owing to faster achievement of parameters for the final product and hygienization of the process waste (i.e. elimination of pathogenic microorganisms and parasites).

The aim of the paper was an assessment of the effect of a commercial liquid biopreparation on the course of aerobic biostabilization process of the undersize fraction separated from mixed municipal solid waste (MSW) and mixed with municipal sewage sludge. The paper also strived to investigate the initially stabilized waste generated in this process in view of their safe environmental application.

2 Materials and Methods

The waste (undersize fraction) was obtained from mechanical-biological installation (MBT) in Krakow (Poland), while sewage sludge came from the municipal sewage treatment plant in Bochnia (Poland). Analyses were conducted, in an insulated BKB100 bioreactor with 116 dm^3 working volume and 99 cm high. The bioreactor, insulated outside with a special thermal mat, inside had 9 sensors for the bed temperature measurement. Construction of the bioreactor makes collecting samples at various periods of the experiment possible. The functioning of the device was described in the papers by Baran et al. [1] and Malinowski [14].

The biopreparation is a liquid composite of yeast, mould, fungi and algae. The manufacturer states that the biopreparation application should result in a considerable water loss. After processing the waste should be more compact and drier.

The undersize fraction was mixed with municipal sewage sludge at 1:1; 2:1 and 3:1 ratios. The applied biopreparation dose was 1 ml per each kilogram of load wet weight. Two different concentrations of the biopreparation were applied in the analyses (it was solved in water at 1:5 and 1:10 ratios - according to the producer's recommendations). The waste and sewage sludge were mixed mechanically in a cement mixer prior to their putting in the bioreactor. The treatment of mixtures prepared in this way lasted for a total of 8 weeks (2 week intensive phase in the bioreactor and 6 week second phase – maturing in the compost pile). The non-mixed undersize fraction and municipal sewage sludge were also investigated.

Physicochemical analyses were conducted to determine the moisture content (MC), organic matter - loss on ignition (OM), C and N contents, C/N ratio and pH. Moreover, the number of parasites and microorganisms in the waste, sludge and in mixtures was estimated in order to assess the obtained material and its potential, e.g. environmental applications [26]. The process temperature was also monitored.

Microbiological analysis was conducted using serial dilutions method according to Koch. The following microorganism groups were determined: total vegetative bacteria and bacterial endospores, mould fungi, *Staphylococcus* spp., *Escherichia coli*, *Salmonella* spp., *Clostridium perfringens* [28]. Parasitological analysis of the samples containing sewage sludge and undersize fraction was conducted by means of reference method, which relies on determining the number of live eggs of intestinal parasites.

The number of live eggs of *Ascaris* sp., *Trichuris* sp. and *Toxocara* sp. intestinal parasites was determined by isolating live eggs from a representative sample of sludge and waste through shaking or mixing, washing using centrifugation and flotation, followed by a microscopic analysis. In compliance with the Regulation of the Minister of Natural Environment of 1 August 2002 on municipal sewage sludge, a total number of live eggs of *Ascaris* sp., *Trichuris* sp. and *Toxocara* sp. intestinal parasites should be determined per 1 kg of dry mass (ATT index). The research was conducted using modified flotation method with sodium nitrate. The method involves application of a saturated solution with a higher specific gravity that the eggs weight, which causes their flotation to the surface [6, 16, 22]. The substances free from these parasites' eggs may be used in agriculture, whereas the content of over 10 invasive eggs is regarded as contamination dangerous from epidemiological point of view and such substances cannot be applied in agriculture.

3 Results

Organic waste (21.2 ± 4.4%) and fine fraction (35.9 ± 5.7%), i.e. with grain size below 10 mm, dominate in the morphological composition of the undersize fraction used in the research. Inorganic inclusions (plastics and glass) constitute a total of 27.2%. Morphological composition of the undersize fraction falls within the range stated among others by: Baran et al. [1], Malinowski [14] and Stejskal et al. [24, 25]. Basic physicochemical properties of the analysed waste and mixtures were presented in Table 1. A sewage sludge additive (with the content of N = 6.6 ± 0.7% d.m) significantly affected the increase in MC, N concentration and loss on ignition in the analysed mixtures.

Table 1. Characteristics of physicochemical properties of waste and mixtures used in the biostabilization process with the biopreparation

Material*	MC	C	C/N	OM
	%	% d.m.	-	% d.m.
UF 100%	32.7	28.2	24.7	51.7
SS 100%	85.9	30.3	4.6	83.3
UF 50% + SS 50% (1:1)	63.3	43.7	13.3	78.8
UF 66% + SS 34% (2:1)	50.8	36.6	18.5	66.4
UF 75% + SS 25% (3:1)	46.1	34.3	20.2	61.7

* UF – undersize fraction, SS – sewage sludge

Sewage sludge used for the analyses contained a high content of intestinal parasite eggs (because it was not stabilized by e.g. calcined lime). ATT index was 995 ± 29. Moreover, the presence of spore forming bacteria, i.e. *C. perfringens* (4000 cfu g^{-1}) and pathogenic microorganisms, including *Samonell*a spp. (1105 cfu g^{-1}) and *E. coli* (33400 cfu g^{-1}) was identified in the analysed material, which suggest that only the temperature exceeding 100 °C might prove adequate for the samples hygienization.

Pathogenic microorganisms i.e. *Staphylococcus* spp. (135100 cfu g^{-1}), *E. coli* (48000 cfu g^{-1}), *Salmonella* spp. (240 cfu g^{-1}) and *C. perfringens* (80 cfu g^{-1}) were the most numerous in the undersize fraction. The total content of intestinal parasite eggs was 857 ± 42 and, like in case of sewage sludge, *Ascaris* sp. eggs were the most numerous group.

As a result of aerobic biostabilization of the undersize fraction, sewage sludge and their mixtures with the biopreparation additive, ATT index decreased on average by 124 ± 36. A very high abundance of *Staphylococcus* spp., especially following the aerobic stabilization process and *Salmonella* spp. are also particularly noteworthy. Comparing the results of bacterial counts from the subsequent waste samples subjected to aerobic biostabilization, it should be stated that the applied process parameters, and also the preparation and sewage sludge additive contributed to the increase in microorganism number. The numbers of individual microorganism groups grew significantly, while in case of pathogenic microorganisms, i.e. *E. coli* and *Staphylococcus* spp., reached the values 624000 cfu g^{-1} (fraction:sludge 2:1) and 294000 cfu g^{-1} (fraction:sludge 1:1), respectively. Therefore a counterproductive effect was achieved, which suggests, that the parameters of aerobic stabilization process were favorable for the development of determined microorganisms. In the research conducted by Wolny-Koładka et al. [27] the content of some microorganisms was also increasing during processing of undersize fraction (100%).

Table 2 shows the effect of applied biopreparation on the maximum temperatures reached during the process, but also on the duration of the intensive (thermophilic) phase, during which the temperature exceeds 45 °C. The processing temperature exceed 60 °C in case of stabilization of the undersize fraction and undersize fraction mixed with sewage sludge at 1:1 and 2:1 ratios, whereas slightly higher temperatures were achieved with the biopreparation addition in 1:10 concentration.

Table 2. Maximum temperatures during waste biostabilization and duration of intensive (thermophilic) phase

Mixture*	Applied biopreparation	Maximum temperature	Duration of the thermophilic phase
	-	[°C]	[days]
UF 100%	1:10	62.4	3
UF 100%	1:5	60.2	4
SS 100%	1:10	42.2	1
SS 100%	1:5	49.8	4
UF 50% + SS 50% (1:1)	1:10	70.4	4
UF 50% + SS 50% (1:1)	1:5	66.7	5
UF 66% + SS 34% (2:1)	1:10	64.2	4
UF 66% + SS 34% (2:1)	1:5	63.8	2.5
UF 75% + SS 25% (3:1)	1:10	56.7	4
UF 75% + SS 25% (3:1)	1:5	54.3	4

* UF – undersize fraction, SS – sewage sludge

Table 3. Final parameters of the stabilized waste

Mixture*	MC	C	OM	pH
	%	% d.m.	% d.m.	
UF 100%	33.4	24.7	36.2	8.5
UF 100%	31.8	25.6	33.1	8.4
SS 100%	77.3	39.3	72.2	7.1
SS 100%	71.3	36.9	69.7	7.4
UF 50% + SS 50% (1:1)	33.3	26.4	42.2	7.9
UF 50% + SS 50% (1:1)	32.6	24.1	36.9	7.8
UF 66% + SS 34% (2:1)	28.9	26.1	41.1	8.3
UF 66% + SS 34% (2:1)	29.5	24.2	38.7	8.5
UF 75% + SS 25% (3:1)	28.6	19.6	28.7	8.6
UF 75% + SS 25% (3:1)	27.9	22.3	35.4	8.9

* UF – undersize fraction, SS – sewage sludge

Final values characterizing physicochemical properties of waste after the process were presented in Table 3. As a result of the conducted process, water content in the sludge and in the analysed mixtures decreased significantly. The content of C declined in each of the analysed variants, but only in one fell below the reference value (20%). Also, only in two cases among all analysed ones, the values of loss on ignition below 35% d.m. were reached. The applied biopreparation did not allow for shortening the process duration, because it should last for at last several weeks more. Hlisnikovsky [8] and Razvi i Kramer [18], reached similar conclusions while testing the preparations based on microorganisms. They tested seven compost additives and demonstrated that the additives were no more efficient than mature compost without admixtures.

4 Conclusions

On the basis of conducted analyses it was found that the number of all analysed microorganisms increased significantly following the aerobic biostabilization process, despite the addition of the biopreparation, which according to its manufacturer was supposed to reveal antimicrobial activity. A physicochemical analysis indicated an insufficient progress concerning the obtained quality parameters of the treatment waste, thus it cannot be considered safe for agriculture use or depositing on a landfill site. The waste should be further processed to lower, among others, its C concentrations and organic matter content. Therefore, it should be said that the analysed preparation does not fulfil its basic function, so it should not be used in the process of the undersize fraction or sewage sludge hygienization.

Acknowledgements. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland (means of Statutory Research No. DS 3600/WIPIE, University of Agriculture in Krakow).

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Empirical Model of Thermophilic Phase of Composting Process

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Abstract. Progress of composting process depends on properties of feedstocks and conditions of decomposition. Factors influencing this process include most of all temperature of composting material, air temperature, feedstock humidity and structure, carbon-to-nitrogen ratio (C/N) and organic matter content in feedstocks. The aim of the present study was to elaborate a model characterizing the pattern of temperature changes in thermopilic phase of composting of dead poultry depending on the structural material used. The studies were conducted in a chicken (*Gallus gallus domesticus)* farm. Compost bins used in the experiment were equipped with perforated bottoms. Five types of straw were used as structural material in the composting process: wheat, oat, barley, rape and corn. The regression model computed in this study predicts temperature changes in the composting material exact to nearly 95% and the predicted values do not statistically significantly differ from empirical values.

Keywords: Model · Compost · Thermophilic phase

1 Introduction

Assessment whether the composting process runs properly is based on determination of physical and chemical properties of composting material, enzymatic activity, oxygen demand, carbon dioxide (CO_2) emission or seed germination test with the use of the final compost. Organic recycling process proceeds correctly primarily when appropriate humidity (40–50%), proper carbon-to-nitrogen ratio (C:N = 25:1) and availability of oxygen (above 5%, recommended 13–21%) are maintained and feedstock particle size is reduced (density below 500 kg.m^{-3}). Optimal combination of these values influences the activity of microorganisms in the composting material, mostly mesophilic and thermophilic bacteria, actinomycetes and fungi. As thermophilic bacteria colonies grow, temperature of the composting material increases which results in deactivation of pathogens, among other things [1–3, 6, 11]. The composting process usually has four main phases: low-temperature (mesophilic) phase involving hydrolysis and oxidation of organic matter, high-temperatures (thermophilic) phase entailing decomposition of quickly biodegradable organic substances, temperature decay phase in which volume of the composting material is further reduced and compost cooling (psychrophilic phase) with formation of stable humus. If organic recycling is to be used

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 129–135, 2019.
https://doi.org/10.1007/978-3-030-16542-0_18

as a method of management of wastes from animal production in view of its agricultural use (as a fertilizer), the hygienization phase is of crucial importance. Activity of microorganisms causes an increase in temperature to 60–77 °C. Such thermal conditions lead to natural sterilization (deactivation of pathogens) in the composting material. The Polish law defines sanitary and hygienic requirements for organic fertilizers and soil amendments to be used for plant production. Composts and ferments must not contain live eggs of intestinal parasites (Ascaris sp., Trichuris sp., Toxocara sp.) or bacteria of the genus Salmonella [9, 10, 12, 15]. The European Union regulations require that composting temperature in the thermophilic phase reaches 70 °C which guarantees proper hygienization of organic matter and allows for compost use as a fertilizer [13, 14, 16].

The aim of the study was to develop a model characterizing temperature changes in thermophilic phase of organic recycling of dead poultry depending on the used structural material.

2 Scope of Research and Study Method

Empirical studies were conducted in a company engaged both in animal and plant production. Material for experiments was collected from a poultry farm producing meat and laying chickens (dual purpose breeds mostly Messa, and Playmouth rock). Compost bins with perforated bottoms were used in the experiments. Five types of partially dried straw: wheat, oat, barley, rape and corn, were used in the composting process as the structural material. Feedstocks included: litter (straw with chicken manure), straw and dead birds in the proportion by volume of 2:1:1. Studies were conducted in thermophilic phase and the relationship between changes in compost temperature and process duration were investigated [4, 5, 7, 8]. Based on these relationships, a regression equation was computed characterizing the pattern of temperature changes during thermophilic phase. Regression curves were calculated using the least square method. A polynomial function of degree 3 was arbitrarily used to develop the model. Coefficients of determination (R^2) were calculated for these regression equations as a measure of how well the regression model fits the data. In terms of predictive value, the obtained model was validated under real conditions (ex post). Predictive strength of the model was validated based on the regression equation which showed the highest coefficient of determination. Predictive strength of the obtained model was estimated by Person's coefficient of linear correlation (R) expressing the relation between the observed and predicted values. Significance of differences between the actual and predicted values was estimated with Student's t-test. Calculations were carried out with the use of Excel and STATISTICA 13.3 software package at a significance level $\alpha = 0.05$.

3 Results and Discussion

The highest value of coefficient of determination (R^2 = 0.9566) was obtained for the function y = $0.0385x^3 - 1.3997x^2 + 13.905x + 29.19$ (composting with wheat straw, Table 1). Strength of the relationship between the observed (temperature measured) and predicted (according to the model) values, expressed by Pearson's coefficient of linear correlation was estimated at R = 0.9529. Relationship between the values predicted by the model and the experimentally measured values is described by a linear function: y = 1.0287x − 0.7701 (R^2 = 0.9081) (Fig. 6). No statistically significant differences were found between predicted and measured values (Student's t-test value t = −1.8245, probability level p = 0.0759). Study results indicate that the obtained regression model (polynomial function of degree 3) was able to predict temperature changes in composting material (dependent variable) based on duration of thermophilic phase (predictor) with an error of ca. 5%. It can be generalized that the developed models (regression equations, Table 1) can be useful in experimental works on organic recycling of dead poultry for estimation of temperature patterns in thermophilic phase (R^2 ranging from 0.8021 to 0.9566). Universal character of regression equations presented in Table 1 can be corroborated by assumptions of the study and experimental design (Figs. 1 and 2):

- feedstocks included: litter, straw and dead poultry in the proportion by volume of 2:1:1 which secured C:N ratio of 25:1 that is optimal for composting process [5, 7, 8] (Fig. 3).
- five types of straw most often used as a structural addition were used as one of feedstocks [5, 7, 8] (Fig. 4).

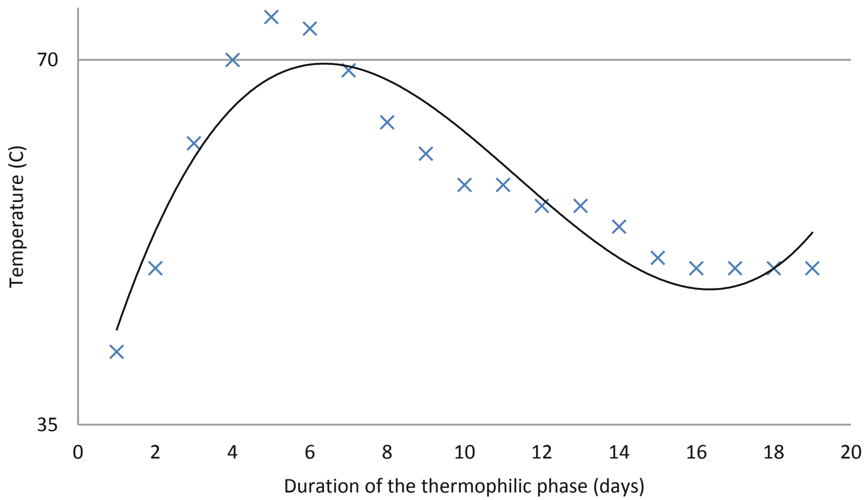

Fig. 1. Regression line representing the pattern of temperature changes during thermophilic phase of composting with the addition of corn straw.

It can be assumed that in practice, it is impossible to construct a model accounting for all factors capable of influencing a given phenomenon. In organic recycling of dead poultry, more detailed predictive models could be computed taking into account also e.g. air temperature, weight and age of dead poultry and litter composition (Fig. 5).

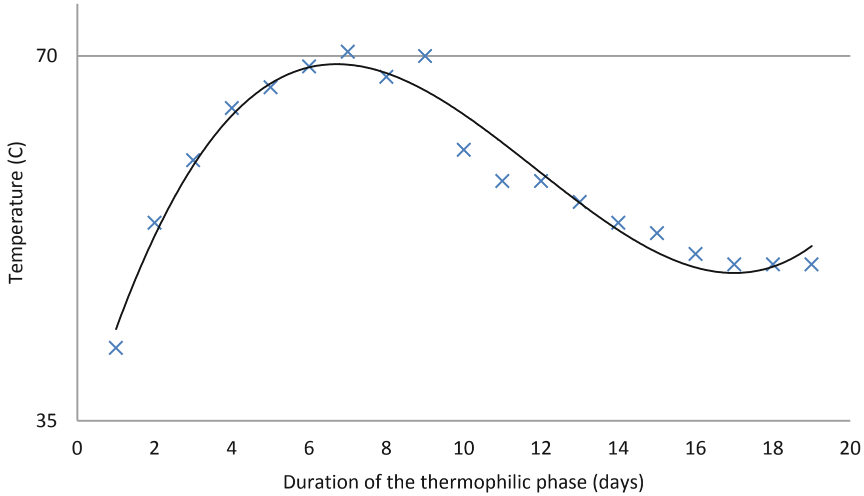

Fig. 2. Regression line representing the pattern of temperature changes during thermophilic phase of composting with the addition of rape straw.

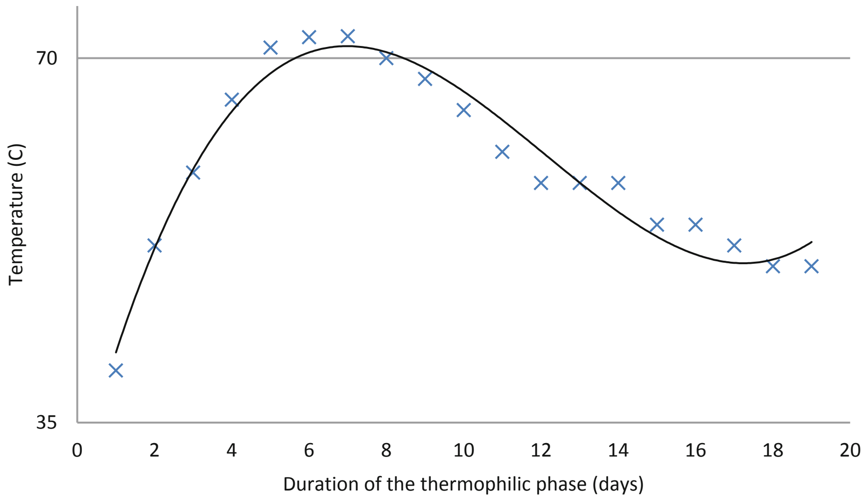

Fig. 3. Regression line representing the pattern of temperature changes during thermophilic phase of composting with the addition of wheat straw.

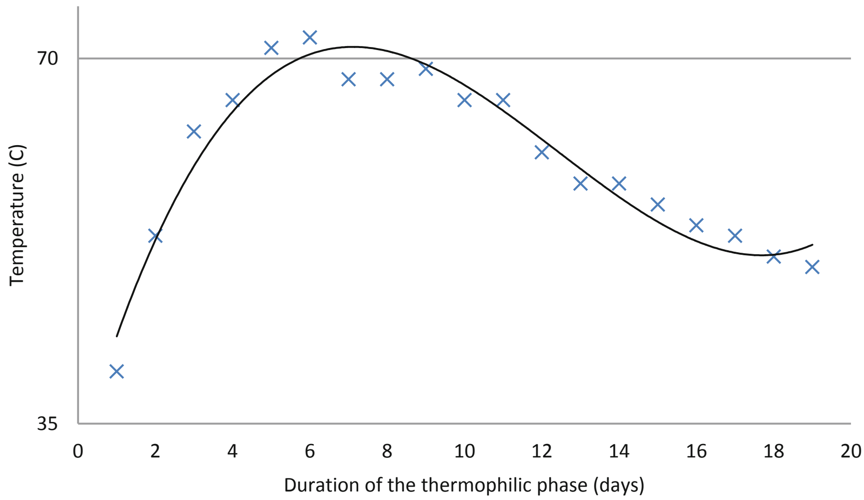

Fig. 4. Regression line representing the pattern of temperature changes during thermophilic phase of composting with the addition of oat straw.

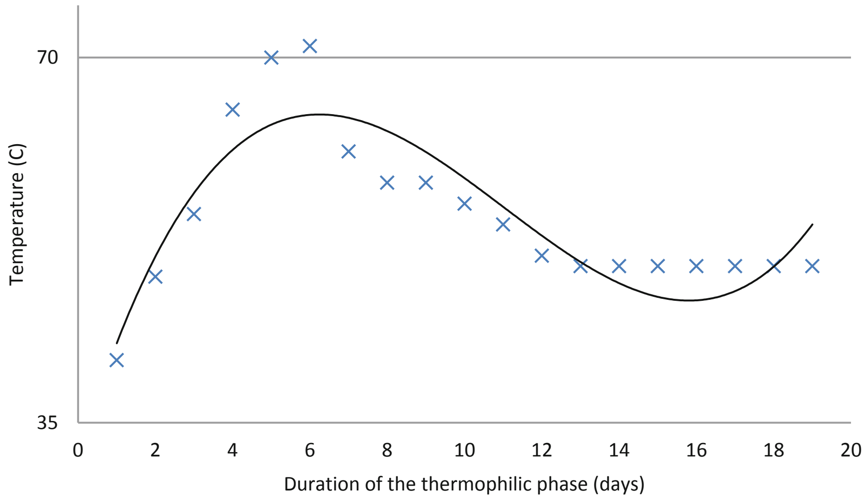

Fig. 5. Regression line representing the pattern of temperature changes during thermophilic phase of composting with the addition of barley straw.

Table 1. Regression equations describing thermophilous phase of composting depending on the used structural fraction.

Applied the structural fraction	Regression equation	Value of the determination coefficient (R^2)
Corn straw	$y = 0{,}0436x^3 - 1{,}4863x^2 + 13{,}614x + 31{,}941$	0,8671
Rape straw	$y = 0{,}0368x^3 - 1{,}3105x^2 + 12{,}612x + 32{,}46$	0,9563
Wheat straw	$y = 0{,}0385x^3 - 1{,}3997x^2 + 13{,}905x + 29{,}19$	0,9566
Oat straw	$y = 0{,}0338x^3 - 1{,}2575x^2 + 12{,}757x + 31{,}826$	0,9469
Barley straw	$y = 0{,}0408x^3 - 1{,}3478x^2 + 12{,}059x + 31{,}867$	0,8021

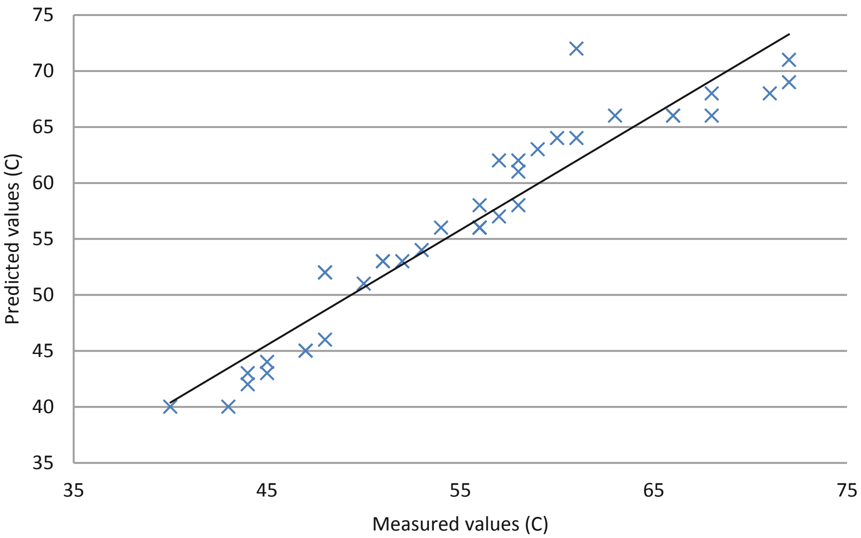

Fig. 6. A scatter plot of actual vs. predicted values

4 Conclusions

1. The regression model developed in this work allows for prediction of temperature changes in the composting material exact to nearly 95% based on duration of thermophilic phase.
2. The predicted values (calculated according to the model) did not significantly differ from actual measured values (determined empirically).

Acknowledgements. This research was financed by Ministry of Science and Higher Education of the Republic of Poland.

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Remediation of Landfill Leachates with the Use of Modified Ashes from Municipal Sewage Sludge

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Abstract. The paper presents investigations into the possibility of using sewage sludge ashes in the process of removal of selected contaminants from landfill leachate. A series of tests was carried out for that purpose using leachate from the Promnik landfill in the Świętokrzyskie Province, Poland. The used sewage sludge ash was obtained by incineration of sewage sludge in laboratory conditions. Additional tests were conducted for sewage sludge ash, which was modified by zeolitization with a fusion method. This modified ash contained zeolite X. The tests were carried out in the process times of 10, 20, 30, 60, 120, 180 and 240 min. Chemical oxygen demand (COD) and selected elements including metals (Cu, Cr, Ni, Pb, Fe, Mg, Zn, Ca, Na, K) were determined in leachate, before and after the treatment process. Furthermore, the following quantities were measured: pH, potential, conductivity, colour and dissolved organic compound (UV254). All analyses performed were compliant with the binding standards. It was observed that ashes used in the experiment proved effective for copper and lead removal from leachate samples. It was shown that the modified ash turned out to be as effective as the ash, which was not subjected to zeolitization with the fusion method. The modified ash of concern can also be used for the removal of organic compounds from landfill leachate.

Keywords: Landfill leachate · Heavy metals · Sewage sludge ash

1 Introduction

The Polish Law on wastes management was based on the Landfill Directive [2]. The principal objectives of the latter include a reduction in the amount of wastes that are produced, the increase in the level of recovery of materials and waste recycling, and the decrease in the quantity of biodegradable municipal wastes delivered to the landfill. Waste storage is the oldest method of waste management [4]. The operation of landfills and the physical, chemical and biological changes that occur at those facilities produce a number of environmental hazards. Among others, they are related to landfill gas emissions, microorganism emissions, odours, noise, pests and highly polluted leachate [15].

Growing awareness of on-going environmental degradation contributes to various actions that concern waste management, including that of sewage sludge. The above mentioned resulted in a ban on its deposition to landfills. The ban facilitates changes in

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 136–143, 2019.
https://doi.org/10.1007/978-3-030-16542-0_19

the strategies of sludge disposal, making thermal methods more popular [11]. In the ash created in sludge incineration, silicon and aluminium compounds prevail, so the ash could be used as a raw material for zeolite synthesis [12].

Landfill leachate is the infiltration water that percolates through the landfill body, together with waste ingredients that were washed out and dissolved. It also contains the products of biochemical reactions that occur in stored waste deposits. Highly concentrated leachate produced in this way requires specialist treatment. Leachate volume and composition, and the rate of its movement through the waste mass can be greatly diversified [17]. Leachate composition reflects changes that occur in the landfill body, thus in the microbiological activity of wastes. Leachate composition together with the volumetric flow rate are the most important parameters in leachate characteristics. Additionally, those two parameters are closely related [16]. The factors that affect the quantity and quality of landfill leachate include, among others, the following [15]: waste storage technique, runoff, type of stored wastes (the degree of compaction, water content), landfill age, and also the area climate. Leachate generated in the operation of the landfill of municipal solid wastes shows much higher concentration of chemical compounds compared with municipal wastewater. Occasionally, the concentration of pollutants in leachate can be very high [18].

The methods used for leachate treatment can be categorised as physical, chemical, biological or physicochemical. Also, they can be combined to operate jointly. The effectiveness of biological processes decreases substantially with the age of the landfill, which is related to refractory compounds that are formed in mature leachate. Therefore, physicochemical methods (advanced oxidation processes, adsorption, membrane methods) provide the optimal solutions [18].

Adsorption involves the accumulation of the substances dissolved in water on the surface of minerals or colloidal particles. The advantages of adsorption on solids include low costs, the process simplicity, and the lack of by-products [3]. Porous bodies such as zeolites, active carbon, ashes from incineration of municipal wastes or sewage sludge provide a particularly advantageous adsorptive material due to their large specific surface [5, 9, 21]. Zeolites are skeletal hydrated aluminosilicates that have crystalline structure, in which numerous channels and chambers are found. Zeolites are used in many fields. In agriculture they act as pesticide and herbicide carriers, and also as an additive to feed and fertilisers. In engineering and environmental protection, they are used for catalytic systems, gas drying and purification, heat exchangers, and immobilisation of nuclear wastes [1]. Specific properties of zeolites, namely sorptive and ion exchange, those of molecular sieves, and also catalytic ones result from their characteristic spatial structure. Magnitude of zeolite adsorption depends on a number of factors, including Si/Al ratio, type, number and arrangement of cations that have ion-exchange ability, the content of micro- and mesopores, structure and chemical composition [19, 21].

Zeolites are more commonly used for wastewater treatment because of their low cost compared to activated carbon and their comparable properties to traditional adsorbents. They are mainly used to remove nutrients, radioactive elements and heavy metals. The application of natural zeolites allows for the removal of 0.4 to even 25.5 mg $N\text{-}NH_4$ per g of adsorbent from wastewater [7]. However, a number of factors influence the final result of the process: pH of the solution, the dose of zeolite, the time of sewage contact with zeolite, the presence of other anions and cations in the solution [19].

High efficiency of sorption of Cd ion (95%), Mn, Zn ion (over 97%) and Fe ions (73%) is demonstrated by synthetic and natural zeolites [6, 14, 20].

The literature does not give the examples of research on the removal of contaminants from landfill leachates with the use of modified sewage sludge ashes by zeolitization.

The paper discusses the results of the attempts to pre-treat leachate using zeolitization of sewage sludge ash with the fusion method, which contained zeolite X [12]. A series of tests were conducted to check whether it is possible to use modified sewage sludge ash for the removal of contaminants from landfill leachate.

2 Materials and Methods

2.1 Examined Material

Leachate samples were collected, stored and examined with respect to their chemical composition in accordance with the current standard PN-ISO 5667-10:1997. Leachate samples were collected from the landfill (10.8 ha) in Promnik (Świętokrzyskie Province), which is a part of the waste treatment plant (WTP). The latter includes, among others, a sorting plant, a composting facility and a digester. Promnik WTP is identified as a Regional Installation for Municipal Waste Processing no. 4, and it serves the population of 390 000 residents. During an annual landfill operation, 27,895 m^3 of leachate is generated on average.

Sewage sludge was collected from mechanical-biological sewage treatment plant located in Sitkówka-Nowiny, the Świętokrzyskie Province, Poland (ERU-289,000, average capacity - 51,000 m^3/d). The sludge was stabilized, dehydrated and dried with a disc dryer. Sewage sludge ash was obtained by sewage sludge incineration at the temperature of 790 °C for 11 min, after earlier drying at 105 °C, and crushed in the mortar to obtain the fraction of <125 µm. Sewage sludge ash was modified by zeolitization with the fusion method, in which zeolite X was obtained (S1, S2). The Sewage sludge ash zeolitization process was conducted at the parameters described [10, 12].

2.2 Research Methodology

Leachate from landfill (pH 8.03, COD 3834 mgO_2/L, colour 5929, TOC 1688 mgC/L, temperature 20 °C ± 1 °C) was used in the tests.

The following doses of modified sewage sludge ash were used in this research: 0.04 g (S1) and 0.08 g (S2), respectively.

0.04 g of sewage sludge ash (SSA), 0.04 g of the modified sewage sludge ash (S1) and 0.08 g of the modified sewage sludge ash (S2) were weighed and placed in 0,5 L conical flasks. Then, 0,4 L of leachate was added. The mixtures were mixed for a specific time at 150 rpm. The contact time was assumed to be 10, 20, 30, 60, 120, 180 and 240 min. Next, the samples were filtered. Changes in the parameters, including pH, potential, conductivity, COD, colour, dissolved organic compounds and metals were assessed for the applied process times.

The contents of metals in the samples were determined using ICP-OES Perkin-Elmer Optima 8000 spectrometer. Mineralization with aqua regia was conducted in accordance with PN-EN ISO 15587-1:2005. COD was determined with the Spectroquant photometric test. Cuvette tests measurements were performed using MERCK Nova 60 spectrophotometer. Prior to the tests, the samples were heated in MERCK TR 320 thermoreactor (120 min at 148 °C). This method corresponds to DIN ISO 15705 and is similar to EPA 410.4, APHA 5220 D and ASTM D1252-06 B. Colour was determined with a spectrophotometric method using UV/VIS spectrophotometer in accordance with PN-EN ISO 7887:2012 standard. Dissolved organic compounds were determined with the spectrophotometric method in the UV range (254 nm wavelength) acc. PN-C-04572:1984.

3 Result and Discussion

Tables 1 and 2 show the results of investigations into the use of raw sewage sludge ash and modified sewage sludge ashes in the remediation of leachate from the landfill site in Promnik near Kielce. The efficiency of the sorption of selected contaminants with the use of sewage sludge ash containing zeolite X is similar to the case when raw ash was applied.

Table 1. Properties of landfill leachate before and after contact time with ash.

Parameters	Sample	Time, min						
		0	10	20	30	60	120	180
pH	SSA	8.03	8.21	8.17	8.20	8.2	8.18	8.2
	S1	8.03	8.20	8.18	8.20	8.18	8.16	8.17
	S2	8.03	8.18	8.17	8.19	8.21	8.20	8.19
Potential [mV]	SSA	-	−80.8	−77.7	−79.2	−79.2	−79.2	−79.1
	S1	-	−79.1	−77.8	−78.6	−80.9	−78.3	−77.8
	S2	-	−79.2	−78.2	−78.5	−78.9	−80.2	−79.2
Conductivity [mS]	SSA	-	178.4	174.2	177.6	170	177.8	179.9
	S1	-	181	178.2	177.2	179.2	178.4	182.1
	S2	-	178.7	177.6	178.4	172.1	179.7	177.7
COD [mg O_2/L]	SSA	3834	3248	3256	3136	3208	3104	3312
	S1	3834	3576	3264	3248	3296	3144	3136
	S2	3834	3352	3216	3240	3272	3232	3184
Colour, [mg/L]	SSA	5929	5719	5445	4878	4898	4596	4655
	S1	5929	5818	5726	4577	5297	5660	4756
	S2	5929	4843	4843	4342	4676	3530	4623
UV254 [cm^{-1}]	SSA	25.71	23.37	23.00	24.03	25.48	23.55	25.84
	S1	25.71	23.16	21.82	23.88	23.31	21.99	22.05
	S2	25.71	21.36	21.55	25.90	20.26	26.14	23.31

SSA – 0.04 g of sewage sludge ash; S1 – 0.04 g of modified sewage sludge ash; S2 – 0.08 g of modified sewage sludge ash

Table 2. Content of metals in landfill leachate after a specific remediation time, ND – not detected.

Samples	Time	Metals									
		Cu	Cr	Ni	Pb	Fe	Mg	Zn	Ca	Na	K
SSA	0	2.75	1.92	0.97	0.08	10.91	147	0.445	107	1639	1333
	10	0.57	1.90	1.05	0.03	11.39	150	0.700	126	1621	1330
	20	0.07	1.98	1.05	0.003	12.13	155	0.504	126	1664	1018
	30	0.17	1.87	1.06	0.10	12.22	150	0.551	128	1610	1336
	60	ND	1.94	1.04	0.04	11.36	153	0.475	122	1616	1327
	120	ND	1.87	1.17	0.02	11.23	150	0.821	137	1605	1276
	180	ND	1.87	1.03	0.01	11.14	154	0.463	120	1637	1369
	240	ND	1.91	1.03	ND	11.35	158	0.699	127	1634	1331
S1	0	2.75	1.92	0.97	0.08	10.91	147	0.445	107	1639	1333
	10	0.23	1.94	0.99	ND	10.69	146	0.634	116	1615	925
	20	ND	2.04	1.08	0.02	11.71	158	0.901	129	1547	505
	30	0.68	2.23	1.33	0.003	13.62	151	1.279	135	1684	1353
	60	ND	1.88	1.02	0.05	10.49	148	0.356	109	1658	1326
	120	ND	1.86	1.01	ND	10.04	150	0.317	104	1636	1277
	180	ND	1.89	1.01	ND	10.42	150	0.435	109	1652	1329
	240	0.01	2.22	1.90	ND	11.26	151	1.126	160	1622	1337
S2	0	2.75	1.92	0.97	0.08	10.91	147	0.445	107	1639	1333
	10	0.24	2.02	1.47	0.17	11.97	150	1.062	159	1678	1346
	20	0.05	1.85	1.00	ND	10.62	145	0.51	101	1618	1287
	30	ND	1.91	1.03	0.05	10.16	149	0.505	101	1638	1370
	60	ND	1.83	1.00	0.03	10.07	150	0.420	99	1627	1334
	120	ND	1.99	1.20	0.09	10.33	148	0.749	119	1635	1326
	180	ND	1.95	1.10	0.01	10.13	145	0.537	104	1640	1328
	240	0.38	2.00	1.27	ND	10.46	148	0.673	119	1635	1317

SSA – 0.04 g of sewage sludge ash; S1 – 0.04 g of modified sewage sludge ash; S2 – 0.08 g of modified sewage sludge ash

At the leachate and sorbent contact time range of 10 to 120 min, a advantage of raw ash over the modified ash can be seen. Further contact time extension causes an improvement in the results obtained when samples S1 (t = 180 min), S2 (t = 180 min) and S2 (t = 240 min) are used. Additionally, it should be noted that the results recorded for the sample marked as S2 reached the extremum at 20.08% of COD reduction. The measured value of COD after 4-h exposure of the leachate was 3064 mg O_2/L.

In the leachate remediation process, COD was reduced, but this change only slightly contributed to the improvement in leachate colour. The observed remediation effect was much better visible, additionally the most promising results were found for sample S2. In this case, already after 2-hour exposure of samples containing zeolite X and landfill leachate, a reduction of more than 40% in the solution colour was observed (Table 1). UV254 did not cause a high reduction, i.e. remediation effectiveness exceeding 20% was observed for only one sample S2. That presents a certain analogy to the results of COD assessment, however, the results obtained in this case seem slightly worse.

The results obtained for the sorption of heavy metals are shown in Table 2. It was shown that the sorbents used in the experiment proved efficient only for copper and lead removal from leachate samples. High effectiveness of copper removal could be obtained after the contact time of 10 min. In this case, the concentration of copper in the leachate subjected to remediation with modified ash (S1) was almost twice lower than in the samples exposed to raw ash (0.234 < 0.566 mg/L), whereas Cu reduction degree clearly exceeded 90%. Comparably good treatment effects were found for sample S2. Extending the sorption time generally leads to improved results and a complete removal of copper. However, it does not seem reasonable to apply the process for longer than 180 min. Similarly to the case reported above, sample S1 yielded good results. They were even better than for copper as complete lead removal was attained. Additionally, the results achieved for samples exposed to ash are considered satisfactory. More than 60% of lead was removed after 10 min, and after 20 min, the outcome was definitely higher than 96%.

The comparison of test results with the results presented in [13] proves that a higher percentage of reduction of COD was obtained in a shorter period of time. Sewage sludge ash (SSA) and modified sewage sludge ash (S1, S2) resulted in the reduction of 19,04%, 18,20% and COD 16,95% respectively after 120–180 min. However, in paper [13], in which natural zeolite was used, the reduction of COD at the level of 20% was obtained after 72 h of the sorption process.

Similarly in the paper [8], in which the tests were base on zeolite synthesised from coal fly ash by a fusion method for the treatment of industrial wastewater, a 100% reduction of lead and copper was discovered. Simultaneously, the above mentioned effect was obtained with the use of doses of sewage sludge ash and modified sewage sludge ash 100 times smaller than the doses of zeolite from coal fly ash. Thus, the mass of the sorbent used will be smaller. The authors of the paper [22] proved that the zeolitic material obtained from sewage sludge ash can be the component of asphalt mixtures. Its introduction to the set of asphalt raw materials had a favourable influence on the reduction of production temperature of this material. Thus, the modified sewage sludge ash sorbent will not be deposited on landfills and will not pose a threat to the natural environment.

4 Conclusions

Increased awareness of growing environmental degradation contributes to taking various actions in the field of waste management, including the issues related to sludge management. A ban on sludge storage facilitates the advancement in sludge removal methodology. A strong interest in thermal treatment methods for sludge disposal has developed, which especially concerns large treatment plants. Sludge incineration ash shows the predominant presence of silicon and aluminium compounds, consequently, it seems suitable to be used as a raw material for zeolite synthesis. Before and after the treatment process, changes in, among others, COD, colour, dissolved organic compounds and heavy metals were determined in the leachate. It was observed that sorbents used in the experiment proved effective for copper and lead removal from leachate samples. It was shown that the modified ash turned out to be as effective as the sewage sludge ash, which was not subjected to zeolitization with the fusion method. The modified ash of concern can also be used for the removal of organic compounds from landfill leachate. It should be added that so far there have been no tests on the influence of modified sewage sludge ash as a result of zeolitization on the effect of landfill leachate treatment.

Acknowledgements. The project was funded by the National Science Centre. The funds were allocated on the basis of the decision DEC-2011/03/D/ST8/04984, Poland.

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Assessing Hydromorphological Characteristics of Small Watercourses Using the River Habitat Survey (RHS) Method

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Abstract. River Habitat Survey method is a popular and widely used method for surveying river hydromorphology. In this paper, two watercourses differing in terms of their hydromorphology and crossed areas located in north-western and central Poland: the Wardynka river and Kanał Habdziński, were investigated. Wardynka is a meandering river, flowing across woodlands with numerous valuable environmental entities, whereas Kanał Habdziński is a straight-channel watercourse revealing major impact of humans on the environment. Data obtained during a field study allowed to calculate two overall (most commonly used) indicators, Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS), which are the resultant of many single basic parameters. Based on calculated numerical values of hydromorphology indicators, HQA score for Wardynka watercourse was 68, and the modified HMS was 19. This allowed to classify the surveyed river as belonging to ecological status class 3, identified as moderate. In the case of Kanał Habdziński, HQA was much lower (33), whereas HMS was 28, which ultimately allowed to classify hydromorphological characteristics of the watercourse as belonging to class 4, corresponding to poor ecological status.

Keywords: Small rivers · River Habitat Survey · Hydromorphology · Ecological status

1 Introduction

For many years, major methods of assessing the quality of running waters have been reduced to their classification according to physical and chemical characteristics of waters. Hydrobiological features were scarcely used to expand river monitoring surveys. Recently however, in assessments of ecological status of rivers scholars have increasingly included also the hydromorphological conditions [1]. These include a set

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 144–153, 2019.
https://doi.org/10.1007/978-3-030-16542-0_20

of characteristics of running waters, related to channel features, river bank management, structure and abundance of macrophytes, as well as to hydrological regime [15]. Assessment of physical and hydrological characteristics complies with objectives of the European Water Framework Directive assuming that Member States are obliged to assess anthropogenic pressures on surface waters, and subsequently, should a need arise, take actions to restore at least good ecological status of the waters [13, 21]. Assessment methods are designed to determine the degree of conservation of valleys and rivers and the scope of anthropogenic modifications. In Poland, genuine attempts at assessing watercourses gave rise to development of a descriptive method [14]. Currently, one of the latest methods of assessing hydromorphological characteristics in the territory of Poland has been the Polish version of the British River Habitat Survey protocol [6].

It allows to characterise rivers and assess their physical structures as belonging to specific classes, and it has been used more frequently than other methods. River Habitat Survey is a method designed to assess river morphology based on detailed gridding. The quality of morphological characteristics of rivers are assessed using the HQA score which depends on the scope and diversity of natural structures. The other indicator, the Habitat Modification Score on the other hand, depends on the scope of modifications driven by humans. The baseline for classifications relying on the aforesaid indicators are reference conditions (values of reference parameters) for watercourses for which RHS was designed [13].

This paper was intended to use the RHS method to assess two watercourses located in north-western and central Poland, differing in terms of human-driven modifications and hydromorphological characteristics.

2 Material and Method

Specific hydromorphological characteristics of 2 small watercourses in the Oder (Wardynka) and Vistula (Kanał Habdziński) catchments, were examined using the River Habitat Survey method (Fig. 1). Each 500 m long survey site was divided in line with RHS methodology into 10 spot-checks. The survey site on the Wardynka river, being the largest tributary of the Stobnica river belonging to the Ina catchment (West Pomeranian Voivodship), was determined by coordinates spanning from N53°15’64.6, E15°62’48.3 to N53°16`06.4, E15°62’19.1. The survey site on Kanał Habdziński (supplying the Wilanówka river, Mazovian Voivodeship) had the following coordinates: from N52°07’88.7, E21°17’46.4 to N52°08’21.3, E21°16’91.0. RHS was carried out in August 2017.

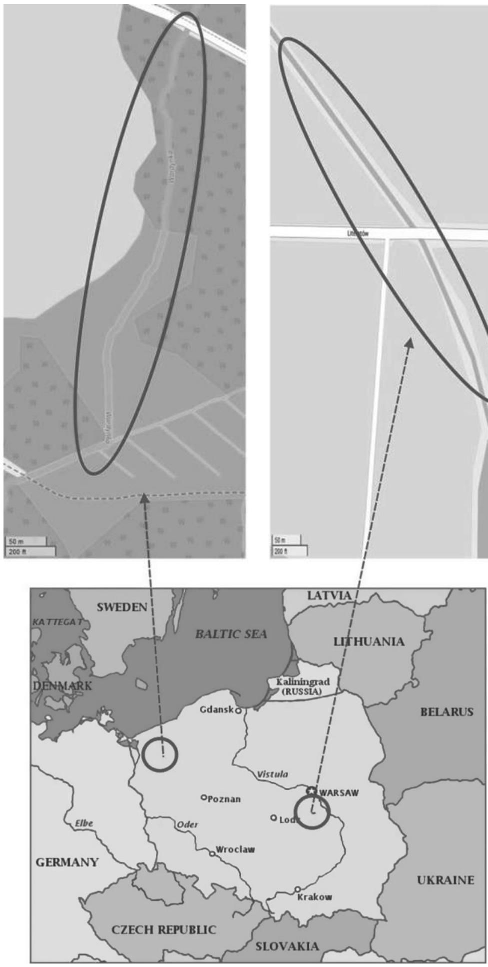

Fig. 1. Map with locations of selected survey sites (own elaboration)

RHS method is based on observations and recording of elements of the river environment. Each river selected to be examined was monitored along survey sites of 500 ms. The first stage involved characterisation of the basic morphological features of the channel and banks, whereas at the second stage, overall assessment of the entire survey site was carried out, considering different morphological forms and transformations not recorded in the first stage. During the first stage, in 10 spot-checks located at 50 m intervals, physical features of the channel were recorded, such as predominant flow-type, substrates of the channel and banks, as well as reinforcements in the cliffs and the channel. Use of adjacent land, as well as water and bankface vegetation structure were identified as well. During the overall assessment of the entire survey site, the description was completed with a range of elements, such as channel dimensions, number of hydraulic structures, stream pools, riffles, point bars or description of the valley. Additionally, any significant elements not assessed at the first stage of the survey were recorded. Consequently, nearly 400 parameters describing hydromorphological features of the watercourse channel were obtained. In order to determine numerical values of these parameters and to enable the comparison across specific survey sections, three indicators used and described in detail in the Polish RHS method were applied. Habitat Quality Assessment (HQA) score describing diversity of natural morphological features of the channel was determined. The HQA score reveals naturalness of the watercourse based on the diversity and extent of natural features found in the watercourse. High score corresponds to the presence of multiple features under high natural value. Another indicator was the Habitat Modification Score expressing the extent of human impact on hydromorphological features of the river. The more hydrological structures and regulation works are found in the river sections, the higher the score.

In order to meet the requirements set out in the European Water Framework Directive (WFD), five-class tiers of the ecological status (I-V) were proposed, based on the overall HQA and HMS scores. Each indicator has five classes (1–5) determined on the basis of the obtained score [20]. In accordance with the WFD, watercourses should belong to ecological status class 1 (high) or class 2 (good).

3 Results

Both survey sites selected for either river showed considerable differences between the surveyed watercourses related to, among others, use of adjacent land, water flow type and extent of valuable morphological features in the rivers (Fig. 2).

Examination of the basic morphological parameters and spot-checks have shown that over the whole RHS site on Wardynka river, the substrate of both banks was mineral ground with peat admixture. In the final spot-check, boulders and stones were additionally recorded, which in this region were also predominant in the bed material. The predominant channel substrates of the Wardynka river were bedrock and gravel (in three spot-checks), as well as bedrock and sand (in seven spot-checks).

Along the whole RHS site, Wardynka river was rapid (6 spot-checks), whereas in some areas it turned into broken standing waves, upwelling and in the final section, free fall flow-type was recorded. Meandering water flow favoured creation of natural morphological features of riparian zones recorded a number of times along the whole survey site, obtaining the total of 11 points. The river channel was inhabited mainly by liverworts and mosses, however in 5 spot-checks the surveyors recorded presence of narrow-leaved submerged and emergent vegetation, and in 2 spot-checks presence of filamentous algae was reported. A typical valley profile was determined as a shallow vee valley. Over the survey season, along the whole survey site the total of 6 riffles and 10 unvegetated point bars was recorded. Among valuable morphological features of the Wardynka river, the surveyors recorded: shading of channel, overhanging boughs, exposed bankside roots, fallen trees and underwater tree roots in the channel, as well as boulders (>1 m) and leafy debris.

Fig. 2. Surveyed watercourses with visible morphological features under high natural value on the Wardynka river (A) and marked tilled land around Kanał Habdziński (B).

Habitat Quality Assessment score for the surveyed section of the Wardynka river was 68, which allows to classify the watercourse as belonging to ecological status class 3 (Table 1). Habitat Modification Score for Wardynka river was 19, which corresponds to ecological status class 3 (Table 1). The above results allow to classify the Wardynka river as a moderate ecological status watercourse.

The other surveyed watercourse was Kanał Habdziński located in central Poland (catchment of the Vistula river). This small river flows mainly across agricultural land. As opposed to the former watercourse (catchment of the Oder), the 500 m long survey site of Kanał Habdziński had a very straight channel and the bank substrate was tilled land only (Fig. 2). Both banks and the channel had no natural morphological features. The predominant substrate of the channel bed was a layer of silt, and in two spot-checks residue amounts of clay and loam were recorded. In the surveyed watercourse section, channel modifications included 2 culverts, and no perceptible flow was recorded. Kanał Habdziński provided highly favourable conditions for reedbed development in the channel, whereas submerged macrophytes could be spotted over the whole survey site.

As opposed to Wardynka river, Kanał Habdziński as a straight-channelled watercourse had no morphologically valuable features. Only one riffle was recorded, with complete absence of any point bars. The only hydrological structures included 2 culverts exerting major impact on the environment. The only visible outcomes of anthropological pressures included draining, bank trimming and removing channel vegetation.

Over the whole survey site, HQA score for Kanał Habdziński was 33, which allowed to classify the watercourse as belonging to ecological status class 4. The score is significantly lower (by more than 50%) when compared with HQA score recorded for the Wardynka river. Low HMS score (28) also points to ecological status class 4 (Table 1).

Table 1. Classification of watercourse ecological status based on HQA and HMS scores (ecological status classes: I – high, II – good, III – moderate, IV – poor, V – bad)

Name of the watercourse	HQA [class]	HMS [class]	Ecological status classes for a HQA and HMS	Ecological status of the watercourse
Wardynka	68 [III]	19 [III]	III	Moderate
Kanał Habdziński	33 [IV]	28 [IV]	IV	Poor

Explanations: HQA - Habitat Quality Assessment; HMS - Habitat Modification Score.

4 Discussion

Hydromorphological assessment of flowing waters is an obligatory task implemented in the European Union member states, as part of the so called Water Framework Directive (WFD), which has been established in the European Parliament Directive [9]. WFD assumes that the ecological status of surface flowing waters is primarily determined by biological elements which depend on abiotic factors related to hydromorphological elements of the river bed and valley and to physicochemical water properties. Assessment of the hydromorphological status of flowing waters with the RHS method aims at determination of reference conditions of a watercourse, and is useful for the management of catchment area, e.g. renaturalization of rivers or anti-flood protection. RHS is a WFD compliant method developed in the UK and follows rapid and simple survey procedures using a standardized approach to characterize the physical habitat and evaluate hydromorphological quality [10].

A number of RHS-based multi-factor analyses during river monitoring have shown that they are an effective assessment method, especially after cross-reference of their results with three different aquatic communities, such as benthic macroinvertebrates, fish and macrophytes [2]. The RHS method has a wide application in various types of rivers [5]. It may be used to assess both lowland [11] and highland [12] watercourses.

The watercourses assessed in the present study were characterised by a different river bed structure. The Wardynka river had mainly rocky and sandy river bed, while in Kanał Habdziński mud was dominant. It should be stressed that a similar bed structure was recorded in previous surveys carried out on other sections of the Wardynka river [19]. The water flow in the rivers was also varied. Wardynka, which is locally a typically mountain river, was characterised with a rapid water flow. Similar results were achieved during the monitoring conducted in earlier years. In their study Spieczyński *et al.* [19] also recorded rapid water flow almost along the whole survey site. Low flow of water in the river and intense overgrowing of the river bed with reed-bed plants was observed in Kanał Habdziński. This slight water movement is conducive to the growth of genus *Potamogeton* which finds more favourable development conditions in stagnant waters [2]. Intense overgrowing of watercourses and small water reservoirs on agricultural areas results from high eutrophication of surface waters from these areas [4].

The studies conducted on the Wardynka river show low HQA score. The results of our studies classify the river to the ecological status class 3. This is a low class considering presence of RHS high-score trees and associated features and morphological features under high natural value, as well as natural morphological features of the banks and the channel. Although Wardynka displays many features under high natural value and in many sites it resembles a mountain torrent, after the analysis of all attributes required for RHS assessment, low results may point to extensive anthropogenic transformations. However, in a previous survey carried out by Spieczyński *et al.* [6] on the Wardynka river, lower HQA score was obtained (48), which pointed to poor habitat quality corresponding to class 4. These differences induce provision of more extensive monitoring by expanding the surveyed section to assess rivers in a number of sites. It would be advisable not only to expand the area of flowing waters hydrological assessment, but also to perform it and compare every couple of years. Such conclusions may also be drawn based on the results of studies conducted on Portuguese rivers [10].

Even lower HQA scores than in the Wardynka river were recorded in Kanał Habdziński. The watercourse revealed not only slight water flow, but also intense overgrowing of the river with macrolytes, combined with poor bottom. Kanał Habdziński is a regulated watercourse, where cyclic maintenance works are conducted.

Similar results were recorded in RHS carried out for two rivers in north-western Poland - Gowienica Miedwiańska and Kanał Młyński [11] subject to major human impact. For these two watercourses, tilled land-use of adjacent areas and visible outcomes of human impact on the environment contributed to their poor ecological status, just as in the assessment of water quality for Kanał Habdziński. Despite low HQA scores and final classification of Kanał Habdziński as having poor hydromorphology, the watercourse was not classified as belonging to class 5, as it was the case with RHS assessment of Osówka watercourse, which corresponded to poor hydromorphological quality [17].

Different values of the HQA score were achieved in studies carried out in the middle and upper section of the Yitong River in Northeast China [18]. Only 7.8% of the studied river sections had its natural character preserved, which is reflected by HMS parameters. This state of affairs exists despite the fact that the river flows across sparsely populated areas, mountainous and with low intensity of land-use. Nevertheless, there are clear differences between the upper, middle, and lower course of the river.

The RHS method is an effective river assessment tool, and with additional analyses of catchment parameters it may link the results of hydromorphology studies with catchment management and human impact on the surveyed watercourse via an overall indicator. Just like any other method, it has some shortcomings, however they have been remedied on an ongoing basis [7, 8].

Due to extensive overgrowing and silting, the surveyed small watercourses are subject to considerable reclamation. This leads to frequent transformations and environmental changes occurring immediately after channel improvement, and restoration of hydrodynamic balance may occur very slowly [16]. This especially applies to the Wardynka river, where its meandering nature and numerous valuable morphological features constitute important nature conservation qualities, and any disturbances may have a damaging impact on biodiversity. Any methods for assessing hydromorphology and ecological status of rivers should be applied on an ongoing basis and they should cover as extensive area as possible, to allow assessment of any changes and transformations in the aquatic environment in the short- and long-term [10].

Another widely used river assessment instrument is the European Fish Index (EFI+) where the final metric value of EFI+ is calculated as the mean probability value ranging from 0 to 1. Specific ranges of the index value are aligned with assessment categories (environmental status of the site), spanning from high to low. Assessment of surveyed rivers based on this index was carried out, among others, on the Wardynka river and Kanał Habdziński [3]. A relatively low EFI+value, indicating poor quality of fish habitats, confirmed poor ecological status classes on particular rivers [6].

5 Conclusions

Despite its methodological imperfections and differentiation in selection of various methods to assess flowing waters, River Habitat Survey (RHS) is still one of the most effective and easy to use methods of watercourse assessment. The River Habitat Survey method could be used not only for the present river reach hydromorphological status evaluation, but also for forecasting morphological and habitat changes impact initiated by river restoration works. Simplicity of conducting field works allows assessment of numerous parameters, which makes it possible to use the data in a comparative analysis of various solutions, including ecological ones, at various time points. The River Habitat Survey method may also be used to forecast the effects of renaturalization works on the rivers. Two small watercourses assessed in the present study were characterised by high differentiation. Kanał Habdziński is an example watercourse with a low habitat quality assessment (HQA) and a high habitat modification score (HMS). HMS was more than half lower than in the Wardynka river, which, despite observed land transformations and changes resulting from human activity at the studied section, preserved some elements of a natural watercourse, resulting in a much higher habitat quality assessment (HQA). During the field tests, it was noticed that history of the river's knowledge is important for RHS method. The studies carried out on the rivers, and consultations with the institutions managing the watercourses revealed that the river has undergone significant transformation over the years. Any information on changes and transformation of the habitats may be used in the future to conduct maintenance works on the watercourses, and may have significant value for planning future works on the rivers.

Acknowledgements. This study was supported due to implementation of the multi-annual programme "Technology and environmental projects supporting innovative, effective and low-pollution management of resources in rural areas", task no. 5 "Knowledge support of the preparation, implementation and approval of works intended to maintain land reclamation equipment", implemented by the Institute of Technology and Life Sciences.

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Habitats and Density of the Invasive Topmouth Gudgeon (*Pseudorasbora parva* Schlegel) in Small Polish Watercourses, in the Light of Threats to the Habitats of Native Species of Fishes

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Abstract. The newly introduced species (alien species) can become invasive and pose a serious economic and ecological threat, causing changes in the habitats of native species, while competing with native species, they can affect the density and biodiversity within the ecosystem. One of the invasive species of fish in Europe is the topmouth gudgeon (*Pseudorasbora parva* Schlegel, 1842). The aim of this study was to assess the habitats of selected topmouth gudgeon's populations in terms of basic hydrological and physicochemical characteristics, as well as to determine the density of the species and the potential impact of the population on native species in small Polish watercourses. Three small watercourses in Odra catchment (Myśla and Wardynka river) and Wisła (Molnica river) were selected for the study, where electrofishing were conducted and water samples were taken for hydrochemical analysis. Among the 9 surveyed sites, the topmouth gudgeon was caught on the 5th. On the Myśla River, it was located on two sites, the same on the Molnica river and on the 1 site on the Wardynka river. In total, 550 fishes (belonging to 10 species) were caught on these 5 sites, including 388 topmouth gudgeon, which accounted for over 70% of the fishes caught. Although the physicochemical conditions of the tested watercourses are not optimal for this invasive species, the increase of density and further colonization of the topmouth gudgeon can be expected, and thus already observed in other watercourses, the impact on indigenous species and habitats occupied by it.

Keywords: Fishes · Topmouth gudgeon · *Pseudorasbora parva* · Invasive species · Small rivers · Habitats

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 154–160, 2019.
https://doi.org/10.1007/978-3-030-16542-0_21

1 Introduction

Invasions of expansive alien animals are one of the most important threats to biodiversity due to the unforeseen effects of the emergence of a new species in the environment. In nature, there are many negative human activities, such as the creation of migration barriers for valuable salmonids through hydrotechnical constructions [7]. The newly introduced species (alien species) can become invasive and pose a serious economic and ecological threat, causing changes in the habitats of native species, and when competing with native species, they can affect the density and biodiversity within the ecosystem [8]. One of the invasive species of fish in Europe is the topmouth gudgeon (*Pseudorasbora parva* Schlegel, 1842). It comes from eastern Asia, where it occurs in the waters of Japan, China, Korea and the Amur river basin. It was accidentally introduced to Europe together with carp stocking material for ponds in the Danube delta (Romania) in 1961 [3]. Since that time, it got into the natural waters of Europe, and in Poland it was recorded for the first time in the 1980s [13, 14]. This success of quickly settling new areas should be explained by the development of international logistics in aquaculture, but also high physiological tolerance, high reproductive potential, a wide spectrum of food and care for offspring [1, 3]. Although there is literature on the spread of this species in polish waters, its behavior, age structure or growth, there is little information about the habitats occupied by this invasive species, especially in the aspect of colonization and impact on native species in small watercourses. The aim of this study was to (I) assess the habitats of selected the topmouth gudgeon's populations in terms of basic hydrological and physicochemical characteristics, (II) determine species density and (III) the potential population impact on native species in small polish watercourses.

2 Materials and Methods

In 2017 monitoring of ichthyofauna was carried out on 26 small rivers of Odra and Vistula catchment areas [4]. Only three small watercourses in the Odra river basin (the Myśla and Wardynka rivers) and the Vistula river (Molnica river) were selected for further research on the topmouth gudgeon's population (Fig. 1), because we noted the occurrence of this species.

On each rivers, 3 sites were selected, which differed each other in hydrological and hydrochemical condition, and were located in the upper, middle and lower reaches of each watercourse. In the period from July 12th to July 21st 2017 fishes were collected and samples were taken for physicochemical analyzes. The fishes were fished with the Electric Fishing Device Type ELT 60 II GI. The following standards recommendations have been taken into account in catches: CEN EN 14011 2003 and PN-EN 14011 2006, because obtaining reliable information on the distribution and dominance of species in rivers requires conducting electrofishing taking into account the specific character of the watercourse (stream, large alluvial river). Fishing at individual site was carried out by wading against the current on sections of at least 100 m. At the fishing site, the caught fishes' species belonging and the number of specimens of each species were determined.

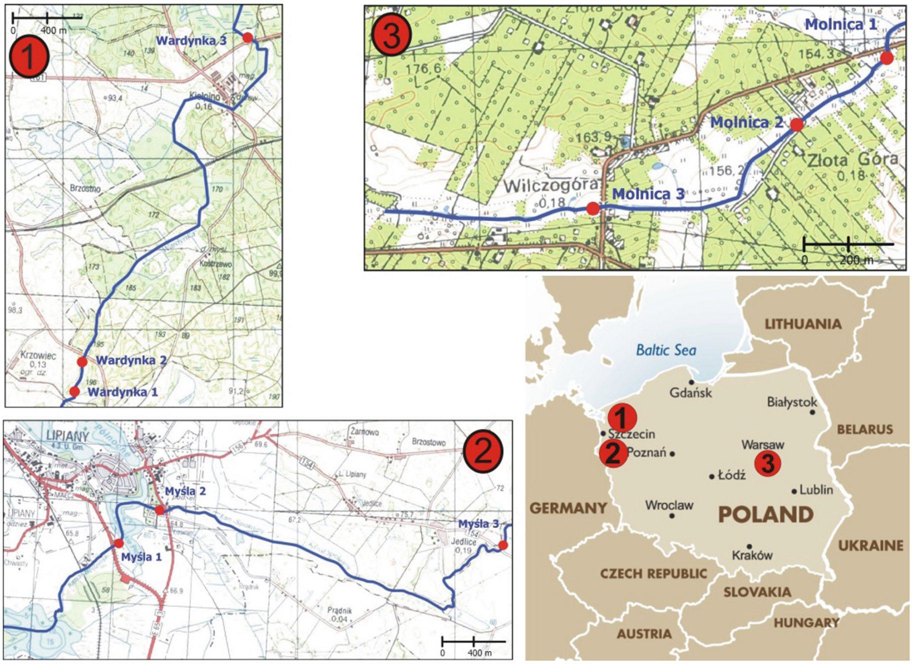

Fig. 1. Map with the location of selected rivers and research stations

In addition, physicochemical studies of water were carried out at individual sites where the topmouth gudgeon were found, specifying: flow rate (using an SENSA RC2 electromagnetic meter equipped with an RV2 probe), pH and oxygen content (using a HACH multiparameter field meter). At the same time, 1 dm^3 of water samples were collected, which were measured in the laboratory with a colorimetric HACH DR890 m for nitrates, ammonium and orthophosphates. The bottom substrate (broken down into stones, gravel, sand, silt) and the degree of overgrowing with aquatic vegetation (in% of the water surface area) were also determined.

3 Results

Among the 9 surveyed sites, the topmouth gudgeon were caught on 5 sites. On the Myśla river, it was located on two, the same on the Molnica river, and on one site on the Wardynka river. In total, 550 fishes (belonging to 10 species) were caught on these 5 sites, including 388 of the topmouth gudgeon, which accounted for over 70% of the caught fishes. The largest number of the topmouth gudgeon was caught at a site located in the upper reaches of the Wardynka river, located in the immediate vicinity of carp ponds. The width of the watercourse was 1.6 m, with an average depth of 0.30 m. The sandy bottom (80% sand layer) only contained 20% of the silt. The aquatic vegetation was made up of common reed (*Phragmites australis* (Cav.) Trin. Ex Steud), flowering rush (*Butomus umbellatus* L.) - belt growth, as well as canadian waterweed (*Elodea* *canadensis* Michx.) and rigid hornword (*Ceratophyllum demersum* L.) - meadow growth. The degree of overgrowing the water table with vegetation was 40% (Table 1). In total 379 fishes were caught in this position (density of 2.37 individuals/m^2), belonging to 7 species, including 291 of the topmouth gudgeon. This species accounted for 74.67% of caught fishes (Fig. 2a), at a density of 1.77 individuals/m^2. Water was characterized by a high phosphate content and conductivity and low flow, although larger than in the case of other watercourses (Table 1).

A total of 54 fishes were caught on 2 sites of the Myśla river, including 28 of topmouth gudgeon (Fig. 2b-c). Higher density of fishes compared to second site, were found at site 1 (0.231 and 0.05 individuals/m^2 respectively) and density of topmouth gudgeon (0.163 and 0.01 individuals/m^2), although both sites were characterized by a leveled bottom and unfavorable physicochemical conditions. However, in the site with a larger population size, a great depth of water was observed on the water surface, which was of a meadow character (the degree of overgrowth was 100% and 40% respectively). The bottom in this site was covered with muddy sediments, and the water was characterized by higher conductivity and the content of N-NO_3 and lower oxygen content (Table 1).

On the Molnica river, in total, 69 the topmouth gudgeon was caught on two sites. The Molnica river flows among areas heavily changed by man (agricultural areas), its trough is straight. The average width on these sections was from 0.6 to 0.9 m, and the average depth from 0.05 to 0.10 m. The bottom in both stands was leveled, consisting of 100% of silt. The aquatic vegetation, rooted in the bottom, was covered with the whole riverbed of the watercourse (100% overgrowth), with the character of meadow lichen. The flow was small (0.01 to 0.03 m/s), and the physicochemical parameters of the water at both sites indicate to its low quality (Table 1). In the site 1 and 2 on the Molnica river were caught 41 and 76 fishes, respectively, with a total density of 0.686 and 0.844 individuals/m^2. At both sites the topmouth gudgeon was dominated (Fig. 2d-e), with the density 0.350–0.533 individuals/m^2.

Table 1. Selected hydrological and abiotic features of watercourses at research sites.

River (site)	pH	EC [$\mu S \cdot cm^{-1}$]	O_2 [$mg \cdot dm^3$]	N-NO3 [$mg \cdot dm^3$]	N-NH4 [$mg \cdot dm^3$]	P-PO4 [$mg \cdot dm^3$]	CV [m/s]	H [%]
Wardynka	7.59	687	3.09	4.41	0.09	0.64	0.21	40
Myśla (1)	7.60	750	2.20	10.60	0.03	0.90	0.14	10
Myśla (2)	7.49	677	7.29	1.96	0.06	1.34	0.02	50
Molnica (1)	7.45	775	8.14	19.99	0.10	0.62	0.01	80
Molnica (2)	7.26	761	7.59	8.25	0.06	0.42	0.03	100

Explanations: EC – conductivity; CV – current velocity; H – the degree of overgrowth with hydrophytes

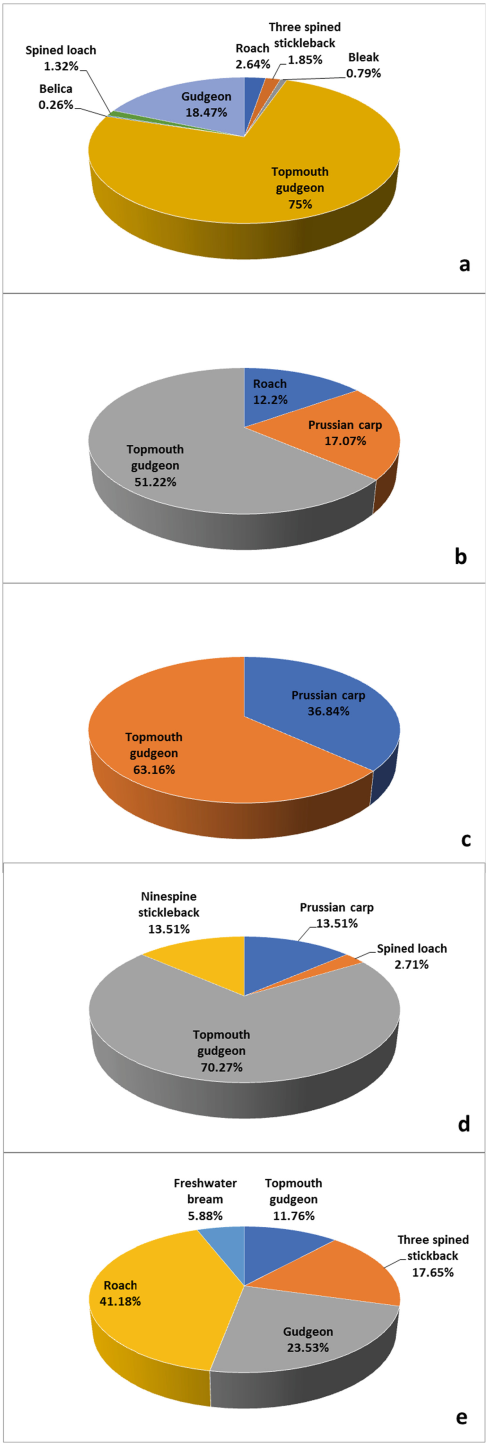

Fig. 2. The structure of fishing on the researched sites (a – Wardynka; b-c – Myśla; d-e – Molnica).

4 Discussion

Since the first observation of the presence of the topmouth gudgeon in Europe, the displacement of this species covered almost the entire continent [1, 3, 8]. In Poland, the occurrence of P. parva has been noted in flowing and standing waters, except in the north-western part of the country [11, 13, 14]. The catch of these fishes in the Wardynka river (the Ina river catchment) and Myśla (the Odra catchment) is the first records of their presence in this part of Poland. Occurrence of this species in Molnica river is not a surprise, because there are some fishing ponds upstream. It should be emphasized that the transport of breeding stock of farmed fishes is one of the transmission vectors of this species [13]. It is probable that this species, migrating down these rivers, settled further watercourses in the Ina and Odra catchments, due to the fact that the speed of settling rivers for this species was set at 7.5 km/year [2]. The fact that it shows great plasticity of life history traits, which facilitates the colonization of new waters, is a facilitation for this species [8]. Successful colonization of this fish in the tested watercourses is undoubtedly favored by the lack of predatory fishes.

Similar phenomenon was noted by Rosecchi et al. [12] in Lake Prespa, where the only predator was a chub (*Leuciscus cephalus*). As demonstrated by Pollux and Körösi [9] population density of this species depends on the type of water. For example, in floodplain lakes it was more abundant than in the rivers of the Netherlands (141 individuals/m^2 (and 0.11 individuals/m^2, respectively). In contrast, in ponds in the southern part of the Czech Republic, the concentration of up to 1.4 individuals/m^2 was found [1]. In polish carp ponds Witkowski [13] noted 300 kg of the topmouth gudgeon from the 5 ha area. In our study, the population density of this species only on the Wardynka river was high and amounted to 1.77 individuals/m^2. In the other watercourses it was much smaller and it was in the range given by Rechulicz [11] for watercourses in the south of Poland.

The excessive inflow of pollutants, especially biogens (the form of nitrogen and phosphorus) from both point sources and area sources, is responsible for the quality and degradation of waters in small rivers [10]. Small rivers flowing through agricultural areas, despite the high biogenic load, are habitats for many ichthyofauna species [4]. Although the physicochemical conditions of the studied watercourses are not optimal for this invasive species, the increase of compaction and further colonization of the topmouth gudgeon can be expected, and thus already observed in other watercourses, the impact on native species and habitats. For example, Barnaescu [3] noted that the juveniles' stages of cyprinids were eaten by the topmouth gudgeon. In this way, these fishes contribute to a drastic decline in the population of native fish species. In addition, the topmouth gudgeon, eating larger species of planktonic and benthic crustaceans, significantly reduces the nutrient resources for which it competes with indigenous species [9, 12]. The presence of this species is associated with the threat of interspecific and intergeneric hybridization. Gozlan and Beyer [5] crossing the topmouth gudgeon with the sunbleak *Leucaspius delineatus* in laboratory conditions, received as much as 86% of vital hybrids. Another extremely dangerous problem for indigenous species resulting from the presence of them in polish waters is the transmission of numerous infectious diseases [11]. The topmouth gudgeon is the carrier of the intercellular protozoan *Sphaerothecum destruens,* which causes an extremely dangerous infection (rosette-like agent), which among others causes necrosis of soft tissues and hepatocytes in cyprinids and salmonids [6]. Hence, this species is considered one of the most dangerous species of invasive fish [8, 9, 11], whose populations in the small polish waters examined in this paper should be covered by monitoring and regular catches. These actions can prevent the spread of this species in the catchments of these watercourses.

Acknowledgements. Work financed by West Pomeranian University of Technology in Szczecin. Project no. 518-08-056-3186-01/18. Rationalization of fisheries management on the lakes and rivers of north-western Poland.

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Utilisation of Bio- and Geoindicators for Assessment of the State of Natural Environment in the South-Western Part of the Świętokrzyskie Mountains

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Abstract. This article presents the results of studies on the pollution of atmospheric air with trace elements in the area of the so-called "Białe Zagłębie" located in the Świętokrzyskie Mountains. As a bioindicator, *Hypogymnia physodes (L.) Nyl.* was used. The lichens on twigs were taken from the Borecka Primeval Forest, and then transplanted into the trees growing in selected points of the "Białe Zagłębie", according to a semi-annual cycle. The obtained results present an analysis of selected trace elements accumulated in the lichen thalli. The average content of accumulated metals was the highest for aluminium (over 427 mg kg^{-1} d.m.) and iron (232 mg kg^{-1} d.m.). Both elements occur in a much higher amount in the second series of exposure, as in the case of lead, copper, nickel, and strontium, whose average content in the lichen thalli did not exceed 10 mg kg^{-1} d.m.

Keywords: Air pollution · Biomonitoring · Trace elements

1 Introduction

An industrial area functioning in the Świętokrzyskie Mountains, which concentrates facilities extracting and processing mineral raw materials called "Białe Zagłębie", causes multi-directional changes in the natural environment [1, 2]. Atmospheric air belongs to these elements of the natural environment which are the most sensitive to such kind of industrial activity. Dusts and gases emitted to the atmosphere during the production process significantly reduce the air quality in this area [3]. Apart from automatic methods determining the level of immission in a given place and time, lichen-indication methods [4] are also commonly used. These methods base on the reaction of living lichens transferred from a relatively clean areas (primeval forests, parks) to those contaminated ones. The confirmed ability of lichens to accumulate pollutants, including metals, in their thalli [5, 6] was used to assess the quality of atmospheric air in "Białe Zagłębie".

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 161–168, 2019.
https://doi.org/10.1007/978-3-030-16542-0_22

2 Study Area and Methods

The study area was located in the south-western part of the Świętokrzyskie Mountains. The *Hypogymnia physodes (L.) Nyl.* lichens, taken from the Borecka Primeval Forest (north-eastern Poland) on approx. 30-cm twigs, were placed in 21 control points at a height of approx. 2 m above ground level, using plastic self-locking bands. The exposure time of lichens in the area of anthropogenic pressure lasted for 6 months (cool half-year period), i.e. from 30th October 2016 to 30th April 2017. On 1st May 2017, the second series of lichens was transplanted into trees growing in the same control points for the next 6 months (warm half-year period), i.e. until 31st October 2017. After each exposure time, the lichens were transported to the Environmental Research Laboratory of the Jan Kochanowski University, where they were detached from the twig bark. The samples were then mineralised using the Anton Paar Multiwave 3000 mineraliser. Mineralisation was carried out using mixture of nitric acid and hydrogen peroxide in a quantitative 3:1. The analytical sample was approximately 0,1 g dry matter. After mineralisation, the samples were subjected to chemical analysis for the content of selected metals (Pb, Cd, Cr, Co, Cu, Ni, Zn, Sr, Al, Fe) using the ICP-MS-TOF OptiMass 9500. Limits of detection was: 0.01 μg/L. In order to control the quality of obtained results, such certified reference materials as ERM-CA713 produced by the Institute for Reference Materials and Measurements in Belgium, were used. Meteorological data for the Kielce weather station was obtained from the Spanish OGIMET portal. The volume of emissions was elaborated basing on the data retrieved from the Regional Inspectorate of Environmental Protection in Kielce. The obtained data was statistically elaborated using the Statistica 13 program. Used Ward's agglomeration, Manhattan distance method.

3 Results and Discussion

The average annual air temperature during the studies (hydrological year 2016) was 7.9 °C; it amounted to 0.7 °C in the cool half-year period (the first series of lichen exposure) and 15.2 °C in the warm half-year period (second series of exposure). The annual rainfall totalled 554.8 mm–207.8 mm in the cool half-year period and 347 mm in the warm half-year one. The relative air humidity varied from 67.1% - the monthly average for June to 88.2% for January with the annual average amounting to 78.1% (81.1% for the cool half-year period and 75.2% for the warm half-year period). During the exposure time, the WSW (13.3%) winds prevailed in the cool half-year period, blowing with the average speed of 2.9 ms^{-1}; while the WNW (16.7%) winds prevailed in the warm half-year period, blowing with the average speed of 2.6 ms^{-1} (Fig. 1).

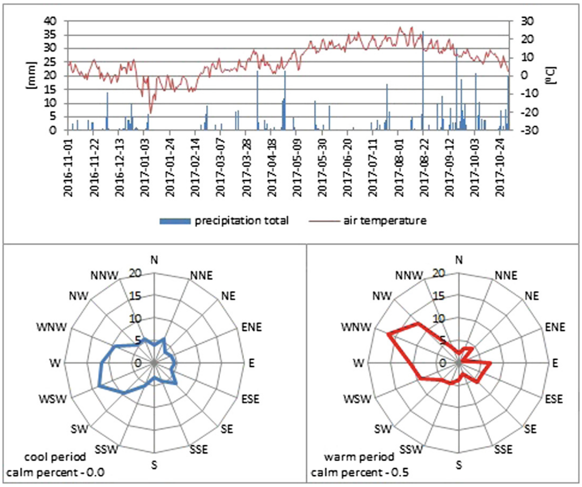

Fig. 1. Meteorological conditions during lichen exposure period (source: https://www.ogimet.com).

The volume of cement dust emissions from the largest cement plants in “Białe Zagłębie”, located in Małogoszcz, Nowiny, Bukowa and Trzuskawica, amounted in total to 263 300 kg in 2016 and 302 200 kg in 2017. During the studies, the cement plant in Małogoszcz has the largest share in cement dust emissions, i.e. over 98 000 kg in 2016 and approx. 124 000 kg in 2017, while the smallest plant in Bukowa – about 33 000 and 50 000, respectively (unpublished data of Regional Inspectorate of Environmental Protection in Kielce).

Transplantation of lichens in the south-western part of the Świętokrzyskie Mountains indicated the accumulation of trace elements in the lichen thalli (Tables 1 and 2). The amount of accumulated metals was calculated for each control point based on the difference between the concentrations of metals in the biota of lichens transplanted into “Białe Zagłębie” and the concentrations of metals in the blank sample tested immediately after taking it from the Borecka Primeval Forest. Cement and lime dusts coming from technological processes belong to one of the most important sources of metal emissions to the air in this area [7]. The content of trace elements in the dust composition results from technological processes based on thermal treatment in furnaces using a specific fuel, i.e. coal, iron ore or waste [8]. Precipitation of dusts containing significant quantities of chromium, lead, cadmium, and iron, present in the vicinity of cement plants poses a direct threat to the environment [9]. The average content of accumulated metals was the highest for aluminium (over 427 mg kg^{-1} d.m.) and iron (232 mg kg^{-1} d.m.). Both elements occur in a much higher amount in the second series of exposure, as in the case of lead, copper, nickel, and strontium, whose average content in the lichen thalli did not exceed 10 mg kg^{-1} d.m.

Table 1. Accumulation of heavy metals in lichen thalli - first series of tests.

Heavy metals	Results by mg kg^{-1} d.m.				
	Average	Median	Min	Max	Standard deviation
Pb	5.23	3.93	1.15	32.11	6.26
Cd	0.03	0.00	0.00	0.32	0.08
Cr	1.69	1.25	0.76	6.71	1.29
Co	0.04	0.00	0.00	0.29	0.08
Cu	5.34	5.68	1.94	8.45	1.91
Ni	1.25	1.02	0.16	3.31	0.87
Zn	20.87	18.06	3.76	68.72	13.80
Sr	3.55	2.31	0.00	11.76	3.68
Al	396.91	325.81	50.17	1534.10	320.16
Fe	222.57	194.34	34.28	644.73	123.97

Table 2. Accumulation of heavy metals in lichen thalli - second series of tests.

Heavy metals	Results by mg kg^{-1} d.m.				
	Average	Median	Min	Max	Standard deviation
Pb	6.74	4.06	1.90	45.45	9.27
Cd	0.01	0.00	0.00	0.15	0.03
Cr	1.18	0.94	0.35	4.64	0.92
Co	0.03	0.00	0.00	0.30	0.07
Cu	6.96	6.10	1.76	18.25	4.38
Ni	1.36	1.01	0.24	3.36	0.92
Zn	39.58	27.77	9.51	203.49	41.38
Sr	18.22	14.62	1.06	54.96	13.56
Al	480.21	369.71	121.68	1859.43	425.85
Fe	245.58	223.26	102.60	676.27	132.59

The increased content of iron and aluminium in the air, apart from the emission from cement plants, is also associated with the weathering process of rocks and minerals [10]. Strontium accumulation was 3.58 mg kg^{-1} d.m. in the cool half-year period and 18.71 mg kg^{-1} d.m. in the warm half-year period. Zinc accumulation amounting, on average, to 21.56 mg kg^{-1} d.m. in the first series was doubled in the next season (40.69 mg kg^{-1} d.m.). Chromium, cobalt and cadmium concentrations in both series of exposure slightly exceeded 1 mg kg^{-1} d.m.

Depending on the location, and above all, the distance from the emitter, the volume of accumulated elements varied considerably; while, the highest concentrations were recorded in the control points located in the vicinity of cement plants and nearby quarries. Aluminium, whose average concentrations exceeded 400 mg kg^{-1} d.m., was accumulated the most by the lichen thalli in the area of Dyckerhoff cement plant in Nowiny and its concentrations amounted more than 1 500 mg kg^{-1} d.m. there (Fig. 2).

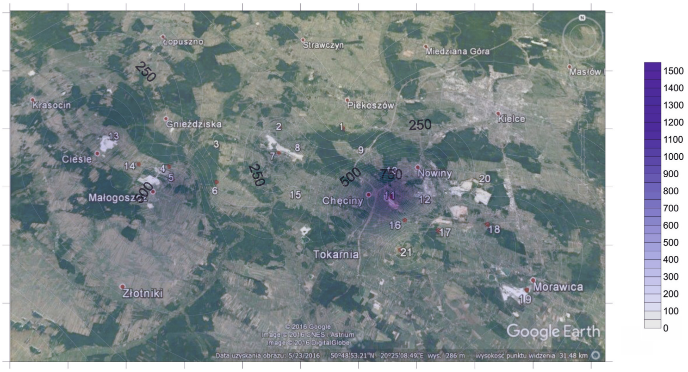

Fig. 2. Map of aluminium concentrations in the lichen thalli exposed in the cool half-year period (mg kg^{-1} d.m.).

All lichen thalli located near the cement plants and quarries were characterised by the increased metal concentrations, except for copper whose high concentrations occurred in the vicinity of the Chęciny crossroad junction being built along the E77 express way (Fig. 3).

Fig. 3. Map of copper concentrations in the lichen thalli exposed in the cool half-year period (mg kg^{-1} d.m.).

During the cool half-year period, the lichens accumulated 5.34 mg kg^{-1} d.m. of copper; while, the highest values (above 7 mg kg^{-1} d.m.) were recorded for the control point in Szewce (near the E77 express way) and in Radkowice (near one of the quarries). In the warm half-year period, in turn, the average Cu concentrations were 6.96 mg kg^{-1} d.m.; while, its highest values were recorded for the lichen thalli exposed in Radkowice (18.2 mg kg^{-1} d.m.), Bolechowice (17.3 mg kg^{-1} d.m.) and Szewce (13.5 mg kg^{-1} d.m.).

The use of Ward's cluster analysis (Manhattan distance) allowed for separating 5 groups (Fig. 4). The first group included those control points where the lichen biota accumulated the largest amounts of lead, i.e. Bolechowice (near the cement plant) and Szewce (near the express way). The next group consisted of the control points with the highest accumulation of cadmium, chromium and cobalt in the lichen biota, located next to plants and quarries (Wola Murowana, Milechowy, Brzeziny, Polichno, Radkowice and Bukowa). The fourth group was characterised by the increased concentrations of copper; however, the location of the control points included in this group was characterised by a small distance from roads (Na Stole, Gałęzice). The last group was made of the lichens from the areas with the highest concentrations of nickel, zinc and strontium. These control points, although located the farthest away from the emission sources (Lipowica, Wymysłów, Jaworznia), were characterised by the increased concentrations of these metals, due to natural topography.

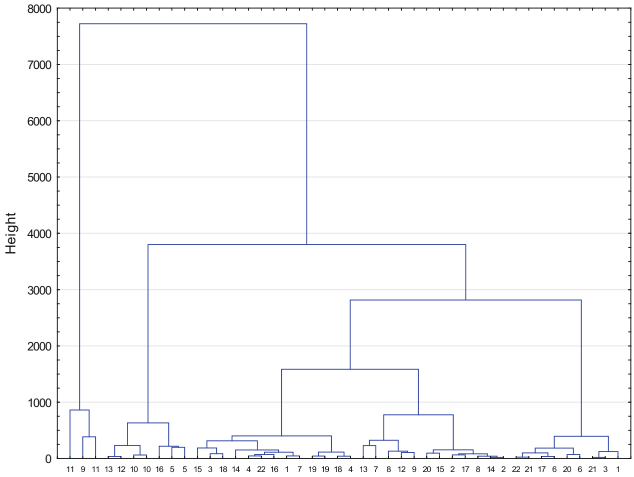

Fig. 4. Ward's agglomeration results, Manhattan distance for the lichen samples exposed in "Białe Zagłębie".

Studies conducted by Białońska and Dayan using the same species of lichen taken from the Borecka Primeval Forest to some industrialised zones in Poland (Bukowno, Młoszowa, Jankowice, Alwernia) for six months had showed significantly higher concentrations of metals compared to those lichens which were exposed in the Świętokrzyskie Mountains [11]. According to the studies, the cadmium concentrations had been 10 times higher; lead and zinc concentrations had been two times higher (except for Bukowno); nickel, copper and iron concentrations had been at a similar level; and chromium concentrations had been lower by half (except for Alwernia) than the metal concentrations recorded for the lichens in the study area. As part of the Integrated Environmental Monitoring (IEM) in Poland in 2010, Sawicka-Kapusta et al. had conducted lichen-indication studies of *Hypogymnia physodes* occurring in its natural environment (in situ) in the IEM study stations [12]. The obtained metal concentrations were close to the values found in the lichen thalli in “Białe Zagłębie” in the case of copper and iron, and several times higher in the case of zinc and cadmium. Koroleva and Revunkov who were studying metals in the *Hypogymnia physodes (L.) Nyl.* on the Sambia Peninsula in the Kalinigrad Oblast found similar concentrations of lead, copper, nickel and strontium, as well as twice as high zinc concentrations and three times higher iron concentrations than those recorded for the control points [13]. Studies conducted by Mikhailova et al. in Russia [14] and Policnik et al. in Slovenia [15], with the annual exposure period of the same species of transplanted lichen, had indicated varying accumulation of iron, lead, copper, cadmium, and zinc throughout the year.

4 Conclusions

- The lichens exposed in the study area accumulated significant volumes of the analysed trace elements, exceeding the concentrations occurring in the Borecka Primeval Forest several times (Cu - 4.2 times, Pb - 2.9 times, Cr - 2.8 times, Ni - 2.1 times, Fe - 1.8 times).
- The level of heavy metals accumulated in the lichen thalli located in the vicinity of facilities extracting and processing mineral raw materials may be the basis for estimating the immediate threat to human health.

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Population Structure of Sandy Everlasting *Helichrysum arenarium* (L.) Moench in Relation to the Advancement of the Secondary Succession of Swards on Sandy Soils

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Abstract. *Helichrysum arenarium* (L.) Moench is a perennial in the Asteraceae family that is under partial protection in Poland whose inflorescences are a source of valuable herbal material. Field observations were conducted over five consecutive growth seasons at permanent study plots in the Bory Tucholskie forest complex, Poland. The plots were in secondary anthropogenic replacement communities, which develop on poor sandy soils. Phytocenoses of initial, medium and most advanced succession were distinguished by the species composition of the communities. The aim of this study was to determine the density and morphological structure of shoots and ramets of the sandy everlastings, and of their potential and actual fertility as the early phase of secondary succession of swards advanced on sandy soils. Many features showed large variations caused by weather, but the stage of successional advancement in the phytocenoses had the greatest effect on the number of sandy everlasting shoots, their mass and morphology. The estimated yield of herbal material from 1 m^2 of a phytocenosis was on average smallest from the plot with the most advanced secondary succession, about half the yield from each of the other two plots. The yield from natural sites varied widely over the years.

Keywords: *Helichrysum arenarium* (L.) Moench · Secondary succession · Population · Density · Morphological structure · Potential and actual fertility · Inflorescences · Achenes · Herbal material

1 Introduction

Helichrysum arenarium (L.) Moench is a perennial in the Asteraceae whose inflorescences are a source of valuable herbal material used since medieval times to treat diseases of the digestive system [5]. In Poland the species has been partially protected since the 1970s. Sandy everlasting can inhabit sandy soils that are exceptionally poor in minerals and dry easily [8] because of its capacity for mycorrhizal symbiosis.

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 169–174, 2019.
https://doi.org/10.1007/978-3-030-16542-0_23

Sandy everlasting populations are being studied in preliminary investigations of cultivating this species, which until recently has been considered unsuitable for cultivation. The study aimed to determine the density and morphological structure of shoots and ramets of the sandy everlasting, and of their potential and actual fertility in relation to the stage of advancement in the early stage of the secondary succession of swards on sand.

2 Materials and Methods

Field observations were conducted in five consecutive growth seasons on permanent study plots in the Bory Tucholskie forest complex (N 53o62′19″, E 17o98′49″; N 53o61′92″, E 17o97′94″; N 53o37′13″, E 17o58′43″). Study plots were selected using generally accepted methods of population studies [1]: species composition and structure of phytocenoses, and density and age of individual sandy everlastings. All study plots were in secondary anthropogenic replacement communities that develop on fallow farmland. Soils inhabited by populations of sandy everlasting were acidic sands or clayey sands low in nutrients [9].

Vegetation on the study plots was classified systematically as loose xerophilous swards on non-lime sands by Matuszkiewicz [4]. Phytocenoses were similar, but their species composition indicated different stages of secondary succession [9]. Thus three levels of change were distinguished: initial, medium and most advanced succession.

The density of shoots per 1 m^2 and morphological features were examined in populations of sandy everlasting from each phytocenosis. Plants for biometric analyses were collected in each of the five growth seasons. The mass of plants, the number of inflorescences on a shoot and of shoots in a clump (ramet), and the number of clumps per 1 m^2 of the study plot were determined. Flowers and achenes in inflorescences were counted. The collected data were analysed statistically and the yield of herbal material was estimated.

3 Results

Subsequent years of study did not differ much in temperature, but differed significantly in the amount of precipitation (Table 1).

Table 1. Precipitation [mm] and mean ambient temperature [°C] during growth of sandy everlasting (data from Mochelek weather station).

	Precipitation					Mean ambient temperature				
	Growth seasons									
Months	1	2	3	4	5	1	2	3	4	5
IV–V	36.6	86.5	117.4	136.9	90.7	10.6	9.4	9.8	9.8	11.2
VI–VII	136.6	93.3	64.1	46.0	210.2	18.4	15.6	17.2	19.6	18.1
VIII	17.7	138.7	43.4	129.0	42.1	18.4	17.9	16.3	16.6	17.8
IX–X	50.7	103.8	32.9	52.7	57.5	9.2	10.8	11.8	12.4	9.7
Total	278.6	539.4	347.1	413.9	522.3	×	×	×	×	×
Mean	×	×	×	×	×	10.9	10.6	10.8	10.8	11.8

Over the five-year period the density of sandy everlasting generative shoots at the study plot in the latest stage of succession was on average about half that at the plot in the medium stage of succession, and a third of that at the early-stage plot (Table 2).

Table 2. Values of the selected features of *Helichrysum arenarium* (L.) Moench in relation to the stage of advancement in secondary succession, measured in 1 m^2, and in a single ramet (clump), based on measurements taken over five growth seasons.

Location	Feature	Stage of secondary succession											
		Early stage of succession				Medium stage of succession				Advanced stage of succession			
		Mean	Minimum	Maximum	V%	Mean	Minimum	Maximum	V%	Mean	Minimum	Maximum	V%
Per 1 m^2	Number of clumps	82.0	6.1	199.1	102.4	53.3	14.0	113.4	73.3	23.4	7.5	47.5	66.6
	Number of generative shoots	228.4	14.0	522.4	99.0	163.5	50.5	294.8	58.5	64.7	18.1	114.0	64.4
	Number of flowers	747.4	34.6	2895.9	161.4	433.8	227.0	757.3	62.6	159.5	43.4	376.0	94.3
	Estimated yield of herbal material [g]	54.0	12.7	144.0	97.2	54.4	35.0	64.1	22.2	25.5	10.1	44.0	50.8
	Number of achenes	623.5	30.8	2396.2	159.6	371.7	180.8	653.2	63.7	134.0	36.9	322.9	95.4
In a single ramet	Dry mass of shoots above ground [g]	1.37	0.27	4.14	115.3	1.69	0.55	4.58	97.2	1.88	0.49	5.87	121.1
	Number of generative shoots	2.9	2.1	4.0	30.4	3.4	2.5	5.2	31.6	2.8	1.7	4.6	39.3
	Number of inflorescences on a shoot	64.6	14.7	108.7	56.4	74.2	19.5	111.9	51.9	59.0	14.9	104.4	57.8
	Number of flowers in an inflorescence	44.2	37.7	51.0	11.2	42.5	40.4	44.4	4.4	42.6	40.0	44.8	4.7
	Number of achenes in an inflorescence	37.8	31.1	42.2	11.3	36.3	32.3	39.3	7.8	35.9	32.6	39.3	6.7

The mass of sandy everlasting shoots in all years varied much less than the number of shoots (Table 2) among the populations in the different phytocenoses, as well as among the stages of development (minimum for propagules, maximum for generative shoots). Analysis of this feature in different growth seasons revealed large differences that might be associated with humidity in different years.

Significant differences were also noted in the number of clumps (ramets) of sandy everlasting per square metre within different phytocenoses (Table 2). The greatest number of clumps was recorded in the youngest population. Advancement of succession led to a decrease in their numbers, initially by 36%, then by 57%.

The number of generative shoots growing per square metre decreased after the decrease in the number of ramets (Table 2). In contrast, the number of shoots with inflorescences in a clump was more stable, modified mainly by precipitation (Tables 1 and 2). The number of inflorescences on one shoot was also relatively stable over the years, and the largest for plants from the phytocenosis at the medium stage of secondary succession (Table 2).

The number of flowers in a flower head also varied slightly, from 38 to 51 (Table 2). Sandy everlasting forms a dense umbelliform panicles of many flowerheads that jointly contain large numbers of single flowers. Conspicuously, in the second growth season in the phytocenosis at the early stage of succession the estimated number of sandy everlasting flowers per 1 m^2 might reach 3 million but did not exceed 35 thousand in the fifth year.

Peak flowering occurred in August and flowering lasted until early autumn. The theoretical mean yield of herbal material was estimated based on detailed measurements of sandy everlasting shoots and the numbers of clumps per unit of surface (Table 2). On average, the largest yield from a ramet might be collected from the population in the community with the most advanced secondary succession, but a square metre in the remaining phytocenoses would be expected to produce twice the yield.

A detailed analysis of the number of achenes produced by sandy everlasting in subsequent growth seasons showed that though they produced huge numbers of conspicuously small flowers, their pollination remained very efficient. This was confirmed by values of generative potential exceeding 80% (the ratio of the number of achenes to the number of flowers) independent of the plot where the plants grew (Table 2).

Sandy everlastings growing in the most advanced secondary succession plot showed lower actual fertility, measured by the number of achenes produced, than the other two plots. Though fewer fruits formed, they were larger than fruits from the other plots.

4 Discussion

These observations showed that sandy everlasting is a species typical of the early stage of the transitional phase of secondary succession on poor soils. Advancement of succession leads to a decrease of this species' participation in the phytocenoses [6, 7]. Fijałkowski and Seroczyńska [2] much earlier pointed out that dicotyledonous perennials and grasses displace sandy everlasting.

Precipitation differed in each growth season in which we observed sandy everlasting, so many of the plant features we analysed showed large variation between years. However, the advancement of succession in the phytocenoses played a key role in the number of shoots, their mass and the morphological structure of the plants.

Simultaneous occurrence of different morphological and developmental stages of shoots in ramets is a typical feature in populations of sandy everlastings. These plants produce vegetative propagules in spring and autumn; between summer and autumn their reproductive effort is focused on developing inflorescences by forming flower heads with numerous achenes. These achenes can germinate immediately after they had been dropped, even during the same growth season. Vegetative propagules in the form of leaf rosettes are formed on underground organs and on lignifying fragments of shoots [6, 7].

Our analysis of selected morphological elements of sandy everlasting specimens showed that each ramet forms a relatively constant number of generative shoots, but these shoots exhibit large plasticity in the production of inflorescences, dependent on precipitation. However, the decreasing number of clumps of sandy everlasting in phytocenoses at successive stages of succession reflected more than the plants' reaction to water availability. The changes observed in populations over five seasons of study might be the result of other plants increasingly co-habiting the phytocenoses and of ageing of individuals, i.e. the progress of secondary succession.

The yield of herbal material varied greatly among years, especially on the plot at the initial stage of secondary succession, which was poor in nutrients. Sandy everlasting flowers over a long period, so collection of the herbal material can also extend over many weeks.

Identifying the features of specimen structure in a species allows researchers to control ecosystem processes and to determine the habitat and the participation of other taxa [12]. This enables a better understanding of the direction of changes, including secondary succession. It can also be concluded which changes in plant features might be expected in different geographical locations [3, 13]. Additionally, some features of plant morphology are considered as indicators [14]. Population studies that include these features can be practically implemented. In the case of sandy everlastings, these studies provided the background for a technology to cultivate this species [10, 11].

5 Conclusions

1. Many features we studied varied in relation to current weather. However, the advancement of succession in phytocenoses was the main factor that affected the number and mass of shoots, and the morphology of *Helichrysum arenarium*.
2. Based on estimates of the herbal material of *Helichrysi inflorescentia* available for harvest it was shown that double the yield might be expected from sites at initial and medium stages of secondary succession than from the most advanced phytocenoses. The yield varied greatly among years.

Acknowledgment. The study was supported by the Polish Ministry of Science and Higher Education, project no. 2P06R 073 30.

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The Application of the WID Method in the Ongoing Control of Urban Trees

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Abstract. The application of systematic monitoring in the ongoing control of urban trees plays an important role in maintaining safety for people and their property. In practice, visual methods are used for routine control of urban trees, including the WID method. In 2014, software was developed to improve the assessment process in the form of the Trees Analyzer application for a mobile device such as a smartphone or a tablet. The criteria and components of the WID method are still being verified. The purpose of the research was to determine the suitability and functionality of the Tree Analyzer application for tree assessment. One hundred trees were assessed in summer and winter season using paper sheets and the Trees Analyzer application for a smartphone. The evaluation time was measured and comments on the functionality and usability of both techniques were noted. The results were compared applying the difference test between the means in the Statistica 6.0 software. The conducted research confirmed the usefulness of the WID method to carry out ongoing control of trees in urban areas. The use of the Trees Analyzer application shortened the time of tree assessment even three times, and tree assessment was easier and more convenient when the software was employed. The comparative studies carried out confirmed that there were no statistically significant differences in the determination of the probability of the fall of the tree using the traditional method and the Trees Analyzer application.

Keywords: Visual identification method for hazardous trees · Tree assessment · WID method · Trees Analyzer application

1 Introduction

In the prevention of threats caused by falling and breaking trees, it is important to assess the condition and mechanical strength of trees with regard to the safety aspect. In practice, visual methods are used for routine control of urban trees. The first methods of urban tree assessment were created in the 1970s in Germany and in the USA. These were: (a) methods assessing the risk of tree fall based on observational data, (b) methods for assessing statics based on the principles of biomechanics, (c) methods of assessing the risk of an accident caused by falling trees [1, 3–5, 11]. International Society of Arboriculture [US] presents the Tree Risk Assessment Qualification (TRAQ) standard for professional tree risk assessment and management program [11]. Some of them, like the VTA-method (Visual Tree Assessment), SIA-method (Static

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 175–183, 2019.
https://doi.org/10.1007/978-3-030-16542-0_24

Integrated Assessment), have gained international popularity and are still evolving [6, 7, 12]. However, it is still believed that there is no ideal method that covers all possible cases of tree damage, which is why new research and methods are emerging on this topic [8]. In 2006, the WID method (visual identification method for hazardous trees) was developed on the basis of a critical analysis of the European and American research between 1951 and 2005, as well as a close study of 261 cases of windfalls and windthrows in Masovia. In the development of the method elements of the fault tree analysis (FTA) and event tree analysis (ETA) were used, which aim at identifying specific relations between the causes and a combination of events which can result in creating a hazard situation and contribute to the damaging process itself. The WID method assesses the level of safety hazard associated with five elementary events such as windthrow, breakage in the base of the trunk, trunk breakage above the apical part to the base of the crown, boughs breakage in the fork, breakage within the crown of the tree. In the WID method, logic diagrams were used to assess the probability of falling or breaking a tree [8, 9].

In 2013, research was carried out to determine the possibility of using the WID method in the systematic control of trees in urbanized areas. The undertaken measurements analyzed the unambiguity of method criteria, clarity of the wording, repeatability of the results of tree assessment and the ease of its use. The study included 126 trees of the *Fraxinus pennsylvanica* and *Fraxinus excelsior* species growing on Rozbrat Street in Warsaw. Two rounds of tests were carried out with an interval of 6 months (January, July) on the same statistical sample. The gathered data was subjected to a comparative analysis. Information on the differences in the inventory of the intensity of the examined trees features was obtained (i.e. slenderness, deadwood, crown surface or extent of damage in individual tree zones) and also on how the risk of accident caused by trees as well as the time of testing in winter and summer varied [2].

Up till 2014, the WID method has been used to evaluate over 1500 trees growing in the urban areas. On the basis of the conducted research, the effectiveness and repeatability of the WID Method was revealed. The analysis of variance of variables performed using the Anova test showed a high degree of compatibility between the results of the assessment. The repeatability of the assessment results was high, at the level of 80%. The features, as assessed in the summer and winter tests, were: the slenderness coefficient and the height of the trees so the parameters that are easy to measure. In the winter study, the underestimated or overestimated evaluation resulted from snow drifts on the side of the road obstructing the observation of tree trunks and the soil under the crown canopy. The differences in winter and summer assessment also refered to the crown's force resistance and the presence of deadwood, where the errors of visual assessment in winter were the result of the lack of leaves on trees. The time consuming assessment was the WID method's shortcoming [8, 10].

In 2014, software in the form of the Trees Analyzer application for a mobile device such as a smartphone was developed to improve the assessment process. The criteria and the components of the WID method are still being verified. In the following years, further improvement of the Trees Analyzer application is planned [10].

The aim of the research is to determine the suitability and functionality of the Tree Analyzer tool for assessing trees by comparing the results of tree assessment using traditional methods and the Trees Analyzer application. The collected results will answer the questions in relation to the advantages and disadvantages of the WID method in the traditional and electronic version and to the guidelines on improving the WID method in the Trees Analyzer application.

2 Materials and Methods

One hundred tree specimens of the following species: *Acer platanoides, Salix alba, Quercus robur* and *Tilia cordata* growing in the Skaryszewski Park were selected for the study. The assessment of trees in the field was carried out in the winter (March) and summer (July). A measuring tape and an altimeter were used to measure trees. Diameter at breast height was measured at a standard height of 1.3 m above the ground level in accordance with the rules adopted by ISA and TROBI. The features of the vicinity and tree defects that affect their statics were evaluated in accordance with the criteria included in the WID method, by Rosłon-Szeryńska [8], separate for each of the five events. The WID method consists of two main parameters presented in the following formula:

$$\mathrm{R}z = Pu \times E\,[0 \div 10\,pkt] \tag{1}$$

where:
Probability of tree fall (Pu), {P_W (probability of toppling); P_N (trunk breakage in the base); P_P (trunk breakage); P_R (breakage in the fork); P_K (breakage in the crown)}, [0 ÷ 10 points], Exposure to risk (E) [0 ÷ 1 point].

The most variable parameter Pu, for which the following hazard categories were determined, was subject to a comparative assessment:

Pu (0–2.99) means the low risk of tree fall, Pu (3–5.99) medium risk,
Pu (6–9.00) high risk, Pu (9.1–10.0) critical risk.

The assessment of fifty trees in the leafless period and fifty trees in foliage period was carried out using paper sheets and the TreesAnalyzer smartphone application. The evaluation time was measured and remarks on the functionality and usability of both techniques were noted. The results were compared applying the difference test between means in the Statistica 6.0 software.

3 Results and Discussion

In order to test the compatibility of tree assessment results with the TreesAnalyzer application in two seasons (in summer and winter season), the difference test between the means was performed.

The mean probability assessment of examined trees breakage in the crown performed in the winter amounted to 3.16/10 points and the one obtained in the summer was slightly higher and equaled to 3.28/10 points. The standard deviation was 1.43 and 1.90, respectively, which means that the differences between the means (p) came to 0.7656.

The mean probability assessment of examined trees breakage within the trunk carried out in the winter was 2.4/10 points and obtained in the summer was slightly higher and amounted to 2.52/10 points. The standard deviation was 1.22 and 1.29, respectively, which means that the differences between the means (p) came to 0.7369.

The mean probability assessment of toppling of the examined trees conducted in the winter with the use of the application was 2.72/10 points and calculated in the summer was slightly higher and amounted to 2.80/10 points. The standard deviation came to 1.62 and 1.68, respectively, which means that the differences between means (p) equaled 0.8646.

The mean probability assessment of examined trees breakage in the base of the trunk carried out in the winter using the application was 1.16/10 points and calculated in the summer was slightly higher and amounted to 1.68/10 points. The standard deviation was 1.62 and 1.37, respectively, which means that the differences between the means (p) came to 0.2264 (Table 1).

The mean probability assessment of examined trees breakage in the fork in the winter was 3.12/10 points and calculated in the summer was slightly higher and amounted to 3.24/10 points. The standard deviation was 1.51 and 1.94, respectively, which means that the differences between the means (p) were 0.8082. It can be noticed that the winter assessment of trees was slightly higher than the summer one each time. The difference between the means (p) came to 0.3606. The differences are significant at $p < 0.05$. The significance tests carried out showed that there are no statistically significant differences in determining the probability of occurrence of the five events between the summer and winter tests.

Table 1. Comparison of the compatibility of tree assessment results in the summer and winter using the TreesAnalyzer software

Research sample	Breakage in the crown	Breakage of the trunk	Windthrow	Breakage in the base of the trunk	Breakage in the fork	Mean
Mean assessment of trees in winter	3.16	2.40	2.72	1.16	3.12	2.51
Standard deviation	1.43	1.22	1.62	1.62	1.51	1.64
Mean assessment of trees in summer	3.28	2.52	2.80	1.68	3.24	2.70
Standard deviation	1.40	1.29	1.68	1.37	1.94	1.64
i.e.:	2.84 ± 0.85					
The difference test between the means; Statistica 6.0	0.7656	0.7369	0.8646	0.2264	0.8082	0.3606

Figure 1 presents a comparison of the mean assessment of trees obtained in winter and summer. The mean probability assessment of tree fall taking into account all five events (regardless of the season) fell into the low ($0 \div 2.99$) and medium (3–5.99) risk category. When analyzing the data, it can be noticed that in the winter season the assessment of trees gave milder results. This is due to the reduction of the crown's force resistance factor due to foliage loss. When analyzing individual cases of trees, it can be observed that only in the probability assessment of breakage in the crown and in the fork the results between the summer and winter scores differed by 2 and more points, which resulted in the change of the risk category from medium (5 points) to high (7 points). This applies to 8% of the tested sample. In other cases, the differences in scores did not change the risk category.

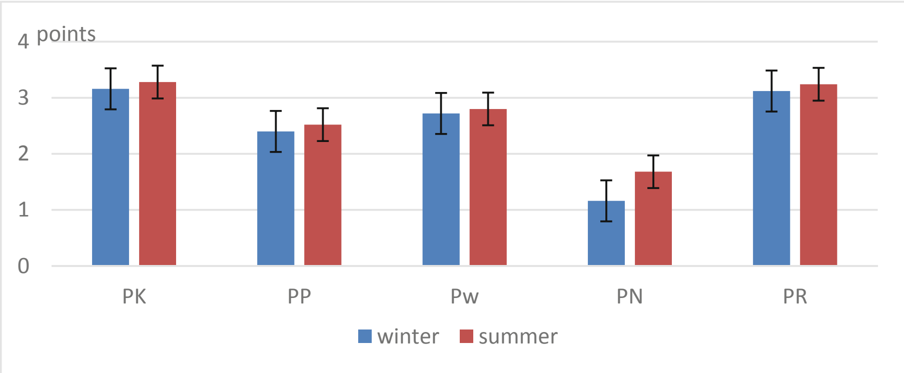

Fig. 1. Mean assessment of trees in winter and summer, including estimation of probability of: (P_K) breakage in the crown, (P_P) trunk breakage, (P_W) toppling, (P_N) trunk breakage in the base, (P_R) breakage in the fork.

In order to test the compatibility of the results of the tree assessment using two different assessment tools (paper sheet and Trees Analyzer application), a significance test of differences between the means was performed. The mean probability assessment of examined trees breakage in the crown performed using the application amounted to 2.44/10 points and calculated in the sheets was slightly higher and reached the level of 2.84/10 points. The standard deviation was 0.96 and 0.85, respectively, which means that the differences between the means (p) came to 0.1254.

The mean probability assessment of examined trees breakage within the trunk carried out using the application was 1.4/10 points and calculated in the sheet was slightly lower and amounted to 1.36/10 points. The standard deviation was 1.04 and 0.95, respectively, which means that the differences between the means (p) came to 0.8877.

The mean probability assessment of toppling of the examined trees employing the application was 2.36/10 points and calculated in the sheet was slightly lower and amounted to 2.24/10 points. The standard deviation was 1.08 and 1.13, respectively, which means that the differences between the means (p) came to 0.7028.

The mean probability assessment of examined trees breakage in the base of the trunk carried out by means of the application was 0.42/10 points and calculated in the sheet was slightly higher and amounted to 0.56/10 points. The standard deviation was 0.73 and 0.96, respectively, which means that the differences between the means (p) came to 0.5643.

The mean probability assessment of examined trees breakage in the fork made using the application was 3/10 points and calculated in the sheet was slightly lower and amounted to 2.92/10 points. The standard deviation was 0.65 and 0.64, respectively, which means that the differences between the means (p) came to 0.663 (Table 2).

The differences are significant at $p < 0.05$. The significance tests carried out imply that there are no statistically significant differences in determining the probability of occurrence of the five events between the manual method and the digital one.

Table 2. The examination of the compatibility of tree assessment results using the TreesAnalyzer software and traditional paper sheets

Research sample	Breakage in the crown	Breakage of the trunk	Windthrow	Breakage of the trunk base	Breakage in the fork	Mean
Mean assessment of trees using the application	2.44	1.4	2.36	0.42	3.00	1.92
Standard deviation	0.96	1.04	1.08	0.73	0.65	1.28
Mean assessment of trees using paper sheets	2.84	1.36	2.24	0.56	2.92	1.98
Standard deviation	0.85	0.95	1.13	0.96	0.64	1.28
i.e.:	2.84 ± 0.85					
The difference test between the means; Statistica 6.0	0.1254	0.8877	0.7028	0.5643	0.663	0.7113

Figure 2 shows a comparison of the mean assessment of trees obtained using the TreesAnalyzer application and the traditional paper sheets. The mean probability assessment of tree fall (Pu), taking into account all five events, fell into the low and medium risk category. Compared to the assessment of trees using traditional paper sheets, the use of the TreesAnalyzer application gave a slightly smoother results when assessing the probability of crown breakage (PK) and breakage in the base of the trunk (PN) as well as slightly higher in the case of other events.

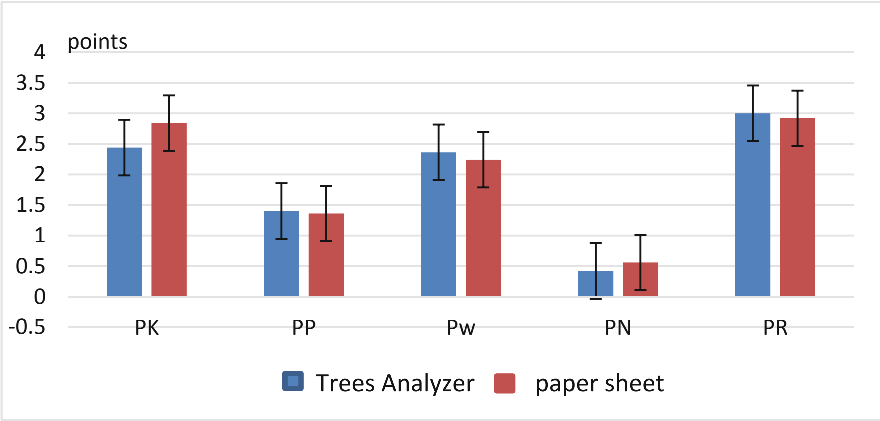

Fig. 2. Mean assessment of trees using the TreesAnalyzer application and traditional paper sheets, including probability assessment of: (P_K) breakage in the crown, (P_P) trunk breakage, (P_W) toppling, (P_N) trunk breakage in the base, (P_R) breakage in the fork.

The time of tree assessment employing the traditional and digital method as well as in the summer and winter period was compared. The mean measurement time using paper sheets amounted to 11:42 min in summer and 09:44 min in winter. However, the assessment of the same trees using the TreesAnalyzer application shortened the mean time to 3:56 min in summer and 2:47 min in winter. The time of summer assessment of trees in both cases was longer due to the presence of foliage hindering the examination of boughs. A summary of the study time is shown in Fig. 3.

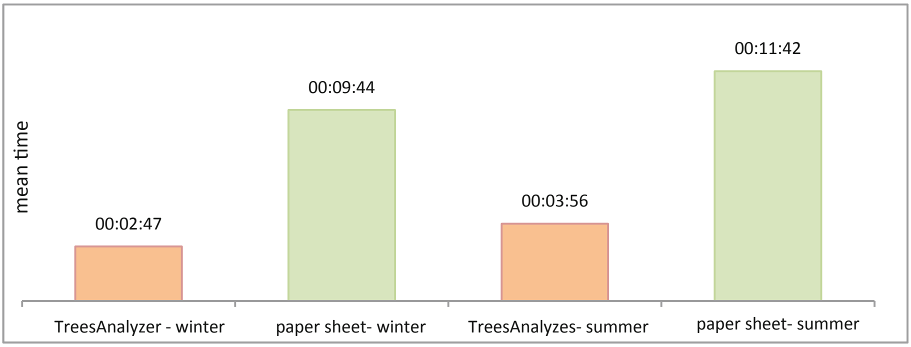

Fig. 3. Mean time of tree assessment using the TreesAnalyzer application and a traditional paper sheet, in winter and summer.

During the research, remarks on practical usability of both tools were noted. A more efficient evaluation and a greater possibility of managing test results (transfer to a spreadsheet, database about a tree, etc.) are the assets of the electronic version. The use of the application, however, leads to the simplification of certain data such as the features of the habitat and features of the tree species, because it does not take into account individual cases, but is only based on general data on the sensitivity of tree species. Technical defects of the application were noticed. The biggest obstacle is the inability to edit the completed analysis. Possible errors noticed after the completion of the electronic sheet can be corrected by undoing particular steps of the evaluation, which results in the loss of data.

The season of the year is also a kind of hindrance. During the frosty or wet weather, the paper sheets get wet and the device on which the software has been installed does not always respond (no reaction to finger touch). It is also worth noting that a too sunny day is not a convenient time for measurement. The sun's rays make it impossible to read information on the screen of the device. Despite these inconveniences, the electronic method of evaluation is more suitable.

4 Conclusion

The research undertaken confirmed the usefulness of the WID method by Rosłon-Szeryńska (2006) for conducting ongoing control of trees in urbanized areas.

The application of the WID method in the TreesAnalyzer application shortened the time of tree assessment even three times, and tree assessment was easier and more convenient when the software was employed.

The comparative studies carried out confirmed that there were no statistically significant differences in determining the probability of falling of the tested tree sample, taking into account five events employing the traditional method and the TreesAnalyzer application.

The Difference in results the average assessment of the probability of falling of the tree, (depending on the season of the assessment) concerned only 8% of the tested sample. Compared to the assessment of trees using traditional paper sheets, the use of the TreesAnalyzer application gave a slightly smoother results when assessing the probability of crown breakage (PK) and breakage in the base of the trunk (PN) as well as slightly higher in the case of other events.

The research undertaken confirmed that the use of new technologies in the visual identification of trees has enormous potential.

Acknowledgement. Research for this document was financed from statutory activities in the Department of Landscape Architecture at the University of Life Sciences in Warsaw. In developing the research presented here, we received helpful data from the City Cleaning Management Authority in Warsaw.

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Reducing the Environmental and Landscape Impacts of Quarries Using Windbreaks and Green-Isolation Zones

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Abstract. The study presents the conception of the windbreaks and the green-isolation limiting dust migration from the granite quarry. Local geology as well as the volume of stone production, technical parameters of rocks and assortment of manufactured aggregates are characterized. The authors have also discussed the climatic conditions with particular reference to prevailing directions of the wind. The article describes the physical-chemical properties of the land dumping grounds and the quarry ground-shafts. The suggested conception of the windbreaks and the green-isolation includes the planting of trees and shrubs within the quarry area and in the windbreaks adjacent to the quarry. The aim of the proposed planting is to reduce the wind speed, to capture the particles of dust and to improve the aesthetic values of the quarry, which will lead to a reduction of the pressure and negative impact of the quarry on the environment, landscape and local inhabitants.

Keywords: Windbreaks · Green-isolation zones · Quarry · Environment · Impact of the quarry · Landscape · Dust reduction · Dust pollution

1 Introduction

Mining and quarrying natural resources results in the impact of the related activities on the environment, landscape and the living conditions of local residents. The operation of mines and quarries strongly affects the natural environment, leading to geomorphological transformations of the land (workings, tips), changes in the hydrological conditions, deterioration of air quality (dust), acoustic climate, reduction of the fauna and flora and a deterioration of the aesthetical values of the area [8, 11]. After the end of mining and quarrying operations it is possible to start dealing with the morphological deformations of the land and the absence of vegetation in order to give them an attractive form [1, 11, 24].

The influence on the environment that results from the mining, quarrying and processing of natural resources may cause local social conflicts [2], in particular referring to dust originating from rock grinding and sifting processes, blasting works,

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 184–192, 2019.
https://doi.org/10.1007/978-3-030-16542-0_25

transport and loading of the excavated material and products, dust from technological roads and product storage facilities.

Appropriate designing and management of a mining and quarrying facility may limit the inconveniences connected with its operations, including by the application of dust emission reduction techniques [22], where the degree of reduction results from the undertaken technological and organizational activities [4]. Common methods of limiting dust emission include: sealing of processes, dust cleaning and sprinkling devices. Their efficiency may reach even up to 90%. Unfortunately, they are not free from disadvantages. The effectiveness of sprinkling depends on the manner of controlling and application of various types of profiling nozzles, the application is limited during the winter and the resulting waste pulp is difficult to store or to use. The sealing of processes and dust cleaning are also difficult to apply, due to the specificity of technological processes. They also require high investment expenditures [22].

The volume of dust emission from quarry areas depends, among others, on the size of the airborne fraction of particles as well as on wind direction and speed [4]. At higher wind velocity, dust particles are lifted more efficiently and transported on larger distances [7, 13]. The amount of dust deposition decreases with the increase in the distance from the emitter and with the presence of various barriers on the route of the dust [25]. The conducted reforestation of mines and quarries may lower their negative influence on the environment. Trees planted in the vicinity of quarries act like filters, trapping dust particles in their leaves or like screens by lowering wind velocity and enabling earlier deposition of dust [15].

Open-work windbreaks (average permeability 50%) provide the highest values of wind velocity reduction, by approx. 60% of the initial speed [3], although on ground level the wind velocity is reduced on the average by approx. 25–30%. On the leeward side, the positive influence of the tree belt is felt at a distance equivalent to 15–20 times its height. However, the most beneficial effects are noted at the distance of approx. 8 times the height of the trees. The tree belt will achieve the size enabling windbreaks at the height of approx. 10 m, i.e. 10 years after planting [3]. It is assumed that the application of windbreak barriers may enable the reduction in emission from storage tips by 30% [18]. Moreover, the trees and windbreaks will have a positive influence on the landscape values of the quarry and its surroundings [10].

2 Methodology, Objective and Scope of the Study

The authors conducted a literature review and analyzed source materials to define the following: quarrying volume, climatic conditions, geological conditions and partly soil conditions. Soil samples were collected from the quarry area (tips and embankments made from humus overburden and tailings that form the acoustic screen – soil embankment) in order to determine their basic physical and chemical properties. Samples were collected at the depth of 0–20 cm, at 4 locations (Fig. 1). Laboratory analyses were conducted at the Regional Chemical Agricultural Station in Wroclaw (accredited by the Polish Centre for Accreditation, No. AB 779), using reference methods of analysis. The content of macroelements was evaluated in compliance with the guidelines of the Cultivation and Fertilization Institute in Puławy [6, 23]. The evaluation of the suitability of the analyzed formations for reclamation [12, 19] was conducted with use of the Skawina method and the (simplified) point bonitation method [12]. The site inspection involved the determination of the species composition of tall greenery.

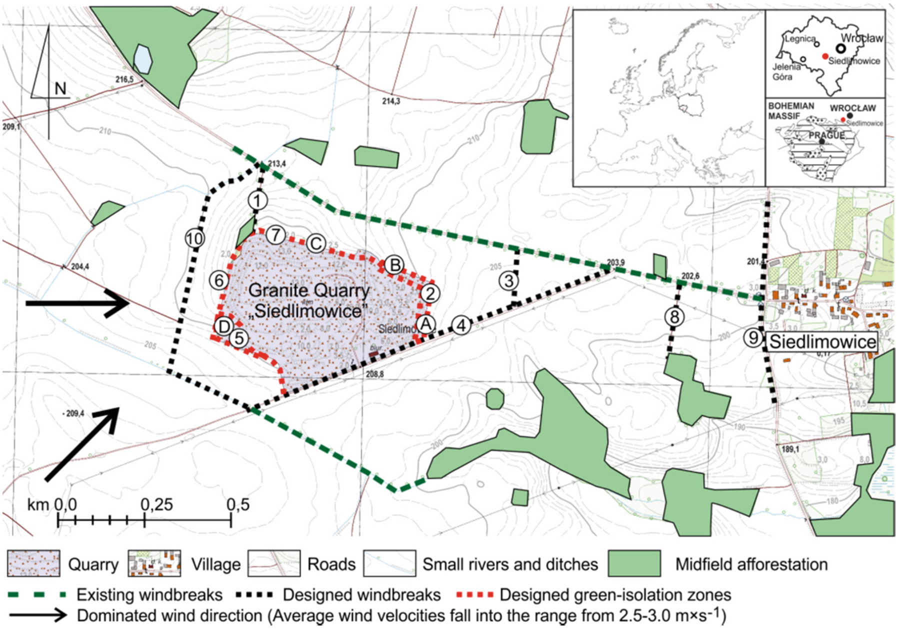

Fig. 1. Location of the "Siedlimowice" granite quarry and design of the windbreaks and green-isolation in the quarry. Zones: 1 – plantings along the road (windbreaks), 2 – multi-level protection screen, 3 – plantings along the drainage ditch (windbreaks), 4 – plantings along the road (isolation and windbreaks), 5 – landscaping arrangement, 6 – spatial barrier, 7 – supplementation of existing greenery, 8 – plantings along the road (windbreaks), 9. – protection of village (windbreaks), 10 – first barrier (windbreaks). A–D sampling sites of soil and land. (Author: B. Jawecki, map from the Marshal of Lower Silesia Voivodeship resources on license No. MGW-I.7522.70.2018_02_CL2, for Bartosz Jawecki).

The objective of this study is to present a concept of introducing windbreaks and a green-isolation belt with the aim to create a spatial barrier limiting dust emission from the quarrying and technological processes at the Siedlimowice Granite Quarry, and thus to protect the Siedlimowice village from granite dust. Apart from protective tall greenery zones located in the area of the quarry, the authors propose windbreaks located in areas adjacent to the quarry. Windbreaks were designed along the roads and drainage ditches, so as not to interfere with areas of agricultural production. The aim of the designed green isolation is to capture airborne dust particles on leaves and branches and to reduce the wind velocity, as well as to improve the aesthetical and landscaping values of the quarry and its surroundings. Basing on the available data including the quarrying volume, the range of manufactured products, climatic conditions (in particular wind) properties of soils and land and the existing tall greenery a spatial arrangement of vegetation was proposed along with the relevant composition of species of trees and bushes. The intention of the concept was to use mainly native species of trees and bushes.

3 Results and Discussion

3.1 Location, Geology, Resources and Quarrying Characteristics

The “Siedlimowice” granite quarry is located in the Lower Silesian Voivodeship, Swidnicki County, Żarów commune, approx. 40 km south-west from Wroclaw and 1 km west from the Siedlimowice village (Fig. 1). The quarry is located in the Sudetian Foothills, in the eastern part of the Strzegomskie Hills, on the border of the Swidnicka Plain [12].

This area is a part of the Strzegom-Sobótka granitoid massif that spreads from the vicinities of Jawor to the south-east up to the Sobótka. The Massif itself is composed of four types of granitoids: biottite-hornblende monzogranite, biotite granite, two-mica granite and biotite granodiorite [14]. The Siedlimowice village is located precisely half way between the Strzegom and Sobótka towns. The granite that occurs there is the two-mica alkaline granite with transition to monzogranite. This kind of rock has much finer grain than both biotite granite and granodiorite, its colour is lighter because of the presence of muscovite, and it has a directional structure along which numerous enclaves, quite common in other rock types [14].

The operations of the “Siedlimowice” quarry, where the rock extraction is conducted with use of open pit and long-wall methods consists of the quarrying area (16.92 ha) and deposit area (11.69 ha). The estimated amount of geological resources at the end of 2016 was 9911 thousand tons and the quarrying volume remains on the level of approx. 1 million tons per year. The quarried rock is used for the production of crushed-stone aggregate, stone aggregate and regular elements, among others for the road, railway and hydro-technical engineering industry [16, 17]. Different kinds of quarried rocks from Lower Silesia are used as construction materials in buildings in other architecture objects [9, 11].

3.2 Climatic Conditions

The quarry is located in the area of a transitional (foothill) climatic region. The climate is mild, warm and moderately humid. The solar conditions in the analyzed area do not show significant differences. The average annual temperature is 8 °C, with July being the warmest month (mean temperature 14 °C) and January the coldest (mean-temperature −2 °C). The vegetation period lasts for 220 days when temperature in the vegetation period is lower than 14 °C. The number of clear days is 55. Total annual precipitation is on the level of 630 mm. This area is dominated by western winds: north-western in winter and south-western in summer [5, 20]. The western winds account for 26% of directional frequency, while southwestern ones account for 12%. Northern and north-eastern winds occur most rarely (5%), while atmospheric stills account for 10–15%. Average wind velocities fall into the range from 2.5–3.0 m $\times$ s^{-1}, with a low share of strong and very strong winds (velocity exceeding 10 m $\times$ s^{-1}). The windiest months are December and January, while July and August are the calmest [5].

3.3 Soil-Samples Conditions

In the direct proximity of the quarry the soil is of the IIIa and IVa class arable soils, classified as good wheat-soil and defective wheat-soil [21].

The analyzed samples are classified as light soils (sample A), medium soils (sample B) and heavy soils (samples C and D). The formations in the embankments are also characterized by a significant share of skeletal structures, mainly stone rubble from the overburden. The pH of the analyzed soils was acidic and strongly acidic, so they will require liming in order to increase the low pH. The content of assimilable forms of NPKMg varied. The nitrogen content was either very low (samples A and B) or very high (samples C and D). The content of phosphorus was classified as very low in all analyzed samples. The content of potassium (K) was evaluated as medium (samples A, B, C) and low. Magnesium (Mg) content was generally very good: average in samples C and D, very high and high in samples B and A, respectively. The low content of organic coal observed in the analyzed soils proved their mineral nature. The content of mineral nitrogen was classified as very low (samples A and B) and very high (samples C and D). It should be noted that the constructed tips and embankments are artificial formations and as such they are characterized by high variability of chemical and physical properties. The evaluation of the suitability of the analyzed formations for reclamation demonstrated that these formations are potentially productive and suitable for the introduction of trees and bushes after improving melioration activities have been conducted.

3.4 General Characteristics of Existing Tall Greenery

Tall greenery in the area of the Siedlimowice granite quarry consists of scattered, irregularly arranged groups, mostly concentrated in the external belt of soil embankments surrounding the quarry. The composition of plants is clearly characterized by a significant share of species of a wide range of environmental tolerance. The dominant species are: *Betula pendula*, *Prunus avium*, *Populus tremula*, *Salix caprea*, *Crataegus monygyna* and *Cytisus scoparius*. Most of the trees and shrubs are located in the lowest parts of the protection embankments, which is probably due to the beneficial water and soil conditions. In the areas adjacent to the quarry there are also mid-field groves and thickets (to the north and east of the quarry) and a forest complex located to the south-east of the quarry. Along the Mrowiny-Siedlimowice road there is a section with trees on both sides, dominated by *Tilia cordata* trees in the area of the Siedlimowice village, while single trees and shrubs grow next to the Siedlimowice-Kalno road [10].

3.5 Design Concept of Windbreaks and the Zones of Green-Isolation in the Siedlimowice Quarry

In order to limit dust emission to the areas surrounding the quarry it is necessary to create barriers – tall greenery screens and windbreaks. In order to improve their operational efficiency, the location of such spatial barriers should take into account dominant wind directions. Greenery screens should be adapted to the existing spatial conditions (soil embankments), soil and (micro) climatic conditions. Due to the disadvantageous water and soil conditions, greenery should be planted at the bottom and at the maximum, up to 0.5 of the height of soil embankments. The proposed greenery screens should be varied in terms of layer structure (a layer of tall trees, a layer of medium-height shrubs and a layer of low bushes) and the composition of species. The screens should be located in the direct proximity of the quarry as well as in parts of the surrounding areas, such as access roads and drainage ditches [10].

The land development design is based on the assumption that the space in question will be divided into several functional zones (Fig. 1) and windbreaks. Zones 1, 3, 8 (*Crataegus monogyna* – respectively 40 pcs., 40 pcs., 45 pcs.) involve the creation of windbreaks along the country road located to the north-west of the quarry and the drainage ditch between the fields east of the quarry and the road near Siedlimowice village. An irregular arrangement of shrubs is proposed for these zones. Zone 2 (*Betula pendula* – 50 pcs., *Prunus avium* – 15pcs., *Pinus nigra* or *Pinus sylvestris* – 10 pcs., *Cytisus scoparius* – 140 pcs., *Rosa canina* – 140 pcs.) includes an earthwork acoustic screen with a multi-level greenery screen. Zone 4 (*Populus nigra* 'Italica' – 190 pcs., *Rosa canina* – 10 pcs.) consists of a road belt spreading from the main road to the quarry, consisting of an open-work spatial barrier in form of a row of tall trees. Zone 5 (*Salix purpurea* – 300 pcs., *Salix caprea* – 300 pcs., *Salix viminalis* – 1500 pcs. *Sorbus aucuparia* – 20 pcs.) is a landscaping arrangement located in the western part of the quarry. The major part of the arrangement consists of shrubs with additional single specimens of trees. In Zone 6 (*Salix caprea* – 20 pcs.), which is a spatial barrier consisting of existing greenery located in the western part of the quarry, only supplementary plantings are foreseen with the aim to densify the existing vegetation belt. Zone 7 (*Crataegus monogyna* – 30 pcs., *Cytisus scoparius* – 20 pcs.) is located in the northern part of the quarry, on the non-exploited part of the deposit. Due to the possible start of excavations in the future and the presence of existing tall greenery, the authors suggest only supplementary planting of shrubs [10]. Zone 9 (*Tilia cordata* – 25pcs.) is the last windbreak before Siedlimowice village. The last zone no. 10 (*Populus nigra* 'Italica' – 160 pcs.) is the first protection windbreak whose role is to decrease (reduce) wind speed before the quarry.

4 Conclusion

Dust emission from quarries often takes the form of unorganized emission that originates from stone excavation and processing (e.g. blasting works, grinding, sifting and loading of raw material) and secondary emission (from transport inside the quarry, loading finished products or tips of finished product). Dust generated by the quarry may often cause social conflicts. The use of technological methods (such as sprinkling, dust cleaning and production sealing) results in a significant limitation of dust emission. Technological methods of reducing dust emission should be supplemented by belts of insulation and protective greenery planted within the quarry area but also windbreaks created in the external direct and indirect surroundings. Apart from reducing dust emission, green-isolation and windbreaks will have a positive influence on the landscape values of the quarry, improving its aesthetical aspects and its perception by the local community.

Green-isolation should be introduced in the parts of the quarrying area that are currently (and were in the past) excluded from excavation and processing operations as well as on tips and earthwork protective screens. The greenery will act as a filter that traps dust particles on leaves and branches and reduce wind velocity in the quarry area. Typical environmental conditions that exist in quarrying areas are usually difficult for plants. This refers in particular to the availability of nutrients and water. A good solution is to support the growth of self-sowing plants. If additional trees and shrubs are planted it is recommended to use species that naturally exist within the quarrying area or pioneer species. In order to accelerate the result in form of dust emission limitation it is acceptable to use fast-growing alien species. In order to maintain the dust limitation results in winter it is recommended to introduce evergreen species of conifer trees. The planting of green barriers and screens conducted in the quarrying area should be supplemented by the creation of windbreaks surrounding the quarry. An appropriate arrangement of such barriers should contribute to the reduction of wind velocity and the limitation of blowing dust particles out of the excavation area. As far as plantings proposed for the zones located outside the quarry area are concerned, the consent of land owners or tenants should be obtained. Local communities and territorial self-government bodies often foster and support such projects.

Even if technological methods are used, it is extremely difficult to completely eliminate dust emission (in particular secondary emission) from the area of a granite quarry. Thus, technological methods of limiting dust emission should be supplemented by belts of isolation and protection greenery planted within the quarry area, but also windbreak belts created in the direct and indirect external surroundings. They will influence the modification of wind conditions and limit the expansion of dust to adjacent areas, as well as improve the aesthetical and landscaping values of the quarry.

Following the analysis of the design concept of green isolation zones and windbreaks at the Sedlimowice Granite Quarry, we arrived at the following conclusions:

1. Green isolation zones and windbreaks should play the role of green filters and reduce granite dust emission from the quarry, acting as a supplement for the technical and organizational methods lowering dust emission from the quarry.
2. The system of windbreaks around the quarry should influence to reduce wind velocity and thus reduce the volume and range of dust emission from granite quarry.
3. Green isolation zones and windbreaks designed around the quarry, should decrease the negative visual impact of quarry elements on the perception of quarries in the landscape.

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An Analysis of Intense Rainfalls in Cracow Area

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Abstract. The study involves an analysis of intense rainfall events determined based on data from 21 precipitation stations located in the area of Cracow. The data was extracted from rainfall sequences from years 2013–2017 at the Municipal Water and Sewage Company (MPWiK [*Miejskie Przedsiębiorstwo Wodociągów i Kanalizacji*]) in Cracow. The analysis was carried out using the sequences of highest intensity from the summer months, i.e. VI–IX. Applying the Chomicz scale, identified were the types of rainfalls which occurred in Cracow in the observed time. It has been shown that the two types of intense rainfall, rainstorms and heavy rainfalls, were prevalent in the selected years of observation whereas regular types were infrequent. Analysed were rainfalls which occurred on the same day of the given observation year at all of the precipitation stations of the MPWiK in Cracow.

Keywords: Intense rainfalls · Rainfall events · Urban catchment · Chomicz scale

1 Introduction

Extreme phenomena occurring in urban catchments have become part of reality. Observable changes in the character of the rainfalls currently occurring during summer months [13] and the increasing trend of urban catchment sealing [3, 4, 17] pose new challenges related to local floodings or floods in general which are urgent issues to be resolved. Special attention should be placed on maximum rainfalls, especially of the following types: heavy rainfalls, rainstorms and torrential rains occurring in urban catchments [10] with varied intensity in different parts within a city. Short-duration intense rainfalls are responsible for the highest discharges in rain water drainage or combined sewage systems [11]. It is currently necessary to carry out systematic observations and quantitative research of those. As a consequence of this research, it may be possible to make appropriate decisions related to rational rainwater management in cities [1, 2, 5, 16], especially knowing that rainstorms in Cracow are predicted to occur more often than before [6].

This study, based on the precipitation data collected by the Municipal Water and Sewage Company in Cracow, presents an analysis of intense rainfalls which occurred in Cracow. This study is a continuation and exploration of a previous research [7].

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 193–202, 2019.
https://doi.org/10.1007/978-3-030-16542-0_26

2 Material and Method

Measurement data of precipitation formed observation sequences recorded in years 2013–2017 at 21 gauging stations located in Cracow, south of Poland (Fig. 1).

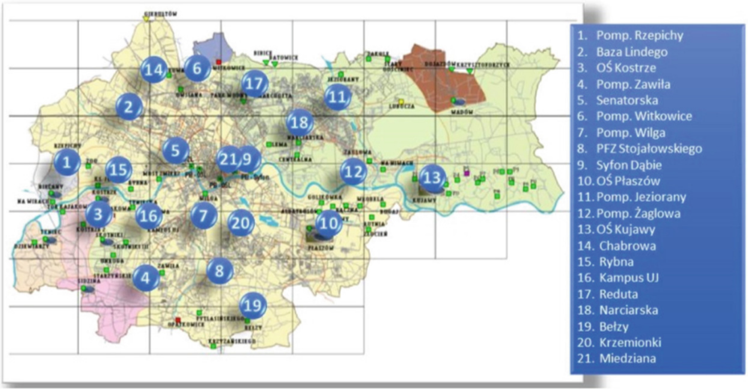

Fig. 1. Locations of the MPWiK precipitation stations in Cracow (source: own work based on the map from MPWiK)

Based on the available precipitation data, identified were rainfalls from summer months VI–IX for each of the stations. The identification of the rainfalls was performed using a criterion of Wischmeier and Smith, commonly applied by researchers both in Poland [12] and abroad [8, 9, 14, 15]. According to this, rainfall was defined as precipitation of minimum 1.3 mm of volume during maximum period of 6 h and however an interval lasting 6 h or a total volume of less than 1.3 mm for 6 h, demanded further separation of the phenomenon into two rainfalls. As a result, 1583 independent rainfalls of varied duration were identified, including 815 of duration up to 6 h (Table 1) which constitutes 51.5% of all precipitation events.

Table 1. The number of rainfalls identified based on the selected criterion at the 21 MPWiK precipitation stations in the area of Cracow; gray field – no data (own work).

Precipitation station	Rzepichy	Lindego	OŚ Kostrze	Zawiła	Senatorska	Witkowice	Pomp. Wilga	PFZ Stojałowskiego	Syfon Dąbie	OŚ Płaszów	Pomp. Jeziorany	Pomp. Żaglowa	OŚ Kujawy	Chabrowa	Rybna	Kampus UJ	Reduta	Narciarska	Bełzy	Krzemionki	Miedziana
year	number of rainfalls n																				
2013	11	4	6	19	13	5	18	13	13	11	16	15	7								
2014	14	15	16	19	15	19	17	17	17	25	18	20	17	3		1		1			
2015	6	10	10	16	13	12		11	0	15	11	16	7	6	2	9	13	15			14
2016	3	11	0	14	4	11	10	11		16	15		14	13		15	16	12	5	14	13
2017				5		0					0	20		7			5	6			4
Sum	34	40	32	73	45	47	45	52	30	67	60	71	45	29	2	25	34	34	5	14	31
All	92	79	63	129	86	89	95	109	65	110	112	123	79	55	5	55	64	63	17	26	67
[%]	37	51	51	57	52	53	47	48	46	61	54	58	57	53	40	46	53	54	29	54	46

For each rainfall the Chomicz scale [9] was used to compute rainfall depth h, duration t, intensity I, efficiency α and rainfall type to determine maximum rainfall events, especially heavy rainfalls, rainstorms and torrential rains. For further analysis selected were only those rainfalls of intensity I $\geq$ 0.10 mm min^{-1}. There was a total of 144 rainfalls of this kind. At the next stage of the analysis, from among those 144 rainfalls selected were those which occurred on the same day of a given year at different stations. The findings were: on 10 June 2013 observed were rainfalls which occurred on the area represented by five precipitation stations, i.e. Rzepichy, Zawiła, Senatorska, Pomp. Wilga and PFZ Stojałowskiego (Table 2), on 15 and 31 July 2014 observed were rainfalls which occurred on the area represented by nine precipitation stations, i.e. Zawiła, Senatorska, Witkowice, Pomp. Wilga, PFZ Stojałowskiego, Syfon Dąbie, OŚ Płaszów, Pomp. Jeziorany and Pomp. Żaglowa (Table 3), on 16 August 2015 observed were rainfalls which occurred on the area represented by fifteen precipitation stations, i.e. Lindego, Kostrze, Zawiła, Senatorska, Witkowice, PFZ Stojałowskiego, OŚ Płaszów, Pomp. Jeziorany, Pomp. Żaglowa, Chabrowa, Rybna, Kampus UJ, Reduta, Narciarska and Miedziana (Table 4), on 25 and 26 June 2016 observed were rainfalls which occurred on the area represented by ten precipitation stations, i.e. Witkowice, Pomp. Wilga, PFZ Stojałowskiego, OŚ Płaszów, Chabrowa, Kampus UJ, Reduta, Narciarska, Krzemionki and Miedziana (Table 5) and on 1 September 2017 observed were rainfalls which occurred on the area represented by five precipitation stations, i.e. Zawiła, Pomp. Żaglowa, Chabrowa, Narciarska and Miedziana (Table 6) (Fig. 2).

Table 2. The characteristics of rainfalls of intensity $I \geq 0.10$ mm min^{-1} from 10 June 2013 at different MPWiK precipitation stations in Cracow (own work).

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm min$^{-0.5}$]	
Rzepichy	10.06.13 18:00	10.06.13 20:40	18.8	170	2.8	0.11	6.64	1.44	I-degree rainstorm (A_1)
Zawiła	10.06.13 18:10	10.06.13 20:10	13.0	130	2.2	0.10	6.00	1.14	Heavy rainfall (A_0)
Senatorska	10.06.13 18:20	10.06.13 20:40	15.8	150	2.5	0.11	6.32	1.29	Heavy rainfall (A_0)
Pomp. Wilga	10.06.13 18:20	10.06.13 20:20	15.0	130	2.2	0.12	6.92	1.32	Heavy rainfall (A_0)
PFZ Stojałowskiego	10.06.13 18:20	10.06.13 21:00	17.6	170	2.8	0.10	6.21	1.35	Heavy rainfall (A_0)

Table 3. The characteristics and types of rainfalls of intensity $I \geq 0.10$ mm min^{-1} from 15 and 31 July 2014 at different MPWiK precipitation stations in Cracow (own work).

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm min$^{-0.5}$]	
Senatorska	15.07.14 13:20	15.07.14 14:00	9.4	50	0.8	0.19	11.28	1.33	Heavy rainfall (A_0)

(*continued*)

Table 3. (*continued*)

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm min$^{-0.5}$]	
Witkowice	15.07.14 13:10	15.07.14 13:40	9.4	40	0.7	0.24	14.10	1.49	I-degree rainstorm (A_1)
Pomp. Wilga	15.07.14 13:20	15.07.14 14:00	30.4	50	0.8	0.61	36.48	4.30	IV-degree rainstorm (A_4)
PFZ Stojałowskiego	15.07.14 13:30	15.07.14 14:20	27.6	60	1.0	0.46	27.60	3.56	III-degree rainstorm (A_3)
Syfon Dąbie	15.07.14 13:20	15.07.14 14:50	13.4	100	1.7	0.13	8.04	1.34	Heavy rainfall (A_0)
OŚ Płaszów	15.07.14 13:30	15.07.14 15:00	12.4	100	1.7	0.12	7.44	1.24	Heavy rainfall (A_0)
Zawiła	31.07.14 17:50	31.07.14 19:20	15.8	100	1.7	0.16	9.48	1.58	IV-degree rainstorm (A_4)
Senatorska	31.07.14 18:10	31.07.14 19:50	21.4	110	1.8	0.19	11.67	2.04	I-degree torrential rain (B_1)
Witkowice	31.07.14 19:00	31.07.14 20:00	7.8	70	1.2	0.11	6.69	0.93	Regular rainfall
Syfon Dąbie	31.07.14 18:20	31.07.14 20:50	18.2	160	2.7	0.11	6.83	1.44	I-degree rainstorm (A_1)
OŚ Płaszów	31.07.14 18:30	31.07.14 19:30	31.0	70	1.2	0.44	26.57	3.71	III-degree rainstorm (A_3)
Pomp. Jeziorany	31.07.14 18:50	31.07.14 19:50	21.2	70	1.2	0.30	18.17	2.53	II-degree rainstorm (A_2)
Pomp. Żaglowa	31.07.14 19:00	31.07.14 20:00	26.6	70	1.2	0.38	22.80	3.18	III-degree rainstorm (A_3)

Table 4. The characteristics and types of rainfalls of intensity I $\geq$ 0.10 mm min^{-1} from 16 August 2015 at different MPWiK precipitation stations in Cracow (own work).

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm min$^{-0.5}$]	
Lindego	16.08.15 13:50	16.08.15 16:40	41.2	180	3.0	0.23	13.73	3.07	III-degree rainstorm (A_3)
Kostrze	16.08.15 13:30	16.08.15 16:20	33.0	180	3.0	0.18	11.00	2.46	II-degree rainstorm (A_2)
Zawiła	16.08.15 14:00	16.08.15 17:00	22.2	190	3.2	0.12	7.01	1.61	I-degree rainstorm (A_1)
Senatorska	16.08.15 14:00	16.08.15 17:00	59.4	190	3.2	0.31	18.76	4.31	IV-degree rainstorm (A_4)
Witkowice	16.08.15 14:20	16.08.15 17:10	25.4	180	3.0	0.14	8.47	1.89	I-degree rainstorm (A_1)
PFZ Stojałowskiego	16.08.15 14:00	16.08.15 17:00	27.8	190	3.2	0.15	8.78	2.02	II-degree rainstorm (A_2)

(*continued*)

Table 4. (*continued*)

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm min$^{-0.5}$]	
OŚ Płaszów	16.08.15 14:00	16.08.15 16:40	41.2	170	2.8	0.24	14.54	3.16	III-degree rainstorm (A_3)
Pomp. Jeziorany	16.08.15 14:10	16.08.15 19:20	31.2	320	5.3	0.10	5.85	1.74	I-degree rainstorm (A_1)
Pomp. Żaglowa	16.08.15 13:00	16.08.15 15:50	37.2	180	3.0	0.21	12.40	2.77	II-degree rainstorm (A_2)
Chabrowa	16.08.15 14:10	16.08.15 17:00	18.2	180	3.0	0.10	6.07	1.36	heavy rain-fall (A_0)
Rybna	16.08.15 13:40	16.08.15 16:40	32.8	190	3.2	0.17	10.36	2.38	II-degree rainstorm (A_2)
Kampus UJ	16.08.15 13:40	16.08.15 16:30	32.8	180	3.0	0.18	10.93	2.44	II-degree rainstorm (A_2)
Reduta	16.08.15 14:10	16.08.15 17:00	31.4	180	3.0	0.17	10.47	2.34	II-degree rainstorm (A_2)
Narciarska	16.08.15 13:10	16.08.15 16:00	50.8	180	3.0	0.28	16.93	3.79	III-degree rainstorm (A_3)
Miedziana	16.08.15 13:50	16.08.15 16:50	76.4	190	3.2	0.40	24.13	5.54	IV-degree rainstorm (A_4)

Table 5. The characteristics and types of rainfalls of intensity $I \geq 0.10$ mm min^{-1} from 25 and 26 June 2016 at different MPWiK precipitation stations in Cracow (own work).

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm min$^{-0.5}$]	
PFZ Stojałowskiego	25.06.16 07:00	25.06.16 08:00	11.6	70	1.2	0.17	9.94	1.39	IV-degree rainstorm (A_4)
OŚ Płaszów	25.06.16 06:50	25.06.16 07:10	13.8	30	0.5	0.46	27.60	2.52	I-degree torrential rain (B_1)
Krzemionki	25.06.16 06:50	25.06.16 07:10	4.6	30	0.5	0.15	9.20	0.84	I-degree rainstorm (A_1)
Miedziana	25.06.16 07:10	25.06.16 07:20	2.6	20	0.3	0.13	7.80	0.58	Heavy rainfall (A_0)
Witkowice	26.06.16 13:00	26.06.16 14:30	18.4	100	1.7	0.18	11.04	1.84	I-degree torrential rain (B_1)
Pomp. Wilga	26.06.16 12:40	26.06.16 13:30	17.0	60	1.0	0.28	17.00	1.20	I-degree torrential rain (B_1)

(*continued*)

Table 5. (*continued*)

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm $min^{-0.5}$]	
PFZ Stojałowskiego	26.06.16 13:00	26.06.16 14:00	17.4	70	1.2	0.25	14.91	2.08	I-degree torrential rain (B_1)
OŚ Płaszów	26.06.16 12:50	26.06.16 13:30	8.4	50	0.8	0.17	10.08	1.19	III-degree rainstorm (A_3)
Chabrowa	26.06.16 13:00	26.06.16 13:20	6.6	30	0.5	0.22	13.20	1.20	II-degree rainstorm (A_2)
Kampus UJ	26.06.16 12:40	26.06.16 13:20	10.8	50	0.8	0.22	12.96	1.53	IV-degree rainstorm (A_4)
Reduta	26.06.16 13:00	26.06.16 13:40	10.0	50	0.8	0.20	12.00	1.41	III-degree rainstorm (A_3)
Narciarska	26.06.16 13:00	26.06.16 13:40	5.0	50	0.8	0.10	6.00	0.71	I-degree rainstorm (A_1)
Krzemionki	26.06.16 12:40	26.06.16 13:40	11.6	70	1.2	0.17	9.94	1.39	IV-degree rainstorm (A_4)
Miedziana	26.06.16 12:50	26.06.16 13:20	15.2	40	0.7	0.38	22.80	2.40	I-degree torrential rain (B_1)

Table 6. The characteristics and types of rainfalls of intensity $I \geq 0.10$ mm min^{-1} from 1 September 2017 at different MPWiK precipitation stations in Cracow (own work).

Precipitation station	Start time of rainfall	End time of rainfall	Rainfall depth h	Duration of rainfall t		Intensity of rainfall I		Efficiency of rainfall α	Rainfall category according to Chomicz
	[dd-mm-yy]	[dd-mm-yy]	[mm]	[min]	[h]	[mm min^{-1}]	[mm h^{-1}]	[mm $min^{-0.5}$]	
Zawiła	01.09.17 23:00	01.09.17 23:00	8.6	10	0.2	0.86	51.60	2.72	II-degree rainstorm (A_2)
Pomp. Żaglowa	01.09.17 22:50	01.09.17 23:20	7.6	40	0.7	0.19	11.40	1.20	Heavy rainfall (A_0)
Chabrowa	01.09.17 22:50	01.09.17 23:10	7.0	30	0.5	0.23	14.00	1.28	Heavy rainfall (A_0)
Narciarska	01.09.17 22:50	01.09.17 00:50	13.4	130	2.2	0.10	6.18	1.18	Heavy rainfall (A_0)
Miedziana	01.09.17 22:50	01.09.17 00:30	10.6	110	1.8	0.10	5.78	1.01	Heavy rainfall (A_0)

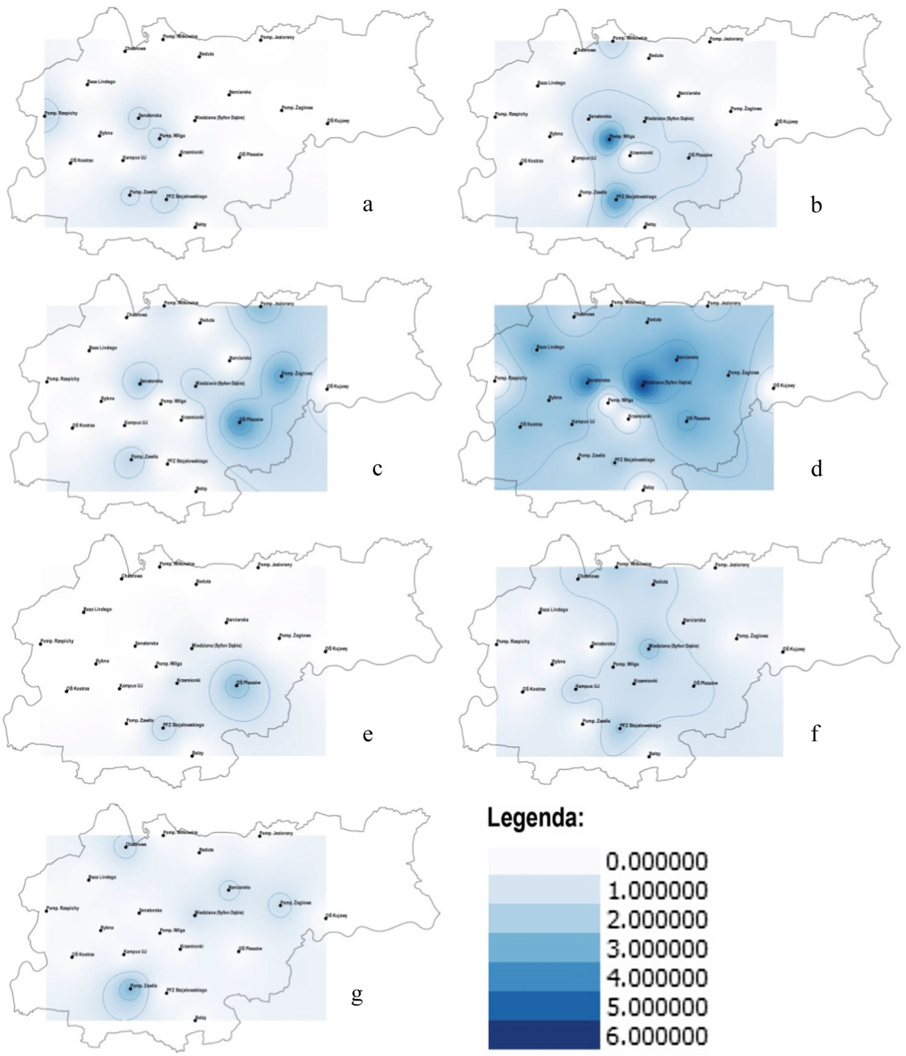

Fig. 2. Maps of rainfalls of intensity I $\geq$ 0.10 mm min^{-1} during observation period from: (a) 10 June 2013, (b) 15 July 2014, (c) 31 July 2014, (d) 16 August 2015, (e) 25 June 2016, (f) 26 June 2016 and (g) 1 September 2017 in Cracow based on the MPWiK precipitation stations; the depth of the blue colour indicates increasing efficiency of rainfall α (source: own).

3 Analysis of Results

At the final stage, analysed were rainfalls which occurred on the same day of a given year at all of the MPWiK precipitation stations in Cracow. Determined were seven days of this kind from different observation years. In each case the start and end times of the rainfalls were identical, or their occurrences were marginally different. The longest duration, in minutes, between the start/end time of two different rainfalls was: 10 June 2013 – 20/50, 15 July 2014 – 20/100, 31 July 2014 – 70/90, 16 August 2015 – 80/210, 25 June 2016 – 20/50, 26 June 2016 – 20/70 and 1 September 2017 – 10/110. The rainfall duration, in hours, in all of the cases was fairly equal and within the following range: 10 June 2013 – 2.2–2.8, 15 July 2014 – 0.7–1.7, 31 July 2014 – 1.2–2.7, 16 August 2015 – 2.8–5.3, 25 June 2016 – 0.3–1.2, 26 June 2016 – 0.5–1.7 and 1 September 2017 – 0.2–2.2. It is particularly worth noting that all rainfalls which occurred during the seven days of observation were predominantly of intense character and were within the Chomicz scale beginning with heavy rainfall type (A_0) and ending with type IV-degree rainstorm (A_4). Regular rainfalls occurred infrequently. In none of the analysed cases were torrential rainfalls observed. Rainfalls which occurred in June 2013 and September 2017 are of similar type according to Chomicz, the only difference being that on 10 June 2013 four out of five of them were heavy rainfalls (A_0) (Rzepichy, Senatorska, Pomp. Wilga, PFZ Stojałowskiego), and only one was a I-degree rainstorm (A_1) (Zawiła), whereas on 1 September 2017 four out of five rainfalls were heavy rainfalls (A_0) (Pomp. Żaglowa, Chabrowa, Narciarska, Miedziana), and only one was a II-degree rainstorm (A_2) (Zawiła). The prevailing type among the rainfalls which occurred in August 2015 was rainstorm and three out of 15 rainfalls which occurred on 16 August 2015 were I-degree rainstorms (A_1) (Zawiła, Witkowice, Pomp. Jeziorany), six of them – II-degree rainstorms (A_2) (Kostrze, PFZ Stojałowskiego, Pomp. Żaglowa, Rybna, Kampus UJ, Reduta), three – III-degree rainstorms (A_3) (Lindego, OŚ Płaszów, Narciarska), two IV degree rainstorms (A_4) (Senatorska, Miedziana) and one heavy rain (A_0) (Chabrowa). The type of rainfalls which occurred at the precipitation stations in July 2014 and June 2016 is changeable – in half of the cases it was rainstorm and in the other half heavy or regular rainfall. On 15 July 2014 the rainfall type was: one out of six were I-degree rainstorm (A_1) (Witkowice), one was III-degree rainstorm (A_3) (PFZ Stojałowskiego) and one case of IV-degree rainstorm (A_4) (Pomp. Wilga) and three out of heavy rainfalls (A_0) (Senatorska, Syfon Dąbie, OŚ Płaszów). On 31 July 2014 two out of seven were I-degree rainstorms (A_1) (Zawiła, Syfon Dąbie), two II-degree rainstorms (A_2) (Senatorska, Pomp. Jeziorany), two III-degree rainstorms (A_3) (OŚ Płaszów, Pomp. Żaglowa) and one regular rainfall (Witkowice). On 25 June 2016 two out of the four rainfalls was: two regular rainfalls (Krzemionki, Miedziana), one heavy rainfall (A_0) (PFZ Stojałowskiego) and one I-degree rainstorm (A_1) (OŚ Płaszów), whereas on 26 June 2016, similarly to 10 June 2013, the prevailing type of rainfall was rainstorm and out of ten rainfalls there were: one regular rainfall (Narciarska), three heavy rainfalls (Chabrowa, OŚ Płaszów, Krzemionki), three I-degree rainstorm (A_1) (Witkowice, Kampus UJ, Reduta) and three II-degree rainstorms (A_2) (Pomp. Wilga, PFZ Stojałowskiego, Miedziana).

4 Conclusion

This study presents an analysis of intense rainfalls which occurred in Cracow between 2013 and 2017. These rainfalls were identified based on precipitation data from the records of the MPWiK in Cracow as rainfall events whose intensity, according to the selected criterion, was $I \geq 0.10$ mm min^{-1}. The application of the Chomicz scale revealed their changeable characteristics in particular observation years, however there was a tendency towards intense rainfalls. In 2013, out of 13 cases, there were 11 cases of intense rainfalls making up 85% of all rainfalls recorded (i.e. 46% of heavy rainfalls (A_0), 23% of II-degree rainstorm (A_2) and 16% of I-degree rainstorm (A_1)), whereas only 2 cases were of regular rainfall, the remaining 15%. In 2014, out of 49 cases, there were 34 cases of intense rainfalls making up 69% of all rainfalls (i.e. 25% of I-degree rainstorms (A_1), 20% of heavy rainfalls (A_0), II- and III-degree rainstorms (A_2 and A_3 – 10% for each) and 4% of IV-degree rainstorms (A_4)) and regular rainfalls occurred in 15 cases, the remaining 31%. In 2015, out of 39 cases, there were 25 intense rainfalls making up 64% (i.e. I-degree rainstorms (A_3) – 33%, II-degree rainstorms (A_2) – 15%, III-degree rainstorms (A_3) – 8%, heavy rainfalls – 5% and IV-degree rainstorms (A_4) – 3%) and regular rainfalls occurred in 14 cases, the remaining 36%. This presents a similar ratio of intense to regular rainfalls as in 2014. In 2016, intense rainfalls made up 51% of all recorded rainfalls (i.e. heavy rainfalls (A_0) – 23%, then I- and II-degree rainstorms (A_1 and A_2) each making up 14% of all recorded rainfalls) as compared to the regular types of which there was 49%. It is visible in this year of observation that the number of intense rainfalls was similar to the number of the regular rainfalls. In 2017, 7 out of 8 cases were of intense character, making up 88% of all recorded rainfalls (i.e. heavy rainfalls (A_0) – 62%, II- and III-degree rainstorms (A_2 and A_3) – each making up 13%) and there was only 1 case of regular rainfall, which made up 12%.

Analysing the rainfalls which occurred on the same day of a given year at particular precipitation stations located at different distances but within an area of one city, Cracow, again have validated the popular statement that rainfall is a random phenomenon, changeable in time and space, as well as of changeable type according to the Chomicz scale. The changeable type of rainfalls could be attributed to different factors, e.g. related to meteorology, climate, landscape, geology, or an overlap of a number of weather phenomena, not necessarily of extreme character. However, these factors were not analyzed in this work. The fact, however, is that intense rainfalls occur more and more often in the city and their type is gradually becoming more intense, moving towards rainstorm. Therefore, it is necessary to continuously analyze them considering the benefits it offers to designing rainfall runoff from the area to the receiver where rainfall scenario is taken as input data for designing rainfall-runoff models, accurate computing the components of water balance in urban catchment or designing rainwater drainage systems.

Acknowledgment. This research was supported by the grant from Ministry of Science and Higher Education Ś1/391/2018/DS. I would like to thank the MPWiK in Cracow for sharing the precipitation data.

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New Approach to Determine the Sum of the Active Temperatures (*SAT*) Exemplified by Weather Conditions of Western Malopolska

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Abstract. The paper presents results of research on thermal conditions around the town of Chrzanów in Western Malopolska (southern Poland). The conditions have been determined with the help of the parameter called "sum of active temperatures" (*SAT*), quite commonly used in climatology and particularly popular among wine growers. New approach in *SAT* concept has been performed: it's value has been calculated based on the results of temperature measurements in selected points of environment in which grapevine (*Vitis* – species) vegetation takes place, that is in the air and in the soil. Moreover, various definitions of "mean temperature" have been applied. The use of different calculation formulae lead to different *SAT* values. In some cases, the differences in the obtained *SAT* values reached several percent. This demonstrates the sensitivity of this "measure" in the context of applied computational techniques. Such a conclusion leads to the discussion on the usefulness of calculation formulae used in research on regional climatic conditions, especially in comparative analysis.

Keywords: Soil temperature · Mean temperature · Temperature sum · Comparative analysis · Grapevine

1 Introduction

The knowledge of regional climatic conditions is a prerequisite for making right decisions in agricultural activities. These conditions determine the amount of rainfall in different seasons, the amplitude of temperature in summer and winter, humidity variations, etc. The sum of active temperatures (*SAT*) belongs to the category of thermal measures. This concept binds, in a way, temperature value with its duration. *SAT* is calculated as the sum of daily mean temperatures throughout the growing season and it only can consist of values which are higher than T_{opt}. If daily mean temperature was less than T_{opt}, it was not taken into account. T_{opt} is defined as the minimum temperature value which is conducive to the start of the growing season for a given plant species or temperature value that supports intensive growth. Often in classic climatological studies, T_{opt} values equal 5 °C, 10 °C or 15 °C, depending on the purpose of the research [3, 4, 7, 13, 15, 16, 18–20]. It can be assumed that the values refer to air

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 203–216, 2019.
https://doi.org/10.1007/978-3-030-16542-0_27

temperature in the space occupied by the green parts of the plant, but the procedure has not been precisely defined. In the case of extremely thermopilic crops, higher values of T_{opt} are assumed; in other cases – lower ones. For grapevine growing, taking into consideration the so-called *terroir*, T_{opt} = 10 °C is assumed [7, 13].

In climatological studies, *SAT* is calculated based on data from meteorological stations, where thermometers are placed in cages at the height of 2 m above the ground level. If *SAT* is designed to identify conditions favorable for plant life processes, mean temperature should be determined for these "areas" of the environment in which vegetation takes place. In the case of traditional crops, *SAT* should be determined in the air and in the soil at different depths (depending on the type of the root system); in the case of aquatic plants - in the air and water; in the case of epiphytes - in the air at the height typical for the plant.

2 Research Method

For the purposes of this study it was assumed that *SAT* will be determined in the "area" where grapevines grow, that is:

- in the air, at the height of 1 m above the ground level,
- in the air, at the height of 5 cm above the ground level,
- in the soil, approx 5 cm beneath the ground level,
- in the soil, at the depth of 25 cm.

Temperature measurements were conducted from 1 January to 31 December 2011 at the site located at N50.159539°, E19.384979° in the western part of the Malopolska region (southern Poland). The measurements were recorded at 1-min intervals. High frequency of data acquisition in temperature studies is necessary for analysis on conductive processes in the soil [1], especially when applying methods based on Fourier decomposition of temperature-course [14]. In this work, such a sampling frequency allows for clear identification of temperature changes over time, because the highest significant components of the process (from particular positions), have periods of several minutes, which was confirmed by preliminary measurements. According to the Nyquist theorem [2], it can be therefore assumed that the temperature courses described above, after conducting appropriate approximation in time, can be treated on a par with analog functions. The presented assumption has been applied in the data analysis.

As already mentioned, temperature measurements were carried out at different levels with the help of electronic sensors Pt-100 with low thermal inertia, useful for temperature measurements in climatologic studies [6]. For the purposes of this study, data from the following measurement points was used:

- POINT 1 – in the air (shadowed), at the height of 1 m above the ground level, at least 10 m away from other objects. It was assumed that this is the level of the growing zone for the green part of the grapevine. In large scale vineyards fruit buds are formed and ripen at this level.
- POINT 2 – in the air (non-shadowed), at the height of 5 cm above the ground level, just beneath the POINT 1. This is the zone of periodic inversion phenomena, which

result in sudden temperature falls or growths as a result of insolation. Different land covers modify conditions of surface heat transfer [5], so, since grapevine growing requires the maintenance of proper soil quality it was assumed, that temperature measurement will be conducted in the soil deprived of natural vegetation (bare fallow).

- POINT 3 – in the soil, approx 5 cm beneath the ground level
  This is the zone of heat exchange between the ground and the air. During spring frosts this zone freezes the fastest.
- POINT 4 – in the soil, at the depth of 25 cm
  This is the zone occupied by roots; mycorrhizal fungi also develop here [10].

Based on the obtained data, mean daily temperature was determined with the help of three different definitions of the mean, according to the formulas:

$$T_{mean} = \frac{1}{24\,\mathrm{h}} \int_{0}^{24\,\mathrm{h}} T(\tau)d\tau \tag{1}$$

$$T_{mean} = \frac{1}{2}(T_{\max} + T_{\min}) \tag{2}$$

$$T_{mean} = \frac{T_{max} + T_{min} + T_{8\,am} + T_{8\,pm}}{4} \tag{3}$$

According to World Meteorological Organisation proposal, daily mean temperature formulae should help better understanding local weather conditions, in particular country [12, 23]. Formula (1) corresponds to this recommendation. Time domain integration, applied here, was conducted after approximating discrete data. Such a definition of the mean represents its conceivably most accurate value.

Formula (2) is very popular in climatological works [12, 21, 22] but, in author’s opinion, it’s the mostly rough and misleading concept of the mean, having regard to its value in agricultural studies. Moreover, it’s often calculated on the basis of simulated (not measured) values of T_{max} and T_{min} [9, 24]. It’s value can be questioned also in cases of long time-lag measurements, neglecting Nyquist’s theorem [2], that usually unables to capture extreme temperatures [10].

Formula (3) represents the concept of the mean adopted in 1996 by the Polish Institute of Meteorology and Water Management as the official method for analyzing the results of meteorological observations in Poland [8].

3 Results and Analysis

In accordance with the adopted assumption, *SAT* was calculated by summing up the mean daily temperatures (calculated with different mathematical formulae), provided that the mean values were higher than T_{opt} = 10 °C. The calculation started from the first day on which this condition was fulfilled. Since the use of different mathematical formulas to determine the mean temperature led to different results, there were situations, especially in spring and autumn, when some of the calculated daily means met the condition $T_{mean} > T_{opt}$, and others did not. Hence *SAT* growth rate for particular mean temperature formulas is different. The process of summing began on the following dates:

- 12 March (formulae (1) and (2)) and 13 March for formula (3)—in point 1;
- 13 March (formulae (1) and (3)) and 12 March for formula (2)—in point 2;
- 15 March (formulae (1) and (3)) and 14 March for formula (2)—in point 3;
- 31 March (for all formulae)—in point 4;

A similar challenge concerns mean values obtained from different measurement points, but on the same day. Since daily mean temperature of air and soil at the surface and in the deeper layers are not the same, there were situations when measurement data from the sensors in the air led to $T_{mean} > T_{opt}$, while on the same day, in the ground $T_{mean} < T_{opt}$. The opposite also occurred. This phenomenon is caused by thermal inertia of the ground, which heats and cools slowly, and soil temperature (also mean temperature) follows the temperature of the air with a certain time shift.

The start and end of the growing season (we are analyzing grapevine growing conditions, but the problem applies to all plants) are not precisely defined points in time. They are not assigned to a specific day of the year. The period of plant growth has fuzzy time limits. It is often the case that vegetation period is inhibited as a result of periodic coolings even in late spring. Conversely, sometimes in the autumn, after the loss of leaves, flower buds can be observed as a result of periodically increased air temperatures. It should be noted here that the beginning and end of the growing season is specific for different species (in the case of grapevine: different seedlings). Therefore in this study, *SAT* is calculated starting from the point in time when mean temperature reached the sufficient level, without trying to resolve the starting time point of the vegetation season. The same applies to the end of the calculation period. The calculations were conducted until the end of November, although *SAT* growths ceased in the early days of this month, namely:

- 8 November for formula (1) and 9 November (formulae (2) and (3))—in point 1;
- 6 November for formula (1); 9 November for formula (2) and 8 November for formula (3)—in point 2;
- 7 November for formula (1); 9 November for formula (2) and 8 November for formula (3)—in point 3;
- 9 November (for all formulae)—in point 4;

The number of days in the year 2011, when $T_{mean} > 10$ °C, depended on where the measuring point was located and which calculation formula was used. It ranged from 200 to 220 days. Detailed information is shown in Fig. 1. For each measuring point, the use of formulas (1) and (3) gives comparable results, while formula (2) leads to an overestimation of the number of vegetation days.

Figures 1, 2, 3, 4 and 5 depicts results of *SAT* calculations. The charts include the period from the first day when $T_{mean} > 10$ °C, that is from 12 March till the end of November.

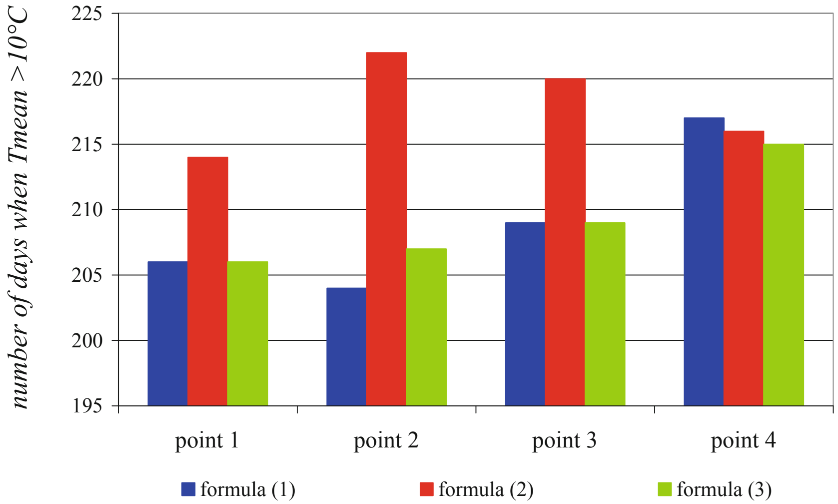

Fig. 1. Number of days in 2011, when T_{mean} > 10 °C, in particular measurement points.

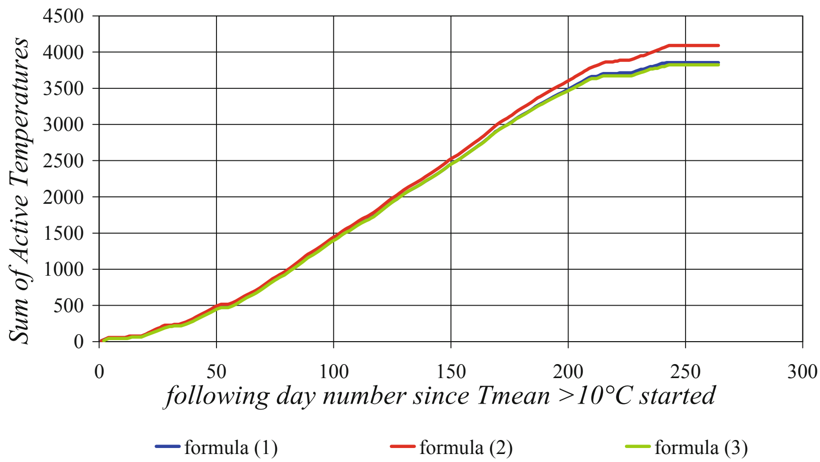

Fig. 2. *SAT* increase during the 2011 growing season. Measurement point located 1 m above the ground. The digits indicate the number of formulas used for determining daily mean temperature.

The graphs confirm that the use of different definitions of daily mean temperature leads to different *SAT* values. Table 1 summarizes the results of the calculations.

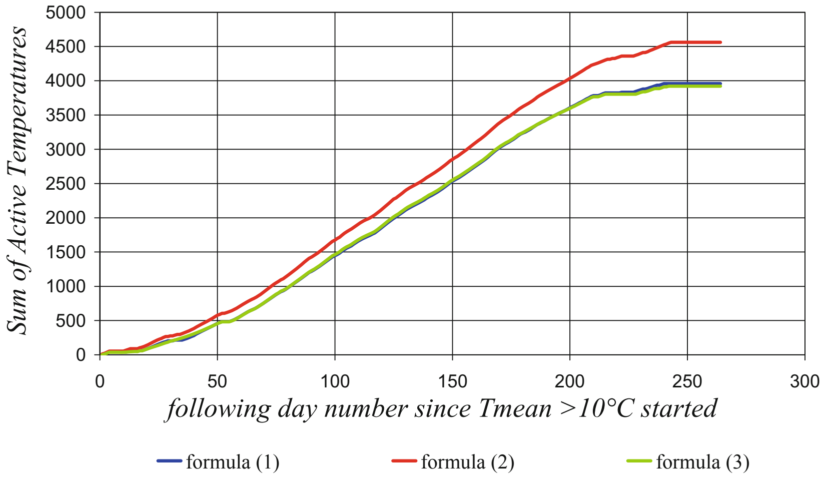

Fig. 3. *SAT* increase during the 2011 growing season. Measurement point located 5 cm above the ground.

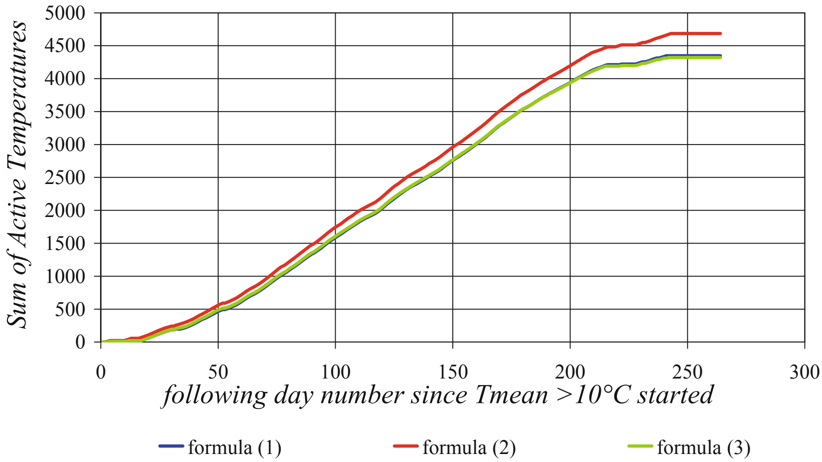

Fig. 4. *SAT* increase during the 2011 growing season. Measurement point located 5 cm beneath the ground level, in the soil.

It is obvious that in certain periods *SAT* grew faster and in certain periods it increased slower. During summer heat waves, daily mean temperatures were higher than their counterparts in spring or autumn, and mean temperature is the time derivative of *SAT*:

$$\frac{d}{dt}(SAT) = T_{mean} \tag{4}$$

Table 1. Calculated *SAT* values (rounded to integers) based on data from individual stations measuring temperature and the daily mean calculation with various mathematical formulae.

Measurement points	Calculated *SAT* values		
	Formula (1)	Formula (2)	Formula (3)
1	3856	4091	3824
2	3959	4563	3920
3	4347	4685	4322
4	4197	4226	4227

Which means that it determines the slope of the curve representing *SAT* increase in time. It is worth pointing out the share of each month of the growing season in the total, annual *SAT* value. This is presented for particular measurement positions in Figs. 6, 7, 8 and 9.

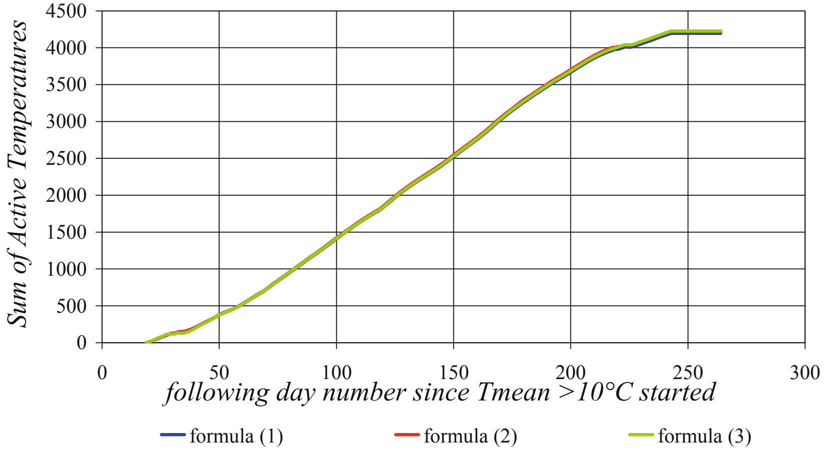

Fig. 5. *SAT* increase during the 2011 growing season. Measurement point located in the soil, 25 cm beneath the ground level.

Having analyzed graphs in Figs. 6, 7, 8 and 9, it becomes clear that the use of different definitions of daily mean temperature leads to discrepancies in the established *SAT* values. Particularly large differences can be observed for measurement points where temperature changes are very dynamic: frequent and significant increases and decreases in temperature value. Such conditions occur primarily where air and soil are in contact. Surface soil layer is subject to the effects of sun exposure, which heats the air near the surface of the ground. In periods of variable cloudiness, the rate of temperature change is really high here. Examples of significant differences in mean temperature values are illustrated in the Figs. 9, 10, 11, 12 and 13. In all the figures, *SAT* monthly values are presented, calculated with different mathematical formulae.

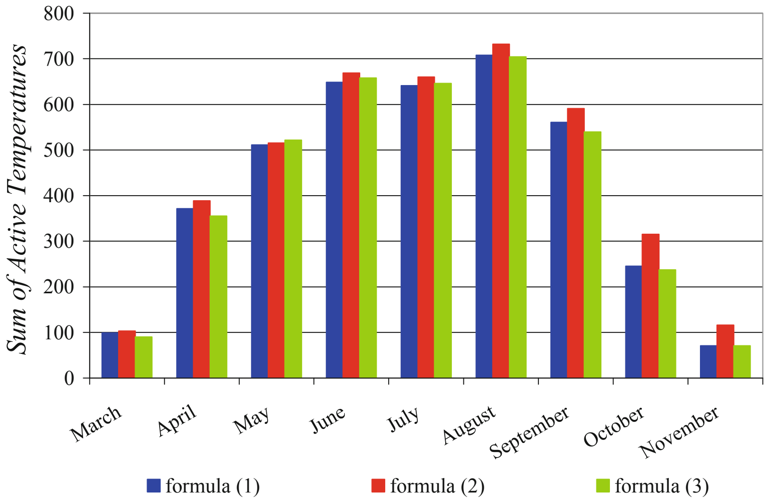

Fig. 6. Monthly *SAT* increments during the 2011 growing season. Measurement point located 1 m above the ground level.

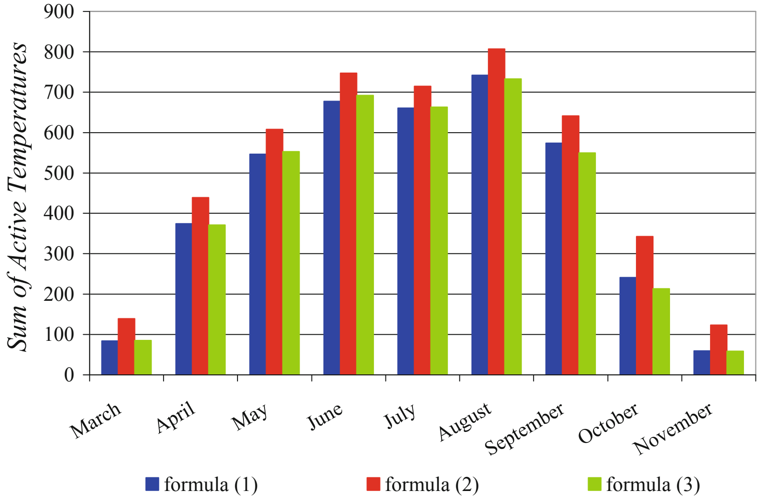

Fig. 7. Monthly *SAT* increments during the 2011 growing season. Measurement point located 5 cm above the ground level.

Therefore the following question arises here: which of the definitions for daily mean temperature best describes thermal conditions conducive to the growth of plants?

The concept of Sum of Active Temperatures is a result of synthetic approach to temperature and the time of its duration. Taking into consideration various stages of plant development (e.g. flowering, leaf growth, fruit development, the so-called

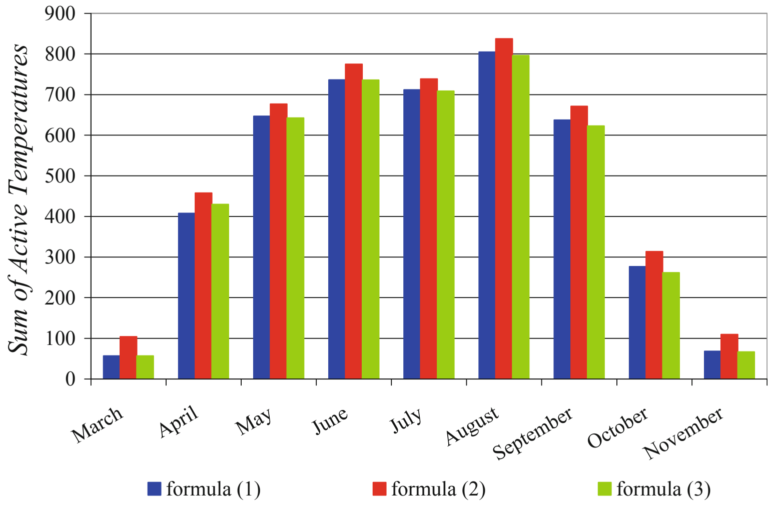

Fig. 8. Monthly *SAT* increments during the 2011 growing season. Measurement point located 5 cm beneath the ground level.

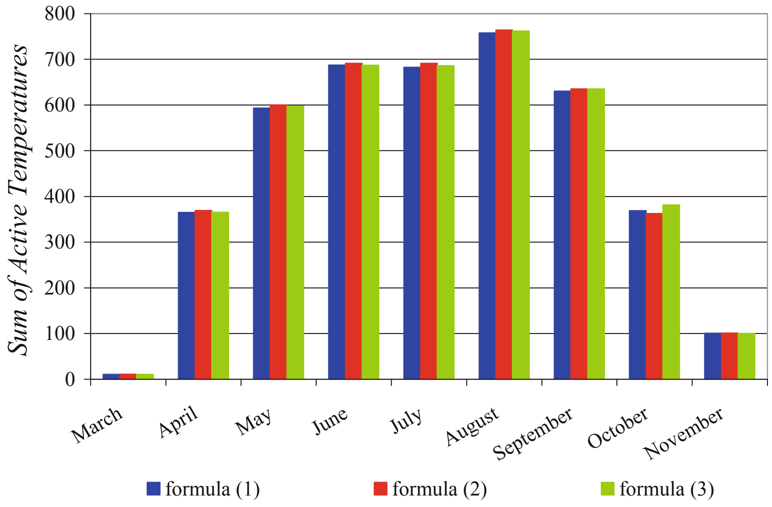

Fig. 9. Monthly *SAT* increments during the 2011 growing season. Measurement point located 25 cm beneath the ground level.

"phonological phases"), it is essential that, for a certain period of time, temperature (of plant growth) remains above the so-called. "physiological zero", which has a specific value for the particular phase. The phrase "a certain period of time" should be emphasized here. This is the time needed for the necessary physical and chemical processes to be implemented and completed. Each phase lasts as long as the sum of the surpluses of daily mean temperatures above physiological zero reaches a certain value

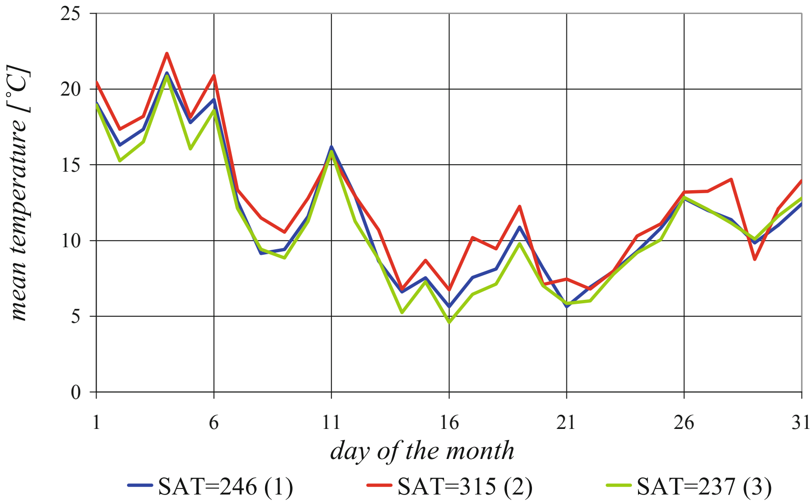

Fig. 10. Daily mean temperatures for October 2011 based on the measurement conducted 1 m above the ground level; the colours indicate which formula was used for determining mean temperature.

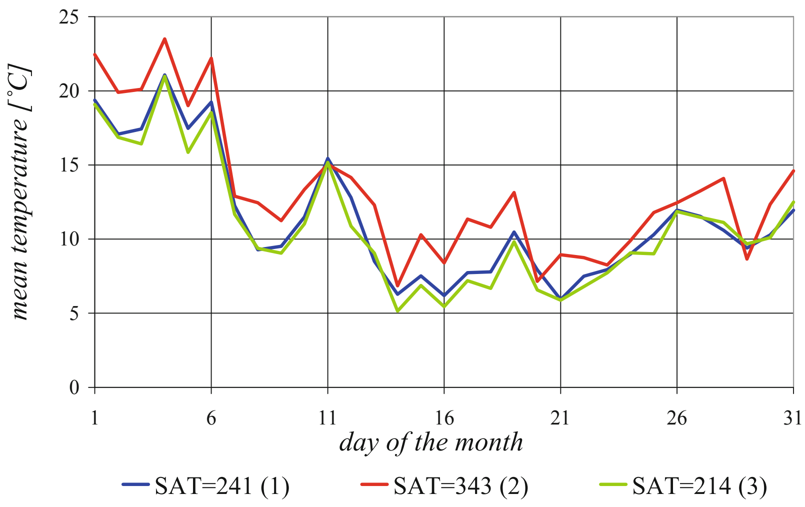

Fig. 11. Daily mean temperatures for October 2011 based on the measurement conducted 5 cm above the ground level.

[11]. In a sense, the plant must “be satisfied with warmth.” Therefore, it is not enough if high temperatures occur for one day. An example of such a situation is illustrated in Fig. 14. A hypothetical daily temperature course presented here may be illustrative of what happens during a cool, cloudy day, when for a short period of time the sky clears out and the temperature rises as a result of insolation (e.g. in the surface layer of soil).

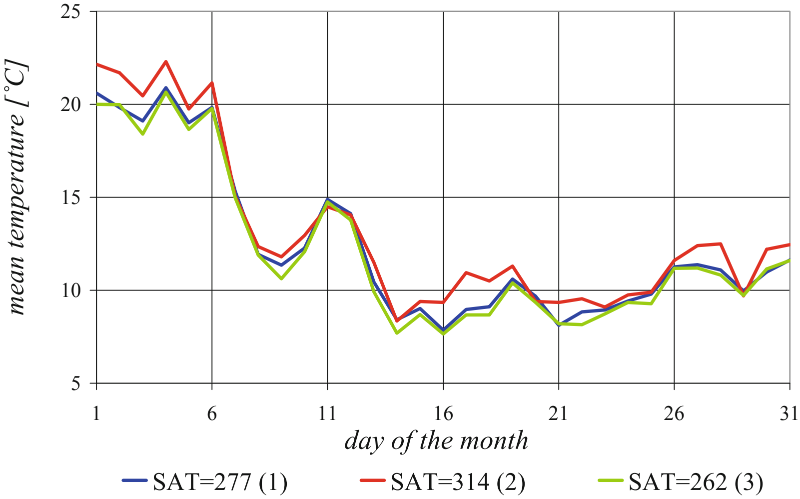

Fig. 12. Daily mean temperatures for October 2011 based on the measurement conducted 5 cm beneath the ground level.

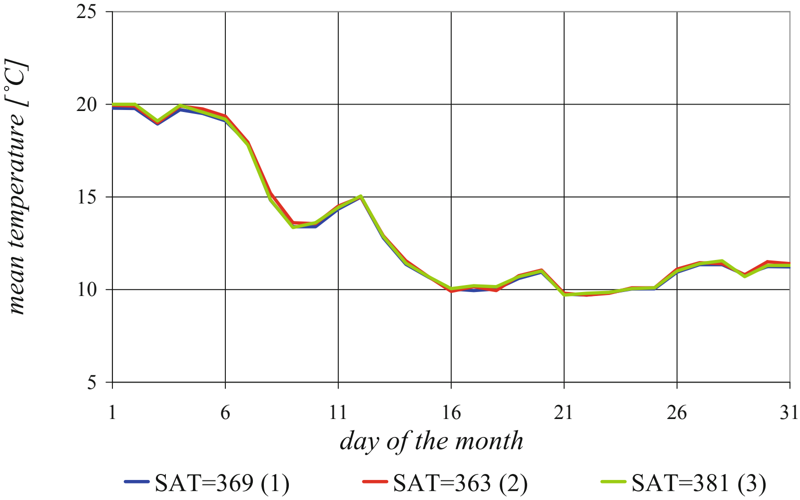

Fig. 13. Daily mean temperatures for October 2011 based on the measurement conducted 25 cm beneath the ground level.

Let us assume that the temperature indicated as T_1 represents daily mean determined with the formula (1), whilst T_2 – with the formula (2). Obviously: $T_1 << T_2$. Assuming that $T_{mean} = T_2 > 10$ °C (when, for example, $T_1 = 4$ °C) we run the risk of an erroneous conclusion that thermal conditions during the analyzed day were conducive to plant growth. In such circumstances, the use of formula (2) seems to be risky. And this is probably the reason why the number of days conducive to grapevine growth presented in Fig. 1 was overestimated.

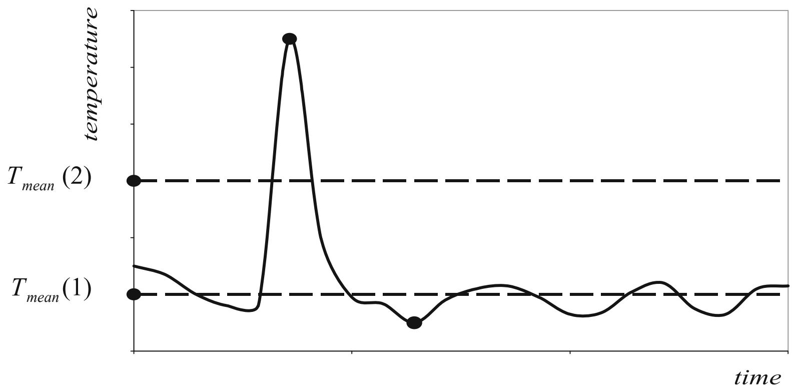

Fig. 14. Exemplary situation when daily mean temperatures calculated with formulae (1) and (2) are significantly different, and formula (2) leads to erroneous interpretation of thermal conditions conducive to plant growth.

The concept of mean temperature calculated with formula (1) does not lead to such significant misinterpretations. From a physical point of view, the Riemann integral represents here the area delineated with the time course of temperature with respect to the time axis. Surface area calculated in such a way can be seen as a "temperature dose". Having split (averaged) it across the whole day we receive the so-called "dose density", "effective temperature value", which determines the intensity of heat transmission to the plant over a certain period of time.

The structure of formula (3) used to determine daily mean temperature indicates that it is a type of an empirical formula. The assumption that temperature values obtained at 8 am and 8 pm will be used for calculating the mean is purely arbitrary, because these are not extreme values. The authors are aware of that as they introduce other real extreme values, T_{min} and T_{max} into the equation. In that context, what is the role of T_{8am} and T_{8pm}? Possibly they are supposed to eliminate the risk of overrating the daily mean, which, as already mentioned, happened in the case of formula (2). Fairly enough, we could conclude that the use of formulas (1) and (3) leads to comparable results. This is shown by figures illustrating the results of the analysis. Therefore it seems justifiable to conclude, without attempting at an analytical proof, that formula (3) is useful in estimating the *SAT*.

The calculated *SAT* values of 4000 for the 2011 growing season have to be considered very high, compared with the values published by climatologists and wine growers [7, 13, 17]. Based on data from specialist literature the expected *SAT* value in Western Malopolska is at <2600. The discrepancy between the two values should be attributed to different methodology of temperature measurements: primarily (in the case of results presented here) due to specific location of measurement points and high frequency of readings, which yields better description of the phenomenon.

The fact that the obtained values were so high indicate the suitability of the region of the town of Chrzanów for wine-growing, even late varieties whose requirements for *SAT* are at >2900 [17].

4 Conclusions

The results of the measurement and *SAT* analysis lead to the following conclusions:

– The use of different definitions of daily mean temperature leads to different *SAT* values.
– Physical interpretation of mean temperature according to formula (1) indicates that this concept can be useful for determining STA as a measure of conditions conducive to plant growth.
– Physical interpretation of mean temperature according to formula (2) indicates that this formula has limited applicability if we want to evaluate thermal conditions conducive to plant growth.
– The concept of daily mean temperature according to formula (3) leads to *SAT* values comparable with the ones obtained using formula (1), so it seems that it is an acceptable and useful concept.
– The number of days in the analyzed year 2011, characterized by conditions favorable for wine growing varied between the range of 200 to 220, depending on the formula used for calculating the daily mean temperature.
– The *SAT* calculated for the area of Chrzanów in 2011 was $\sim$3800 in air, 1 m above the surface; $\sim$3900 in the air, on the ground; $\sim$4300 in the surface layer of the soil; $\sim$4200 in the soil at the depth of 25 cm.
– In all measurement points during the year, the fastest *SAT* growth occurred in August.

Acknowledgments. The research was financed by statutory activity subsidy from the Ministry of Science and Higher Education of the Republic of Poland.

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Comparison of Sweet Cherry *Prunus avium* L. Tree Water Requirements in the Regions of Isparta (Turkey) and Bydgoszcz (Poland)

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Abstract. The aim of the present research was to compare sweet cherry tree water requirements in the vegetation period (IV–X) in the regions of Isparta (Turkey) and Bydgoszcz (Poland). The comparative analysis included precipitation values in the regions of Isparta and Bydgoszcz in the years 1984–2014. The calculation model by Hargreaves modified by Droogers and Allen [5] was applied in order to estimate the reference evapotranspiration (ET_0). Potential evapotranspiration, identified with sweet cherry tree water requirements, was determined using the method of plant coefficients proposed by Doorenbos and Pruitt [2]. In each of month considered, higher sweet cherry water requirements occurred in the Isparta region. The highest sweet cherry trees water requirements for the research period were reported in July and they amounted to an average of 238 mm and 118 mm for the Isparta and Bydgoszcz regions, respectively. Sweet cherry tree water requirements throughout were higher by 102% in the region of Isparta than in the region of Bydgoszcz. Higher irrigation requirements in the province of Isparta compared to the region of Bydgoszcz result mainly from the smaller amount of precipitation and differences in the distribution of precipitation during the vegetation period.

Keywords: Sweet cherry · Water requirement · Isparta region · Bydgoszcz region

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 217–224, 2019.
https://doi.org/10.1007/978-3-030-16542-0_28

1 Introduction

The sweet cherry *Prunus avium* L. production in the world is 2.32 million tons in 439692 ha. Turkey is ranked first in sweet cherry production with a share of about 26% due to geographical location, climatic and soil conditions and is ranked in the top four with USA (12.4%), Iran (9.5%) and Chile (5.3%) with a sweet cherry production of 0.6 million tons according to 2016 data [7]. The sweet cherry cultivates for both fresh consumption and export in Turkey. The main export destination of the Turkish sweet cherry is Russia, the European Union, the Middle East and some Far East countries [22]. Fruits of sweet cherry growing in south-western Turkey in the Isparta province are characterized by a sweet taste and aroma. Due to the desirable properties of fruits, as much as 80–95% of their production is exported [2, 3]. Isparta region that provides almost 3.56% of total sweet cherry production of Turkey with 21364 tons, has an important role in sweet cherry production for Turkey [21].

In Poland, the sweet cherry is mainly grown for a domestic market, but it is also exported to other countries. According to data provided in 2016, the area of cultivation of this species is about 10.000 ha and 53.8 thousand tons fruits were obtained and 50% of their production was exported to Germany and Russia [7, 8, 16, 19].

Sweet cherry trees are classified as a group of plants with moderate water requirements [6, 13, 15, 18]. In the literature, there are information about cultivation or water requirements of sweet cherry trees in the area of Isparta (Turkey) and Bydgoszcz (Poland) regions [2, 13, 21]. In mentioned regions, a comparative analysis of water requirements for apple trees was also carried out by Rolbiecki et al. [14].

2 Materials and Methods

The paper uses the thirty-year period (1984–2014) temperature and precipitation values for the Bydgoszcz and Isparta regions. In order to determine reference evapotranspiration (ET0), the calculation model by Hargreaves modified by Droogers and Allen [5] and Treder et al. [20] was applied:

$$ETo = HC\ Ra(Tmax - Tmin)^{HE}\left(\frac{Tmax - Tmin}{2} + HT\right)$$

where: HC = Empirical coefficients provided by the authors = 0.0025, Ra = Radiation over the atmosphere (mm day − 1), $Tmax$ = Maximum temperature (°C), $Tmin$ = Minimum temperature (°C), HE = Empirical coefficient provided by the authors = 0.5, HT = Empirical coefficient provided by the authors = 16.8.

Potential evapotranspiration, identified using sweet cherry tree water requirements, was determined by means of the plant coefficients method [11]. Coefficient “k” values for sweet cherry orchards at full development were used, as proposed by Doorenbos and Pruitt [4].

The results were statistically verified by determining the values of mean, median, maximum and minimum, standard deviation as well as the coefficient of variation. An attempt was also made to define potential trends of changes in the indicators of sweet cherry tree water requirements in both regions with the analysis of linear regression. The calculations involved the use of an Excel spreadsheet.

3 Results and Discussion

During the vegetation period (April–October), in the thirty one-year period (1984–2014) under study, the coefficient of variation in sweet cherry trees water requirements accounted for 3% and 6% for regions of Isparta and Bydgoszcz, respectively (Table 1). Sweet cherry water requirements showed a lower variation in the Isparta region than in the Bydgoszcz region. The coefficient of sweet cherry tree water requirements variation, in respective months of the vegetation period, ranged from 5% (September) to 9% (April) and from 9% (August) to 14% (September) in the Isparta and the Bydgoszcz regions, respectively.

Table 1. Statistical characteristics of the sweet cherry tree water requirements during the vegetation season (mm).

Month	Minimum		Maximum		Mediana		Mean		SD		VC (%)	
	I	B	I	B	I	B	I	B	I	B	I	B
IV	47.5	25.9	68.3	42.7	58.3	33.2	59.0	33.7	5.4	3.7	9	11
V	104.8	48.3	132.3	75.5	118.9	65.1	118.0	64.7	8.0	6.6	7	10
VI	170.0	80.0	204.9	126.0	189.00	97.9	189.1	98.7	10.5	10.1	6	10
VII	205.6	96.5	290.0	150.3	234.2	116.8	238.4	118.5	15.5	14.0	7	12
VIII	184.1	78.8	252.0	115.2	213.0	98.0	213.0	97.5	13.0	9.1	6	9
IX	138.2	41.0	170.8	66.3	155.0	51.3	154.0	52.1	7.5	7.3	5	14
X	66.0	15.4	87.9	24.5	79.0	19.4	78.0	19.7	6.2	2.2	8	11
IV–X	998.4	418.1	1120.0	533.3	1048.0	493.3	1049.0	484.8	27.1	30.7	3	6

Explanations: B – Bydgoszcz region, I – Isparta region, SD – standard deviation, VC – variation coefficient

Temporal variability of the sweet cherry tree water requirements in consecutive years of the period 1984–2014 in the Isparta and Bydgoszcz regions is shown in Figs. 1 and 2. In the period 1984–2014 in the both regions the sweet cherry tree water requirements tend to increase. According Rolbiecki and Piszczek [13] in region of Bydgoszcz in the forecast period (2016–2050), the water requirements will increase, in each pentad within, from 13.0 to 14.5 mm. An increase in the water requirements of plants can be caused of the forecast climate changes [1, 9, 12].

The sweet cherry tree water requirements were higher in the region of Isparta in each of the seven months (Fig. 3). The highest sweet cherry trees water requirements during the vegetation season (April–October) for the research period (1984–2014) were reported in July and they amounted to an average of 238 mm and 118 mm (Fig. 5) for the Isparta and Bydgoszcz, respectively. Slightly lower sweet cherry tree water requirements occurred in the successive summer months: August and June, respectively

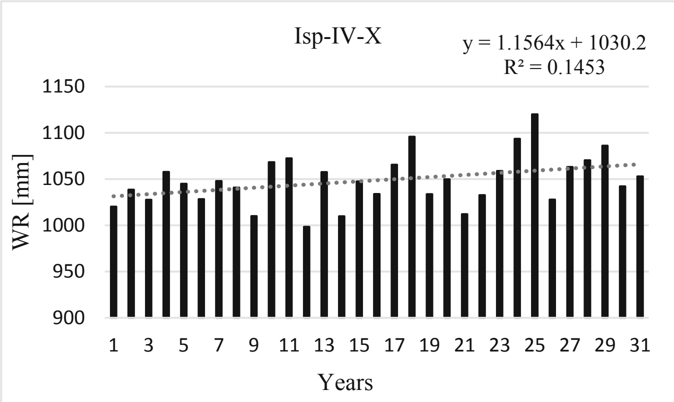

Fig. 1. Temporal variability of the sweet cherry tree water requirements (April–October) in consecutive years of the period 1984–2014 in the Isparta region.

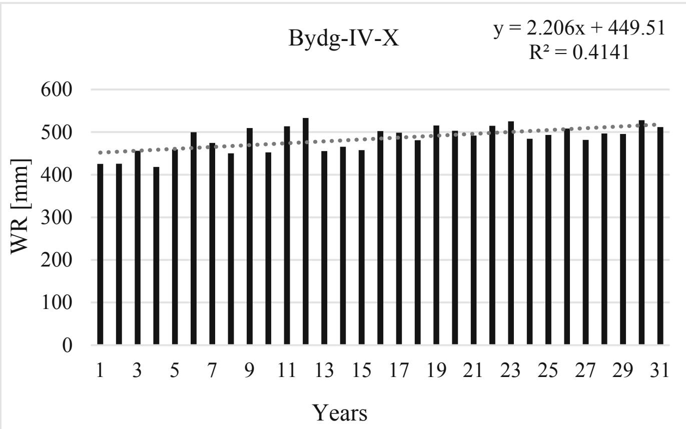

Fig. 2. Temporal variability of the sweet cherry tree water requirements (April–October) in consecutive years of the period 1984–2014 in the Bydgoszcz region.

for the regions and months, amounting to 213 mm and 189 mm as well as 98 mm and 99 mm.

Cumulative sweet cherry tree water requirements during the vegetation season (April–October) in the region of Isparta amounted 1049 mm while in the Bydgoszcz region it was 484 mm (Fig. 4). Sweet cherry tree water requirements during the vegetation season (April–October) for the research period (1984–2014) throughout were much higher in the region of Isparta than in the region of Bydgoszcz by 102%.

A comparison of the sweet cherry water balance developed for respective months of the vegetation period shows that a positive water balance occurred only in October, exclusively in the region of Bydgoszcz (Fig. 5). In region of Isparta, the water requirements sweet cherry tree during all analyzed months exceeded the total natural

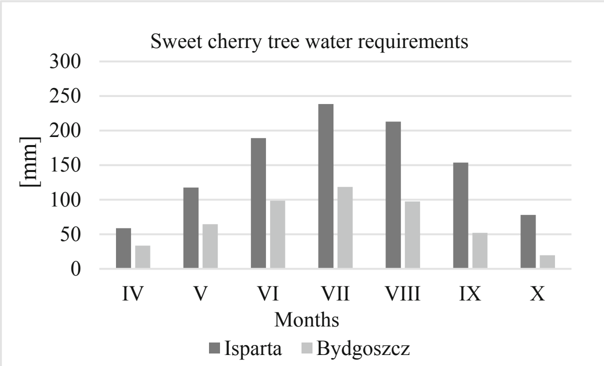

Fig. 3. Sweet cherry tree water requirements during the vegetation season (April–October) in the Isparta and Bydgoszcz regions.

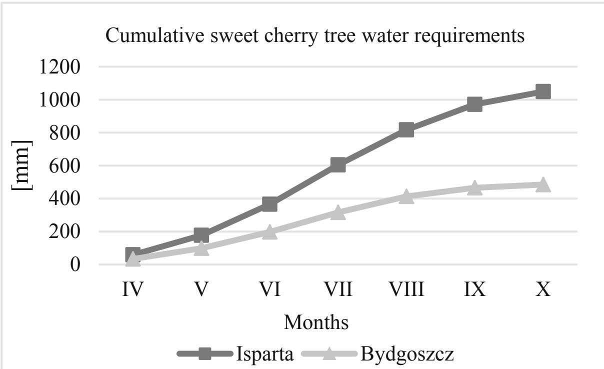

Fig. 4. Cumulative sweet cherry tree water requirements during the vegetation season (April–October) in the Isparta and Bydgoszcz regions.

precipitation, which indicates a negative balance in the analyzed months. The highest rainfall deficits occurred in July for the Isparta and Bydgoszcz regions and were 219 mm and 47 mm, respectively. A lower precipitation deficits were recorded in August (−200 mm) in the region of Isparta and in June in the region of Bydgoszcz (−41 mm).

Natural precipitation deficits must be covered in respective months with water provided with supplementary irrigation. The curves plotted for the sum of the indicators under study point to seasonal irrigation requirements of sweet cherry tree (Fig. 6). In the Isparta region they amount as much as 825 mm for the period between 1 April and 31 October. In the Bydgoszcz region, the seasonal irrigation requirements for sweet cherry (April–October) were only 144 mm. According to Rzekanowski et al. [17] for high yields, fruit plants in Bydgoszcz region (Poland) should receive from 100 to 200 mm of water by applying supplementary irrigation in addition to natural precipitation.

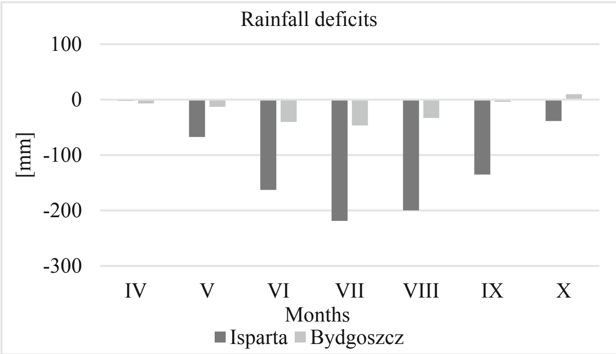

Fig. 5. Rainfall deficits during the vegetation season of the sweet cherry tree (April–October) in the Isparta and Bydgoszcz regions.

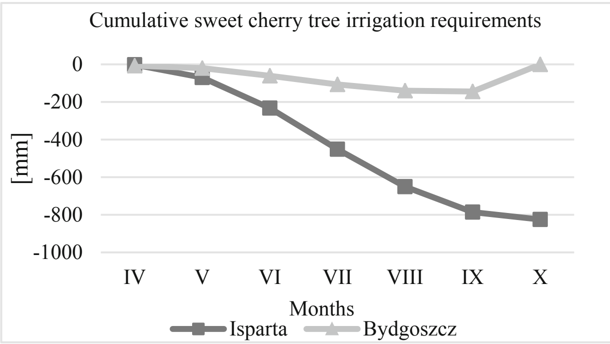

Fig. 6. Cumulative sweet cherry tree irrigation requirements during the vegetation season (April–October) in the Isparta and Bydgoszcz regions.

Higher irrigation requirements in the province of Isparta compared to the region of Bydgoszcz result mainly from the smaller amount of rainfall during the vegetation season (April–October). In the Isparta province the sum of precipitation from April to October for the years 1984–2014 was only 223.7 whereas in the region of Bydgoszcz it was much higher (351.2 mm). Differences in requirements for sweet cherry irrigation also resulted from the difference in the distribution of rainfall during the vegetation period of the examined plant in the compared regions (Table 2). In the Isparta region, higher precipitation occurred in April and May and in October in the growing season, whereas in the region of Bydgoszcz in June, July and August. As reported by Kadayifci et al. [10], in Isparta province annual average rainfall is only 520 mm 162 mm of this amount falls in months May and October. Therefore, additional irrigation is needed in this region for high yields.

Table 2. Course of precipitation (rainfall) during the vegetation season (April–October) in the Isparta and Bydgoszcz regions.

Month	Minimum		Maximum		Mediana		Mean	
	I	B	I	B	I	B	I	B
IV	12.7	0.4	153.6	77.0	50.8	21.1	56.7	26.7
V	8.5	5.0	107.4	11.5	45.7	46.4	50.1	51.7
VI	0.6	15.5	82.9	133.8	25.45	49.3	26.2	58.2
VII	0.0	7.0	88.2	146.1	10.6	71.0	19.5	71.8
VIII	0.0	12.0	45.4	210.0	8.95	56.0	13.36	64.4
IX	0.0	9.0	99.2	122.6	10.4	40.6	18.5	47.9
X	0.0	2.3	140.7	111.8	30.6	19.9	39.3	29.6
IV–X	21.8	51.2	117.4	912.8	182.5	304.3	223.7	350.2

Explanations: B – Bydgoszcz region, I – Isparta region

4 Conclusions

Sweet cherry *Prunus avium* L. tree water requirements during the vegetation season (April–October) for the research period (1984–2014) throughout were higher by 102% in the region of Isparta in comparison to the region of Bydgoszcz. Cumulative sweet cherry tree water requirements during the vegetation season (April–October) in the region of Isparta amounted to 1049 mm while in the region Bydgoszcz was 484 mm. The highest sweet cherry trees water requirements were in July and they amounted to an average of 238 mm and 118 mm. Seasonal irrigation requirements of sweet cherry tree amount to as much as 825 mm (April–October) in the region of Isparta while in the Bydgoszcz region amount to 144 mm. Higher irrigation requirements in the province of Isparta compared to the region of Bydgoszcz result not only from the smaller amount of rainfall but differences in the distribution of rainfall during the vegetation period.

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Pine Bark and Activity of Arylsulphatase and Rhodanese as Biological Quality Indicators of the Bydgoszcz Agglomeration

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Abstract. The aim of this study was to determine the pH and the concentration of calcium, potassium, magnesium, sodium sulphur, lead, nickel and cadmium in bark *Pinus sylvestris* L. and in soils, located in Bydgoszcz agglomeration, Poland. The activity of arylsulphatase and rhodanese taking part in transformation sulphur in soils were detected. Soils are contained natural content of sulphates or the soils had increased content but were not contaminated with this compound. The low content of lead, nickel and cadmium in pine bark reaction studied, there was a clear difference in contamination of both bark and soil with heavy metals. There was a correlation between the content of organic carbon and lead and nickel concentration in soils. The activity of rhodanese and arylsulphatase was not disturbed by the accumulation of sulphates or heavy metals. The analysis of the main components (PCA) showed that the content of potassium, sodium and magnesium in soils influenced the content of these elements in the pine bark.

Keywords: Biomonitoring · Bark *Pinus sylvestris* L · Enzymes in soils

1 Introduction

Emissions from cities is a result of pollution from technological processes carried out in numerous industrial plants, from heating processes in the municipal sector and fuel combustion in road transport [16]. In the urbanized area, the predominant component of the aerosol is dust particles in which the chemical profile is present, e.g. heavy metals, forms of carbon compounds, PAHs, anions and cations [14]. Bioindicative methods give a real picture of the state of the natural environment because living organisms record cumulative, toxic effects and respond to them with a defined reaction [23]. Enzymes are critical in soil biogeochemical processes [29]. Enzymatic activity of soil for an important role in soil ecosystems [4, 26], as well as polluted soils [27]. Rhodanese (EC 2.8.1.1.) splits the S-S bond of thiosulphate, forming S and sulphite,

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 225–233, 2019.
https://doi.org/10.1007/978-3-030-16542-0_29

and then S is oxidized into sulphite by sulphur oxygenase, and sulphite is oxidized into sulphate by sulphite oxidase [1]. Arylsulphatase (EC 3.1.6.1) R-O-SO_3 + H_2O → ROH + H + SO_4^{2-} [24]. Research of Kandeler et al. [13] has shown that arylsulphatase activity is sensitive to heavy metals, more acid phosphatase, urease, and invertase were less affected by them. Wainwright [28] presents that rhodanese activity was higher in polluted than in unpolluted soils. The bark of common pine (*Pinus sylvestris* L.) is a sensitive and common bioindicator [8]. Pine bark accumulates impurities in the outer peridermy seams in a passive way and through luminescence throughout the year and makes it possible to use it for research when the availability of other bioindicators is impossible due to the growing season [5]. Bark sulfur concentration depicts the relative bulk deposition [21].

The aim of the study was to determine the pH and the concentration of sulfur, calcium, magnesium, sodium, nickel, lead, cadmium, nickel and copper in the necrotic bark *Pinus sylvestris* in the Bydgoszcz agglomeration, Poland.

2 Materials and Methods

Surface soil samples (A horizon, 0–20 cm) from 5 representative soil profiles were collected in the areas of native vegetation. Soil samples were taken from selected locations in the region of agglomeration of Bydgoszcz: 1. Białe Błota (53°05′59.0″N 17°55′29.8″E), 2. Zbigniew Załuski Park at the Leśny housing estate (53°08′25.2″ N18°02′06.9″ E), 3. Chemical Plant Zachem (53°05′55.0″N 18°04′18.7″E), 4. Forest Park of Culture and Recreation in Myślęcinek (53°09′47.4″N 18°02′05.3″E), 5. Bydgoszcz Electomechanical Belma (53°07′45.6″N 17°53′59.1″E). Bydgoszcz is located in the northern part of Poland in the macroregion of the Toruń-Eberswald Pradolina within three great river valleys (Brda, Vistula and the Pradolina of Noteć-Warta). Soil samples were air-dried and sieved with 2 mm sieve. Basic soil properties were assayed in air-dry soils: pH potentiometrically in H_2O, organic carbon (C_{org}) using the Primas analyzer from Skalar, total sulfur (TS) and S-SO_4^{2-} were determined according to Bardsley-Lancaster [2], arylsulphatase activity (AR) [EC 3.1.6.1] [9], rhodanese activity (RD) [EC 2.8.1.1] by Tabatabai and Singh [25].

From the places from which the soil was taken, also necrotic bark from three trees with a diameter of 50 to 55 cm, spaced about 2 to 4 m apart, was obtained. The bark was obtained from the trunk at a height of 1.5 m from the ground, four samples from every tree. The determination of bark toxicity was carried out by assessing its pH (pH value) and then the content of lead, cadmium, copper and zinc was determined. In order to determine the pH value, the bark samples were dried at 65 °C for 3 h, the pH was measured using a pH meter. In the soil and plant material, the total content of K, Na, Ca, Mg, Pb, Cd was determined by atomic absorption spectrometry (ASA) using a PHILIPS PU 9100X spectrometer.

A principal component analysis (PCA) was performed to select the (group of) soil attributes. PCA is a technique that indicates the connection, and grouping them with major similarity [19].

3 Results and Discussion

The analysis of the collected samples confirmed the acid reaction (pH in H_2O 3.99–4.87) of all the studied soils. The acidity of tree bark is considered a very sensitive indicator of environmental pollution [3]. The average value of pine bark taken from trees was within the limits of 3.15 to 4.10. These results were similar to the average physiological acidity of *Pinus sylvestris* L. bark of 3.30. Chrzan [7, 8] achieved slightly lower results. The organic carbon content in the soils ranged from 3.100 mg kg^{-1} (station 3) to 81.9 mg kg^{-1} (station 5). The high C_{org} content was most likely the effect of the inflow to the soil environment of fresh organic matter. The soil Bydgoszcz agglomeration showed arylsulphatase activity in the range 0.04 mM pNP g^{-1} h^{-1} to 0.158 mM pNP g^{-1} h^{-1} (Table 1). The highest activity of this hydrolase was observed in the soils located on the forest Białe Błota. The activity of rhodanese detected in all the samples of soils was very diverse and depended on the sampling locations (Table 1). The highest activity of rhodanese was determined in the soil from the park at Osiedle Leśne (0.787 μM SCN^{-} g^{-1} h^{-1}) and it was 64-fold higher than rhodanese from the soil from the forest in Białe Błota (0.018 μM SCN^{-} g^{-1} h^{-1}). Enzymatic activities can reflect the biological state in the soil [9]. Wainwright [28] shows that rhodanese activity was higher in polluted than in unpolluted soils. The results indicate that microbial S-oxidation occurs in soils exposed to heavy atmospheric pollution.

Sulphur is essential to plant metabolic processes as a component of different organic compounds, for example, glutathione, methionine, cysteine, cystine, biotin, lipoic acids, thiols, sulphoquinovose. On the other hand, an excessive concentration of SO_2 and SO_4^{2-} in the air leads to degradation and to the development of chlorosis and necrosis. The total sulfur content in the soil was 20.44 mg kg^{-1} and according to the limit sulfur content in the surface layer of light soils [18], stand 1 contained natural content of sulphates while the other soils had increased content but were not contaminated with this compound. The concentration of the Bydgoszcz agglomeration was ranged from 4.083 mg kg^{-1} (position 5) to 8.341 mg kg^{-1} (position 3). The density was lower than the sulfur in Finland [21] where the concentration was 0.174 g kg^{-1} is 0.728 g kg^{-1}. The high sulfur content results explain the total emission of SO_2 from sources in the Kola Penisula, which was estimated about 600,000 tonnes per year, the bridge of which was derived from the smelters [21]. Soil deposition from atmospheric sulfur pollution [17] has been reduced by more than 85% in the last three decades [22]. Therefore the concentrations of sulfur from *Pinus sylvestris* L. from the Bydgoszcz agglomeration was low.

The abundance of sand rocks in the nutrients of plants is not the same and depends on the parent rock, mineral composition and the weathering process. The optimum ratio of macroelements in soils varies within wide limits [15]. The analysis of macronutrients (S, K, Ca, Mg, Na) showed variation between the studied soils. The highest content of these macronutrients was found in soils collected from the soil from forest in Białe Błota (0.343 mg S kg^{-1}, 10.10 mg K kg^{-1}, 5.800 mg Ca kg^{-1}, 1.600 mg Mg kg^{-1}, 2,300 mg Na kg^{-1} The density of these bioelements was also the highest in the pine bark also taken from the forest from Białe Błota (8.341 mg S kg^{-1}, 464.0 mg K kg^{-1}, 11.90 mg Ca kg^{-1}, 183.0 mg Mg kg^{-1}, 484.0 mg Na kg^{-1} (Table 2). The lowest contents of S, K, Ca and Pb were determined in soils located on the forest at Belma (0.171 mg S kg^{-1}, 4,800 mg K kg^{-1}, 0.500 mg Ca kg^{-1}, 5.420 mg Pb kg^{-1}). In the pine bark from this place, the lowest contents were also 277.0 mg K g^{-1}, 5.200 mg Ca kg^{-1}, 103.0 mg Mg kg^{-1}, 217.0 mg Na kg^{-1}, 0.612 mg Pb kg^{-1}.

Table 1. Physical and biochemical and chemical attributes of soil samples from Bydgoszcz agglomeration.

Parameters	Site						
	1	2	3	4	5	Mean	SD
pH	3.990	4.580	4.390	4.870	4.490	4.464	0.320
TOC g kg^{-1}	18.60	47.70	3.100	7.000	81.90	31.66	33.08
RD µM SCN^{-} $g^{-1}h^{-1}$	0.064	0.787	0.018	0.232	0.379	0.296	0.309
ARL mM pNP $g^{-1}h^{-1}$	0.158	0.128	0.024	0.029	0.212	0.110	0.082
S-SO_4^{2-} g kg^{-1}	14.76	21.94	21.75	21.08	22.69	20.44	3.227
TS mg kg^{-1}	0.340	0.337	0.343	0.171	0.201	0.278	0.085
K g kg^{-1}	6.700	5.900	10.10	4.800	9.200	8.060	1.740
Ca g kg^{-1}	0.800	1.100	5.800	0.500	1.000	1.840	2.230
Mg g kg^{-1}	0.900	1.100	1.600	1.200	1.300	1.220	0.260
Na g kg^{-1}	1.200	1.500	2.300	2.100	1.800	1.780	0.440
Pb mg kg^{-1}	14.20	31.00	7.750	5.420	32.20	18.10	12.74
Ni mg kg^{-1}	8.300	16.40	8.240	9.600	17.20	11.95	4.471
Cd mg kg^{-1}	<0.2	<0.2	<0.2	<0.2	<0.2	–	–

Site: 1. Białe Błota, 2. Park Z. on the Osiedle Leśne, 3. Chemical Plant ZACHEM, 4. Forest Park of Culture and Recreation in Myślęcinek, 5. Bydgoszcz Electromechanical Plant BELMA
SD-standard deviation

According to Kabata-Pendias [11], the limit values for lead content in surface soil levels are from 30 to 70 mg kg^{-1}. In the studied soils, these were contents below this background except for the soil taken from the park at Osiedle Leśne where it was 31.00 mg kg^{-1}. The studied soils do not exceed the limit metal content for soils containing anthropogenic contaminants determined by Kabata-Pendias [11]. The content of the bark was bigger than the soil in which the trees studied were growing (Tables 1 and 2). The results are in line with the results obtained by Chrzan [8].

Municipal pollution, metallurgy of iron and steel, fuel in the main source of Cd in the air. It is used for the production of plastics, dyes, glass, accumulators and anti-corrosive protection [11, 12]. Wet and dry development containing a rich source of the element which is supplied to the soil [5]. The element presents a high mobility in a soil environment. National regulations [10], for industrial sites: <15, for agricultural land: <5 [20]. The content of Cd in investigated soils was low (<0.2 mg kg^{-1} s.m.).

Table 2. Physical and chemical attributes of pine bark from Bydgoszcz agglomeration.

Parameters	Site						
	1	2	3	4	5	Mean	SD
pH	3.800	3.600	3.150	4.100	3.700	3.667	0.350
TS g kg^{-1}	5.720	5.395	8.341	7.524	4.083	6.213	1.710
K mg kg^{-1}	310.0	308.0	464.0	277.0	307.0	333.2	74.38
Ca g kg^{-1}	5.500	6.600	11.90	5.200	9.100	7.660	2.824
Mg mg kg^{-1}	129.0	142.0	183.0	103.0	157.0	142.8	29.97
Na mg kg^{-1}	267.0	353.0	484.0	217.0	359.0	336.0	102.0
Pb mg kg^{-1}	1.200	2.400	0.810	0.612	2.732	1.540	0.953
Ni mg kg^{-1}	<0.2	<0.2	<0.2	<0.2	<0.2	–	–
Cd mg kg^{-1}	<0.2	<0.2	<0.2	<0.2	<0.2	–	–

Site: 1. Białe Błota, 2. Park Z. on the Osiedle Leśne, 3. Chemical Plant ZACHEM, 4. Forest Park of Culture and Recreation in Myślęcinek, 5. Bydgoszcz Electromechanical Plant BELMA
SD-standard deviation

In order to determine the similarities between the 5 sites of soil extraction and bark from the pines, the grouping method was applied. It was based on pH, TS, Mg, Ca, Na, Ni, Pb and Cd. The results of a cluster analysis (CA) is illustrated with the dendrogram in Fig. 1A and B. The grouping procedure allowed to distinguish two clusters focusing soils with similar properties (soil from Białe Błota, Myślęcinek, and around Zachem and one cluster with similar properties (soil from Forest and around Belma), whereas in the case of bark, two clusters that cluster the bark with similar properties (soil from Białe Błota, Mielęcinek, and Osiedle Leśne and around Belma and Ouliner (around Zachem).

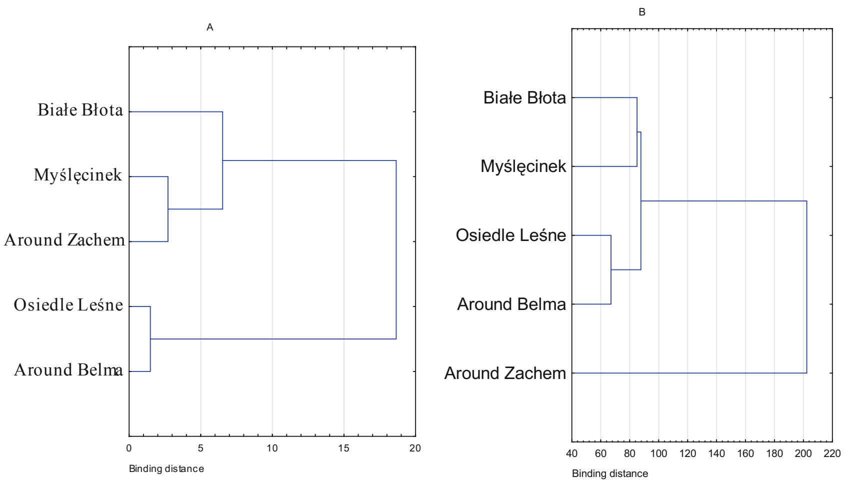

Fig. 1. Dendrogram differentiation position content of TS, Ca, K, Mg, Na and Pb, Ni, Cd A - in soils, B - in pine bark.

Inter-relation between measured soil properties are provided in Table 3. Organic C is positively and significantly correlated with Ni ($r = 0.924$, $p < 0.05$) and with Pb (0.934 at 0.05% level of significance). The correlation between TOC and Pb correlation that was also reported by other authors and explained in terms of binding power of soil organic matter [6, 12]. Also, Pb shows the positive correlation with Ni (0.939 at 0.05% level of significance). It was significantly correlated between Mg and Na (0.896 at 0.05% level of significance). In our research we do not received a significant correlation between enzymes activities and metal content in soil agglomeration of Bydgoszcz. Generally, earlier studies showed that an increase of metal pollution in a soil induces a significant decrease of enzyme activities that was confirmed by the negative correlations between metal content and soil enzymes [13, 29]. In the pine bark, negative correlations were found between metal content and another parameters: between the bark pH value and the Ca content ($r = -0.879$, $p < 0.05$), K ($r = -0.975$, $p < 0.05$), Mg ($r = -0.48$, $p < 0.05$) and Na were obtained($r = -0.975$, $p < 0.05$). There was also a negative relationship between TS and Pb ($r = -0.892$, $p < 0.05$) as well as positive between the content of Ca and Mg ($r = 0.944$, $p < 0.05$) and Na ($r = 0.977$, $p < 0.05$). However, Chrzan [8] did not find, on the basis of a static analysis, a significant relationship between the Pb, Zn, Cu, Ni concentration in the soil and in the bark at any of the researched sites.

Table 3. Correlation coefficient (R) and linear regression models for selected properties of soils of Bydgoszcz agglomeration.

Variables		Regression equation	R	R^2
Dependent	Independent			
Soil				
Mg	Na	$y = -0.0096 + 1.5373x$	0.896	0.802
Ni	Pb	$y = -13.87 + 2.6765x$	0.939	0.881
Ni	TOC	$Y = -50.02 + 6.8362x$	0.924	0.853
Pb	TOC	$y = -12{,}28 + 2.4269x$	0.934	0.872
Pine bark				
Pb	TS	$y = 8.6775 - 1.601x$	−0.892	0.795
Mg	Ca	$y = -5.037 + 0.00889x$	0.944	0.891
Na	Ca	$y = -1.089 + 0.02604x$	0.977	0.954
pH	Ca	$y = 33.704 - 7.100x$	−0.879	0.772
pH	K	$y = 1050 - 195.6x$	−0.975	0.950
pH	Mg	$y = 441.15 - 81.34x$	−0.948	0.898
pH	Na	$y = 1380.4 - 284.7x$	−0.975	0.950

The PCA has been investigated in order to understand most important variables for the variability in the investigated soils. PC1 and PC2 explained 46.6% and 25.9% of the total variability (Fig. 2). On the side of the axis of factor 1 (constituent 1, PC1), it is strongly associated with bark pH ($r = 0.952$), TS in bark content ($r = 0.923$,) with Pb in soil content ($r = -0.820$), Pb in bark ($r = -0.798$) organic carbon ($r = 0.769$),

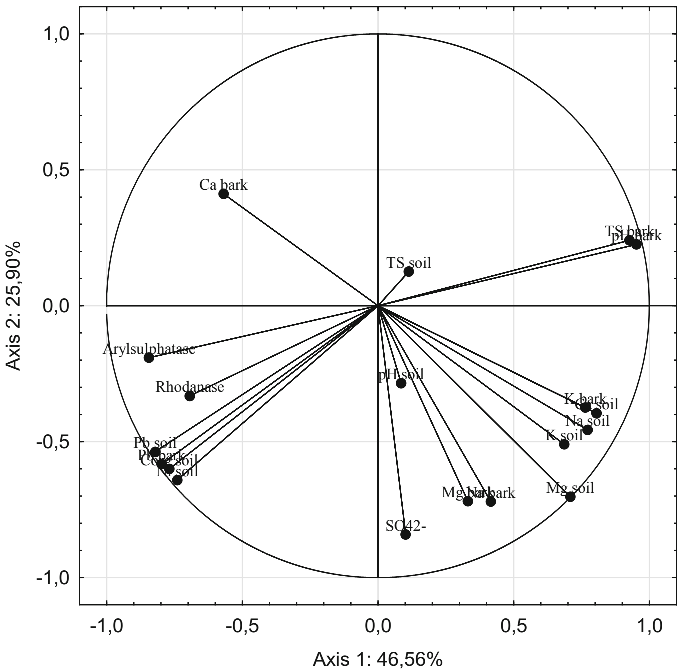

Fig. 2. Configuration of variables in the system of the first two axes of principal components.

content in the soil of calcium (r = 0.805), potassium (r = 0.686), magnesium (r = 0.708), Na (r = 0.772), and arylsulphatase activity (r = −0.844) and rhodanese (r = −0.693), firmness in the bark K (r = 0.764).

The value of the second constituent (PC2), which explains the effect, is negatively affected by the sulphate content in the soil (r = −0.842) and the content in the bark of Mg (r = −0.719) and Na (r = −0.720). The PCA cluster showed that concentration on Ca, Na, K, and Mg in soils had a great influence on the variation of Na, K and Mg in bark in *Pinus silvestris* L. and Pb in bark and between C_{org} and the enzyme's activity evidencing a strong geochemical affinity.

4 Conclusion

The low concentration of heavy metals of lead, nickel and cadmium in the surface layer of the Bydgoszcz agglomeration soils classify them into the category of soils with natural content. In the pine necrosis bark, the accumulation of lead and nickel and cadmium was lower than in soil. Soils taken from the forest in Białe Błota contained natural content of sulphates, while the remaining soils had increased content but were not contaminated with this compound. The activity of rhodanese and arylsulphatase was not disturbed by the accumulation of sulphates or heavy metals. The analysis of the main components PCA analysis showed an effect on their C_{org} activity and lead content, which can be used in the bioindication of soil contamination with this heavy metal. The analysis of the main components (PCA) showed that the content of potassium, sodium and magnesium in soils influenced the content of these elements in the pine bark. The accumulation of compounds from the air in the outer pine decks takes place on the surface. The passive nature of accumulation of pollutants in pine bark leads to the less content accumulation of compounds than in soil where the distribution of bioelements like sulphur, calcium, potassium and magnesium depends on geochemical and biogeochemical processes.

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Water Needs of Black Locust *Robinia pseudoacacia* L. in the First Three Years of Growing in the Reclamation Plantings in Poland

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Abstract. Black locust, considered an ornamental plant, is often used in the soil reclamation process, because it enriches the soil with nitrogen. High seedling survival rate in the first stage of reclamation depends mainly on sufficient water conditions controlled by irrigation, which in turn requires determining the plant's water needs. The aim of the research was the estimation of black locust water needs during the first three years of growing. Potential evapotranspiration, as the measure of the plant water needs, was calculated in the study. The formula of Blaney-Criddle, modified by Żakowicz for Polish conditions, by using the adjusted crop coefficients, was applied. The calculations were carried out for the growing period (April–October) during the thirty years period (1981–2010), for five agro-climatic regions of Poland. The results

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 234–242, 2019.
https://doi.org/10.1007/978-3-030-16542-0_30

presented a rising tendency in the black locust water needs for all tested 30 years and in each considered region. The water needs during the growing season increased in each ten years period of the analyzed 30 years by 9.8 mm in the central-eastern and south-eastern regions, by 9.4 mm in the south-west region, by 8.3 mm in the north-east region and by 5.8 mm in the north-west region.

Keywords: *Robinia pseudoacacia* L. · Water needs · Polish conditions

1 Introduction

As an early succession and nitrogen-fixing plant, black locust *Robinia pseudoacacia* L. grows rapidly as a pioneer tree under a wide range of site condition and it is considered as a drought tolerant tree species [12, 22, 23]. In the Central Europe black locust has proven to be relatively drought tolerant in comparison to other temperate deciduous tree species. In the State of Brandenburg (Germany) for instance, with a continental climate and annual precipitation below 600 mm, the species has been successfully cropped for wood production for more than 250 years. The tree notably grows also in post-mining reclaimed areas where soil water availability is limited and drought can occur both in spring and summer [13]. Black locust requires well-drained soils with adequate moisture until the associated nitrogen-fixing Rhizobium bacteria are able to thrive [18]. Black locust is a valuable honey and ornamental plant [16]. It has been successfully used in the reclamation plantings [1, 2, 17, 26]. High seedling survival rate of the plantings is the basic strategy of the first stage of reclamation. The effective introduction of the plants on the reclamation area requires, on the one hand, the selection of appropriate species and high quality of the seedlings [4], on the other hand, ensuring sufficient water condition by irrigation treatments [25]. Although, the mature plants of black locust can adapt to the drought conditions, young seedlings (younger than 3 years old) require optimal water conditions, which are ensured by the irrigation that supplement periodic precipitation deficiencies [13–15, 25].

The aim of the present research was an attempt to estimate the water needs of *Robinia pseudoacacia* L. in the first three years after planting. Particularly, the black locust water requirements were analyzed during the period of the highest water needs that, usually, starts at the beginning of June (full development of the leaves) and lasts to the end of August.

2 Materials and Methods

The study assumes that the water needs of black locust *Robinia pseudoacacia* L. are equal to the crop potential evapotranspiration (ETp) under the conditions of sufficient soil water supply. The black locust water needs were determined using the plant coefficient method as the ratio of the reference evapotranspiration (ETo) and the plant coefficient (k). The water deficiencies were determined as the difference between the potential evapotranspiration totals (ETp) and the atmospheric precipitation totals (P). The reference evapotranspiration was calculated using the formula of Blaney-Criddle, modified by Żakowicz [25] for Polish conditions. The crop coefficients for black locust in the first three years after reclamation, adapted to the reference evapotranspiration, also were estimated using Żakowicz's method. The values of crop coefficients (k) ranged from 0.70 in April to 0.95 in October.

The water needs of black locust during the growing season (April–October) in the years 1981–2010 were determined for five agro-climatic regions of Poland [10], including following regions: north-east (N-E), central-north-west (C-N-W), central-east (C-E), south-west (S-W) and south-east (S-E) with the representative meteorological stations located in Olsztyn, Bydgoszcz, Warsaw, Wrocław and Kraków, respectively, (Fig. 1).

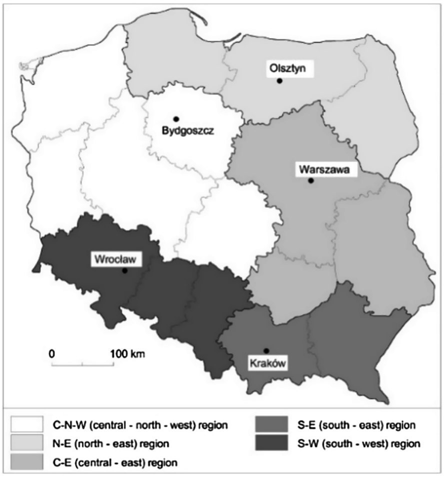

Fig. 1. Agro-climatic regions of Poland with the representative meteorological stations (according to [17]).

3 Results and Discussion

In every of the considered regions during the studied thirty years period (1981–2010), a significant upward trend of black locust water needs during the growing season (April–October) was noted (Table 1). The weakest relationship (r) (significant at p = 90%) occurred in the C-N-W region, while in the other regions this correlation was stronger (significant at p = 99%). In each of ten years period of the studied thirty years, the black locust water needs between April 1 and October 31 increased by 5.8 mm in the C-N-W region, by 8.3 mm in the N-E region, by 9.4 mm in the S-W region and by 9.8 mm in the C-E and S-E regions.

In the years 1981–2010, in all studied regions, a tendency to increase the black locust water needs in the period of high water requirements, was observed (Fig. 2). On average, in Poland during the considered thirty years, the black locust water needs in the month June–August increased in each ten years period by 7.1 mm. Moreover, with

Table 1. Equations of the trend for black locust water needs in the growing season (April–October) in the years 1981–2010. Explanations: ***significance for $\alpha = 0.01$ (p = 99%); *significance for $\alpha = 0.1$ (p = 90%).

Region of Poland	Trend equation	r	Tendency of water needs (mm per decade^{-1})
N-E	y = 0.833x + 518	0.477***	8.3
C-N-W	y = 0.584x + 557	0.324*	5.8
C-E	y = 0.979x + 552	0.537***	9.8
S-W	y = 0.941x + 534	0.521***	9.4
S-E	y = 0.985x + 519	0.552***	9.8

the exception of the C-N-W region, the temporal variability of black locust water needs was significant in the other four studied regions of Poland. In each ten years period of the considered thirty years, the water needs of black locust, in the time from June 1 to August 31, increased in the range from 4.7 mm in the C-N-W region to 8.1 mm in S-E region. In the N-E, C-E and S-W regions this raise slightly exceeded 7 mm.

The average potential evapotranspiration (ETp) of black locust in Poland during the years 1981–2010 in the period of high water requirements (June–August) was 329 mm (Fig. 3). The largest water needs occurred in the C-N-W (341 mm) and C-E (340 mm) regions. While, the lowest water needs were observed in the N-E (324 mm) and S-E (316 mm) regions. The average precipitation deficiencies for black locust in Poland in the period of high water requirements (June–August) amounted to 112 mm. The highest rainfall deficits in the period June–August in the years 1981–2010 occurred in the C-N-W (152 mm) and C-E (129 mm) regions, lower in the N-E (108 mm) and S-W (109 mm) regions and the lowest in the S-E region (64 mm).

The relations between precipitation totals and precipitation deficiencies (or excess) in the period of June–August are presented in Fig. 4. In the N-E region, as well as on average in Poland, rainfall deficits were noted in each year of the considered long-term. In the S-E region, precipitation deficiencies occurred in 25 years, in the S-W region in 27 years, in the C-E region in 28 years and in the C-N-W in 29 of the studied years.

The greatest water needs of black locust in the first three years after reclamation were observed in the central regions (C-N-W and C-E), what was consistent with the results published by [20, 21, 26]. In the present study, during the thirty years period, a tendency to increase the black locust water needs in the growing season was observed in all regions of Poland. Previously, similar trend was reported also by [11]. The climate changes predicted for the near future, will increase the water requirements of plants, including also the plants grown as the reclamation plantings. Therefore, there is a necessity to undertake some adaptation activities, such as irrigation treatments, the importance of which will grow with the intensification of unfavorable climate changes [3, 6–9, 11].

The results obtained in the present study should be helpful in the arrangement and programming of black locust irrigation system [15, 24, 25]. The irrigation is one of the most important melioration treatments that provide the correct development of tree and shrub seedlings in the plantings and cultivations carried out, among others, in the forest

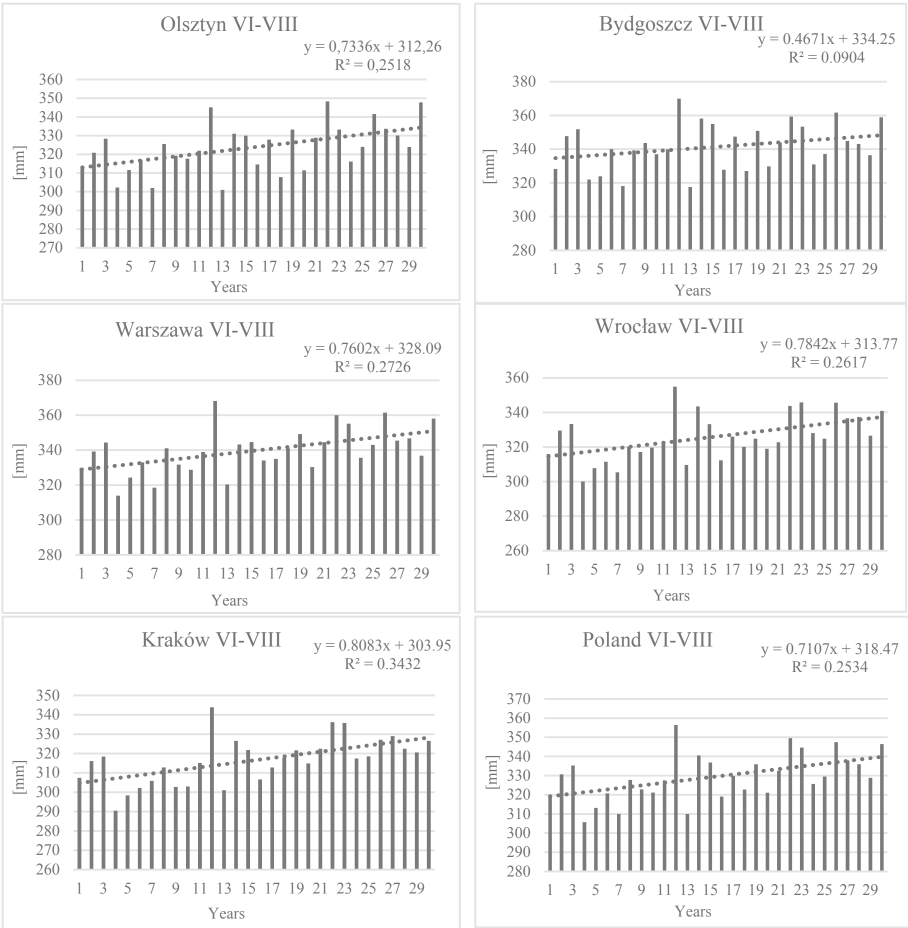

Fig. 2. Temporal variability of black locust water needs (ETp) in the period June–August in the different regions of Poland (meteorological stations representative for the regions).

nurseries [19]. The results of many field experiments performed in the region of Bydgoszcz presented a positive effect of irrigation applied together with other melioration treatments (revitalization), on the seedlings growth of trees species, such as: European larch [5], little leaf linden [4].

The usefulness of micro-irrigation for the black locust grown in the nest arrangement of reclamation plantings has been confirmed in the field experiments carried out in the central Poland, where the irrigation using the water of diverse quality (discharge water from sewage treatment plant, rainwater) positively influenced the tree height, the size of trunk and crown surface of the black locust plants [24, 25]. In the experiment carried out in Brandenburg University of Technology two years old black locust trees were irrigated by an automatic drip irrigation system [13, 14, 18].

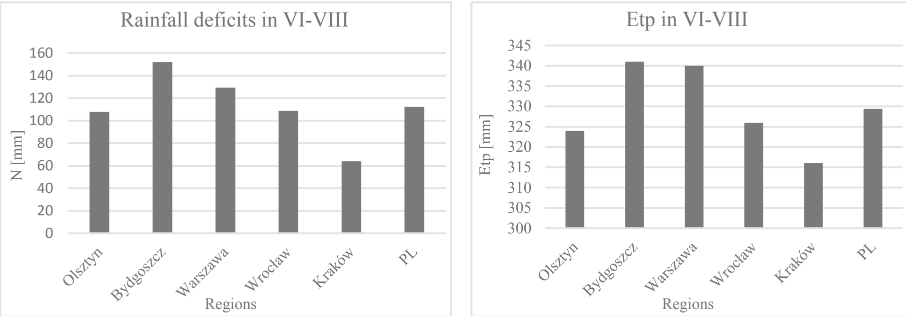

Fig. 3. Long-term (1981–2010) average water needs (ETp) and rainfall deficits (N) of black locust in the period June–August in the different regions of Poland.

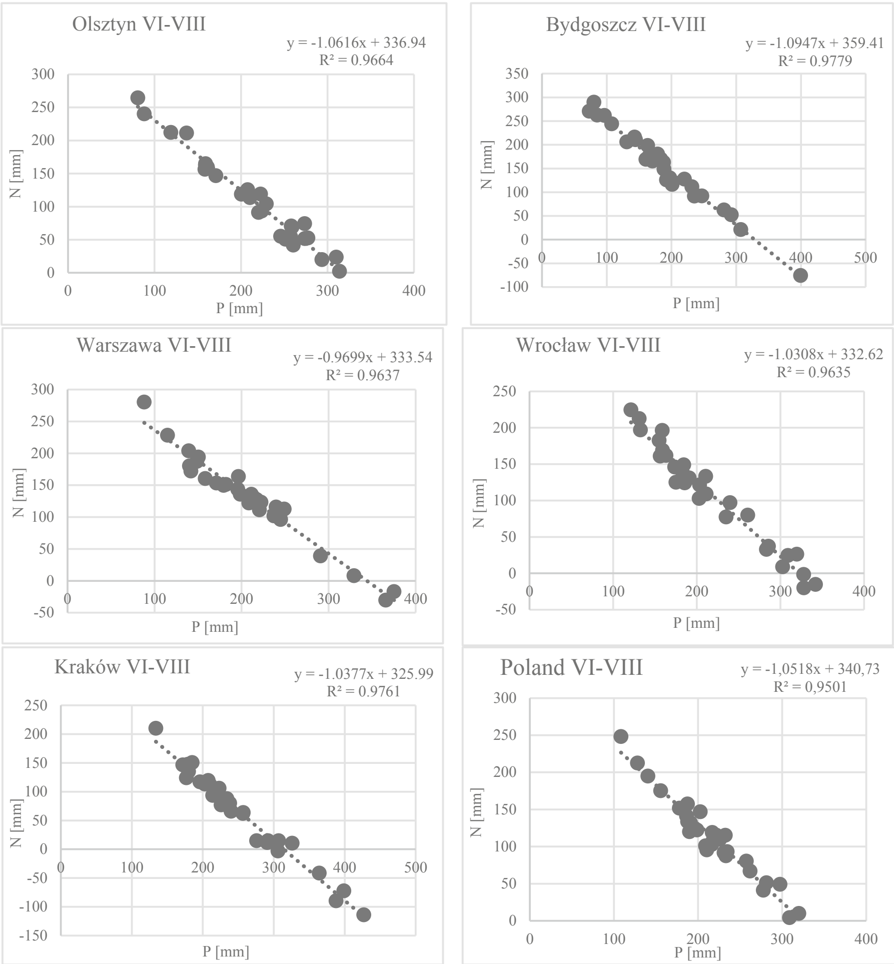

Fig. 4. Relationship between precipitation totals (P) and rainfall deficits (N) for black locust in the period June–August in the different regions of Poland.

4 Conclusions

1. In Poland, the water needs of black locust in the first three years after plantings estimated for the period of the largest water requirements (June–August) for the years 1981–2010, was on average 329 mm. The highest water needs, in the period of June-August were observed in the C-N-W (341 mm) and C-E (340 mm) regions. The lowest water needs were noted in the S-E (316 mm) and N-E (324 mm) regions.
2. In each ten years period of the studied thirty years, a tendency to increasing the water needs in the months June–August ranged from 4.7 mm in the C-N-W region to 8.1 mm in the S-E region.
3. In Poland, the average long-term rainfall deficits for black locust in the period of June–August amounted to 112 mm. The highest precipitation deficits in this time occurred in the C-N-W (152 mm) and C-E (129 mm) regions, lower in the N-E (108 mm) and S-W (109 mm) regions and the lowest in the S-E region (64 mm).
4. In the N-E region, as well on average in Poland, the rainfall deficits for black locust in the period of June–August occurred in each of the considered thirty years. In the S-E region precipitation deficiencies occurred in 25 years (83% of the studied years), in the S-W region in 27 years (90% of the studied years), in the S-W region in 28 years (93% of the studied years), and in the C-N-W region in 29 years (97% of the studied years).

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Content of Heavy Metals in Fodder from Sward of Grasses and Legumes from Selected Organic Farms in Poland as a Criterion of Fodder Quality

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Abstract. Limited fertilization, often forced by conducting an organic farming production, may lead to deficiency of some elements in soil. This may translate into a decrease in the quantity and quality of crop yields. The aim of the research was to assess the quality of sward from organic farms in the context of using the sward for feed purposes. 55 organic farms were analyzed (25 additionally conduct conventional animal production). Samples of mixed grasses and small-seed legumes were collected from each farm. After mineralization, content of heavy metals was determined in the plant material by ICP-OES method. The content of zinc in the samples was generally too low, also the copper content in some of the samples was too low for using the biomass for feed purposes. A very high content of iron and manganese was observed in almost all of the samples. Mean iron content in the samples was approximately 8 times higher, and manganese – approximately 3 times higher than the optimum content in fodder. A high content of Cd, Pb, Cr and Ni was not observed. The sward from the animal production farms had a lower mean content of zinc and lead than the sward from the farms without animals; the differences in the content of other analyzed elements were not statistically significant. Feeding animals exclusively with roughage obtained from the studied farms could pose a risk to the animal health and decrease animal productivity.

Keywords: Sward · Organic farming · Heavy metals · Iron · Manganese

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 243–251, 2019.
https://doi.org/10.1007/978-3-030-16542-0_31

1 Introduction

Chemical composition of fodder influences the state of health of animals and their productivity (including reproductivity, but also production of milk and other products) [1, 3, 14, 23]. Physiological functions of micronutrients often results from their role as a part of enzymes. Zinc activates enzymes that, among other things, take part in bone formation, immune defense, and synthesis of nucleic acids [16, based on different sources]. This element is also important for maintaining proper structures of proteins by forming zinc finger structures. Zinc also regulates expression of genes [28]. Manganese is important for antioxidation processes and synthesis of connective tissue [29, based on different sources]. Iron plays a role in oxygen transport by building heme proteins, it also builds redox system enzymes. Iron is not toxic to animals, but its deficiency leads to anaemia. Copper plays a role in cellular respiration, formation of bones and nervous system, melanin production, superoxide detoxification [29, based on different sources]. It also mobilizes iron stores. Chromium takes part in metabolism of carbohydrates and lipids [29, based on different sources]. Nickel affects functions of some hormones, the redox system and the immune system [30].

To assess the quality of fodder, it is also important to discuss the content of elements that are not crucial for organism growth and development, but which are toxic or even lethal in high doses. Cadmium has genotoxic and carcinogenic effects [1] – these effects also apply to other heavy metals; they may also act embryotoxically and teratogenically. The negative effect of cadmium exposure results among other things from the fact that it mimics essential elements, namely calcium, zinc and iron [24]. Lead is another toxic heavy metal. Unlike cadmium, lead is very dangerous for cattle, especially young ones (they are very susceptible to this metal). Waldner et al. [38] informed about frequent cattle lead poisoning. Other authors also pointed out that, among food-producing animals, lead poisoning occurs most often with respect to cattle [37]. Lead affects the central nervous system, the digestive system and the hematological system [37]. Exposure to lead can also reduce fertility in males [23]. It also interferes with metabolism of calcium and vitamin D [37]. Similarly to cadmium, the negative effect of lead partially results from its ability to mimic calcium.

Chemical composition of plants depends on their biological properties, weather conditions, and on soil properties: soil type, pH value, moisture, organic matter content, content of total and available forms of macro- and micronutrients [10, 13]. Of course, the lack of microelements in soil translates into the lack of them in grass forage [19]. Relations between elements in soil (and later in fodder) are also important – excessive fertilization with one element may block the uptake of the others [32]. High iron content can cause problems with manganese and zinc absorption. Copper and calcium are other antagonists to zinc [2]. Copper absorption can be also decreased by the presence of other elements – the most important interactions are: Cu-S-Mo, Cu-S, Cu-Fe and Cu-Mn [15, 32, 35].

Organic farming covers about 1% of the world's agricultural area [31]. It may seem little, but in point of fact organic farming belongs to the fastest growing sectors of agriculture. In 2016, the area under organic farming in European Union (28 countries) was 6.69% [7]. This area increases with time – in 2012 it was 5.62%. Countries with the largest area under organic farming include: Spain, Italy, France, Sweden, the United Kingdom, the Czech Republic and Poland [7]. Proper nutrient management is pointed out as one of the main challenges of organic farming [20, 35, 41]. In organic farming, it is forbidden to use fertilizers produced with synthetic ingredients. Natural fertilizers (of plant, animal or mineral origin) are allowed for use, they include: compost, manure, mulch, seaweed [26, 31, 33]. It is also possible to use leguminous plants (the so-called "green manure"). The ways of supplementation of nutrient deficiencies in soils are strongly limited. The number of fertilizers approved for use in organic farming is limited. Because of that, maintaining nutrient balance is very difficult [36, 41]. This may lead to improper chemical composition of the cultivated plants. However, Gomiero [11, 12] points out that there may be no statistical differences in chemical composition between organic and conventional production.

The aim of the research was to assess the quality of sward from selected organic farms (55 organic farms were selected for the research; 25 of those farms additionally had conventional animal production) in the context of using it for feed purposes. The content of selected heavy metals (micronutrients and potentially toxic elements: Zn, Mn, Fe, Cu, Cd, Pb, Cr, Ni) was determined in the plant material.

2 Materials and Methods

The research was conducted in 2016, in 55 organic farms. All the farms had been subjected to a system of control and certification of the certification body, and based on the inspections performed in 2015 they met the requirements of EC Regulation No. 834/2007 of 28 June 2007 on organic production and labelling of organic products [3]. All the farms had been converted. The studied farms were located in Dolnośląskie (17), Lubuskie (13), and Warmińsko-Mazurskie (25) provinces. Among the studied farms, 25 had conventional livestock production. All farms with animal production were located in Warmińsko-Mazurskie province. The area of the studied farms ranged from 30 to 90 ha.

A sample of sward from the first crop was collected from each farm, from a randomly selected field. On all fields from which the samples were collected, a perennial mix of grasses and small-seed legumes was grown, with different share of legumes. The share of legumes resulted from changes in species composition of the sward which were caused by habitat and climatic conditions. The collected samples of sward were dried, homogenized and mineralized in an open system in a muffle furnace at 450 °C. Then they were diluted in nitric acid solution. The analytical sample was 3 g dry matter. Concentration of heavy metals (Zn, Mn, Fe, Cu, Cd, Pb, Cr and Ni) in the obtained solutions was determined by ICP-AES method (inductively coupled plasma-atomic emission spectrometry) on an Optima 7600 spectrometer manufactured by PerkinElmer. Wavelengths that were used to determine the concentration of the studied elements as well as detection limits and content of the analyzed elements in the reference material are presented in Table 1.

Table 1. Parameters of the ICP-AES analysis as well as the content of heavy metals in the reference material.

Heavy metal	Wavelength	Detection limit	Declared content in reference material	Measured content in reference material	Recovery
	nm	mg dm^{-3}	mg kg^{-1}	mg kg^{-1}	%
Zn	206.200	0.0059	24	24.62	102.6
Mn	257.608	0.0014	47	48.56	103.3
Fe	238.204	0.0046	185	201.2	108.8
Cu	327.393	0.0097	9.4	9.125	97.1
Cd	228.802	0.0027	0.03	0.033	108.3
Pb	220.353	0.042	1.6	1.725	107.8
Cr	267.707	0.0071	6.5	6.412	98.6
Ni	231.604	0.015	4	3.856	96.4

Results of the chemical analysis were subjected to a statistical analysis. A univariate analysis of variance was performed; type of production was the factor in the analysis (plant production or plant and animal production). Significance of variance in the mean values was determined using Duncan's test, at the significance level of $\alpha \leq 0.05$. Statistica 12 [StatSoft, Inc.] was used for statistical elaboration of the results. For more accurate analysis of the results, the mean content of the analyzed elements was completed with minimum, maximum and median values.

3 Result and Discussion

Assessment of fodder quality involves determination of the content of micronutrients and potentially toxic elements. The optimum amount of zinc in grassland fodder ranges from 50 to 100 mg Zn kg^{-1} [32]. According to Falkowski et al. [8, 9], fodder should contain 30–50 mg Zn kg^{-1}. The sward from farms with animal production had statistically significantly lower (by 40%) mean content of zinc than the sward from farms with exclusively plant production, where it amounted to 34.38 mg Zn kg^{-1} (Table 2). Zinc content in all of the samples from the sward from farms with animal production was too low to use it for feed purposes; zinc content in most of the samples from farms without animal production was also improper. Enjalbert et al. [6], after conducting a study on cattle, linked zinc deficiency with low milk production, problems with locomotion, diarrhoea and poor growth. Parakeratosis (a skin disease) is another possible result of zinc deficiency [16].

The optimum manganese content in grassland fodder should be between 40 and 70 mg Mn kg^{-1}. According to Falkowski et al. [8, 9], fodder should contain 50–100 mg Mn kg^{-1} (the content in meadow sward for cattle should be 50 mg Mn kg^{-1}). More than 1000 mg Mn kg^{-1} is a toxic content in forages [19, 34]. The mean manganese content in biomass of the studied sward collected from farms with animal breeding and in those without animal production was 159.8 and 145.1 mg Mn kg^{-1}, respectively, and was not statistically varied (Table 2). The mean manganese content in the samples was approximately 3 times higher than the optimum content in fodder. Higher than optimum content of manganese in the studied biomass was recorded in almost all cases. A large excess of manganese is neurotoxic and leads to brain disorder [37]. However, as stated by Jenkins and Hidiroglou [18] in their research on preruminant calves, concentration of manganese even several times higher than recommended may not have a disadvantageous effect (at the same time, manganese content in some tissues may occur). The researchers did not exclude a toxic effect of prolonged exposure to manganese excess.

Table 2. Statistical parameters of the content of selected heavy metals in sward.

Heavy metal	Farms without animal production				Farms with animal production			
	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
	mg kg^{-1}							
Zn	17.48	62.99	34.38 a*	32.01	14.05	26.83	20.59 b	20.13
Mn	60.54	326.8	145.1 a	132.3	54.30	294.6	159.8 a	175.4
Fe	142.1	1937	831.3 a	698.1	125.9	1722	755.7 a	545.5
Cu	4.315	9.880	6.778 a	6.877	3.958	8.100	6.030 a	6.200
Cd	0.145	0.623	0.332 a	0.345	0.124	0.567	0.279 a	0.217
Pb	0.829	2.856	1.625 a	1.539	0.667	1.650	1.155 b	1.125
Cr	2.660	7.663	4.594 a	4.272	3.067	8.050	4.516 a	4.275
Ni	2.012	4.772	3.286 a	3.151	1.408	8.333	3.067 a	2.683

*mean values in the rows marked with the same letters do not differ statistically significantly at the significance level $\alpha \leq 0.05$; according to Duncan's test

The optimum iron content in grassland fodder should be within the range from 40 to 80 mg Fe kg^{-1} [13]. Falkowski et al. [9] give values between 50 and 200 mg Fe kg^{-1} as optimal for fodder. However, the optimum content of this element in meadow sward for cattle should be 30–50 mg Fe kg^{-1} [8]. According to Juknevičius and Sabienė [19], more than 1000 mg Fe kg^{-1} is a toxic content in forages. The mean iron content in the biomass of sward from farms with animals was 755.7 mg Fe kg^{-1}, whereas sward from farms without animals contained, on average, 831.3 mg Fe kg^{-1} (Table 2). The mean values were not statistically varied. The amount of iron in all of the studied samples was too high. It was found that the optimum content of iron in fodder was exceeded almost five-fold in approximately 80% samples. Iron favours formation of reactive oxygen species. However, iron toxicity rarely occurs in animals [37].

The optimum copper content in feed should be between 7 and 10 mg Cu kg^{-1} [8, 9]. It was established that the mean copper content in biomass of the sward collected from farms with and without animal production was 6.030 and 6.778 mg Cu kg^{-1}, respectively, and was not statistically varied (Table 2). The studied samples had the optimum copper content or the content was too low to use it for feed purposes. Copper deficiency is associated with poor performance or health of calves [6].

Maximum tolerable content of cadmium and lead in feed materials is 1 and 10 mg kg^{-1}, respectively [4]. The content of these elements was not exceeded in the sward from the studied farms (Table 2). Mean cadmium content in biomass of the sward collected from farms with and without animal production was not statistically varied – it amounted to 0.279 and 0.332 mg Cd kg^{-1}, respectively (Table 2). There was variation in lead content. The sward from farms with animal production had statistically significantly lower (by 29%) mean content of lead than the sward from farms with exclusively plant production, where it amounted to 1.625 mg Pb kg^{-1}.

Chromium and nickel are elements whose content in feeds is not standardized. Nevertheless, their high concentration in feed can be the cause of various animal diseases. More than 20 mg Cr kg^{-1} indicates high content of this element in grassland feed [10, 15]. Mean chromium content in the studied samples from farms with and without animal production was 4.516 and 4.594 mg Cr kg^{-1}, respectively, and no difference in accumulation of this element was observed in individual groups (Table 2). The mean nickel concentration in the sward from organic farms with animal production was 3.067 mg Ni kg^{-1}, whereas in the group of farms without animals the amount of this element was 3.286 mg Ni kg^{-1}. As in the case of chromium content, there were no statistically significant differences in nickel content between the studied groups of farms. The determined amounts of chromium and nickel in all of the studied samples were not high and do not pose a threat to animals.

The results of the conducted research indicate that plants cultivated in accordance with organic farming principles are of low feed value. Additional animal production did not significantly influence the content of most of the analyzed elements in the biomass. Only in the case od zinc and lead was the mean content in the sward from farms with animal production statistically lower than in the sward from farms with only plant production. In all of the farms, fertilization on certified lands is not conducted. However, in farms with animal production grazing takes place periodically. Grazing can lead to chemical and botanical changes in sward [40]. This measure can change the content of available forms of nutrients in soil [27]. It is important to highlight that the mechanism of grazing impact on soil properties is complicated. Not only does grazing change chemical properties of soils, it can also influence soil temperature and moisture [39]. The more intense the grazing, the higher the soil temperature in the warm season and the lower in the cold season (which is a result of the amount of the above-ground plant parts and during winter also of the height of the snow cover). Grazing also reduces water storage in soils, especially in the early growing season. The impact of grazing on soil biological properties has also been confirmed [27].

In the studied farms, organic plant production and parallel traditional plant production are conducted. Organic biomass is utilized for feeding of conventional animals, also fed with traditional feed (roughages, concentrates). As a supplementation, the majority of the farms also use mineral additives. That is why no health problems are observed. López-Alonso et al. [22] also pointed out that giving concentrated feed containing mineral additives (present in high and balanced amounts) is one of the major methods of metal introduction in conventional farming.

The presence of conventional animal production in farms conducting organic plant production begs the question about the validity of its possible conversion to organic animal production. However, conducting organic animal production can be difficult because of insufficient consumer confidence in the standards of that production [34, 35]. Hovi et al. [17] also draw attention to the challenges associated with organic animal production. At the same time, demand for that production has increased in recent years [21, 30]. In Poland, organic farms with organic animal keeping are not common. In 2013, animal production was conducted alongside plant production only in 10% of the organic farms [12, 31, 33]. General lack of organic animal production strongly limits the development of organic farming. Animal production is a potential source of valuable fertilizers like manure. Without it, and of course with a considerable reduction in the use of external means of production, permanent negative balance of plant nutrients in organic farming is highly possible. This can disturb homeostasis of agroecosystems and relations of elements in plants [5, 25]. However, organic animal production does not guarantee nutrient balance in a farm. This is because when feed is produced on farmers' own fields, the amount of available elements may also be permanently reduced. Regardless of the kind of production, a positive environmental effect of organic farming, requires a rational fertilization policy.

4 Conclusions

The chemical composition of biomass organic grasses with small-seed legumes was improper from the point of view of using it for feed purposes. Feeding animals only with roughage obtained from the studied lands could pose a risk to animal health and decrease animal productivity. Some of the samples of the sward from grasses and small-seed legumes from the studied organic farms had too low content of zinc and copper. Additionally, very high content of iron and manganese was observed in almost all of the studied samples. It deteriorates the feed value of the obtained plant biomass.

The studied biomass samples did not have high content of cadmium or lead which would disqualify the biomass from being used as feed. The content of chromium and nickel was also not high and does not pose a threat to animals.

The mean content of most of the studied elements did not vary whether or not a farm had animal production. Zinc and lead content was an exception. The mean content of these elements in the sward from farms with animal production was statistically significantly lower (by 40% and 29%, respectively) than in the sward from farms with exclusively plant production.

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Assessment the Phytoaccumulation of Trace Elements in Plants of Evening Primrose *Oenothera biennis* L. from Kuyavia-Pomerania Provinces (Poland)

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Abstract. The aim of the study has been the phytoaccumulation of trace elements in the plants of evening primrose *Oenothera biennis* L. from the areas of Kuyavia-Pomerania province. The soil and plants were sampled from natural stands (the edges of woodlands) from selected locations in Kuyavia-Pomerania province: A – Łosiny (53°44′29.1″N; 17°55′45.9″E), B – Okole (53°07′50″N; 17°58′24″E), C – Rynarzewo (53°3′55.42″N; 17°49′3.25″E), D – Łochowo (53° 07′19″N; 17°50′19″E). The plants were collected in July 2017 at flowering and fruit development stages. In dried and mineralized plant material and in soil samples the total content of Zn, Cu, Mn, Fe, Pb, Cd and Ni was assayed with the Atomic Absorption Spectrometry (AAS) with spectrometer PHILIPS PU 9100X. The content of carbon was assayed with analyser Vario Max CN, made by Elementar. The soils were not polluted with heavy metals. The content of Pb, Cd in the evening primrose organs did not exceed the admissible pollution norms. The lowest amount of Pb (<0.2 mg kg^{-1} d.m.) did not exceed the admissible pollution norms. The lowest amount of Pb (<0.2 mg kg^{-1} d.m.) was found in seeds. The plants from stands C, D accumulated considerable amounts of Mn. The content of that element in stems and leaves ranged from 45.1 mg kg^{-1} in d.m. in stand A to 575 mg kg^{-1} of d.m. in stand D, whereas in seeds – on average from 18.9 mg kg^{-1} of d.m. in stand A to 265.5 mg kg^{-1} of d.m. in stand D.

Keywords: Trace elements · Herbal plants · *Oenothera biennis* L. · Phytotherapy · Phytoaccumulation

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 252–259, 2019.
https://doi.org/10.1007/978-3-030-16542-0_32

1 Introduction

Due to a serious threat of diseases of affluence to the societies and a search for alternative methods of preventing such diseases, over the recent years an interest in the plants showing health-enhancing effects as well as the secondary metabolites of the plants which increase the immune system effectiveness has been growing [5, 6, 13].

The medicinal plants representing the family Onagraceae, used to increase the immune system effectiveness, are representatives of the genus *Oenothera*. The genus includes a few dozen, difficult to distinguish from one another, species both in the wild and cultivable. The most common is evening primrose *Oenothera biennis*. In our conditions it grows up to 1.5 m. The medicinal material of evening primrose is acquired from seeds and seed-pressed oil and, after cooking, all the parts of the plants are edible: young leaves, green shoots, sacs and roots. The seeds contain up to 24% of oil, 15% of protein rich in sulphur amino acids and tryptophan, 43% of fibrin and starch, phytosterols, enzymes (inhibitor trypsin), vitamin E and mineral salts [25]. The oil derived from the evening primrose shows the content of more than 80% of essential fatty acids, about 10% of which is made up of, very rare in nature, gamma-linolenic acid (GLA) and 70% of linoleic acid [2, 25]. Besides the extracts from herbal material contain polyphenol compounds with antioxidant effect and they are a source of many biopharmaceuticals supporting the therapy of the diseases of affluence: atherosclerosis, arterial hypertension, diabetes, to mention just a few, as well as preparations applied in diet prophylaxis or skin regenerating and soothing cosmetics [8, 14, 19].

Due to valuable properties of the seeds, the evening primrose plants are grown on plantations and the material is acquired from natural stands. Often, however, the plantations of evening primrose and its resources in a natural state coincide with the area of industrial contamination or traffic fumes. Evening primrose is a plant which occurs in ruderal stands on sandy set-asides and grasses, frequently along traffic routes or industrial areas [25]. The global technical and technological advancement has resulted in the pollution of natural environment with trace elements, including the elements indispensable for living organisms (microelements), elements of an unknown physiological role as well as toxic elements. Plants, including the medicinal ones, next to metals essential for life, accumulate also heavy metals [11, 16]. The harmfulness of heavy metals is mostly related to their capacity for bioaccumulation [9, 21]. An increase in the concentration of trace elements in the tissues of herbal plants can lower the medicinal value of the material as well as it can be the cause of diseases [22, 28].

Herbal plants can be used as bioindicators of unfavourable changes in the environment [23]. Determining the content of heavy metals in medicinal plants facilitates an ongoing quality control of the pharmacopoeia material.

The aim of this research has been to evaluate the content of heavy metals in terms of a change in their concentration in respective morphological parts of evening primrose plants from natural stands in Kuyavia-Pomerania province.

2 Materials and Methods

The content of trace elements (Zn, Cu, Mn, Fe, Ni, Pb, Cd) was assayed in soil samples and evening primrose plants. The samples for analyses were taken in three replications from selected locations of Kuyavia-Pomerania province: A – Łosiny (53°44′29.1″N; 17°55′45.9″E), B – Okole (53°07′50″N; 17°58′24″E), C – Rynarzewo (53°06′21″N; 17°82′27″E), D – Łochowo (53°07′19″N; 17°50′19″E). The soil was sampled from the plant rhizosphere (0–20 cm), air-dried and sieved through the sieve with mesh 2 mm in diameter. The grain size composition was determined with laser particle size meter, Mastersizer 2000, made by Malvern. The reaction was potentiometrically determined using the pH-meter after providing the soil samples with 1M KCl solution, in the ratio soil/solution of 1:2.5. The content of carbon was assayed with analyser Vario Max CN, made by Elementar.

The plants were collected in July 2017 at the generative stage. The aboveground plant parts (seeds, flowers, leaves and stems) were separated from the roots, rinsed in distilled water and air-dried. The plant material was crushed in the agate mortar and homogenized. The samples, 300 mg each, were exposed to microwave digestion in mineralizer Speedwave Two (Berghof) with the wet mineralization method (5 ml 65% HNO_3, 1 ml 30% H_2O_2). In the plant material as well as in the soil samples, the total content of Zn, Cu, Mn, Fe, Pb, Cd and Ni was assayed with Atomic Absorption Spectrometry (AAS) with the use of spectrometer PHILIPS PU 9100X.

The results of the content of heavy metals in part of the plant are expressed as the mean ± standard deviation (SD). The data was analysed using one-way analysis of variance applying ‘Statistica for Windows’.

3 Results and Discussion

The soils showed mostly the grain size composition of loamy sand. The soil sampled from the rhizosphere of the evening primrose growing at Rynarzewo was the only one which demonstrated the grain size composition of sand. The soil analyses demonstrated that the soils reaction ranged from acid to neutral. The content of Corg ranged from 20.1 to 28.4 g kg^{-1} (Table 1).

Table 1. Granulometric and selected properties of analyzed soils.

Place sampling*	Grain size composition (%)			pH 1M KCl	Corg (g kg^{-1})
	Sand (mm) φ 2.0 − 0.05	Silt (mm) φ 0.05 − 0.002	Clay (mm) φ < 0.002		
A	77.98	20.65	1.37	6.83	28.4
B	76.34	21.75	1.91	6.51	22.0
C	87.71	11.33	0.96	4.71	20.1
D	83.77	14.89	1.34	6.19	25.4

*place sampling: A – Łosiny, B – Okole, C – Rynarzewo, D – Łochowo

Table 2. The average content of metals: Zn, Cu, Mn, Fe, Pb, Ni, Cd (mg kg^{-1}) i Fe (g kg^{-1}), in the roots zone.

Place sampling*	Metals						
	Zn	Cu	Mn	Pb	Ni	Cd	Fe
A	42.5	6.8	345.0	13.5	12.1	<0.2	10.2
B	32.6	5.9	298.0	12.8	10.2	<0.2	8.9
C	59.0	4.7	314.0	9.7	7.4	<0.2	7.7
D	35.8	9.4	321.0	13.5	10.3	<0.2	8.6
Mean	42.5	6.7	319.5	12.4	10.0	<0.2	8.9

* place sampling: A – Łosiny, B – Okole, C – Rynarzewo, D – Łochowo

Evaluating the soils from 4 sampling locations in terms of the content of heavy metals (Zn, Cu, Mn, Fe, Pb, Ni, Cd), it can be concluded that the total content of metals did not exceed the admissible contents provided for in the law [10]. The results of the total content of trace elements in soil are provided in Table 2. With the contents of respective metals in soil samples, one can order them as follows: Cd < Cu < Ni < Pb < Zn < Mn < Fe. For all the stands there were found the lowest contents of Cd (<0.2 mg kg^{-1} of d.m.), while maximum Fe contents were accumulated in the soils from sampling location A (on average 10.2 g kg^{-1}).

There was noted a varied content of metals in evening primrose plants depending on the stand they were sampled from. The ions of the trace elements can be ordered following their decreasing mobility: Fe > Mn > Zn > Cu > Pb > Ni = Cd (Table 3).

Table 3. Content of metals: Zn, Cu, Mn, Fe, Pb (mg kg^{-1} d.m.) in dry weight of evening primrose *Oenothera biennis* L.

Place sampling*	Metals	Evening primrose *Oenothera biennis* L			
		Seeds	Flowers	Leaves + shoots	Root
A	Zn	27.95 ± 2.1	41.05 ± 1.8	35.45 ± 2.0	34.60 ± 3.1
	Cu	2.35 ± 0.3	2.00 ± 0.2	2.20 ± 0.2	<0.2
	Mn	18.90 ± 1.2	33.50 ± 2.4	45.10 ± 3.0	25.75 ± 2.4
	Fe	95.50 ± 20.1	1749.00 ± 108.0	240.50 ± 19.0	1949.00 ± 120.0
	Pb	<0.2	1.85 ± 0.5	1.90 ± 0.6	2.75 ± 0.9
	Ni	<0.2	<0.2	<0.2	<0.2
	Cd	<0.2	<0.2	<0.2	<0.2
B	Zn	34.00 ± 3.4	43.35 ± 4.8	37.50 ± 5.6	44.15 ± 3.7
	Cu	1.35 ± 0.4	0.75 ± 0.2	1.15 ± 0.4	<0.2
	Mn	152.50 ± 38.1	39.75 ± 7.5	63.35 ± 8.2	24.10 ± 6.5
	Fe	160.50 ± 50.5	1602.50 ± 226.9	170.50 ± 22.7	1959.00 ± 343.1

(*continued*)

Table 3. (*continued*)

Place sampling*	Metals	Evening primrose *Oenothera biennis* L			
		Seeds	Flowers	Leaves + shoots	Root
	Pb	<0.2	1.10 ± 0.2	1.30 ± 0.4	1.40 ± 0.6
	Ni	<0.2	<0.2	<0.2	<0.2
	Cd	<0.2	<0.2	<0.2	<0.2
C	Zn	45.40 ± 8.8	43.75 ± 7.6	44.30 ± 9.4	76.65 ± 12.3
	Cu	10.00 ± 2.5	7.00 ± 1.9	8.10 ± 2.8	5.80 ± 1.4
	Mn	194.50 ± 66.6	58.10 ± 10.7	339.50 ± 99.8	87.05 ± 14.5
	Fe	92.30 ± 23.6	1433.00 ± 223.8	150.00 ± 33.1	2046.00 ± 401.9
	Pb	<0.2	2.00 ± 0.2	2.00 ± 0.3	2.50 ± 0.7
	Ni	<0.2	<0.2	<0.2	<0.2
	Cd	<0.2	<0.2	<0.2	<0.2
D	Zn	35.00 ± 5.5	46.25 ± 10.1	38.25 ± 7.2	37.9 ± 9.9
	Cu	2.80 ± 0.7	5.35 ± 1.7	3.75 ± 1.6	1.95 ± 0.5
	Mn	265.50 ± 90.1	200.00 ± 27.6	575.00 ± 62.1	81.45 ± 8.1
	Fe	91.90 ± 21.7	1795.50 ± 293.8	144.50 ± 34.0	1691.50 ± 343.1
	Pb	<0.2	1.15 ± 0.1	1.30 ± 0.3	2.60 ± 0.2
	Ni	<0.2	<0.2	<0.2	<0.2
	Cd	<0.2	<0.2	<0.2	<0.2

*place sampling: A – Łosiny, B – Okole, C – Rynarzewo, D – Łochowo; results are mean ± SD (standard deviation)

An average higher Fe content in the plant parts was assayed in roots (1911.38 mg kg^{-1} of d.m.) and flowers (1645.00 mg kg^{-1} of d.m.) than in shoots (176.38 mg kg^{-1} of d.m.) and seeds (110.05 mg kg^{-1} of d.m.) (Table 3). The highest Fe content was found in the seeds collected from stand B (160.5 mg kg^{-1} of d.m.). Lamer-Zarawska [15] reported similar contents of the element in the seeds of the plants collected from natural stands, Markiewicz et al. [17] from the plants from controlled plantations. The authors reported, on average, from 116.9 to 130.9 mg kg^{-1} of d.m., respectively. As reported by Kobierski et al. [13] the content of that trace element in aboveground parts of common nettle, yarrow and dwarf everlasting was maximum for respective species 506 mg kg^{-1} of d.m., 364 mg kg^{-1} of d.m. and 260 mg kg^{-1} of d.m. Buliński and Błoniarz [3] as well as Golcz et al. [7] showed considerable Fe contents in the tissues of marjoram (1037.5 mg kg^{-1} of d.m. and 853.8 mg kg^{-1} of d.m.). The variation in the content of that element depends on the age and the morphological plant part [12].

The content of manganese in the plants varied and it ranged from 18.90 mg kg^{-1} of d.m. in evening primrose seeds from stand A to 575.0 mg kg^{-1} of d.m. in the stems and leaves of the plants from stand D (Table 3). Manganese is uptaken by roots as divalent cation and transported to aboveground plant parts. Excessive amounts of this element are accumulated in cell walls or physiologically little active places of leaf cells and generative organs, which is a natural defence process of plant organisms against stress

[1]. In all the plant parts collected from stands C and D there was observed a greater accumulation of Mn, which could have been due to a higher content of the forms of metals available to plants in soil (Table 2). In the vicinity of Łochowo and Rynarzewo in the material studied, in evening primrose seeds recorded the highest content of that element: 265.50 mg Mn kg^{-1} of d.m. and 194.5 mg Mn kg^{-1} of d.m. Markiewicz et al. [17] in the seeds of primrose derived from plantation, assayed the content of Mn reaching up to 353 mg Mn kg^{-1} of d.m. In the research of the mineral composition of evening primrose, Markiewicz et al. [18] reported a definite dependence of the amount of elements in seeds on soil richness.

The lowest zinc content was reported in the seeds of primrose growing at Łosiny (27.95 mg Zn kg^{-1} of d.m.), whereas the maximum values, around 76.65 mg Zn kg^{-1} of d.m., were recorded in the roots of the plants from Rynarzewo (Table 3). The average content of that trace element in the seeds from all the sampling locations was 35.59 mg Zn kg^{-1} of d.m. In the seeds of evening primrose plants from the controlled plantation, Markiewicz et al. [17] assayed a higher zinc content (50.1–53.9 mg Zn kg^{-1} of d.m.), while Ražic et al. [24] as well as Ulewicz-Magulska et al. [26] noted the content of that metal up to 78.25 mg Zn kg^{-1} of d.m. in other herbal plant species, which, according to the authors, points to a high zinc bioaccumulation capacity in the plants under study.

In the present research the content of Cu in plant tissues was low and it ranged from 10.0 mg kg^{-1} of d.m. in the seeds of evening primrose from Rynarzewo to <0.2 mg kg^{-1} of d.m. in the roots collected at Łosiny and in the vicinity of Okole (Table 3). In the medicinal material the contents are comparable with the contents reported by Lamer-Zarawska [15] as well as by Markiewicz et al. [17].

The evening primrose plants were not polluted with Ni, Cd, Pb (Table 3). In all the organs analysed the content of Ni and Cd was below the detection threshold of the analytical method applied (< 0.2 mg kg^{-1} of d.m.). According to WHO [27], the admissible content of Cd in medicinal plants should not exceed 0.3 mg Cd kg^{-1} of d.m. Similarly the lowest amount of Pb in tissues (< 0.2 mg kg^{-1} of d.m.) was noted for evening primrose seeds, whereas the highest content of that metal was assayed in roots (on average in all the stands 2.31 mg Pb kg^{-1} of d.m.). The plants uptake easily soluble forms of Pb^{2+}, which accumulates in roots due to the immobilisation in cell membranes and forming bonds with lipids, and then it penetrates to aboveground parts [20]. According to WHO [27], the admissible lead content in medicinal plants is 10 mg Pb kg^{-1} of d.m., while, according to Farmakopea Polska [4], the limits for the concentration values for that element in dried plant material may not be higher than 5.0 mg kg^{-1} of d.m.. Markiewicz et al. [17] recorded a similarly very low Pb content in the evening primrose seeds from controlled plantations (0.038 mg Pb kg^{-1} of d.m.). Kobierski et al. [13], on the other hand, studying the bioaccumulation of heavy metals in other herbal plants, recorded high values of the bioaccumulative indicator for roots as well as aboveground parts of dwarf everlasting (above 10 mg Pb kg^{-1} of d.m.) from the same natural stands as the evening primrose plants analysed in the present research. The results could have been due to the fact that the degree of trace elements accumulation in the plant depends on many factors, e.g. species, development stage, soil conditions as well as the interactions between the elements uptaken by plants from the environment [12, 13].

4 Conclusions

1. The content of trace elements in the plants of evening primrose from natural stands, especially in the seeds, constituting the medicinal material, is similar to the chemical composition of seeds from plantation.
2. Especially the content of Pb, Cd in respective parts of the evening primrose plants collected from the natural stands of Kuyavia-Pomerania province does not exceed the admissible pollution norms.
3. Medicinal raw material coming from the described location can be safely used in phytotherapy.

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Sustainable Development

Solecki Fund as Instrument in the Hands of Rural Development Policy Makers

The Case of Rural Communes of the Lodz Metropolitan Area in Poland

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Abstract. The so called solecki fund (village fund) is an instrument that helps actively and directly engage local communities in all sorts of transformations of their respective territories. The fund is dedicated to solectwo, an auxiliary administrative unit, a subdivision of rural communes (gmina in Polish), but also of rural parts of urban-rural communes. Solectwo is established pursuant to the resolution of a Commune Council and because of its structure and financial resources it receives in the form of a solecki fund it may exert substantial impact upon the living conditions of local population as well as actively support and promote development policy of a commune.

Our studies were undertaken to identify the scope and scale of spending from solecki fund in rural communes of the Lodz Metropolitan Area. Our diagnosis and the inventory of tasks helped us classify them. Statistical and spatial analyses show that not all rural communes decide to use the solecki fund and most projects are infrastructural investments. An important conclusion from the survey is that environmentally-friendly projects involve the highest outlays.

Keywords: Solecki fund · Local development · Rural commune

1 Introduction

1.1 Rural Development in Poland

The existence of a specific local system is a trait typical of local development. Local system is understood as a territory governed by a community, within which this community can satisfy its everyday needs. A commune constitutes a local system and is characterised by: social bonds resulting from living within the same territory, direct relationships, as well as formal and informal dependences between its residents. Thus,

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 263–271, 2019.
https://doi.org/10.1007/978-3-030-16542-0_33

the local system makes part of individual, typical traits and properties, separate and autonomous in its modus operandi within a set of similar systems [10]. After Castells, Jałowiecki argues that a local system is a living system developed, transformed and experienced by people with locality being its main characteristics [9]. "Locality" in this case means the closeness of elements, relations and processes, the history and tradition of a territory, its present and future [4]. The crucial role is thus played by the local community who co-creates the local system and whose actions impact its development.

Community development encapsulates an array of processes and phenomena taking place within the local community, which initiate and integrate a number of diverse activities designed to meet local community needs, improve their quality of life and wellbeing. Local community initiatives, civil attitudes and engagement in common issues provide the starting point for developing an effective local policy. According to Łojko, in order to have an effective and comprehensive development policy in a commune, two conditions must be met: on the one hand, local communities should be aware of their own needs and be able to self-organise themselves around common interests; on the other hand, local authorities in the commune should be able to skilfully "read" these needs and based on them develop community development programmes [13]. By taking part in the policy development process, local community exerts direct or indirect impact upon decision-making and increases chances to successfully address social issues arising out of the scarcity of goods or their competitive use. Through negotiations and entering into agreements they may reduce or eliminate ramifications in meeting social needs [2].

1.2 Solecki Fund in Rural Development

Solecki funds (village funds) are instruments that help actively and directly involve the local community in transformations. They are available in a solectwo, that is in an auxiliary administrative unit[1] in rural communes and in rural parts of urban-rural municipalities. Solectwo is established based on the resolution of the Commune Council and because of its organisational structure and financial resources allocated within the framework of the solecki fund it may substantially shape living conditions and actively support and stimulate commune development policy.

Legal basis for the solecki fund can be found in the Solecki Fund Act [15] while its form, procedures and organisational principles are identical for all the communes. Resources for the solecki fund are ring fenced in the commune budget, which receives

[1] Auxiliary administrative units are established pursuant to the resolution of the Commune Council and their responsibilities are defined in statutes of the commune.

funds from the central budget through redistribution of financial resources[2]. Although the fund is not created for a specific purpose, resources transferred to it from the state budget importantly support rural development through the implementation of concrete measures.

The fund helps motivate the local community to actively engage in local issues, build social relationships, and civil attitudes. By making reference to the fundamental values of local self-government, such as: independence (autonomy), participation (democracy), effectiveness and productivity [14], its idea reflects the principle of subsidiarity. In this case, the latter has got a practical dimension since the fund enables local community to decide on how resources allocated to them by the commune will be spent, even though an auxiliary administrative unit such as a solectwo does not have legal personality and may act within the boundaries delineated by responsibilities entrusted to it and use allocated financial resources.

Solecki fund is an optional instrument and its use remains within the discretion of local authorities and depends on the specificity of the local system and applied policy. Being aware of the multiplicity of instruments and their specificity based on time, nature, source, scope, and impact, local authorities may adapt them to their own needs. This is also the case of the solecki fund and how it is used. The key question is thus to what extent the instrument is used and what areas it covers. Our survey intended to identify the scale of using the solecki fund and the scope of investment interventions suggested by local community and their classification. It is a pilot study covering rural communes within the functional Lodz area (Lodz Metropolitan Area). We applied targeted sampling approach because we focused on communes situated within the sphere of influence of a big city [6].

[2] Solecki fund can be used upon the adoption of the resolution to ring fence these resources in the commune budget. How the resources from the participatory budgeting exercise are used depends of the size of the solecki fund, which is identified in accordance with formula (1) specified in the Solecki Fund Act.

$$F = \left(2 + \frac{L_m}{100}\right) K_b \tag{1}$$

where:

F – resources allocated to a given solectwo, not higher than decuple of K_b,

L_m – population of a solectwo as at 30 June of the year preceding the fiscal year,

K_b – base amount, quotient of actual current income of a commune, referred to in regulations on public finance, for the year 2 years preceding the fiscal year and the number of people living in a given commune as at 31 December of the year 2 years preceding the fiscal year identified by the President of the Central Statistics Office of Poland.

Pursuant to the provisions of the Solecki Fund Act communes, which implement such arrangements may receive partial reimbursement of costs, depending on the base amount calculated for a particular commune in relation to the average base amount for the country. In accordance with the assumptions, three the following thresholds for reimbursement have been calculated:

1. 40% for communes with the base amount below the national average;
2. 30%, when base amount in the commune is between 100 and 120% of national average;
3. 20%, when base amount is above 120% of the national base amount.

2 Materials and Methods

2.1 Case Study Area

Lodz, the heart of the Lodz Metropolitan Area (LMA), is the third largest city in Poland when it comes to population. The LMA includes four counties (poviats): Brzezinski, Lodzki Wschodni, Pabianicki, Zgierski, and Lodz a city with county prerogatives; in total seven urban communes, five urban-rural communes, and sixteen rural communes. Our in-depth analysis focused on rural communes within the LMA.

The LMA covers the area of 2,499 km^2 accounting for 13.72% of the total area of Lodz voivodeship. In 2016 the area hosted over 1.082 million residents representing 43.56% of all the population of the region. Within the LMA rural areas represent 79% of its total size and are inhabited by 13.8% of the population of this functional area. Rural communes cover 56.8% of the LMA and are inhabited by slightly more than 10% of residents of the metropolitan area. They are exposed to strong urbanisation pressure connected with urban sprawl of Lodz producing changes in economic and social spheres. Independently of geographic location, rural areas within metropolitan areas are subject to pressures exerted by central cities [3, 5, 12, 16]. The further we get from the centre, the more prominent role played by agriculture, which is why function-wise these areas make references to traditional rural functions.

Counties within the LMA differ with respect to the structure, they include between 3 and 5 rural communes. Lodzki Wschodni poviat covers the smallest number of rural communes, while Pabianicki poviat includes the biggest number of such communes The rest of poviats have got 4 rural communes.

2.2 Data Used in Analysis

We analysed solecki funds in rural communes within the LMA based on the source data from budget related resolutions adopted by communes for solecki funds in 2016 and data from the Statistics Poland. Data from public statistics have helped us identify rural communes in the LMA, which decided to ring fence resources for the solecki fund in 2016. We could also assess the dynamics, with which resources from the solecki funds were used over the period 2014–2016. Desk studies into budget resolutions of selected rural communes for solecki funds allowed building the database of projects and further analyses necessary to accomplish our research goal.

Our significant research effort was dedicated to the working out of criteria that would help divide tasks financed from the solecki fund. In the first stage we availed ourselves of helpful budget-based classification used to plan the income and expenditure in communes. Following an in-depth analysis of all the identified projects, we applied an additional criterion of the project goal. As a result, we identified 8 groups of responsibilities, such as: modernisation of public establishments (C1), improving access to information and better communication between local authorities and the residents (C2), improving the quality of technical infrastructure (including roads and street lighting) (C3), promotion of a solectwo (C4), provision of spaces where people can meet and integrate (also leisure spaces) (C5), organising cultural and educational events (C6), expanding the share of green areas in the solectwo (C7), and the remaining tasks not classified above (C8). Moreover, analysis of projects helped us find out projects with positive environmental impact connected with sustainable rural development.

For the presentation of quantitative data (voivodeships, counties and communes) we used vector data from the Head Office of Geodesy and Cartography. These materials provided foundations for the presentation of results of analyses and formulation of conclusions relating to the spatial distribution of obtained results.

3 Results

Solecki fund is an instrument of the development policy in 7 out of 16 rural communes included in the survey and located within the LMA (as at the end of 2016). The fraction of communes that use solecki funds was largely differentiated across individual counties (poviats). In Pabianicki poviat all 5 rural communes used this instrument while in Zgierski and Lodzki Wschodni poviats only some communes (in these two particular instances communes of Zgierz and Nowosolna) established such funds. In Brzezinski poviat not a single commune decided to ring fence a solecki fund in the commune budget in 2016 (Fig. 1). It only confirms little interest shown by rural communes in using the instrument. Perhaps its short back track history is crucial in this case. Other potential reasons may include a rather conservative approach of local authorities and lack of pressure from local communities due to the lack of awareness or incomplete information about how a solecki fund works.

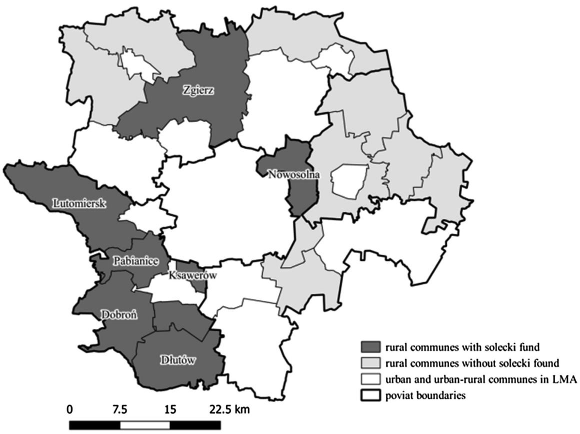

Fig. 1. Solecki Fund in rural communes in the Lodz Metropolitan Area Source: own compilation based on spatial data from the Head Office of Geodesy and Cartography and statistical data from the Statistics Poland

In accordance with methodological assumptions, we identified the dynamics of change with respect to the size of resources allocated to the solecki fund in individual communes. The highest increase in the use of resources from a solecki fund of over 40% was reported for the commune of Dobroń. On the other extreme there is the commune of Ksawerów, in which the use of resources from the solecki fund dropped by 63.78% compared to 2014. Lutomiersk in 2016 launched the solecki fund for the first time, Zgierz commune also has a short history of using the fund (the 2nd edition of the fund).

Conducted analyses allowed us to identify the structure of how resources are spent depending on which class, out of the eight listed, they belong to. Taking the entire surveyed community as a point of reference, we must conclude that 48.33% of solecki funds are allocated to infrastructural investment projects in technical infrastructure, roads, and traffic safety. Substantial resources were used for the modernisation of public establishments. These projects consumed more than 25% of solecki funds in communes covered by the survey. Outlays on organising meeting spaces and places where local community could integrate represented 15.73%. In the remaining classes of expenditure the share of solecki fund was much lower, up to 5% (Table 1). Such a structure of expenditure is also connected with unit value of individual projects, which is confirmed by correlation between the indices of structure and average value of project of 0.949.

Analysis of data has also shown that 12.61% of solecki fund in the LMA communes goes for environmentally-friendly projects. In the case of discussed community the average value of such projects amounted to PLN 12,420.12, which was more than the total average financial rate of absorption of a project. It was also higher than any average calculated for the proposed eight classification groups. Survey considering individual indices for communes allowed us to conclude that the major portion of solecki fund was allocated to environmentally-friendly projects in Ksawerów, where the index was slightly higher than 54%. The lowest environmental expenditure was observed in Lutomiersk, less than 3.5%. Regardless of the commune, expenditure structure within categories corresponded to the structure of the entire community.

Table 1. Structure of funding tasks within the solecki fund in rural communes in the LMA

Commune	Structure of expenditure by categories [%]								Share of resources spent on environmental projects [%]
	C1	C2	C3	C4	C5	C6	C7	C8	
Nowosolna	19.28	5.25	34.00	0.00	31.66	7.72	2.06	0.03	8.69
Dłutów	46.96	2.72	22.63	0.00	20.12	0.00	1.46	6.11	22.46
Dobroń	11.94	0.08	85.90	0.00	1.26	0.00	0.83	0.00	8.81
Ksawerów	13.56	1.21	66.10	1.81	12.94	4.38	0.00	0.00	54.03
Lutomiersk	37.89	0.00	37.51	0.00	19.95	4.65	0.00	0.00	3.45
Pabianice	30.33	0.73	44.31	0.49	11.25	10.16	2.74	0.00	10.58
Zgierz	27.56	1.24	50.56	4.30	14.32	1.73	0.29	0.00	10.07
Total	**27.52**	**1.41**	**48.33**	**1.26**	**15.73**	**4.23**	**1.02**	**0.51**	**12.61**

Source: own compilation based on budget data.

Taking account of the number of projects carried out by solectwo in individual communes we note big disproportions ranging from 0 to 6 projects. The analysed community includes solectwo units, which do not use the fund even though it is available in the commune and used by the neighbouring auxiliary administrative units. This is the case of solectwo units in communes, such as: Dobroń, Ksawerów, and Pabianice. Communes covered by the study include also highly active solectwo units in, e.g., communes of Ksawerów, Pabianice, and Zgierz. The structure of projects in communes is clearly dominated by infrastructural projects, which absorb the most of solecki fund and are the biggest group of projects (85.9%). Infrastructural projects come from categories: C1, C3, C5, and C7. Soft investment projects are more scarce (categories C2, C4, C6, and C8). Importantly, residents realise the need to have spaces where they could meet or integrate, projects in this category represent ca. 18% (Table 2).

Table 2. Projects carried out under the solecki fund in rural communes of the LMA

Commune	Total [no.]	Projects broken down by categories [no.]								Environmentally-friendly projects [no.]
		C1	C2	C3	C4	C5	C6	C7	C8	
Nowosolna	40	4	3	19	0	10	2	1	1	1
Dłutów	36	17	3	8	0	5	0	1	2	7
Dobroń	24	4	1	17	1	0	0	1	0	2
Ksawerów	15	2	1	6	1	3	2	0	0	4
Lutomiersk	52	16	0	20	0	11	5	0	0	1
Pabianice	58	17	1	19	1	11	8	1	0	4
Zgierz	72	19	3	28	5	13	2	2	0	6
Total	**297**	**79**	**12**	**117**	**8**	**53**	**19**	**6**	**3**	**25**

Source: own compilation based on budget data.

4 Conclusion

"Modern public management is not feasible without the participation of civil society stakeholders" [8]. Social engagement is indispensible for proper operation and development of a territorial unit, it is the reflection of the principle of subsidiarity and characteristics of civil society; it also confirms the openness and flexibility of local authorities [1, 7]. Nevertheless, we need to identify conditions of active involvement of local community, identification of areas, methods and forms of cooperation between local authorities and residents.

Solecki fund dedicated to rural and urban-rural communes is a practical solution, in which living in a given location (specific, distinct space – solectwo) conditions purposeful behaviours and actions [11]. As a result, small communities become the main subjects and animators of changes while tasks carried out under the fund are designed to improve the quality of life of local community.

The pilot survey carried out in the communes of LMA showed that the instrument, which is exclusively dedicated to rural areas, is used to a small extent. First of all, not all communes use it, secondly, not all villages within the commune participate in solecki fund. The motives for abandoning the use of this instrument are deliberate, because funds from the solecki fund are redistributed from the state budget. So what are the reasons for the limited use of the solecki fund. The conducted research allowed to indicate three sources:

1. Lack of knowledge of local governments and the local community about the possibilities of use and implementation rules of solecki fund (knowledge gap);
2. Lack of institutional and organizational capacity of the commune administration to prepare and support the solecki fund procedures (institutional gap);
3. Lack of sufficient social capital to exert pressure on local authorities to launch solecki fund (social capital gap).

In conclusion, we can say that the potential of the solecki fund is not used despite the fact that it is a real chance to develop civic activity in rural areas and an instrument for co-managing a commune that allows a real impact on meeting local needs.

Conducted studies clearly demonstrate that there are still shortages and shortcomings in meeting their basic needs. The structure of solecki funds in analysed communes shows that the condition of technical infrastructure, predominantly roads and commune structures, is the main issue in rural communes. That is the effect of many years during which the problem was neglected creating an urgent need to act in this field. Strangely enough, soft projects, the easiest and the cheapest initiatives to be carried out under the solecki fund, do not feature prominently in actions undertaken at the level of a village.

Conducting a literature and empirical study allows to formulate conclusions and recommendations. First of all, solecki fund creates an opportunity to activate inhabitants, build social relations and civic attitudes around key local needs. Secondly, it is a marginalized instrument in the development policy of communes. Thirdly, its formula, including village meeting and voting, it is difficult to read and requires clarification of the procedure. Fourthly, there are significant shortcomings in the field of information and education policy on the inclusion of the local community in the decision-making process using solecki fund.

We should highly appreciate the initiative to use the solecki fund by communes. It opens up opportunities to carry out the most necessary and indispensible tasks and helps local authorities engage people within solectwo units; involvement in the decision making process helps building up relationships between residents and local authorities.

Acknowledgments. Financial support for this study was provided by Department of Regional Economics and Environment, Faculty of Economics and Sociology, University of Lodz.

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Strengthening the Social Capital in Rural Areas Through the Rural Renewal Program. A Case Study of Opole Voivodeship

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Abstract. Opinions regarding the limited resources of the social capital in Poland are quite common. The country is particularly often referred to as a place with a lower level of organization of its inhabitants. Therefore, a change is necessary towards a greater activation of local communities and creation of social organizations aimed at solving local problems. The effective implementation of development programs may provide considerable support for the introduction of these changes. The Rural Renewal Program may serve as a particularly good example in this respect because the local community is not only the beneficiary, but mainly the initiator of the actions taken.

The purpose of the paper is to present how Rural Renewal Program affects the activity and social bonds of rural areas inhabitants. Therefore, research was carried out in July and August 2017 among the leaders of Local Action Groups, i.e. the people most involved in the implementation of the Rural Renewal Program of Opole Voivodeship. Each leader is responsible for responsible for tasks implementation in his/her village within the program. The research sample covered 72 of more than 600 rural administrative units (601 units in 2015) participating in the Program, that is over 10% of their entire number. So the article is an attempt to determine the impact of the implementation of this program on the social capital of rural areas covered by the survey. It is worth emphasizing that the first regional rural renewal program was in fact initiated in Opole Voivodeship 20 years ago. Since that time, sufficient experience has been gained to draw conclusions regarding the benefits of the program, its successful aspects and the areas that need to be changed.

The results of the research have shown that there is a relatively high level of trust towards non-governmental organizations among the leaders of Local Action Groups. There is also concern for the weaker members of the community. On the one hand, the main constraints to their activity are the behavioral factors resulting from the attitude of the residents of their village (the lack of commitment) and the bureaucracy involved in funds raising. However, the very fact of respondents' activity within the framework of the Rural Renewal Program should be positively assessed in the context of social capital building.

Keywords: Sustainable development · Social capital · Rural areas · Rural Renewal Program

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 272–280, 2019.
https://doi.org/10.1007/978-3-030-16542-0_34

1 Introduction

The change in the political system has resulted in creating adequate conditions for the development of grass-roots initiatives of local residents. Poland's accession to the European Union enabled the local communities to obtain funds for common goals, which were primarily launched within the framework of programs aimed at rural development. With the EU's new financial perspectives, there has been a shift in the directions of spending on rural development initiatives. Stępień and Czyżewski [1] draw attention to the aspect that is the main priority for the "Rural Development Programme 2014–2020", namely the importance of increased competitiveness of agriculture, built through three initiatives: investments in farms, young farmers and the creation of producer groups and organizations. However, given that the funds allocated in the budget of the above-mentioned RDP for the spatial development of rural areas and also used to finance the rural renewal are at the same time being reduced, the achievement of lasting effects under this priority seems to be debatable [1].

However, the social capital of the area always remains the guideline on how to put the funds in use in a reasonable manner. By implementing the Rural Renewal Program, local leaders can initiate social capital growth processes in their area, and their experience can serve as a valuable source of knowledge about the social processes that take place in rural areas.

The purpose of the paper is to present how Rural Renewal Program affects the activity and social bonds of rural areas inhabitants. Therefore, research was carried out in July and August 2017 among the leaders of Local Action Groups, i.e. the people most involved in the implementation of the Rural Renewal Program of Opole Voivodeship. The article is an attempt to determine the impact of the implementation of this program on the social capital of rural areas covered by the survey.

Extremely interesting are the results of the research conducted by Krzyminiewska [2] on the human capital in rural areas and on the role of economic education in the process of building this capital and in the social development.

The aim of supporting the sustainable development of rural areas is to provide alternative sources of income and to shape agricultural production in accordance with the environmental requirements and in a manner that ensures the preservation of the landscape assets. Such a support is also important as far as the improvement of the social and the technical infrastructure is concerned. All of the actions taken are designed to reduce unemployment, including structural unemployment. The sustainable development of rural areas is connected with the concept of their multifunctionality, with the shaping of the conditions for diverse economic activities carried out with respect for environmental aspects, with the development of social and cultural functions, and with the attention to ensuring good living conditions for the inhabitants. It is true that the rural infrastructure, such as: local roads, sports facilities or sewage systems, seems to be the factor that is often more visible and one that encourages actions aimed at improving it. But the social capital remains an important element of the sustainable development, which was expressed in the Declaration of the United Nations Conference on the Human Environment, adopted in Stockholm in 1972, resulting in commencing the work on defining sustainable development in the ecological, economic and social context. To ensure sustainable development, as defined in the Rio Declaration, participation of a conscious society is required. That is because one of the superior principles of creating conditions for effective achievement of goals is constant and consistent raising of public awareness, as well as an increase in the public access to information and its participation in the decision-making process. The sustainable development also anticipates the activity of both individuals and social groups. This is where the social capital comes to the fore.

The social capital, as one of the three components of the intellectual capital, with the other two: the human capital and the structural (institutional) capital, creates human relations and is based on trust and civic participation. From the macroeconomic point of view, the social capital is seen as a source of strategic competitiveness and, due to its specific characteristics, becomes a subject of socio-economic research. This component of the intellectual capital plays a special role in sectors of the economy under transformation. This also applies to rural areas, located outside industrial areas and far from urban agglomerations. They are characterized by their close relationship with natural environment, low population density, and dependence on agricultural business activity [3].

The social capital is a phenomenon that is not easy to measure due to the elusive nature of its components, including, for example, trust, sense of belonging or cooperation. However, it is possible to examine these factors indirectly, for instance by evaluating the activity of local people, their actions, which are signs of the social capital. That is because its essence is team competition based on mutual relations of members of a given community. Apart from trust and common values, important features of the social capital also include manifestations of local self-organization and civic engagement [4, 5]. The social capital can thus be understood as a social network governed by moral or customary norms that bind individuals to a society in a way that enables them to interact with others for the common good.

2 Material and Method

The presented research was conducted among the leaders of local action groups operating under the Rural Renewal Program in Opole Voivodeship. Such an approach can be justified on the basis of the model of rural renewal, published by Wilczyński [6]. According to this model the key areas of rural renewal include: shaping the intangible conditions that contribute to the quality of life, improving the living standards through the development of the material sphere and improving the economic conditions. Intangible conditions relate to neighborhood and interpersonal relations, participation in community life, possibility of creating and using the cultural, educational, leisure and recreation opportunities, and meeting current living needs. Material sphere means for example technical infrastructure, local community facilities, housing and equipment. And economic conditions include working and earning opportunities and related investments, as well as raising funds for common goals by the local community. During the research all these areas were examined, but this study only presents a fragment of the results on social capital.

The results obtained in July and August 2017 represented more than 10% of the rural administrative units participating in the Program. The research sample has covered 72 of more than 600 rural administrative units (601 units in 2015) participating in the Program. 72 leaders of Local Action Groups were assessed. The employed research method were: telephone interviews and an electronic questionnaire consisting of 30 closed questions with a possibility to complement the given answer in an open question "Other (specify)" – which, however, was very rarely used by the respondents. As regards the social capital, the following issues were verified: strengthening the sense of social bond and knowledge flow, proposing solutions to the problems of rural population, the level of involvement of the village leaders and civic affairs, types of activity of leaders, information flow on the activities of the municipality authorities, social exclusion groups in rural areas, barriers to full participation of the inhabitants in social life and problems encountered by the leaders in their work for the village.

3 Research Results

The structure of the responses given by the target group of the "Village Renewal Program" indicates that they are most likely to include local residents and leaders, local government organizations, youth, women and children (Fig. 1). In the opinion of the surveyed respondents To a medium extent, actions are being implemented whose target groups are: senior citizens, farmers, tourists and men, while to the slightest and small extent they concern the unemployed, the disabled and entrepreneurs. Respondents were asked to evaluate areas that benefited the local community by its participation in the Rural Renewal Program (Fig. 2), and they most often pointed to the integration of the rural community (70% of the responses indicated good and the highest rating) and the sense of identity by the local community (68% of the responses for good and highest rating).

Among the other benefits, the improvement of the quality of life and stability were emphasized – 56% of respondents declared that the degree of improvement was good and very good, with a further 32% of respondents who thought that the change in this regard was sufficient. According to the respondents, the feeling of social ties and the flow of knowledge (Fig. 3) was built to the greatest extent by: an integrated community of the area (96% of respondents answered "definitely yes" and "yes"), an effective local action group (93% of responses in total) and cultivating the tradition of the area (92% of indications in total). The surveyed local community leaders directly pointed to the key importance of the social capital and cultural heritage for the functioning and development of local communities, which is also consistent with other research findings. The respondents were also asked what actions would solve the main problems of inhabitants. They mainly pointed to social and economic factors. Organizing trips, tours, cultural events and family fests got 92% of answers "yes" and "definitely yes", securing conditions for job creation through incentives for entrepreneurs are very important to 85% of the surveyed leaders. 82% of them noted that building cycling lanes as well as organizing summer recreation for children and the youth are important to the residents of their village. More than 80% of surveyed leaders think that there is need for greater involvement of people in self-employment and self-development and Christmas and casual occasions meetings. Also 79% of them notice the need of creating meeting and organizing sightseeing and natural tours in order to activate seniors.

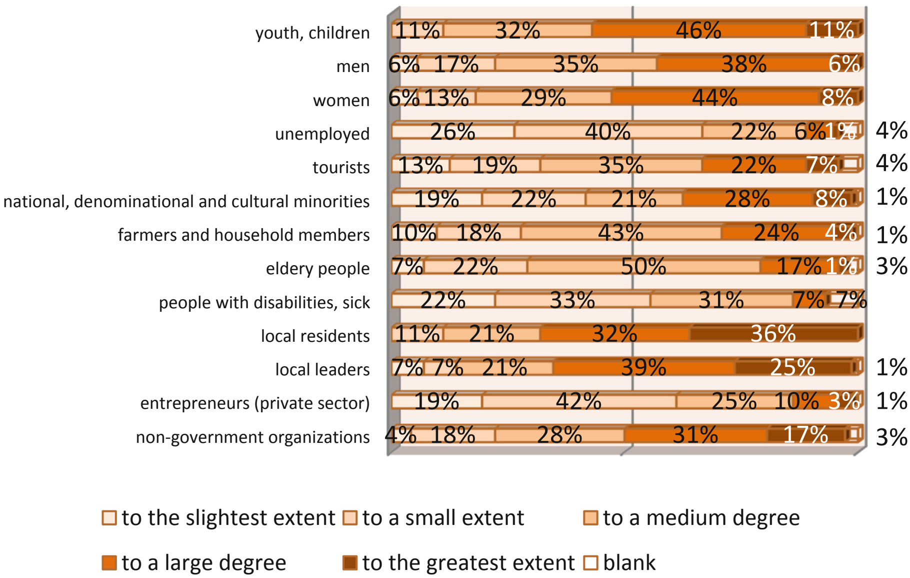

Fig. 1. The groups indicated by the respondents as the target ones for the implementation of the Rural Renewal Program (RRP) (Source: Own study based on empirical research)

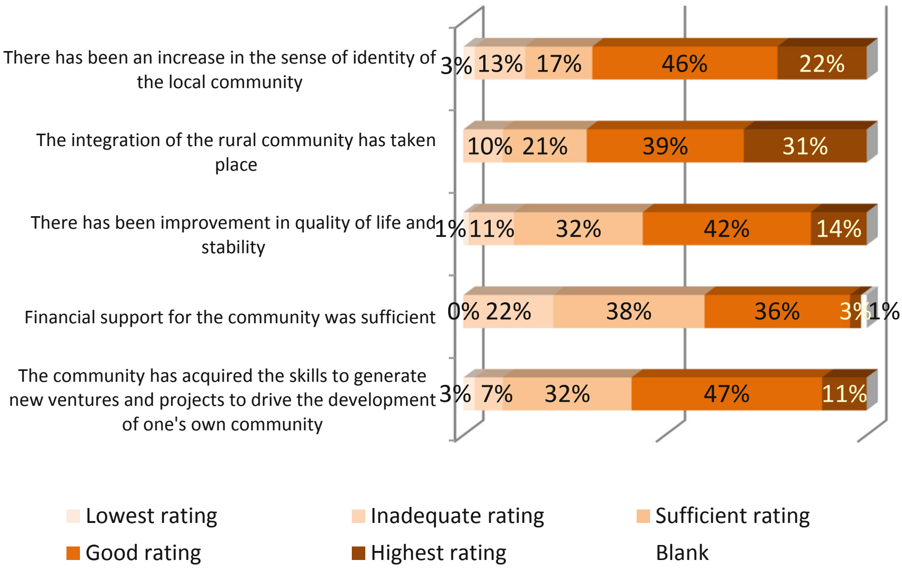

Fig. 2. Evaluation of the areas in which rural communities benefited from the Rural Renewal Program (RRP) (Source: Own study based on empirical research)

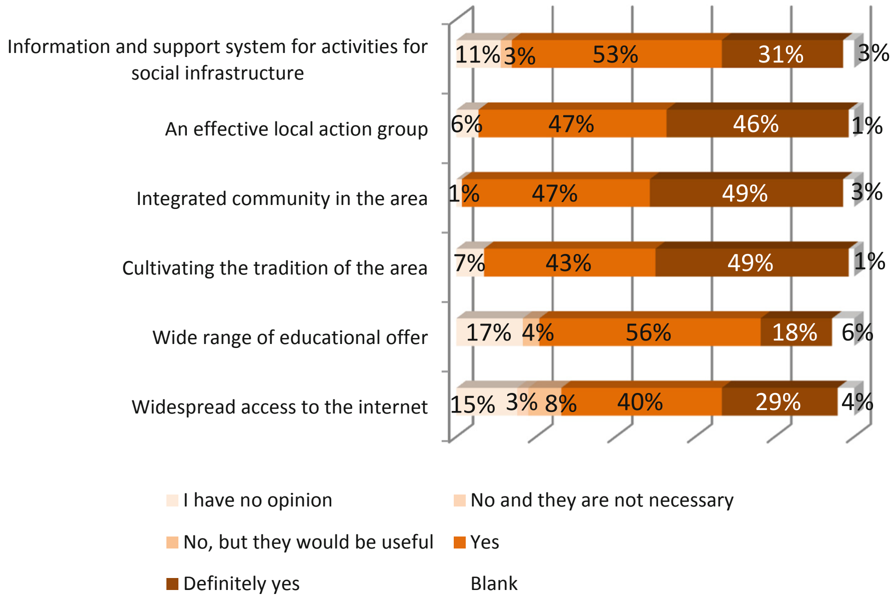

Fig. 3. Actions that could strengthen the sense of social bond and the knowledge transfer (Source: Own study based on empirical research)

Only two of the above-mentioned actions were aimed at the economic needs of the inhabitants, while most of them were community-based and could increase the intensity of local community contacts. This indicates that the need of building social relationships in surveyed villages is strong. It is also worth noting that they are targeted at vulnerable groups in these communities, i.e. children and seniors. Interestingly, these answers respond to the question of socially excluded groups. In respondents' opinion both groups: seniors and young people are not identified as excluded. This may indicate that these groups in the studied environment are not left alone and do not alienate themselves or withdraw from social life. The space created for them is actively managed, which seems to be a good testimony to the social capital of the surveyed villages.

The structure of the answers to the question about the form of obtaining and transmitting information about the life of the village indicates that the respondents prefer direct communication. And so, they talk to their neighbors or other people about the problems of the village (up to 99% of responses), participate in meetings with representatives of the municipality (90% of replies), are active in searching information on the Internet, checking plans, resolutions, protocols and other documents related to the locality (almost 92% of replies for each). Data in this regard were recalled by Skubiak [7], indicating the use of the Internet by rural residents between 25 and 64 (27.5% compared to 64.2% of urban residents). Also according to research results obtained by Ziemiańczyk and Krakowiak-Bal [8] although modern technologies are used in Poland mainly by young people and the population of the largest cities, the distance between the use of modern social communication technologies is not as significant as some might imagine or as some stereotypes suggest.

The leaders, in their majority, personally initiate activities for the local community (90% of responses) and were actively involved in Voluntary Fire Brigades and school affairs. In contrast, relatively few of them were active in social media (32%). Their evaluation of information methods about the actions of the authorities was the confirmation of the communication practices of the respondents. Meetings with representatives of the office or councilors, or information via the local media or the official website of the municipality office (almost 92% of replies) were recognized by the respondents as the most comfortable for the residents. In view of local leaders, the main obstacle to full participation of villagers in social life was the reluctance to engage in activity (almost 85% of replies) or the lack of need to participate in social life (almost 74% of replies). This is in line with the findings published by Sokołowska and Szwiec [9] who found 10% of respondents in the research sample who were reluctant to attend rural meetings and any other activities. This seems to confirm the opinions of leaders in this year's research. The more objective reasons (Fig. 4) do not play any significant role.

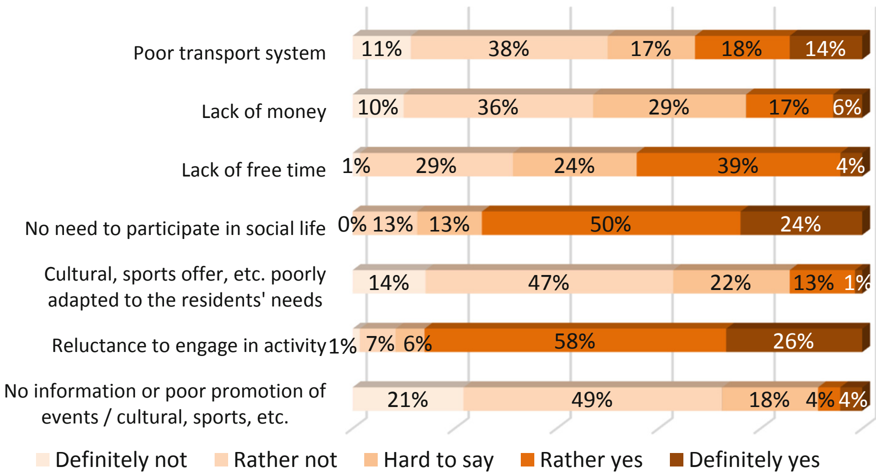

Fig. 4. Barriers to full participation of residents in social life (Source: Own study based on empirical research)

On the other hand, among the problems encountered in the work for the village, the leaders indicated the overly complicated formalities related to raising funds for actions (68% of responses) and the related difficulties in obtaining funds (almost 53% of replies). They also experienced staffing issues related to the maintenance of good staff (half of indications). As the least important, from their point of view, they indicated the lack of premises or a place for regular meetings (75% of replies), lack of access to important information (a little less: 72% of indications) and lack of trust in non-governmental organizations (68% of replies). Especially the last factor confirmed the relatively high level of trust in the communities represented by the respondents.

4 Conclusions

The answers given by the surveyed leaders seem to provide – in line with their perspective – a relatively high level of trust towards non-governmental organizations and concern for the weaker members of the community in which they operate. On the one hand, the main constraints to their activity are the behavioral factors resulting from the attitude of the residents of their village (the lack of commitment) and the bureaucracy involved in funds raising. On the other hand, the very fact of respondents' activity within the framework of the Rural Renewal Program should be positively assessed in the context of social capital building, as the Rural Renewal Program has a positive impact on the social capital:

- by enabling the start of bottom-up initiatives relevant to local communities,
- by multiplying contacts between their members in new social contexts, not related to work or functions and life roles, but rather to the local environment,
- by creating opportunities for local community members to test new skills and competences in joint actions,
- by building a lasting relationship of cooperation within the local community, based on mutual knowledge and discernment of skills and capabilities, and on the individual (engaging) members.

Due to the fact that the respondents were leaders, the conducted research is of a partial and preliminary character and will require, at the subsequent research stages, to be supplemented with opinions of a wider group of rural areas inhabitants in Opole Voivodeship. The next stage of the study will allow building a dynamic picture of changes on the level of the social capital and directions for its development through the instruments included in the Rural Renewal Program based on a systematic review of data.

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The Rural Renewal Program as a Source of Financing Small Architecture Forms Increasing the Chances of Rural Development (The Case Study of the Opolskie Province)

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Abstract. Rural renewal as a method of development is one of the ways to achieve development goals, understood not only in the context of improving the quality of infrastructure, but improving, in a broad sense, the quality of life, which will not be achieved without residents' involvement.

The aim of the article is to present the Rural Renewal Program (the case study of the Opolskie Province) as a source of financing small architecture forms making the rural area more attractive, which can be expressed by the number of material undertakings (including small architecture forms) implemented by individual rural administrative units and their value.

In order to achieve the goal, the reports of rural councils (about 600 per year) on the implementation of the Rural Renewal Program (in years 2013–2015) were analyzed. Rural renewal, initiated in the Opolskie Province as early as 20 years ago, is the longest-running program for activating local communities and, at the same time, the first program that applied the long-term strategic planning method at the rural level. The process of rural renewal significantly stimulates local communities and builds society. Activation of residents entails the emergence of new cultural, recreational-integrational, educational and renovation projects. These activities restore identity, integrate residents and increase the value of rural life.

Keywords: Rural renewal · Rural areas · Small architecture forms

1 Introduction

In the programming period for 2014–2020, the European Union financial support addressed to Polish agriculture and rural areas is focused on the implementation of the objectives set out in the Strategy for Sustainable Rural Development, Agriculture and Fisheries, which reflects the EU policy priorities in the sustainable - economic, social and ecological development of rural areas.

The success of the implementation of sustainable development depends on the treatment of all the listed objectives (domains) in a similar way that is applying a comprehensive approach. These issues are particularly visible at the commune (local) level, as the development of self-governing communities should be perceived as a

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 281–292, 2019.
https://doi.org/10.1007/978-3-030-16542-0_35

process of steadily increasing the quality of life of local communities, supported by mutually sustained social, economic and ecological factors.

Inseparable from sustainable development, multifunctional rural development is an important direction of the Common Agricultural Policy (CAP) and means the need to implement rural development by adding and expanding functions and activities that improve the quality of life of inhabitants of these areas.

Rural renewal as a method of development constitutes one of the means to achieve development goals, understood not only in the context of improving the quality of infrastructure, but improving, in a broad sense, the quality of life, which will not be achieved without residents' involvement.

The aim of the article is to present the Rural Renewal Program (the case study of the Opolskie Province) as a source of financing small architecture forms which make the rural area more attractive and which can be expressed by the number and value of material undertakings (including small architecture forms) implemented by individual rural administrative units.

To accomplish the goal, the reports of rural councils (about 600 a year) on the implementation of the Rural Renewal Program (in years 2013–2015) were analyzed and such information as: the number of rural councils participating in the program, the value of funds employed for the implementation of various types of material projects and their number, illustrating the level of public involvement in building small infrastructure to improve the living conditions of the local community was articulated.

2 Ideas for Rural Development

Before the Rural Renewal Program is presented as a source of financing material undertakings with particular emphasis on financing elements of small architecture affecting the improvement of living conditions, relaxation, the quality of social capital in rural areas, it is worth discussing two basic ideas for rural development, i.e. the ideas of sustainable development and multifunctional development.

The concept of sustainable development establishes the bedrock of the EU policy, the implementation of which in relation to rural development requires the involvement and cooperation of numerous entities, both in relation to the EU institutions and operating in the areas of individual member states. Actions targeting rural areas, which constitute the majority of the EU territory, are the resultant of regional agricultural and cohesion policies, and these in turn combine the concept of stable and sustainable development [1].

In the programming period for 2014–2020, the EU financial support addressed to Polish agriculture and rural areas is focused on the implementation of the objectives set out in the Strategy for sustainable rural development, agriculture and fisheries, which reflects the EU policy priorities in the sustainable - economic, social and ecological development of rural areas.

The objectives of the RDP for years 2014–2020, and especially one of them: "The increase in the quality of human and social capital, employment and entrepreneurship in rural areas", are consistent with the assumptions of sustainable development and are based on the use of local resources.

This objective combines two concepts of rural development, i.e. both sustainable and multifunctional development.

It is commonly accepted that multifunctional development of rural areas is the idea of village activation and diversification of economic activity, according to which the future of the rural population is connected not only with agriculture, but also with other sectors of the economy. Multifunctional development of rural areas is connected with the introduction of an increasing number of new non-agricultural functions: production, trade, and service into the rural space [2].

Multifunctional development of the village is inseparably connected with the process of its renewal, that is, shaping the living conditions of residents in rural areas, whose animator and entity is the local community. Rural renewal leads to personal involvement of inhabitants, resulting from responsibility for their own future and a sense of participation in the community and co-creation, for it activates the basic capital that every society has at its disposal, that is human and social capital [3].

Summing up the issues related to the implementation of rural development, both sustainable as well as multifunctional development, it should be noted that as a result of the development, these areas should become an attractive place for working, living, relaxing and engaging in agricultural or non-agricultural activities, preserving unique natural, landscape and cultural values of these areas for future generations.

The presented information shows that in order to implement the idea of rural development, both sustainable and multifunctional, it is necessary to ensure an appropriate standard of living in rural areas, which will contribute to improving the conditions for human capital development. Unfortunately, currently poorly developed technical and social infrastructure of the village is one of the most serious barriers to rural development. The activities as part of the rural renewal program which are to mobilize local communities to undertake projects to improve the conditions and quality of rural life, create conditions for the development of economic, social and cultural functions of the village are the response to this situation. As part of this action, the implementation of investment (property) activities in the field of modernization and equipment of facilities having cultural, recreational and sports functions, renewal of objects characteristic of the rural architecture of the region and their adaptation for cultural and social purposes, modernization of public space in the village (pavements, squares, parks, markets) as well as projects contributing to the development of public infrastructure related to the development of tourist functions of the village are also supported.

3 Rural Renewal Program in the Opolskie Province

Germany is a pioneer of the idea of rural renewal programs in Europe. Analyzing the decades-long experience of Western European rural renewal programs, it can be stated that there are two ways. The first one starts in Germany, especially in Bavaria, Baden-Württemberg and Rhineland-Palatinate, and the other in Lower Austria. Due to the differences in carrying out the renewal processes in these countries (historically conditioned), one can talk about two ways of village renewal: top-down or “Bavarian” and bottom-up or “Lower Austrian” [4]. However, it should be emphasized that despite some differences, both ways aim at a common goal, which is to improve living conditions in rural areas and to induce the involvement of residents in the development of their villages.

In Poland, the earliest dissemination of the idea of rural renewal in the form of a specific “Rural Renewal Program” took place in the Opolskie Province. Hence its influence on other regional programs and the shape of support from the EU funds for rural renewal projects determined at the central level. It should be noted that the Opole Program was influenced by partner inspiration for the Opole region that is the Rhineland-Palatinate, and was developed being supported by the experiences of the Land of Lower Austria.

According to Wilczyński [5] “The renewal of the countryside is an innovative conception of development of rural areas, which came into existence on the turn of the 1970s and the 1980s in German-speaking countries (in certain lands of Germany and Austria) and was the reaction to the then growing crisis of these areas. The crisis resulted from transformations in the sphere of agriculture (a radical decrease in the number of holdings and “industrialization” of agricultural production), as well as the socioeconomic transformations, among others, in the organization of trade and services, which brought on a loss of workplaces in favor of urban centers” [5].

It is to a similar effect that other authors express their opinions, among others. Jaszczak et al. [6] who believe that actions realized within the framework of renewal programs of rural areas in Europe offer a response to problems connected with transformation of space, economic development or identification of rural communities [6].

According to Niedźwiecka-Filipiak [7], the main aim of the Village Renewal Program is to improve the living conditions of inhabitants, to find new possibilities of earning their living, to raise the standard of existing infrastructure with simultaneous preservation of the cultural heritage. This is connected with both landscape, spiritual legacy, traditions, customs and holidays of the old times, which are disappearing in the modern world becoming totally urbanized [7].

According to Wilczyński [8], the concept of rural renewal is an exceptional trend - it strongly underlines the significance of the human factor as the subject and driving force of development. It assumes that the bedrock for the increase in the standard of living and satisfaction from living in the village is the mobilization of all own resources and the use of external assistance, available, inter alia, from the European Union structural funds [8].

The use of EU funds and their involvement in local development is closely related to the activities of local councils, the most important determinant of which is civic self-awareness and bottom-up determination of priorities for socio-economic development. The primary goal in this context is to increase the quality of life of rural residents, especially the increasing importance of non-productive functions. Living in the countryside and deriving satisfaction from this is for numerous social groups the basic factor in the construction of local action strategies [9].

Rural renewal is the effect of cooperation of residents who want to improve their surroundings through changes in: infrastructure, services, architecture, culture, social life, education, agriculture, space, communication, etc. Rural renewal is also an opportunity to change the mentality of its inhabitants and to inhibit the process of disintegration. It manifests itself not only in economy and architecture but also in social life, culture and natural environment.

The Opolskie Renewal Program has been operating since 1997 and is the longest-running regional program in rural areas in Poland. It is a distinguishing feature and a hallmark of the region and one of the most important national social innovations in the field of rural development. The pioneer's position and activity in promoting experiences caused that other regional programs largely adapted the Opole solutions. The number of program participants since its takeover by the province council in 1999 has doubled every 4 years. After 10 years of the program's operation (2007), the number of formally submitted rural administrative units reached the number of 551. The further increase was, however, slower; in 2012, 719 rural administrative units (70% rural administrative units in the region) were formally submitted from all rural and urban-rural communes.

In 2010–2015, the number of rural administrative units participating in the program fluctuated; however, it ranged from 600 to almost 700 (Figs. 1, 2 and 3).

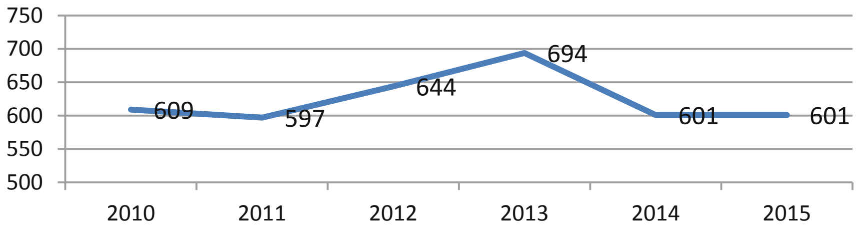

Fig. 1. The number of rural administrative units in which undertakings were implemented as part of the Rural Renewal Program in the Opolskie Province (Source: own study based on annual reports of the Rural Renewal Program implemented by rural administrative units of the Opolskie Province).

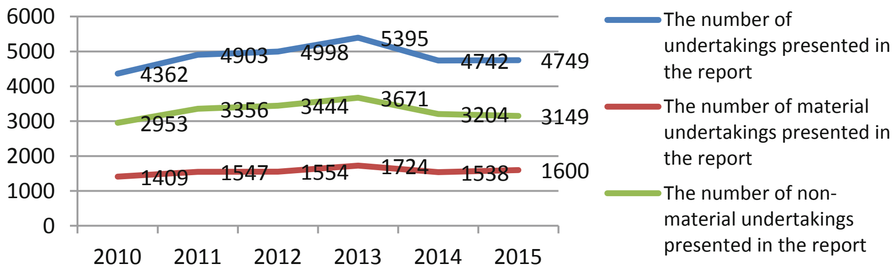

Fig. 2. The number of undertakings implemented as part of the Rural Renewal Program in 2010–2015 (Source: own study based on annual reports of the Rural Renewal Program implemented by rural administrative units of the Opolskie Province).

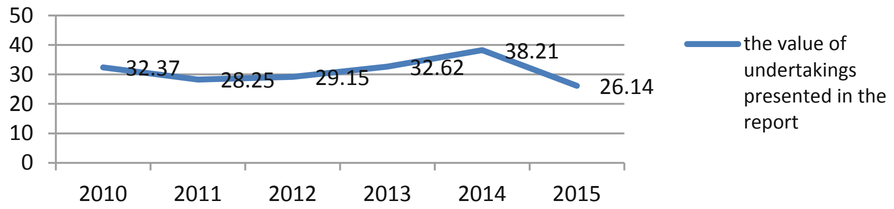

Fig. 3. The value of undertakings implemented as part of the Rural Renewal Program in 2010–2015 (in KPLN) (Source: own study based on annual reports of the Rural Renewal Program implemented by rural administrative units of the Opolskie Province).

Rural renewal brought a number of effects in places where it occurred as a development process. In the villages, there were significant changes in the appearance of public spaces and properties and improvements in facilities for community life, celebration and recreation became evident. To recreate the past of the village and use it as a "material" of development, tradition, history and souvenirs were utilized on a mass scale.

Rural renewal also allows maintaining the vitality of rural areas and stimulating the growth of their attractiveness as a place of work and residence, and as a consequence, the quality and living conditions of the inhabitants of rural areas improves.

Being a leader of the rural renewal program, or at least high advancement of this process, makes a rural administrative unit stand out from a commune and even a region, becoming a more profitable place for depositing funds, because the success of undertaking is easier there.

The multitude and multiplicity of events became one of the fundamental results of the renewal process. Numerous villages carry out several dozen cyclical undertakings every year. The versatility of undertakings implemented by villages and their addressees proves that rural renewal activities support sustainable development, thus one that harmoniously combines economic, social, cultural and environmental needs. Co-operation of municipalities and villages results in projects that improve the quality of life and, what is extremely important, shape the image of the village.

The number of undertakings implemented ranged from 4362 to 5595 on an annual average with a significant majority of non-financial undertakings over the financial ones.

The value of projects (financial and non-financial) implemented in the rural administrative units of the Opolskie Province as part of the program amounted to PLN 26.14 million in 2015 to PLN 38.21 million in 2014.

The further part of the study presents information on the number of material undertakings per 1 (in units) per year and the average annual value of property undertakings per village (in KPLN) in individual communes of the Opolskie Province together with their ranking.

Table 1 shows a big difference in the activity of individual rural administrative units in the Opole Province, both due to the number of financial undertakings carried out on a yearly average per 1 rural administrative unit in a given commune (per unit), as well as the average annual value of financial undertakings carried out by rural administrative units in a given commune (in KPLN). Undoubtedly, the rural administrative units of the Skarbimierz commune implemented the greatest value of financial undertakings (including those related to small architecture). The analysis showed that it was mainly a consequence of significant co-financing of these undertakings from external sources, as well as contribution of the commune. Most rural administrative units carry out 1 to 3 material undertakings a year, and their total value usually ranges from 10 up to 30 KPLN per year. The number of realized enterprises by individual villages as well as their value are chiefly a resultant of the activities of leaders of the village renewal program and the possibilities of acquiring external means to finance the own contribution of each village. There is no denying that there are also rural administrative units that do not carry out even on average one undertaking per year, and the value of undertakings amounts to several PLN per year. Spatial distribution shows that there are no significant disproportions concerning individual poviats. However, one should note the greater activity of rural administrative units in such poviats as: Brest, Strzelce, and Nysa, while lower in rural administrative units in the following poviats: Namysłów and Oleski.

Table 1. The number of financial undertakings on an annual average per one rural administrative unit in the commune (in units) and the average annual value of financial undertakings per rural administrative unit in the commune (in KPLN) in 2013–2015. (Source: own study based on annual reports of the Rural Renewal Program implemented by the provinces of the Opolskie Province).

Place in the ranking taking into account the number and value of undertakings	Rural administrative units	The number of financial undertakings per 100 residents (in units) per year	The mean annual value of financial undertakings per village (in KPLN)
1	Skarbimierz	4.36	236.79
2	Prudnik	4.26	50.95
3	Strzelce Opolskie	3.88	52.36
4	Leśnica	3.5	74.21
5	Kietrz	4.44	31.62
6	Dąbrowa	3.7	36.75
7	Lasowice Wielkie	3.43	37.6
8	Olszanka	3.33	33.77
9	Krapkowice	4.06	28.25
10	Walce	4.28	24.37
11	Skoroszyce	3.67	28.48
12	Nysa	2.73	44.37
13	Kamiennik	2.79	33.71
14	Kolonowskie	3	32.23
15	Paczków	3.09	25.92
16	Baborów	2.48	31.87

(*continued*)

Table 1. (*continued*)

Place in the ranking taking into account the number and value of undertakings	Rural administrative units	The number of financial undertakings per 100 residents (in units) per year	The mean annual value of financial undertakings per village (in KPLN)
17	Ozimek	2.22	39.38
18	Branice	3.64	21.35
19	Lewin Brzeski	3.27	22.29
20	Głogówek	2.7	22.91
21	Gogolin	2.41	25.81
22	Łambinowice	2.1	32.02
23	Świerczów	2.56	21.73
24	Zdzieszowice	1.56	75.33
25	Reńska Wieś	2.33	21.86
26	Biała	2.18	23.33
27	Murów	3.44	13.71
28	Tułowice	2.78	16.93
29	Bierawa	2.33	21.58
30	Zawadzkie	4.33	8.61
31	Izbicko	2.48	17.67
32	Jemielnica	2.76	14.9
33	Wołczyn	1.5	32.25
34	Pawłowiczki	2.25	18.17
35	Głubczyce	1.81	23.41
36	Popielów	2.24	17.99
37	Pakosławice	2.12	19.77
38	Lubsza	2.07	20
39	Grodków	2	19.27
40	Radłów	1.83	19.87
41	Turawa	2.37	13.14
42	Pokój	0.6	29.75
43	Korfantów	2.09	13.43
44	Praszka	1.92	13.72
45	Gorzów Śląski	2.14	11.3
46	Chrząstowice	1.81	15.06
47	Kluczbork	1.82	13.33
48	Tarnów Opolski	1.72	15.68
49	Komprachcice	1.67	16.55
50	Wilków	1.29	19.18
51	Prószków	1.74	12.65
52	Niemodlin	1.8	10.02
53	Głuchołazy	1.2	16.54

(*continued*)

Table 1. (*continued*)

Place in the ranking taking into account the number and value of undertakings	Rural administrative units	The number of financial undertakings per 100 residents (in units) per year	The mean annual value of financial undertakings per village (in KPLN)
54	Zębowice	1.89	5.06
55	Olesno	1.5	12.16
56	Otmuchów	1.71	6.59
57	Ujazd	1.8	3.1
58	Domaszowice	1.33	8.55
59	Rudniki	0.86	11.9
60	Polska Cerekiew	1.5	6.34
61	Namysłów	1.27	7.65
62	Dobrodzień	1.24	7.82
63	Cisek	0.79	9.37
64	Lubrza	0.55	9.68
65	Byczyna	1.06	4.88
66	Łubniany	0.6	5.75
67	Dobrzeń Wielki	1	1.9
68	Strzeleczki	0.33	4.47

The subsequent part of the study presents data on the number of financial undertakings carried out on an annual average in a rural administrative unit and their values – case study of the two most active rural administrative units in the given poviat, in the years 2013–2015. These data were also analyzed by assigning both quantity and value of financial undertakings (including mainly small architecture forms) for such purposes as: recreational and integrational, educational, religious worship, building road and other infrastructure, improving equipment and ecological (Table 2).

Table 2. The number of financial undertakings carried out in the village on an annual average and their value – case study of the two most active villages in the given poviat, in the years 2013–2015 (Source: own study based on annual reports of the Rural Renewal Program implemented by rural administrative units of the Opolskie Province).

The number of financial undertakings in a rural administrative unit (in units) per year	The mean annual value of financial undertakings in a rural administrative unit (in KPLN)	Rural administrative unit	Poviat
3.33	75244.50	Różyna	Brzeski
6.00	432280.08	Lipki	Brzeski
1.33	104020.41	Dziećmarów	Głubczycki
7.33	86624.33	Pilszcz	Głubczycki

(*continued*)

Table 2. (*continued*)

The number of financial undertakings in a rural administrative unit (in units) per year	The mean annual value of financial undertakings in a rural administrative unit (in KPLN)	Rural administrative unit	Poviat
4.67	35630.33	Gościęcin	Kędzierzyńsko-Kozielski
3.67	54904.67	Łężce	Kędzierzyńsko-Kozielski
6.33	34564.33	Lasowice Wielkie	Kluczborski
3.67	118085.74	Skałągi	Kluczborski
8.67	49477.67	Walce	Krapkowicki
2.00	137429.00	Żyrowa	Krapkowicki
1.33	147837.47	Krogulna	Namysłowski
4.67	34228.67	Biestrzykowice - Miodary	Namysłowski
5.00	136710.83	Kępnica	Nyski
9.67	69105.99	Trzeboszowice	Nyski
5.00	53510.00	Jastrzygowice	Oleski
3.00	58012.69	Żytniów	Oleski
8.33	73218.33	Chróścina	Opolski
3.67	217566.67	Schodnia	Opolski
7.67	71634.33	Pogórze	Prudnicki
6.00	136576.82	Niemysłowice	Prudnicki
2.67	437710.80	Łąki Kozielskie	Strzelecki
7.67	95910.00	Kadłub	Strzelecki

The data presented in tabular and graphical form show that the dominant goal of financial undertakings is to improve the recreational and integration infrastructure (construction and renovation of rural clubs, recreation squares, carports, playgrounds). Then significant funds are allocated to road and other infrastructure (this mainly concerns the purchase of stones for rural roads and their renovation, building their lighting, the same applies to rural playgrounds). In the least, funds from the Rural Renewal Program are allocated for expenses related to religious worship, ecology and education. However, many of these activities are carried out as part of non-financial activities, e.g. educational activities (workshops, training and camps), ecological activities (planting trees, shrubs from donated material) (Figs. 4 and 5).

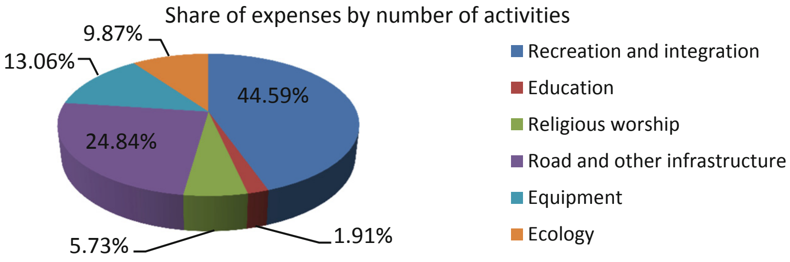

Fig. 4. The structure of financial undertakings with a breakdown by purpose (by number of activities) implemented as part of the Rural Renewal Program in 2013–2015 (Source: own study based on annual reports of the Rural Renewal Program implemented by rural administrative units of the Opolskie Province).

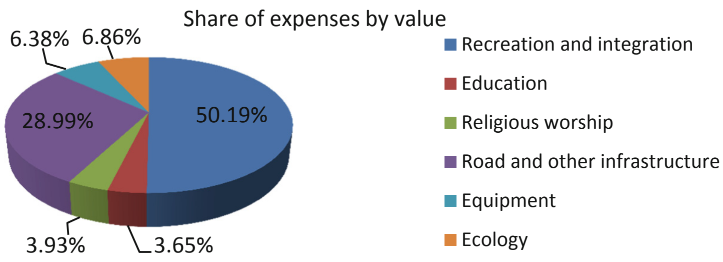

Fig. 5. The structure of financial undertakings with a breakdown by purpose (by number of activities) implemented as part of the Rural Renewal Program in 2013–2015 (Source: own study based on annual reports of the Rural Renewal Program implemented by rural administrative units of the Opolskie Province).

4 Summary

Against the background of generally outlined problems concerning rural areas and strategies for their development, i.e. sustainable and multifunctional, the aim of the undertaken research was to present the Rural Renewal Program implemented in the Opolskie Province and some of its achievements in the field of infrastructure improvement - forms of small architecture.

The implementation of joint ventures leads to the mobilization and cooperation of the society, strengthens faith in one's own strengths, stimulates optimism, and most importantly stimulates bottom-up activities at the rural level. The bottom-up action is the most important feature of rural renewal programs, and the involvement of rural leaders in favor of a new idea, consistent with the intention of these smallest communities is often the key issue of launching the program.

The Rural Renewal Program implemented in the Opolskie Province allows rural communities to decide directly on the goal. Therefore, the implementation of socially desirable initiatives contributes to sustainable socio-economic development, activates the population and results in the improvement of the quality of life in rural areas.

5 Conclusions

(1) Rural renewal programs, implemented so far, have proved to be a very effective concept and method of rural development. With a small amount of resources, numerous rural communities were mobilized for high activity, generating significant effects of strong pro-development importance.
(2) Generally, it can be assumed that rural renewal activities support sustainable development that is one that harmoniously combines economic, social, cultural and environmental needs.
(3) Most rural administrative units carry out 1 to 3 financial undertakings a year, and their total value usually ranges from 10 KPLN to 30 KPLN per year.
(4) Spatial distribution shows that there are no significant disproportions regarding the activity of rural administrative units in individual poviats. However, one should note the greater activity of rural administrative units in such poviats as: Brzeski, Strzelce, and Nysa, and lower in rural administrative units in poviats: Olesłów and Oleski.
(5) Financial undertakings implemented by individual rural administrative units concerned mainly the improvement of recreational and integrational infrastructure, road and other infrastructure, and to the least degree, they were related to religious worship, ecology and education.

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Sustainable Development thru Eco-Innovation Activities

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Abstract. The activity of innovative activity of enterprises represents one of the important elements of regional and national development. The purpose of the paper is to assess relationship between eco-innovation activities and sustainable development in European countries. Analysis includes organizational eco-innovations implemented by enterprises. In analysis were included eco-innovation projects, expressed by environmental friendly certificates ISO 14001 and 5001. The level of sustainable development of analysed countries has been expressed as Sustainable Development Goals Index (SDG). Results indicate a positive relationship between the eco-innovative activities and level of sustainable development. Although ecological innovations are rarely implemented and there is a small percentage of companies with environmental friendly standards. This kind of activity is mostly conducted in sectors manufacturing metal, food and chemical products, in construction, and electrical and optical equipment. This paper highlights the significance of ecological innovations, and importance of the activities in this matter undertaken by enterprises for sustainable development of the entire country.

Keywords: Organizational eco-innovation · Sustainable development · Environmental friendly certificates

1 Introduction

The concept of sustainable development assumes building a competitive economy based on the effective and sustainable use of resources. Among instruments to achieve this goal are investments in ecological innovations. The term eco-innovation calls attention to the positive contribution that industry can make to sustainable development and a competitive economy. They are to ensure the competitive advantage of enterprises, regions, nations, without detriment to the quality of the natural environment and to enable more efficient use of resources. Eco-innovation (also environmental innovation, ecological innovation or sustainable innovation) has been used to identify all forms of innovative activities and solutions that contribute to a sustainable environment through the development of ecological improvements [2, 12]. According to the

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 293–300, 2019.
https://doi.org/10.1007/978-3-030-16542-0_36

definition eco-innovation is an innovation that improves the efficiency of the use of natural resources in the economy, reduces the negative impact of human activities on the environment or strengthens the resilience of the economy to environmental pressures [10]. These include new production processes, new products or services, new business and management methods whose implementation will favor environmental protection or significantly reduce environmental risks and reduce the negative effects of raw materials consumption. Eco-innovations appear in various industries and mainly concern reduction of waste and the greenhouse effect, optimization of the natural resources use or reduction of pollution and increase of energy efficiency [6, 7]. The definition of eco-innovation indicates that in addition to limiting the harmful impact of economic processes on the environment, the productive use of natural resources is also important. Therefore, apart from the ecological dimension, the economic dimension (cost reduction) and security issues are also crucial (reduction of dependence on raw materials supplies). There are two approaches to eco-innovativeness: eco-efficiency and resource efficiency [11]. In this context, energy efficiency is becoming an important issue and theses solutions are sought and supported, which allow for savings and optimal energy consumption, as well as the economical management of resources, including energy. One of the solutions is an effectively implemented energy management system, which may become one of the critical conditions for the business success.

Ecologic innovative solutions are also important at different territorial level. In the European Union is assumed to achieve a resource-efficient Europe and an economic growth with eco-innovations [1, 4]. They will play a key role in saving resources on a global level, and all public and private parties involved appear to share a common perspective and to agree on the benefits of its implementation.

However, apart from the importance of eco-innovation, there are a number of barriers to their implementation, which are: market uncertainty, uncertain return on investment or negligible culture of excluding eco-innovation from an organisation's strategy [4, 9]. That is why the level of eco-innovativeness varies across countries, sectors and industries.

The purpose of the paper is to assess impact and relationship between eco-innovation activities and sustainable development in European countries. Analysis includes organizational eco-innovation entered in enterprises. In this approach, eco-innovation activities include the number of environment friendly certificates ISO 14001 and 50001. Both standards have a similar goal, which is to reduce the negative environmental impact of an organization.

The ISO 50001 standard was developed in response to the needs and requirements of modern market, where effective energy management is the key determinant of development and an important element contributing to environmental protection. The content of the standard indicates how to create systems, processes and principles in organizations necessary to improve the use of energy in their operations. It also promotes the idea of systematic energy management, which leads to reduction of cost and greenhouse gas emissions.

The ISO 14001 standard contains requirements for an environmental management system. Their fulfillment can help organizations to achieve environmental and economic goals. The basic task of the standard is to support environmental protection and to prevent pollution.

2 Material and Method

In analysis were included eco-innovation projects, which are expressed by certificates ISO 14001 and 5001. ISO 14001 is a standard concerning the environmental management system. It specifies the requirements for an environmental management system that an organization can use to enhance its environmental performance. ISO 14001 is intended for use by an organization seeking to manage its environmental responsibilities in a systematic manner. It applies to any organization, regardless of its size, type and nature, and refers to the environmental aspects of its operations, products and services. ISO 14001 is used to systematically improve environmental management. This standard undoubtedly contributes to the environmental pillar of sustainability. And some research results indicate that enterprises with implemented ISO 14001 declare, as a result of innovation, benefits due to decrease in material intensity and energy consumption of processes within the organization as well as a reduction in fees for using and changing the environment (environmental fees) [5].

The other eco-innovative activity analysed in this paper is implementation of energy management expressed by ISO 50001 standard. It concerns cost reduction, reduction of the greenhouse gases emission and energy efficiency. ISO 50001 supports organizations in all sectors to use energy more efficiently, through the development of an energy management system, which helps organizations to save money, and at the same time helps to protect resources and combat climate change. Firms to improve energy performance, reduce costs and meet customer expectations implement it.

The total number of certificates ISO 14001 and 50001 registered in 2017 in European countries and by industrial sectors was included in the analysis. Data source is the ISO Survey of certifications [3]. To compare these numbers ISO index was calculated (number of certificates per 100,000 enterprises).

The level of sustainable development of European countries has been expressed as the 2017 SDG Index (Sustainable Development Goals (SDGs)) [8]. It is a composite measure that aggregates 83 indicators on all 17 Sustainable Development Goals (SDGs) to provide countries with a quick assessment of how they are performing relative to their peers. The SDG Index score signifies a country's position between the worst (0) and best (100) outcomes.

Data set includes 37 countries described by following variables: ISO 14001 index, ISO 5001 index and SDG index.

To determine the relationship between eco-innovation activities and sustainable development a Spearman's rank correlation coefficient was adopted. It is a nonparametric measure of statistical dependence between the rankings of two variables. It assesses how well the relationship between two variables can be described using a monotonic function.

According to the formula:

The research questions posed at this paper are:

Q1: What is the impact of eco-innovation activities undertaken by enterprises on the level of countries sustainable development?

Q2: In which countries and which sectors eco-innovation activities are the most popular?

Q3: Is the eco-innovative activity a domain of most innovative countries?

3 Results and Discussion

The number of environmental certificates in European countries is rising. Definitely more numerous (almost eight times more) are ISO 40001 certificates, than ISO 5001 (see Table 1). The diversification in the number of certificates between 37 analyzed countries is also significant. The annual average rate of change in the number of ISO 40001 in 2011–2017 was 1.8%. While the number of ISO 5001 is growing dynamically, and increased in the period 2011–2017 by an average of 93.4%. It means clearly rising interest of enterprises in a more effective and less expensive energy management and use. Unfortunately, the percentage of companies with ISO certificates is still very low. The average value for analyzed countries is only 0.4%.

Table 1. Basic statistic of data set.

Variable	Unit	Average	Min	Max	Stand. deviation
Sustainable development (SDG)	–	76.7	65.5	85.6	4.9
Environmental management (ISO 14001)	No. of certificates per 100 000 enterprises	2979.6	17.0	17559.0	4389.4
		343.0	1.8	855.0	232.2
Energy management (ISO 500001)	No. of certificates per 100 000 enterprises	523.1	3.0	8314.0	1475.2
		44.2	0.0	296.8	66.9

Environmental management system (ISO 14001) is more often implemented in industrial sectors. Almost 19% of all ISO 14001 certificates are applied in construction, and 10% are in metal products, electrical and optical equipment and in wholesale and retail trade (see Fig. 1).

The half of all companies, which implement environmental management system in 2017, are located in only four countries: in United Kingdom (15.6% of all certificates), Italy (13%), Spain (11.6%) and Germany (11%).

The energy management system (ISO 50001) is particularly important in an energy-intensive industry (including construction, transport and industry) to meet the requirements and regulations regarding greenhouse gas emissions. This system is implemented most often in sectors, which produce: metal (12.5%), food products, beverages and tobacco (9%), chemicals (8.6%) and rubber and plastic (8%) (see Fig. 1). Certificates registered for companies in Germany (43%), United Kingdom (16%), and France (12%) represent over 70% of all certificates in European countries.

However, regarding ISO index, the countries with the highest values of ISO 14001 are Sweden, Romania and Switzerland. The highest index of ISO 50001 is calculated for Germany, Luxemburg and UK. This list overlaps only partially the group of the most innovative countries in Europe, which are (in 2017): Sweden, Denmark Finland, Netherlands, United Kingdom and Luxemburg (Q3). This means that the innovations of countries' economies are based, for the most part, on the other solutions than on eco-innovation activities. On the other hand, Sweden which is the most innovative country in Europe has also the highest ISO 14001 index.

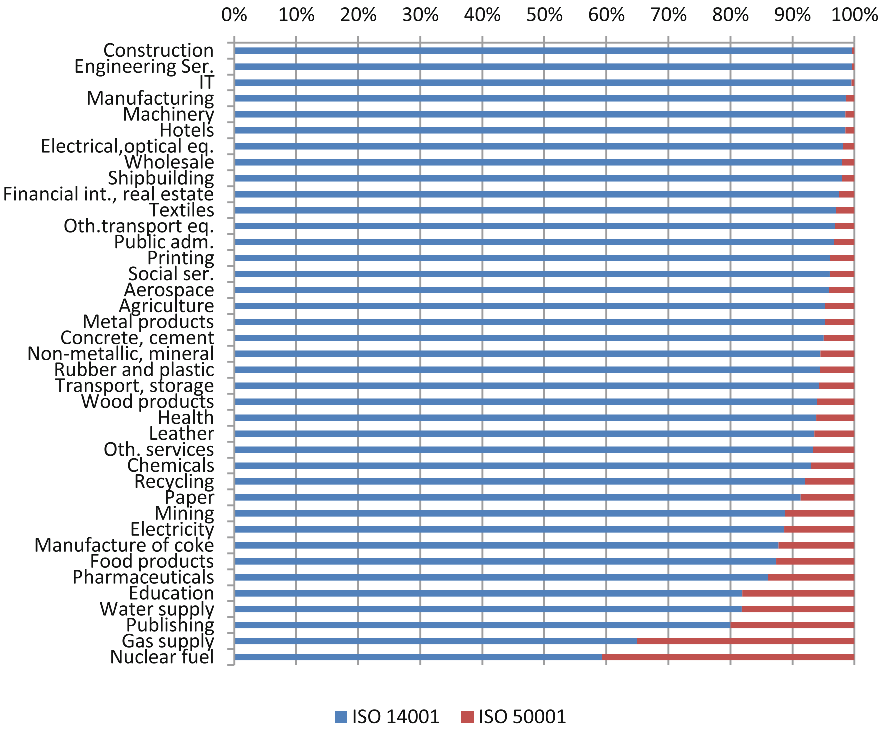

Fig. 1. Share of certificates ISO 14001 and ISO 50001 by sectors.

It is also worth to note, that the indicated, most eco-innovative sectors as wholesale, construction, food production are very often undertaken on the rural areas. It means that these economic activities could be treated as innovation wizards at rural areas.

To achieve the goal of the analysis and to answer the research question Q1 regarding relationship between eco-innovation activities and level of sustainable development of the countries, Spearman's rank correlation coefficient was calculated (see Table 2). Calculated values of r_s indicate a positive relationship between the eco-innovative activities and level of sustainable development. The higher ISO indexes implemented in enterprises, the higher level of country's sustainability and vice versa.

Table 2. Spearman's correlation coefficients r_s.

Variable	ISO 4001 index	ISO 5001 index	SDG index
ISO 4001 index	1.0		
ISO 5001 index	0.43	1.0	
SDG index	0.51	0.44	1.0

All correlations are significant at $p < 0.05$

Stronger correlation was detected between SDG index and implementation of environmental management system (ISO 14001).

It can be caused by more popularity of 14001 standard, much more often implemented in enterprises.

The relationship between ranks of 37 countries according to SDG and ISO indexes presents Fig. 2. Countries are divided into 4 groups based on the average value.

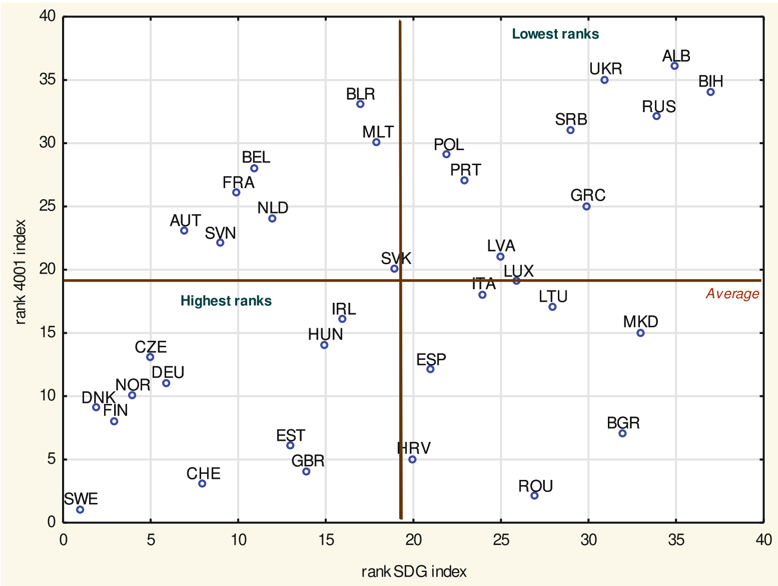

Fig. 2. Scatter plot comparing countries ranks in ISO 4001 and SDG indexes.

In the data set, countries with the highest ISO index values are scattered across the Europe. Twenty percent of the analysed countries are more sustainable then eco-innovative (i.e. Austria, France Belgium). The efforts to obtain high level of sustainable development are focused on the other aspects then eco-innovativeness. Poland, for now, belongs to the weaker countries groups, in both rankings, but it is higher ranked in sustainability than in ISO indexes (see Fig. 2).

4 Conclusions

Ecological innovations seem to be effective tools for implementing the concept of sustainable development. Presented results confirm a positive relationship between these two phenomena: Eco-innovative activity (organizational eco-innovation) and country's sustainable development (Q1). Although this activity is still rarely undertaken and there is a small percentage of companies with analysed standards. Environmental management system is implemented mostly in sectors of: construction, metal products and electrical and optical equipment, while the energy management is applying mostly in sectors manufacturing metal, food and chemical products (Q2). The highest share of implemented organizational eco-innovations was calculated for Sweden, United Kingdom and Romania (Q2). It only partially covers the list of the most innovative countries (Q3). It may be concluded that ecological innovation are developed and entered not only in regions considered the most innovative.

On the one hand, eco-innovations contribute to improving the relations between implementing entities and the environment, and on the other hand, they contribute to technical progress being one of the basic conditions for building a competitive advantage of systems. Enterprises implementing ISO certificates expecting the more sustain resources management, with respect of social, environmental and economic aspects. The reason for entering such organizational eco-innovation is to improve energy efficiency, reduce energy costs (energy consumption) and reduce greenhouse gas emissions. These goals are common with the sustainability requirements and challenges.

Acknowledgements. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland (means of Statutory Research No. DS 3600/WIPIE, University of Agriculture in Krakow).

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Homogeneity of Rural Communes with Respect to Green Areas

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Abstract. Green areas are fundamental to local communities as they fulfil important leisure and aesthetical functions. Their role in rural communes is also vital for accomplishing social functions. Studies discussed below are based on measures constructed using statistical data available in the section "Green Areas" of the Local Data Bank. Percentage indicators are used as input data to Ward's method applied to assess the homogeneity of rural communes with respect to types of green areas.

Obtained results allowed us to comprehensively assess rural communes from the perspective of the occurrence of different clusters that we identified across Poland. At the same time we could assess the location of these clusters in space and link them with the basic, qualitative evaluation of data used in the studies. An important conclusion in the study is that the major role in the clustering of rural communes plays the index of the share of communal forests in the total area of communes.

Keywords: Homogeneity of rural communes · Green areas · Ward method · Rural commune

1 Introduction

Administratively, rural communes occupy 62.3% of Poland's territory. They are inhabited by slightly more than 28.5% of the country's population. These data coming from Statistics Poland provide the snapshot of the situation as at the end of 2016. Administrative approach, the most common in public statistics, helps identify the following types of green areas in communes: recreational and walking parks, green spaces, green belts in streets, borough open spaces, as well as cemeteries and communal forests. According to Statistics Poland, recreational and walking parks are organised areas extending across more than 2 ha with facilities offered to people, such as: walking paths, benches, playgrounds, beaches, etc. Green spaces whose area is in principle smaller than 2 ha complement the first category. Green belts in streets are organised alongside streets or footpaths. Borough open spaces are trees, bushes and other plants placed in between residential buildings or within housing areas and used for recreation but also as insulation and decoration. Cemeteries are pieces of land specifically designated as burial grounds with accompanying green areas. Communal forests include forests supervised and managed by local authorities of a given commune.

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 301–306, 2019.
https://doi.org/10.1007/978-3-030-16542-0_37

Scientifically speaking, we must admit that the above listed types of green areas do not make a complete and exhaustive set of categories that the term covers, to which attention has been drawn also in the subject-matter literature [2, 3]. Nevertheless, we must accept that in order to assess the intensity of the presence of particular types of green spaces across the country, statistical data provide sufficient grounds to unambiguously decide how homogeneous rural communes are when it comes to the presence of green spaces. At the same time, we need to bear in mind that these types of green areas remain public resources, accessible to everyone without restrictions, which is important for the leisure function. On top of that, green areas perform other functions that shape local micro-climate [6]. Studies were undertaken to assess the presence of clusters of rural areas in the country and reveal whether there is any link between the formation of such clusters and their distance from major regional centres.

2 Materials and Methods

2.1 Case Study Area

The analysis covers the entire area of Poland, all of rural communes in the country in 2016. Time frame was decided by the availability of data at Polish statistical authority, Statistics Poland. At that point of time, rural communes represented 62.9% of all units in the country (2,478 communes). In nine voivodeships the percentage of rural communes is higher than the country average. In the remaining seven voivodeships the reported number of rural communes was below the country average (Table 1).

Table 1. Share of rural communes in voivodships

Voivodeships	Total number of communes	Percent of rural commune
Dolnoslaskie	169	46.2
Kujawsko-Pomorskie	144	63.9
Lubelskie	213	78.4
Lubuskie	82	48.8
Lodzkie	177	75.1
Malopolskie	182	66.5
Mazowieckie	314	72.6
Opolskie	71	50.7
Podkarpackie	160	68.1
Podlaskie	118	66.1
Pomorskie	123	65.9
Slaskie	167	57.5
Swietokrzyskie	102	68.6
Warminsko-Mazurskie	116	57.8
Wielkopolskie	226	50.4
Zachodniopomorskie	114	43.0

Source: own work based on Local Data Bank.

2.2 Methods and Data

Data used in the analysis come from Statistics Poland and refer to green areas in communes in accordance with the division applied in data collection system. They were used to calculate indicators of the share of individual types of green areas in the area of communes. These indicators later became foundations for the building of clusters applying Ward's method and using Euclidean distance. This method allows identifying homogenous clusters of rural communes based on specific set of indicators. Ward's agglomeration method uses variance analysis to estimate distances between clusters and creates clusters with the most congruent objects; moreover, it represents the highest efficiency of clustering [4, 5].

Ward's method could be applied as a result of using Statistica 12.5 software. For the analysis the cut-off value for clusters was selected at the point where the value of single-link between elements exceeds 5% of the complete-link. This assumptions also helped identify groups of objects whose variance compared to the base distance is the lowest. Additionally, we visualised and identified spatial diversity of elements within clusters and further investigated it at national and regional levels.

3 Results

Analysis conducted using the statistical software allowed us to find out that the cutoff value for clusters was equal to the link proximity distance of 25. At this level the assumption concerning the value of link between clusters higher than 10 (i.e. 5% of the complete link calculated in the analysis) was fulfilled. By finding this value we could form five homogenous clusters (Fig. 1).

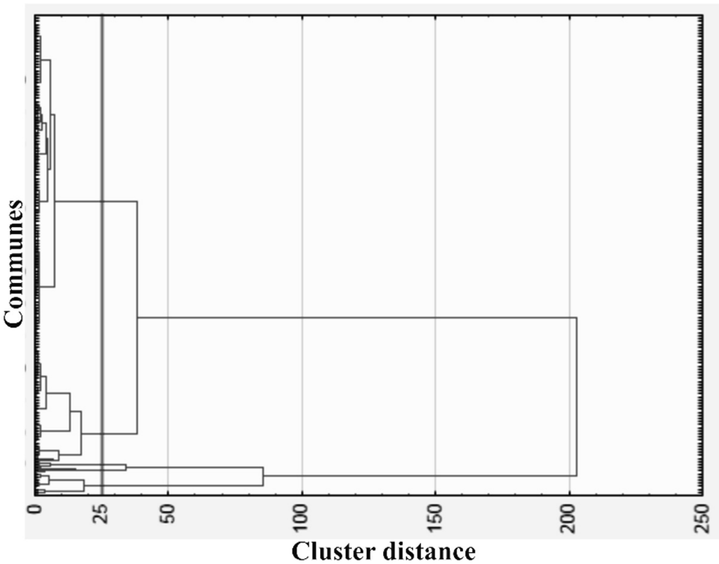

Fig. 1. Homogeneity of rural communes with regard to green areas – Ward's method. Source: own work based on Statistica 12.5.

Based on obtained results we learnt that the biggest group of communes was found in cluster 2 which included over 69% of all communes. From the qualitative point of view we need to stress that these communes represented the lowest potential of green areas in all analysed categories. Cluster 4 exhibited similar attributes but communal forests were slightly more important in it. It was also the second biggest cluster bringing together 29.93% of communes. Next, there was cluster no. 5 in which communal forests covered between 0.5% and 2% of commune area. This cluster included 5% of all analysed rural communes.

Further, with respect to variances there was cluster 1; communal forests in communes within this cluster covered between 2% and 4.2% of the total area of a commune. They represented 1.41% of the total population included in the study. The smallest group of homogenous objects was found in cluster 3 for which the distinguishing feature was the biggest share of communal forests, over 4.5%, in the total area of this territorial unit. This cluster included only 0.64% of the investigated communes (Fig. 2).

Fig. 2. Clusters of rural communes with regard to green areas. Source: own work based on Local Data Bank.

These results have brought us to the conclusion that rural communes with the biggest share of green areas and, at the same time, with the biggest share of communal forests as percentage of the total area of a commune can be found in clusters 1 and 3. Geographically, these territorial units are located in voivodeships in the south of the country, i.e., in Podkarpackie, Malopolskie, Slaskie, and Dolnoslaskie voivodeships. The remaining voivodeships are dominated with units that, based on the Ward's method, have been classified as clusters 2, 4, and 5. These clusters differed slightly with respect to qualitative assessment when it comes to the share of communal forests in the total area of the unit.

4 Conclusion and Discussion

We need to admit that – looking from the perspective of statistical data that we used – rural communes in Poland do not differ very much although Ward's method helped us identify clusters that varied significantly from the rest. The heart of Ward's method lies in identifying clusters which are later assessed in qualitative terms by researchers who have the right to suggest solutions that are potentially better suited to the needs of the users of space. Our study followed the same line of thinking and it allowed for qualitative assessment of clusters.

An important conclusion drawn from this exercise is that by leaving aside differences in the share of communal forests in the total area of communes we would face big difficulties in identifying differences between classes. Thus, we suggest extending the set of data used in the study with other categories of green that can be identified outside of public statistics in the category of green areas.

Results which did not confirm the hypothesis that laid foundations for our research about the relationship between types of communes and their location vis-à-vis big cities were relevant for the study. It turned out that for this particular set of statistical data such relationships were not quantified.

For the development of rural communes the share of green areas in public spaces is important as they contribute to the upgrading of the living standard of local population and perform recreational function in urbanised areas of rural communes. This relationship is clear in studies conducted in cities [1], it can also be justified in rural areas, however, it calls for more in-depth studies based on new statistical and spatial data that would allow capturing relationships other than those discussed in presented studies.

Acknowledgments. Financial support for this study was provided by Department of Regional Economics and Environment, Faculty of Economics and Sociology, University of Lodz.

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Economic Missions and Brokerage Events as an Instrument for Support of International Technological Cooperation Between Companies of the Agricultural and Food Sector

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Abstract. The necessity of international cooperation between enterprises and the diffusion of innovations is indispensable in an environment characterized by complexity and dynamic development. Due to limited financial resources, micro-, small and medium-sized enterprises (SMEs) are experiencing difficulties in accessing high-quality commercial services of searching for partners for advanced technological cooperation. However, companies that build their competitive advantage based on innovative solutions are increasingly willing and more likely to use the extensive catalog of support instruments offered by the Enterprise Europe Network. The quantitative data that characterize selected aspects of the potential and functioning of the Enterprise Europe Network (in the years 2008–2014).

Keywords: Economic mission · EEN · Support · Agri-food sector

1 Introduction

The agri-food sector is one of the largest subsystems of the national economy. This is mainly due to the fact that it satisfies the most important basic needs of the society [6, 9]. Entities of the agri-food sector produce food directly and participate in its

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 307–312, 2019.
https://doi.org/10.1007/978-3-030-16542-0_38

distribution, which makes them important components of the economy [3, 12]. However, as economic development progresses, the role of agriculture in generating national income decreases in relation to the food industry, trade and services [8].

The necessity of international cooperation between enterprises and the diffusion of innovations is indispensable in a complex and dynamically developing environment. Due to limited financial resources, micro-, small and medium-sized enterprises (SMEs) are experiencing difficulties in accessing high-quality commercial partner searching services to establish advanced technological cooperation. However, companies that build their competitive advantage based on innovative solutions are increasingly willing and more likely to use the extensive catalog of support instruments offered by the Enterprise Europe Network (EEN). The quantitative data that characterize selected aspects of the potential and functioning of the EEN (in the years 2008–2014) and the results of structured interviews with representatives of centers supporting agri-food enterprises in the field of cooperation (with questions built on the recommendations of prediction techniques) were subject to empirical analysis in the process of their internationalization. The following research questions were posed:

1. What were the most frequent directions of the economic missions and brokerage events in the agro-food sector?
2. What quantitative and qualitative effects have been achieved by enterprises participating in the economic missions and brokerage events?

1.1 The Character of the Agri-Food Sector

The main links of the food complex are agriculture and the food industry (agri-food sector). Entities of the agri-food sector produce food directly and participate in its distribution, as important elements of the economy [3, 12]. However, with the economic development, the role of agriculture in generating national income decreases as related to the food industry, trade and services [8]. This is a regularity, which can be explained mainly by a lower income flexibility of demand for food products than that for other goods or services. A specific feature of the sector is also a limited size of food demand and an increase in the efficiency of all agricultural production factors, which is higher than the growth rate of demand [7]. As in other branches of the national economy, the directions of development of the industry are determined primarily by the aspiration of food producers to maximize profits. The demand resulting from the maximized utility of consumption, generally applicable law and the level of subsidies from public funds are also important [10]. The development of the agri-food sector is also evidenced by the growing export of agri-food products [2].

1.2 Support for International Cooperation of Enterprises

Literature shows that entrepreneurial orientation is an important function of the enterprise's survival [1, 4, 11]. An important variable determining the international technological cooperation of enterprises is the possibility of using public instruments to support innovative development of their organization [5].

The Enterprise Europe Network is an initiative of the European Union aimed at providing support for business innovation for small and medium-sized enterprises (SMEs) in Europe. The EEN remains the world's largest business and innovation support network and currently consists of 625 partner organizations located in more than 60 countries. Over 4,000 internationalization experts and technology transfer practitioners offer a wide range of services supporting entrepreneurship and innovation for enterprises. The members of the Enterprise Europe Network are chambers of commerce, regional development agencies, SMEs, research institutes, universities, as well as technology and innovation centers. The network's offer includes a number of specialized services, provided in a one-stop-shop formula.

It is the largest European network of business and innovation support, providing high quality integrated services to SMEs. The idea of the EEN is to provide integrated information, business cooperation, innovation and technology transfer in support of small businesses and innovative SMEs.

Economic missions are a platform that not only allows improving the establishment of direct contacts, but also exchanging innovative technologies and initiating and establishing new business partnerships with organizations from similar industries. The missions are the cheapest direct form of reaching the right potential business partner in its natural environment. They enable not only familiarizing with the partner's capabilities, but also with its closest business and legal environment. In turn, a brokerage meeting is a quick and direct form of seeking a partner for cooperation. It is an opportunity to exchange information about innovative technologies and new trends, as well as to search for business and technological partners. The participants themselves can choose partners for direct B2B meetings, in accordance with the type of cooperation sought before the event. In this way, the time at the fair can be more effectively planed.

2 Material and Method

Analysis of data in the EEN network reports on the support of the agri-food sector shows there are 56 countries in the world (out of 185) that have held company missions meetings and 47 that organized brokerage events between Jan 2016 and Apr 2017. To illustrate the different types and number of meetings the cartogram method was used and ArcMap 10.6 program. The Gastner-Newman anamorphic cartogram is a thematic type of maps that presents the relative values of the examined attribute of two-dimensional objects created by the division of the area into countries. The map created using this method shows the magnitude of the phenomenon through the variability of the size and shape of the reference unit (country). The total number of meetings is divided into 7 progressive classes (i.e. the higher the class, the greater the difference in extreme values), including the "0" class. Classes have a diverted color scheme (the smaller the number, the darker the color) for improved visualization. This method of presentation violates the common approach to data visualization, in which each area on the map must be reflected in reality. The anamorphosis stresses the territorial diversity of a given phenomenon at the expense of deforming its real boundaries. It uses more the theory of perception of the phenomenon than its physical reference to reality through the use of scale.

3 Results

Analysis of used data shows countries in which the largest number of meetings in both company missions (>1000) and brokerage events (10000–15000) was held. These are: Spain, France and Germany, as illustrated by Figs. 1 and 2.

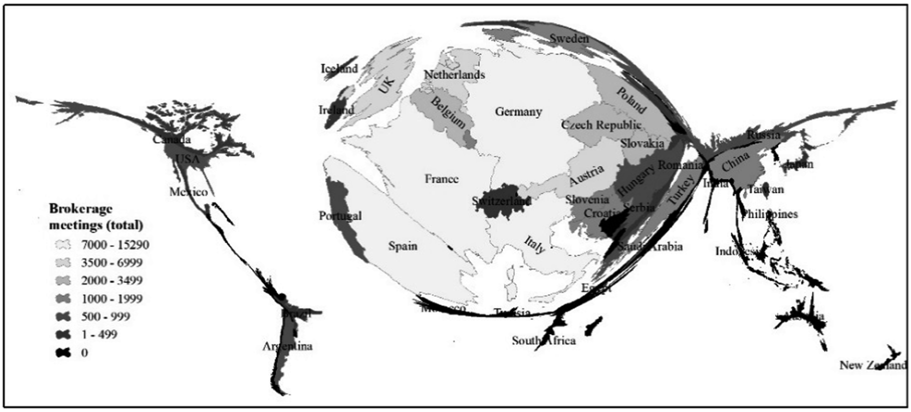

Fig. 1. Brokerage meetings of the agri-food sector organized by the EEN network between January and June 2017.

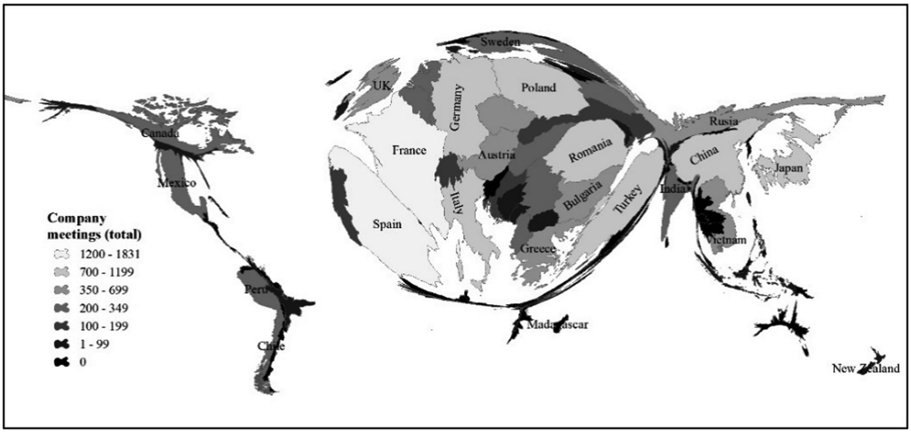

Fig. 2. Trade missions of the agri-food sector organized by the EEN network between January and June 2017

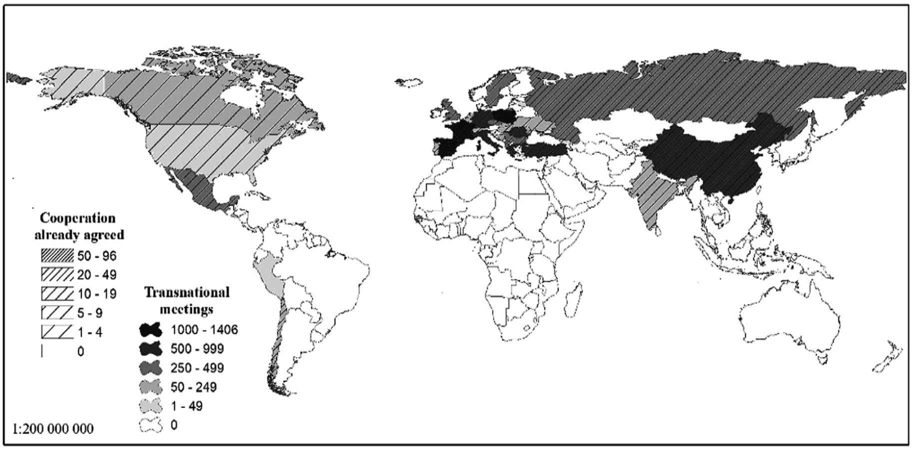

Fig. 3. Effectiveness of the trade missions and brokerage meetings of the agri-food sector organized by the EEN network between January and June 2017.

Poland, Romania and Turkey also ranked high in company missions. Most of the meetings had a transnational character, however only a few of them were fully international (Armenia – brokerage events; Armenia, Paraguay and Japan – company missions).

Very few meetings were concluded with a cooperation agreement, except company meetings in Chile (21%) and brokerage events in Moldova (8%). The effectiveness of company missions and brokerage events presented in Fig. 3 relates to the agreed collaboration and participation in international meetings. Spain, France and China remain leaders in this area. The amorphous cartograph presents the distribution of the effectiveness of the international activity of enterprises representing the agri-food sector.

4 Conclusions

There is no doubt that economic missions and brokerage meetings are among effective forms of promotion on international markets and support the establishment of technological cooperation of agri-food enterprises. These are the cost-conscious tools for enterprise development. Therefore, it is necessary to use public information tools to support the internationalization of economic activity. The EEN network is one of tools, which are subject of further research by the authors in terms of effectiveness.

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Examining Sources of Farmers' Knowledge as a Premise Behind Realization of the Smart Village Conception. A Case Study of Opole Region

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Abstract. The aim of the study is to point to the need of doing research on the system of agricultural knowledge and information as a premise behind realization of the conception of smart village in the territorial framework. Accepting the assumption that intelligent agriculture lies at the foundation of transformation of rural areas, the author indicates the role of the system of agricultural knowledge and information in the process of modernization of agricultural holdings. In the article, questionnaire-based survey research was used in relation to the sustainable development of agriculture in Opole Region. In order to assess the level of adaptation of agricultural holdings to economy based on knowledge, the author used the method of mapping the sources of knowledge and information related to farming. On its basis it was concluded that the examined farmers make use of a variety of sources to acquire knowledge and information, among them being traditional ones, agricultural counseling and Internet-based platforms. It is TV that still remains the main source of information concerning the domestic agricultural policy, whereas counselors provide knowledge on managing environment and requirements and standards connected with agricultural production in the EU. Internet platforms are winning farmers' greater and greater trust in all areas of knowledge and information which are indispensable for management of an agricultural holding today.

Keywords: Agricultural Knowledge and Information System · Smart village · Intelligent agriculture

1 Introduction

The conception of a smart village was born as a reflection on sustainable territorial development in the European Union [3, 15], similarly as it happened in the case of smart cities [1]. One can find a number of initiatives of creating smart villages in the global and European space, being described in the literature of the subject [18]. The new approach to a territory, which perceives not only its geo-economic features, allowed establishing infrastructural, social, human and information-oriented premises for "a better life in rural areas" [5]. It is an expression of the growing awareness of assets of a place and territory in spatial planning [7, 13].

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 313–320, 2019.
https://doi.org/10.1007/978-3-030-16542-0_39

Initially, sustainable development of rural areas was connected with the paradigm of their multifunctional development. Its implementation exposed the need for activating specific resources existing in rural areas and contributed to endogenization of their development, as well as searching for smartness of local structures [17]. In turn, fuller and fuller making use of the specific resources of rural areas enforced a change of the development paradigm from multifunctional to an integrated one which lays the emphasis on strategic planning of development and strengthening the principle of subsidiarity.

In the debate on the Common Agricultural Policy 2020 Plus, which has been carried out for some time now, the following questions are of key importance: its orientation towards results, new institutional frameworks for the principle of subsidiarity, resistant and smart agriculture, securing the continuity of all capitals existing in rural areas – in particular – the natural capital, which is the condition of supplying public goods by the country and agriculture. The European Commission suggests that the strategic plans of the CAP should be created in member countries on the basis of the goals which were negotiated for the whole integration group. As regards the environmental management, it is proposed that the requirements of the GAEC (Good Agricultural Environmental Conditions), greening, as well as agricultural-environmental and climatic programs should be concentrated in one packet of requirements and instruments defined and monitored on the national/regional level, with taking into consideration the ladder of sustainable development and features of ecosystems existing on the given territory. This change is expected to provide adjustment of actions to regional and local needs and also a greater supply of public goods. Systems of knowledge and information addressed to farmers and inhabitants of the country should offer effective support for undertaking modernization-related actions.

The system of knowledge and information related to agriculture, which serves to implement a well-thought-over (reflective) modernization of the country and agriculture is multifaceted and is becoming more and more complex. For a smart transformation of the country and agriculture it is indispensable to assess the position of individual sources of knowledge and information in a variety of different thematic areas which are vital to this process.

The appearance of smart villages requires interpenetration of different kinds of knowledge: scientific, expert and confidential local knowledge. In order to secure the right conditions for the process to develop it is necessary to equip rural areas with the infrastructure of broadband Internet. All the documents which deal with the conception of smart villages give this as an indispensable condition for its realization.

2 Aim, Subject and Methods of Research

The aim of the research is linking tasks connected with adaptation of agricultural holdings to the European model of agriculture and intellectual assets which are at the disposal of the holdings. These tasks relate to all the areas of sustainable transformation of agricultural holdings and, in particular: environmental requirements, requirements of quality relating to produce and agricultural sources, market connections of farms and possibilities of entering into contracts, diversifying agricultural activity, support instruments of the CAP, as well as the national policy of the state. The subject of the research is the system of knowledge and information with reference to agriculture (Agricultural Knowledge and Information System - AKIS). It is the most often defined as "a set of agricultural institutions and organizations and/or persons, as well as liaisons and interactions between them, engaged in creating, collecting, selecting, processing, passing and using knowledge and information in order to develop sustainable agriculture through support of taking decisions and solving problems" [12]. The system stems from a number of sources. Each of them builds its thematic profile in a different manner. The position of individual sources in the system, on the other hand, depends on the farmers' trust in the knowledge and information which the given source renders available. This is a peculiar characteristic of a reflective modernization. The impact of the scientific and expert knowledge on farmers' decisions depends on the degree of active trust that is placed in the types of knowledge. In turn, the trust is dependent on the institutional environment and structures of co-management.

Sources of agricultural knowledge and information were made the subject of studies within a cyclical research project dealing with sustainable development of family-run trade agricultural holdings based in Opole Province. The primary material for the studies came from the questionnaire-aided interview with 100 managers of agricultural holdings, conducted in 2014 and 2018 in communes which are representative of the intensive and medium-intensive agriculture. The research was carried out with the use of the same population of respondents selected on purpose. The changes concerned merely the liquidated holdings. The average size of agricultural holdings in 2018 amounted to 51 ha of arable land (in 2014 - 47 ha of arable land). The average age of the proprietor in 2018 is 46 years (compared to 45 in 2014). Managers of trade agricultural holdings possess high professional qualifications and as regards their education the following were found out: 13% (in 2014 – 11%) hold higher education, 47% (in 2014 - 49%) – secondary education, 38% – vocational and 2% - elementary, respectively in the years under examination.

In their studies on the agricultural knowledge and information, the authors applied the mapping method. The conception of making use of a map of knowledge as a tool to locate sources of knowledge was put forward by M. Epler in the 1990s. Then, it was popularized by, among others, Probst, Raub and Romhardt [14]. This method proves of key significance to realization of the idea of a smart village, since it can be applied to implement the project of smart agriculture and also is indispensable to secure its stability. Nowadays, the method of mapping knowledge and its sources is gaining acclaim from a larger and larger group of researchers who deal with the question of transfer of knowledge (KT) in agriculture. It is applied, among others, to make evaluations and inventories of the institutional structure of the agricultural counseling system in 27 countries of the EU [8]. Mapping sources of knowledge is widely used today in research of the role of ITC in the development of agriculture [11]. There are also attempts made to examine transfer of knowledge on the territorial level [10].

3 Research Results and Discussion

The agriculture in Opole Region has been covered by the Common Agricultural Policy which changed its institutional matrix, especially with reference to the area of managing the environmental function. At the same time, the formal norms of the new CAP have clearly corresponded to the informal ones rooted in the consciousness of the population inhabiting the rural areas of the region. The institutional equilibrium which developed in the wake has translated into the readiness of farmers to implement ecological modernization. Simultaneously, the area-related premiums (direct payment) paid out to farmers were acknowledged as an adequate instrument of managing income risk, which allowed introducing changes in the organization of production, chiefly: simplifying the structure of crops and deepening specialization [2]. Consequently, the intensification of production and environmental management have delineated the area of strategic choices made by managers of agricultural holdings functioning in Opole Province. This type of agriculture development strategy is frequently defined as sustainable intensification [9]. Its realization assumes "more knowledge per one hectare" [4, 16]. In the long-term perspective for farmers in Opole Region the technological optimization of production and acquiring knowledge make the principal autonomous targets of their economic activity. As regards operational management, the farmers make use of different sources of knowledge and information.

As far as the method of mapping sources of knowledge is concerned, it is vital to both indicate the main sources of information and define thematic areas relevant to effective managing a production entity. Thus, selection of the source of knowledge and information is decided by: current validity of the thematic area and preceding processes of learning. Mapping the sources of knowledge takes into account thematic areas connected with: market information, agricultural policy, environmental norms, transaction process and quality requirements. In the 2018 research edition, this catalogue was expanded with the following: information on the existence of pathogens (indispensable in integrated plant protection) and information on climatic threats.

Comparing the research results obtained in 2014 and in 2018, it is possible to notice changes in the significance of the individual areas of information (see Table 1). In 2014, the farmers concentrated mainly on market information (the first place in the ranking list), processes of adjustment to the EU requirements (which resulted primarily from the "greening CAP" – ranking the second), the national agricultural policy (the third place), CAP support instruments (ranking the fourth), as well as information on new varieties of plants and breeds of animals (the fifth place). In contrast, in 2018, due to the growing uncertainty connected with institutional, technological, income and climatic risks, the first places in the ranking list of thematic areas were taken by: the national agricultural policy, CAP support instruments, market information, information on indispensable processes of adjustment to the EU requirements and that on climatic threats. On the basis of the presented ranking of information looked for it is possible to propose the thesis that modernization processes in agriculture demand institutional support of the agricultural policy to a greater and greater extent.

Table 1. Areas of thematic knowledge and information according to their importance to farmers.

Information/knowledge	Place in the ranking	
	2014	2018
Market information	1	3
CAP support instruments	4	2
Principles of good farming practice and SMR (Statutory Management Requirements)	8	9
Ability to enter into contracts	12	11
Legal knowledge	7	8
National agricultural policy	3	1
Information on new varieties of plants and breeds of animals	5	6
Information on necessary processes of adjustment of the holding to requirements (standards) binding in the EU	2	4
Information of quality requirements set with reference to raw materials and agricultural produce	11	10
Information on the possibility of production of renewable energy	6	–
Information on climatic threats	–	5
Information on the occurrence of pathogens and protective actions	–	7

The changes in the system of agricultural knowledge and information are significant as well. In the network which the system forms, it is mainly the positions of individual sources of knowledge which undergo changes (see Table 2).

Table 2. Ranking of sources of information and knowledge according to their significance to farmers.

Source of information/knowledge	Place in the ranking	
	2014	2018
TV	1	1
Radio	6	7
Agricultural counselors	4	3
Magazines	3	4
Training courses	5	6
Commune workers	10	10
Employees of cooperative banks	12	12
County Department of Agricultural Market Agency	11	11
County Department of Agency of Development and Modernization of Agriculture	8	8
Information from neighbors	9	9
Internet	2	2
Sales representatives	7	5

On the basis of the data in Table 2, it can be concluded that the significance of expert knowledge is on the rise. It is available on TV, the Internet, from agricultural counselors, in magazines, from trade representatives and during training courses.

Studies on rooting of the system of agricultural knowledge and information in the social networks of farmers in Opole Region have been carried out since 2008. A comparative analysis of the individual editions of the research points to the growing importance of the Internet as a source of knowledge and information. It was found out in the research of 2018, for example, that all the households of the examined farmers have access to the Internet. It is not used as a source of knowledge and information related to agriculture by mere 9% of the respondents. They are farmers at the age of 60 and more, who own holdings of 10–15 ha. On the other hand, the Internet was indicated as the main source of information in all thematic areas primarily by young farmers and the owners of holdings, who begin implementing a new specialization. Figure 1 presents main sources of information, in particular, the thematic areas limited to six basic “knowledge islands”.

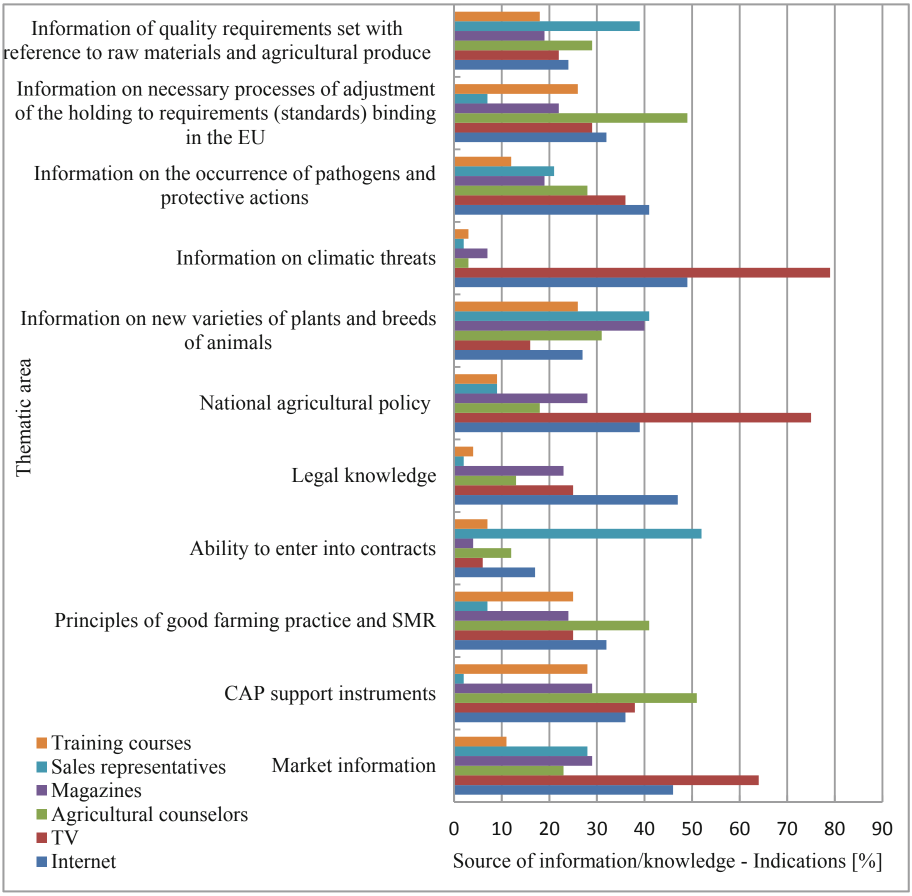

Fig. 1. Main sources of information and knowledge according to the thematic areas in 2018.

Farmers use the Internet to search mainly for legal knowledge and information on the appearance of pathogens. The Internet is also a source of market information, knowledge related to good agricultural and environmental practices, information on possibilities of entering into contracts. Comparing the research results obtained in Opole Province with similar studies carried out in Masovia [6] proves that farmers' preferences relating to sources of knowledge and information searched for on the Internet differ from region to region.

Smart agriculture means agriculture which is able to manage knowledge and information in operational activity. The high position of Internet platforms, agricultural counselors and magazines among the sources of knowledge can make a premise of smart modernization of agricultural holdings in Opole Province. This conclusion concerns mainly young farmers and holdings searching for new specializations.

4 Conclusion

Realization of projects of "smart village" is not possible without smart agriculture. Such a direction of its modernization requires making constant improvement to the AKIS, further informatization of rural areas, as well as new technologies which secure a green economic growth.

Knowledge – to be capable of having an impact on processes of farmers' decision taking – requires active trust on the part of the interested. To a greater degree this is trust in institutions dealing with dissemination of knowledge and information and to a lesser extent – a result of its critical analysis.

On the basis of research conducted in Opole Province it can be observed that TV maintains its leading position in such thematic areas as: market information, the national agricultural policy and information on climatic threats. Agricultural counselors are also a reliable source of information relating to principles of good farming culture and information on indispensable processes of adaptation to the requirements of the CAP. As far as modernization of agriculture based on knowledge is concerned, the relevance of sales representatives is increasing: it is they who, owing to additional services, provide knowledge on possibilities of entering into contracts, offer information on new varieties of plants and breeds of animals, as well as deliver information on requirements of quality which must be met by agricultural produce.

In comparison with the earlier research, the position of the Internet as a source of knowledge and information has changed qualitatively. This is the most universal source of information used in operational activity. The Internet is the main source of legal knowledge and information indispensable to manage integrated protection of plants. This medium occupies the leading position as regards the other thematic areas, as well.

It is possible to conclude, too, on the basis of the conducted studies, that the AIKS, on being expanded with virtual platforms of cooperation between academic centers, implementation centers and farmers, will have made a significant factor in transformation of traditional and modernized agriculture into smart agriculture in the future.

Agriculture definitely has a chance to be an attractive place of work if it is smart agriculture, that is if it makes use of information-telecommunications technologies in agricultural production and in organization of transaction process to a greater extent.

These technologies can change the character of work in agriculture in a dramatic way and contribute to the appearance of new business models. Smart agriculture provides a chance of a better use of the resources that rural areas have to offer and makes the beginning of transformation of the European space in the direction of discovering its local intelligences. Systematic examination of knowledge transfer in agriculture in European regions makes a significant premise of this process. The evaluation of the system of agricultural counseling on the level of European Commission [8] offers considerable support for this type of research.

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Agricultural Producer Groups as an Example of Commercial Organizations in the Agricultural Sector

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Abstract. The paper analyzes the conditions for the functioning of agricultural producer groups, which are a modern example of commercial activity in the agricultural sector. Based on the available static data, the growth dynamics of the number of business entities in question was determined, i.e. approx. 120 newly formed groups on average annually. Production of pigs, grains or oilseeds, and poultry was the dominant production in the grouped agricultural enterprises. The analysis allows to conclude that the form of cooperation of agricultural producers presented in the work undoubtedly favors the improvement of the market competitiveness of agricultural producers, and this is the main objective of any commercial organization. Thus, contemporary formalized forms of cooperation between agricultural producers bear many common features attributed to enterprises from other sectors of the national economy.

Keywords: Cooperation of agricultural producers · Agricultural producer group · Agricultural production

1 Introduction

The task of agricultural producers is to produce enough food to meet the needs of the population. In the current economic reality, the problem is not to produce it, but to find regular customers who will provide adequate payment. It is difficult for an individual Polish producer to prepare large volumes of high quality, reproducible produce for sale at the lowest possible price, while ensuring continuity of supply, product promotion and profitability of production. In addition, the weakness of individual producers is the inability to negotiate terms and the sale price of manufactured products [11, 12]. The producer often becomes a minor client of processing plants. Individual producers may

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 321–327, 2019.
https://doi.org/10.1007/978-3-030-16542-0_40

strengthen their position by organizing themselves into groups. By joining this form of economic activity, producers gain a stronger position against potential buyers of their products and, above all, a competitive advantage on the. Poland's agrarian structure is characterized by high fragmentation. Almost 70% of agricultural enterprises have less than 5 ha of area [4]. Linking the agricultural enterprise with the market resulted in the need to adapt its production to the demands of competition, and therefore the need to introduce more and more modern technologies. Currently, agricultural enterprises are at different stages of development, both in Poland and worldwide. The higher the level of development, and the closely related the enterprise is with the market, the more often there is cooperation between producers, mainly to improve the economic efficiency of management. One of the examples of these activities is the observed dynamic development of agricultural producer groups, which are a manifestation of the development of entrepreneurship among producers. As a result, emerging producer groups are an example of commercial organizations in the agricultural sector.

The aim of the paper is to address the conditions for the functioning of agricultural producer groups, which are a modern example of commercial organizations in the agricultural sector. Based on available statistical data, the level and directions of development of the agricultural producer groups in question were presented. Based on the literature study and the knowledge gained so far in the course of authors' long-term research on groups of agricultural producers, the benefits for agricultural producers resulting from organizing in and associating with commercial organizations, which are emerging groups of agricultural producers, were indicated.

2 Development of Cooperation Between Producers in the Agricultural Sector

The cooperative movement in Poland has a rich tradition, dating back to the second half of the 19th century. In the socialist era, agricultural cooperatives were among the flagship slogans of state policy towards agriculture, although their form was slightly degenerate. At the end of the 1980s, the share of cooperatives in the purchase of agricultural products was over 60%. Following the change of the economic system to capitalism, the role of the cooperative was significantly weakened (the share of cooperatives in the purchase of produce dropped to several percent). In the 1990s, actions were undertaken to change the cooperative system in Poland and to support other forms of self-organization of producers. An important attempt to encourage agricultural producers to form groups in the free market economy was taken in 2000 by adopting the Act on Agricultural Producer Groups and their Associations [4]. In principle, in each of the subsequent EU and national aid programs that have been important for Polish agriculture, starting from 4 PHARE and SAPARD, to RDP 2004–2006, 2007–2013 to the currently implemented RDP 2014–2020, part of the support was addressed to groups of agricultural producers. At present, individualism, i.e. a strive to ensure independence, still prevails in Poland, but unfortunately it usually takes place at the expense of an appropriate position on the market. In this situation, more potent buyers and production suppliers often dictate the conditions. This situation was observed, e.g. in the 1980s in the former EU-15 countries, where the weaknesses of family farms, both material and social, were revealed, as a result of technical progress and growing civilization requirements. Similarly to the current situation in Poland, the producers had difficulties selling their products and modernizing the technical base. In the 1970s and 1980s in Germany, an increase in the bargaining position on the recipient side was observed, which was not accompanied by a similar concentration on the side of agricultural producers [2]. This situation has led to attempts to seek new organizational and legal forms that would allow leveraging the effects of technical progress while maintaining the family character of the agricultural enterprise [6, 7]. This eventually led to the development of group activity and the emergence of formalized forms of cooperation between agricultural producers. The actions taken significantly improved, e.g. agrarian structure in these countries [9].

3 Material and Method

The analysis carried out in the study was based on statistical data obtained from reliable sources, i.e. the public databases of the Agency for Restructuring and Modernization of Agriculture and the National Network of Rural Areas. The work uses the descriptive-comparative method; the analysis of conditions includes current guidelines for the functioning of agricultural producer groups in Poland, To determine the level of development, the time period from 2001 to 2014 has been taken into account.

4 Discussion and Results

Agricultural producers organize into groups in accordance with the provisions of the Act of 15 September 2000 on Agricultural Producer Groups and their Associations and amendments of other acts (Journal of Laws No. 88, item 983, as amended). In order for a producer group to be created, the following requirements must be met, consisting of stages such as: A founder's meeting; Registration of the group as an entrepreneur; Registration of the group as a company; Preparation of agricultural producer group action plans; Entry of the producer group in the Marshall's Office register; Financial aid for a group of agricultural producers to establish and support their administrative activities.

The decision on choosing the business form requires analyzing the possibilities that are acceptable in the national law and choosing the one that best suits the nature of the producer group's activities. According to the Polish law, a producer group is free to choose the legal form in which it will operate, which will be the most advantageous. Agricultural producers have a choice of joint activities in the form of: cooperatives, companies, unions and associations (Table 1).

Table 1. Available legal forms under which producer groups can function in the Polish legal system.

Specification	A cooperative	A LTD company	A union	An association
The nature of the organization	Economic but also social	Any	Socio-professional, but also economic	Social
Area of operation	No restrictions	No restrictions	Republic of Poland	No restrictions
Members of the organization	Natural and legal persons	Natural and legal persons	Natural persons	Natural persons
The number of founding members	At least 5 natural persons	1 and more	At least 10 natural persons	At least 15 natural persons

Source: [11]

For comparison, Table 2 presents the criteria for recognition of producer organizations in selected EU countries.

Table 2. Criteria for recognition of producer organizations.

Member country or individual regions	Minimum number of members	Minimum value of commodity production (ECU million**)
Belgium, Germany, Spain (except the Balearic and Canary Islands), France, Greece*, Italy, the Netherlands, Austria, the United Kingdom (except Northern Ireland)	40 or 10 or 5	1.5 or 2.5 or 3
Denmark, Ireland, Northern Ireland, Greece*, Balearic Islands and Canary Islands, Portugal (except Madeira and the Azores)	15 or 5	0.5–1
Finland, Sweden, Greece (regions other than those listed above)	10 or 5	0.25 or 0.5
Greece (islands), Luxembourg, Madeira and Azores	5	1

*Separate individual regions of Greece; ** unit of account in the European Monetary System (replaced by the euro in a ratio of 1 ECU = 1 EUR on 1 January 1999) Source: [9]

As other business entities, producer groups are required to register in the business register in the National Court Register. The next step is to report to the Statistical Office and obtaining the National Business Registry Number (REGON) number. After obtaining the entry in the National Court Register, the group becomes a business entity. This does not mean, however, that it is a producer group in a proper sense. In order to obtain this status, the group needs to enter the register kept by the Marshall's Office competent for the headquarters of the group. However, before a group can submit a registration application, it must prepare a Group Action Plan. The group's action plan is an important document defining the directions of the group's activities for at least 5 years. Properly constructed, this document will allow for efficient and effective achievement of the group's assumed goals and will ultimately contribute to its economic success. An action plan is a document consisting of two parts: descriptive and financial. The descriptive part should contain basic information about the business, such as name or address, as well as a description of its activity (the company's objective, directions of development for the company as a whole and for individual holdings, characteristics of the company's managers, planned scale of production of the member holdings and their sales volume, investment plans, investment action schedule, investment financing structure) and a marketing plan (objectives, market analysis, pricing, product, distribution, promotion and advertising strategy). The second part of the action plan is the financial part in which the amount of capital needed for the group's functioning and sources of financing is indicated. The plan should be a roadmap of the group's activities; its final content will depend on the requirements set by the law for members of the group. The more precise the information it contains, the greater the chances of effective cooperation between the group members, which will ultimately contribute to the success of the venture.

5 Financial Aid for Groups of Agricultural Producers to Establish and Support Their Administrative and Investment Activities

According to art. 35 of the European Council Regulation No. 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) (OJ L 277/1, 21.10.2005, as amended), support is provided to facilitate the creation and administrative operation of producer groups. However, according to the opinion of the European Commission, this support may also be used for investment purposes, as long as the group pursues the objectives of setting up the groups defined in art. 35 of the European Council Regulation No. 1698/2005. At the same time, the amount that can be allocated for investments depends on the group's decision. The purpose of creating an agricultural producer group is to adapt agricultural production to market conditions and jointly introduce goods to the market. This includes preparation for sale, improvement of management efficiency, production planning with particular emphasis on its quantity and quality, concentration of supply and organization of sales of agricultural products (centralization of sales and deliveries to wholesale customers), as well as protection of the natural environment, and establishing common rules for information on production, with particular reference to the collection and availability of products. A producer group creates new opportunities for farmers and contributes to: - improving product quality through the use of a uniform production technology; - creating a visible brand of goods; - reduction of production costs through joint purchase of production means; - the possibility to select contractors and negotiate prices with them; - eliminating brokers; - the possibility of using a common machine park; - ensuring a homogeneous breeding material; - creating the possibility of exchanging information in terms of production and technology; - providing jobs in rural areas; - establishing common rules regarding production information, with particular reference to harvesting and production availability; - raising production standards; -

rationalization of storage and distribution costs [6, 11, 13, 14]. As on Dec 31, 2014, 1,351 groups of agricultural producers were entered in the registers kept by voivodship marshals, of which 65% operate as limited liability companies, 31% in the form of cooperatives, 3% as unions, and 1% as associations. The number of registered groups is growing; in 2010, 157 groups were registered, in 2011, 227 groups were registered, in 2012-242, and in 2013-486. Currently, most groups of agricultural producers operate in the following voivodships: Wielkopolskie (419 groups), Dolnośląskie (130 groups) and Kujawsko-Pomorskie (123 groups). The least organized are agricultural producers in the Świętokrzyskie and Małopolskie voivodships, where the number of groups is the lowest, i.e. 15 and 19, respectively. Agricultural producer groups are most often established by the producers of pigs, cereal or oilseeds, and poultry. Pig producers are organized in 312 groups, producers of cereal or oilseeds in 307 groups, poultry producers in 274 groups, and producers of cereal in 100. Producers of milk formed 102 groups, producers of oilseeds - 69, of cattle - 56, and of potatoes - 33. In other industries, organization is low, below 10. The most numerous are groups of tobacco producers (11 120), of pigs (4 948), of milk (4 170), of cereal or oilseeds (2740) and of poultry (1 496). In total, all groups of agricultural producers in Poland associate 27 878 members.

6 Conclusions

The observed development of agricultural producer groups is an example of strengthening of the institutional structure in the primary agricultural production sector. Supporting the cooperation of agricultural producers by encouraging them to create producer groups translates into their activation in terms of creating commercial organizations [1, 7]. The above-mentioned considerations may indicate that, in particular, the purpose of the groups is to adapt the production of the associated agricultural holdings to market requirements, to jointly bring goods on the market, including preparation for sale, centralization of sales and delivery to wholesale customers [3, 10]. The described form of cooperation of producers undoubtedly favors the improvement of market competitiveness, and this is, among other things, the objective of any existing commercial organization. Thus, contemporary formalized forms of cooperation between agricultural producers bear many common features attributed to enterprises from other sectors of the national economy [15]. However, in order for the development of agricultural producer groups to continue, actions should be taken to raise the awareness of individual producers regarding the benefits that come from membership in an agricultural producer group, which may include: 1. Improved production planning and adapting it to the needs of recipients; 2. Reduction of production costs in the agricultural holding through joint purchases of means of production, joint use of equipment, preparation of products for sale and organization of sale; 3. Improved access to information; 4. Greater investment opportunities thanks to the combination of capital.

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The Measurement of Sustainable Development Level in the Aspect of Selection of Indicators and Measurement Methods

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Abstract. The idea of sustainable development appeared several decades ago and was a response to the growing environmental problems associated with the irrational natural resources management, conducted, in particular, by highly developed countries. Despite many local and international efforts, the list of universal indicators monitoring sustainable development, applicable both to developed and developing areas, has not yet been clearly defined. No specific methods for measuring sustainable development, which would allow for objective determination of the level of sustainability and the direction of its course, have been specified. The paper indicated the possibility of diversifying research results resulting from the adopted method of specification of sustainable development indicators and the applied method of measuring the level of sustainability, which may lead to unreliable results. A set of 71 indicators was employed and the various areas of sustainable development were described synthetically, i.e. the social, economic, environmental and institutional-political domains. The linear ordering of provinces was performed using their taxonomic distance from the reference object. For comparative purposes and determining the direction of development, data from the years 2010 and 2016 were utilized.

Keywords: Sustainable development · Indicators · Methods · Problems

1 Introduction

The notion of sustainable development was originally defined in the UN document 'Our common future' in 1987 as such a development in which the needs of the current generation are satisfied without jeopardising the needs of future generations [5]. The very idea of sustainable development was the response to the growing environmental problems associated with the irrational exploitation of natural resources, a huge burden on the natural environment by pollution and negative effects of industrialization and mechanisation of agricultural production [1].

From the beginning of its development, the notion of sustainable development has been of interest to researchers from numerous areas of science. So far, however, they have been struggling to measure the development in all its spheres, i.e. social, economic and environmental, assuming that sustainable development should include

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 328–336, 2019.
https://doi.org/10.1007/978-3-030-16542-0_41

parallel activities in these three areas, without diminishing the importance of any of them. It has been noted that rich countries, which have achieved a high level of social and economic development, attach great importance to the protection of the natural environment. Poor countries, in turn, behave differently - the need to protect the natural environment is secondary in relation to economic and social needs [1, 9]. Taking the above into account, it can be concluded that countries with different levels of development are in different places in the process of sustainable development [4]. Therefore, the question should be asked about the assumption of the equal importance of all three domains in all circumstances. In addition, the question of identifying a point considered to be one in which development can be treated as sustainable arises. Until now, such a point or object has not been established, and the opinions of researchers are often radically divergent [2, 6].

According to the International Institute for Sustainable Development [3], there are 173 indicators defining the level of sustainable development. These indicators are used in different countries. In Poland, according to the CSO (GUS) study from the year 2015, 101 indicators were distinguished to monitor sustainable development in four domains and 24 areas [10]. The choice of indicators to the national list was determined by the degree of compliance with the definition and significance of the indicator for sustainable development. Phenomena which were special and particularly important for Poland were also taken into account. It should be underscored that for some indicators, it was not determined whether it was a driver, i.e. it promoted sustainable development or an inhibitor. Treating the indicator as a driver or an inhibitor arises then from the subjective assessment of its importance and different interpretation resulting from it.

It was assumed that the increase in the value of the synthetic index indicates a balanced direction of development. In the analyzed period, both changes towards the balancing of development and in the opposite direction were shown. Methodical inaccuracies related to the measurement of sustainability were pointed out. Different methods of classifying areas due to the sustainability of development, presented in the study, lead to ambiguous research results. The ranking of the researched areas varies depending on whether it was determined by adopting the average value of the synthetic sustainable development index or by using the classification-point method.

2 Aim, Material and Method

The aim of the study is to present differences in the assessment of the degree of sustainable development of Polish provinces, depending on the interpretation of individual indicators adopted for research that monitor the development. The aforementioned interpretation concerned, in particular, the fact whether the indicator was treated as a driver or an inhibitor of sustainable development and the problem of treating the indicator as the one which would monitor a specific domain. To compare the data, the research was based on statistical data from the year 2010 and the year 2016.

First, the values of the synthetic indicator of sustainability level were presented in accordance with the classification of indicators adopted by the Central Statistical Office [10]. Then, after a detailed analysis of the indicators, the grouping was modified. For example, the indicator of the number of cars per 1000 inhabitants, treated in social domain as a driver, was perceived as an inhibitor in the environmental domain. Similarly, the indicator of water consumption in households per capita per year in the social domain was a driver, while in the environmental domain it was an inhibitor. Table 1 presents a detailed breakdown of changes introduced in the classification of sustainable development indicators.

Table 1. Changes introduced in the classification of sustainable development indicators.

Indicator according to CSO classification	Indicator according to modified classification
Social domain: 1. Number of cars per 1000 inhabitants (stimulant) Social domain: 2. Water consumption in households per capita per year (stimulant) Social domain: 3. Average meat consumption per capita per month (stimulant) Social domain: 4. Crimes identified by the police in completed preparatory proceedings per 1000 inhabitants (inhibitor)	Environmental domain: 1. Number of cars per 1000 inhabitants (inhibitor) Environmental domain: 2. Water consumption in households per capita per year (inhibitor) Environmental domain: 3. Average meat consumption per capita per month (inhibitor) Environmental domain: 4. Crimes identified by the police in completed preparatory proceedings per 1000 inhabitants (stimulant)
Economic domain: 1. The length of expressways and motorways per 100 km^2 (stimulant) Economic domain: 2. The average price of a one-way normal ticket for a city bus (stimulant) Economic domain: 3. Consumption of mineral fertilizers per 1 ha of agricultural land (stimulant) Economic domain: 4. Presence of large livestock units per 1 hectare of arable lands (stimulant) Economic domain: 5. Share of large farms in the total number of farms (stimulant)	Environmental domain: 1. The length of expressways and motorways per 100 km2 (inhibitor) Environmental domain: 2. The average price of a one-way normal ticket for a city bus (inhibitor) Environmental domain: 3. Consumption of mineral fertilizers per 1 ha of agricultural land (inhibitor) Environmental domain: 4. Presence of large livestock units per 1 hectare of arable lands (inhibitor) Environmental domain: 5. Share of large farms in the total number of farms (inhibitor)
Environmental domain: 1. Share of Natura 2000 areas in total area (stimulant) Environmental domain: 2. The share of legally protected areas in the total area (stimulant) Environmental domain: 3. Amount of mixed municipal waste collected by households per capita per year (inhibitor)	Economic domain: 1. Share of Natura 2000 areas in total area (inhibitor) Economic domain: 2. The share of legally protected areas in the total area (inhibitor) Economic domain: 3. Amount of mixed municipal waste collected by households per capita per year (stimulant)

The assessment of sustainability level of provinces was carried out employing a synthetic measure, which was the basis for the creation of rankings [7, 8]. The determination of the synthetic measure of development was preceded by the normalization of variables according to the formula:

$$x_{ij}^{'} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \tag{1}$$

where:

x'_{ij} - the value of the transformed (normalized j-th diagnostic feature of sustainable development in the i-th object (province),
x_{ij} - the actual value of the j-th diagnostic feature of sustainable development in the i-th object,
min_{xj} - the minimum value of the j-th feature of sustainable development,
max_{xj} - the maximum value of the j-th feature of sustainable development.

This transformation resulted in the values of features being in the range [0; 1]. The examined indicators were treated as drivers or inhibitors of sustainable development, whereas the substitution of inhibitors for drivers was made employing the following formula:

$$x_{ij}^{'S} = \frac{1}{x_{ij}^{'D}} \tag{2}$$

where:

$x_{ij}^{'S}$ - sustainable development driver obtained by transforming inhibitors $(x_{ij}^{'D})$ of the development.

The reference object was such an object that was characterized by the highest values of drivers and the lowest values of inhibitors.

The synthetic measure of sustainable development of i-th object (province) was determined using the formula:

$$d_i = 1 - \frac{d_{i0}}{d_0} \tag{3}$$

where:

$$d_{i0} = \left[\sum\nolimits_{j=1}^{p} \left(y_{ij} - y_{0j}\right)^2\right]^{\frac{1}{2}} \tag{4}$$

is the Euclidean distance of the i-th object from the reference object, while d0 is the distance between the pattern and the antipattern. The antipattern is characterized by the lowest values of drivers and the highest values of inhibitors [7].

The analysis of the level of sustainability was carried out for the years 2010 and 2016.

3 Findings

Table 2 presents the calculated values of the synthetic indicator for all domains (social, economic, environmental and institutional-political), taking into account the classification of the Central Statistical Office. It was assumed that the increase in the value of the synthetic indicator denoted a sustainable direction of development. Based on the data presented in Table 2, it can be stated that in the analysed period the changes both towards sustainable development (an increase in the value of the synthetic index) and in the opposite direction (a decrease in the value of the synthetic index) were evident.

Table 2. The values of the synthetic sustainable development indicator (d_i) of provinces according to domains (dimensions) in the years 2010 and 2016 determined on the basis of the classification of indicators consistent with the Central Statistical Office.

Province	Social domain d_{is}			Economic domain d_{ig}			Environmental domain d_{ie}			Institutional-political domain d_{ip}		
	2010	2016	Change	2010	2016	Change	2010	2016	Change	2010	2016	Change
Dolnośląskie	0.36	0.45	0.09	0.36	0.40	0.04	0.26	0.24	−0.03	0.45	0.53	0.08
Kujawsko-Pomorskie	0.38	0.37	−0.00	0.31	0.32	0.01	0.36	0.35	−0.02	0.35	0.34	−0.01
Lubelskie	0.32	0.36	0.03	0.22	0.24	0.02	0.32	0.32	−0.01	0.25	0.27	0.03
Lubuskie	0.38	0.38	0.00	0.29	0.31	0.02	0.41	0.42	0.01	0.40	0.41	0.01
Łódzkie	0.40	0.40	0.00	0.28	0.34	0.06	0.23	0.21	−0.02	0.38	0.46	0.08
Małopolskie	0.49	0.47	−0.02	0.32	0.34	0.02	0.33	0.28	−0.05	0.26	0.37	0.11
Mazowieckie	0.46	0.46	−0.00	0.40	0.43	0.03	0.25	0.26	0.01	0.27	0.27	0.01
Opolskie	0.44	0.42	−0.01	0.32	0.30	−0.02	0.25	0.27	0.01	0.49	0.52	0.03
Podkarpackie	0.24	0.27	0.03	0.24	0.25	0.00	0.47	0.44	−0.03	0.34	0.35	0.01
Podlaskie	0.39	0.40	0.01	0.20	0.23	0.03	0.46	0.43	−0.03	0.29	0.27	−0.02
Pomorskie	0.50	0.51	0.01	0.44	0.45	0.01	0.33	0.34	0.01	0.36	0.39	0.03
Śląskie	0.44	0.47	0.04	0.36	0.34	−0.01	0.24	0.21	−0.03	0.35	0.36	0.00
Świętokrzyskie	0.26	0.29	0.03	0.24	0.16	−0.08	0.27	0.28	0.01	0.46	0.34	−0.12
Warmińsko-Mazurskie	0.32	0.29	−0.03	0.25	0.17	−0.08	0.48	0.42	−0.07	0.46	0.31	−0.15
Wielkopolskie	0.54	0.53	−0.01	0.39	0.39	0.00	0.35	0.30	−0.05	0.42	0.45	0.03
Zachodnio-Pomorskie	0.34	0.39	0.04	0.31	0.31	−0.01	0.31	0.30	−0.01	0.45	0.41	−0.04

Table 3 presents the calculated values of the synthetic indicator of sustainable development, determined applying modified, against the adopted by the Central Statistical Office classification, classification of sustainability indicators. In this case also, development was denoted both in the sustainable direction and in the opposite one. As a result of alternations in the classification of indicators, there were changes, which involved, inter alia, a change in the direction of sustainable development into the opposite or vice versa.

Table 3. The values of the synthetic indicator of sustainable development (d_i)) of provinces according to the domains (dimensions) in the years 2010 and 2016 determined in line with the modified classification of variables.

Province	Social domain d_{is}			Economic domain d_{ig}			Environmental domain d_{ie}			Institutional-political domain d_{ip}		
	2010	2016	Change	2010	2016	Change	2010	2016	Change	2010	2016	Change
Dolnośląskie	0.35	0.35	−0.01	0.37	0.41	0.04	0.30	0.29	−0.01	0.45	0.53	0.08
Kujawsko-Pomorskie	0.34	0.30	−0.04	0.28	0.29	0.01	0.33	0.34	0.01	0.35	0.34	−0.01
Lubelskie	0.31	0.31	−0.01	0.22	0.27	0.04	0.41	0.39	−0.02	0.25	0.27	0.03
Lubuskie	0.30	0.22	−0.08	0.26	0.28	0.02	0.38	0.39	0.01	0.40	0.41	0.01
Łódzkie	0.35	0.34	−0.02	0.29	0.35	0.06	0.28	0.26	−0.02	0.38	0.46	0.08
Małopolskie	0.49	0.42	−0.07	0.31	0.38	0.07	0.34	0.32	−0.02	0.26	0.37	0.11
Mazowieckie	0.49	0.43	−0.06	0.48	0.53	0.05	0.21	0.24	0.03	0.27	0.27	0.01
Opolskie	0.36	0.32	−0.04	0.33	0.31	−0.02	0.28	0.31	0.03	0.49	0.52	0.03
Podkarpackie	0.25	0.24	−0.01	0.24	0.25	0.00	0.50	0.44	−0.06	0.34	0.35	0.01
Podlaskie	0.36	0.34	−0.03	0.17	0.22	0.05	0.46	0.44	−0.02	0.29	0.27	−0.02
Pomorskie	0.45	0.38	−0.08	0.42	0.45	0.03	0.31	0.34	0.03	0.36	0.39	0.03
Śląskie	0.39	0.38	−0.01	0.40	0.39	−0.01	0.27	0.24	−0.02	0.35	0.36	0.00
Świętokrzyskie	0.22	0.18	−0.04	0.19	0.12	−0.08	0.31	0.35	0.03	0.46	0.34	−0.12
Warmińsko-Mazurskie	0.31	0.21	−0.10	0.19	0.13	−0.07	0.42	0.42	−0.00	0.46	0.31	−0.15
Wielkopolskie	0.42	0.37	−0.07	0.36	0.39	0.03	0.26	0.24	−0.02	0.42	0.45	0.03
Zachodnio-Pomorskie	0.33	0.27	−0.06	0.30	0.31	0.01	0.34	0.35	0.01	0.45	0.41	−0.04

Table 4 presents the ranking of provinces due to the level of sustainable development. The ranking was established on the basis of the mean value of the synthetic indicator from individual domains and by applying the classification and point method.

On the basis of the data included in Tables 2, 3 and 4 a correlation analysis was conducted between the variables describing particular domains in the years 2010 and 2016 employing classification of variables determined by the Central Statistical Office and the modified classification. The values of Pearson's linear correlation coefficients were calculated for the data in Tables 2 and 3 while the Spearman rank correlation coefficient was determined for the data in Table 4. The results of the above analyses are presented in Table 5.

Analysing the data in Table 5. it can be concluded that in the case of the social and economic domains. the changes in the Pearson's linear correlation coefficient are minimal. In the case of the environmental domain, however, there was a significant change in the value of the correlation coefficient. The positive value of the linear correlation coefficient in the case of the variable classification adopted by the Central Statistical Office indicated development in a sustainable direction. The modified classification of indicators, in the case of the environmental domain, indicates the opposite direction of development (negative value of the linear correlation coefficient), i.e. lack of sustainability in development of the natural environment. The analysis of Spearman's rank in none of the domains showed significant differences in the classification of provinces.

Table 4. Ranking of provinces and its changes based on the CSO classification and modified classification (the bottom row) according to individual domains in the years 2010 and 2016.

Province	CSO		Modified		CSO		Modified	
	2010				2016			
	Mean	Points	Mean	Points	Mean	Points	Mean	Points
Dolnośląskie	6	6	3	3	3	3	1	2
Kujawsko-Pomorskie	9	11	13	13	11	11	12	13
Lubelskie	16	16	15	16	15	15	14	14
Lubuskie	5	5	10	10	4	4	10	10
Łódzkie	13	13	12	12	8	8	7	7
Małopolskie	8	7	8	5	6	5	3	3
Mazowieckie	11	8	5	8	7	9	4	8
Opolskie	4	3	4	2	5	6	5	4
Podkarpackie	14	15	11	14	13	12	11	11
Podlaskie	12	12	14	11	12	13	13	12
Pomorskie	2	2	1	1	1	1	2	1
Śląskie	10	10	7	7	10	7	8	6
Świętokrzyskie	15	14	16	15	16	16	16	16
Warmińsko-Mazurskie	3	4	9	9	14	14	15	15
Wielkopolskie	1	1	2	6	2	2	6	5
Zachodniopomorskie	7	9	6	4	9	10	9	9

Table 5. Values of linear correlation of Pearson's and R Spearman's coefficient between the values of the synthetic indicator of the sustainability level and the ranking of provinces in the years 2010 and 2016 in particular domains.

Type of variable classification	Social domain		Economic domain		Environmental domain		Institutional-political domain	
	Pearson	R Spearman	Pearson	R Spearman	Pearson	R Spearman	Pearson	R Spearman
According to CSO	0.936	0.923	0.798	0.882	0.960	0.950	0.648	0.903
Modified	0.924	0.967	0.737	0.806	−0.661	0.871	0.648	0.903

4 Conclusion

Presented research results indicate significant difficulties related to measuring the sustainability of development. These difficulties result from the selection of appropriate variables whose criteria are not unequivocally specified. In addition, arbitrariness, caused by subjective assessments of researchers in qualifying variables to a specific area that monitors a specific domain, is evident. Also, it is not explicitly specified which of the adopted indicators are drivers and which are inhibitors of sustainable development. Maximum, minimal, and in particular optimal values of indicators were not set, which would clearly indicate the fact of sustainability. It should be stated that the same value of the monitoring indicator in different cases, i.e. in relation to different levels of development (social, economic, environmental, institutional-political) may be a driver or an inhibitor of sustainable development. The determined value of the indicator, depending on the level of socio-economic development, may be optimal, too low or too high.

Particular attention should be paid to the fact that the indicators being a driver of one of the domains are also an inhibitor of another domain. The inclusion of a specific indicator in the monitoring group of a particular domain should be determined, inter alia, by the general level of socio-economic development of a given area.

Different methods of classifying areas due to sustainable development, presented in the study, lead to ambiguous research results. The ranking of the surveyed areas varies depending on whether it was determined using the mean value of the synthetic indicator of sustainable development or using the classification and point method.

The observations presented above denote the necessity of adopting uniform standards referring both to the criteria related to the selection of sustainable development indicators, the unambiguous inclusion of indicators in the group which monitors specific domain, determining the value of optimal indicators which would monitor depending on the level of socio-economic development and the environmental condition of the area. In addition, there is a need to establish uniform methods for measuring sustainability which would clearly and objectively indicate the level of sustainability and the direction of changes.

Acknowledgements. This research was financed by Ministry of Science and Higher Education of the Republic of Poland.

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Environment Friendly Power Generation

Theoretical and Real Efficiency of Monocrystalline PV Modules in a 2-Year Cycle

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Abstract. This paper contains an analysis of operation of photovoltaic power plant in an annual cycle for years 2016 and 2017. Its operation began when the intensity of solar radiation exceeded the value of several dozen W/m^2 and lasted up to several W/m^2. During the energy conversion in PV power plant, the temperature of photovoltaic modules fluctuated in the range from −25 °C up to 67 °C.

Based on the data collected regression models have been developed that explained changes in the amount of electric energy generated in monocrystalline PV modules, depending on the available solar radiation energy and external temperature.

Keywords: PV plant efficiency · Photovoltaic energy · PV plant lifetime

1 Introduction

In recent years we have seen significant growth of interest in the use of solar radiation energy for generation of electricity, both among entrepreneurs, as well as private persons. In May 2018 the total installed capacity in PV amounted to ca. 300 MW, nearly 40% of which comprised systems licensed by Energy Regulatory Office. In the following years further development within this scope is planned, and according to experts from the Institute for Renewable Energy, the capacity of photovoltaic systems in 2020 should reach the level of 1.2 GW or even 3.2 GW (if the scenario in favour of reduction of costs of statistical transfer is implemented) [1].

Unfortunately, the installed capacity itself is not a good indicator, both for the energy sector, as well as the potential investors. When it comes to practical issues more attention is drawn to the scale of production of electricity in reference to the installed capacity.

Energy yield depends mainly on meteorological conditions in the PV power plant location and its structural parameters [2, 3]. Based on the conducted tests it results that energy yield from installed capacity unit may change in a broad range from 0.1 to 1.7 TWh/GW [4, 5].

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 339–344, 2019.
https://doi.org/10.1007/978-3-030-16542-0_42

2 Materials and Methods

The paper analysed the efficiency of 4.2 kWp photovoltaic power plant built of monocrystalline modules made with silicon technology. The modules of PV power were directed to the south and mounted at an angle of 32° in relation to the horizontal plane. The analysis was carried out for PV modules based on hourly time intervals for daily energy production. The research was carried out in a two-year cycle. This period covered the entire year 2016 and 2017. The analyses carried out concerned the theoretically available amount of energy possible to obtain in the PV power plant.

3 Results and Discussion

The monocrystalline panels used in the test were characterised by maximum capacity of 300 Wp and conversion efficiency of solar radiation energy at the level of 15.46%. However such values are obtained only for specific module operation parameters (1000 W/m^2 solar irradiance, 1.5 Air Mass, and cell temperature of 25 °C). In the real conditions photovoltaic panel operates within a very broad range of changes, both in the intensity of solar radiation, as well as the temperature of the cells. Based on the performed analyses it results that the analysed PV power plant commenced its operation when the intensity of solar radiation exceeded the value of several dozen W/m^2 and operated up to several W/m^2. Whereas the temperature of PV modules fluctuated in the range from −25 °C to 67 °C.

In order to illustrate the potential of available amount of solar radiation energy in the PV power plant location on the basis of multiannual data, accumulated amount of available energy was determined, but only for time periods, in which conditions for operation were fulfilled. The amount of energy determined on the basis of long-term observations was compared to the real data registered during the tests.

The carried out analyses suggest that within a year ca. 1130 kWh of solar radiation energy is available per each square metre of surface inclined at an angle of 30^{o} with the azimuth in southern direction. Most energy, above 50%, is available in the period of only four months of the year, i.e. from May until August. In the analysed two-year cycle slightly lower value of the annual availability of energy was observed when compared to the multiannual cycle, at the level of 1040 and 1074 kWh/m^2, accordingly.

On the basis of the information on the availability of amount of solar radiation energy allowing for generation of electricity in the analysed period of time, rated efficiency of energy conversion in PV panels and efficiency of inverters amount of electric energy available for the specific months of the year has been theoretically designated. Then its value was compered to the real production of electric energy.

The conducted simulation reveals that the real amount of electric energy obtained after its conversion into sinusoidal alternating voltage is lower than the theoretically available value by approx. 5–6 kWh/m^2 in the annual period. Increasing disparities between the expected and the observed level of energy production was visible over the summer months. Such a situation derives to a large extent from the change in efficiency of energy conversion in PV panels, depending on the intensity of solar radiation and operating temperature of PV cells (Fig. 1).

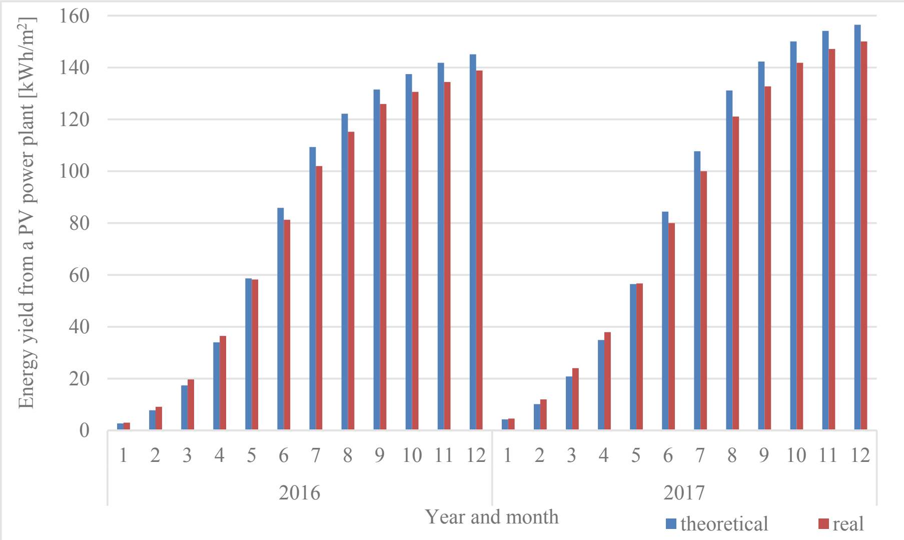

Fig. 1. Comparison of accumulated theoretical and real energy yield from monocrystalline panels in a two-year period

Based on the catalogue data of panels we may find that power generated by PV panels with the intensity of solar radiation of 300 W/m^2 amounts to only 30% of the nominal value that is obtained with 1000 W/m^2. The availability of solar radiation energy in the specific ranges is presented in Fig. 2.

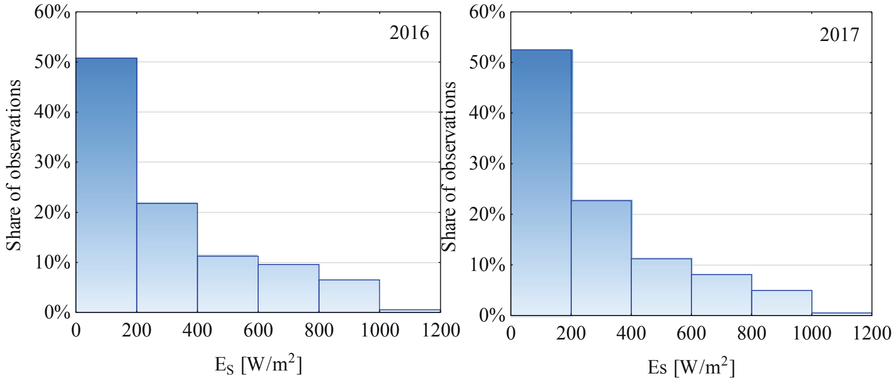

Fig. 2. Histogram of high rate of intensity of solar radiation

In the PV power plant location there are difficult conditions for work, due to the fact that approx. 60–70% of observations that describe the intensity of solar radiation are at the level below 300 W/m^2, for which it is possible to obtain only 30% of nominal capacity. The analysed PV modules could operate with capacity close to the nominal one for only few percent of the operating period.

Apart from the intensity of solar radiation, also the operating temperature of the cells influences the energy yield. The chart (Fig. 3) illustrates the dynamics of electricity production as expressed in kWh per unit of installed power in the PV power plant in 2016. The amount of generated energy was influenced mainly by the parameters of the solar radiation energy and the temperature of PV modules.

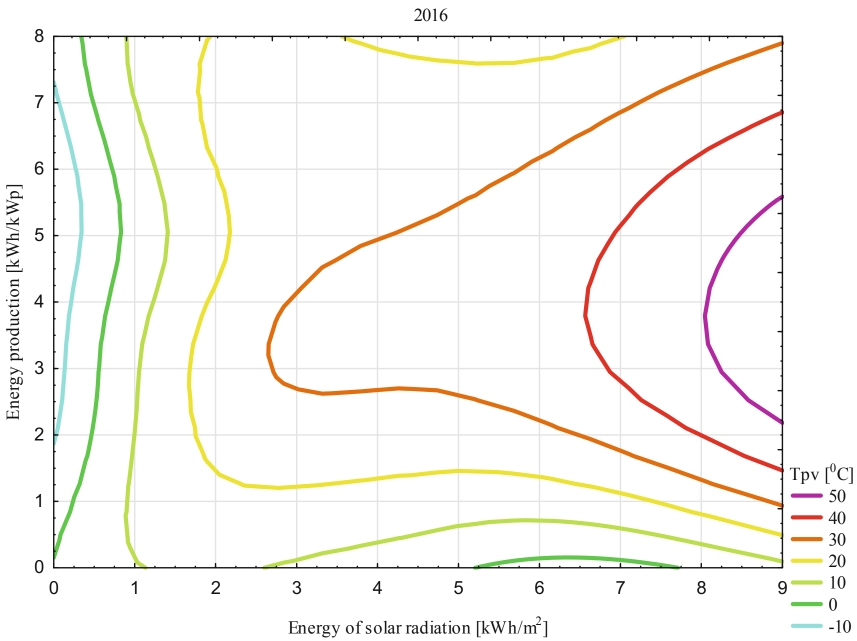

Fig. 3. Characteristics of electricity production dependent on the daily amount of available solar radiation energy and the temperature of the mono PV modules (2016)

An analogous characteristic was generated for operating conditions of PV power plant in 2017 (Fig. 4). While analysing the parameters presented in Figs. 3 and 4 it may be stated that modules made of monocrystalline silicon in 2017 were subject to lower thermal stress when compared to 2016. However, it had no significant impact on the amount of energy produced, because coefficients in correlation Eqs. 1 and 2 for module temperature obtained values on a similar level.

The correlation equations for energy production were determined on the basis of the monitored operating parameters of the PV system in the course of the experiment. The values of the energy production are independent, taking into account the years 2016 and 2017. The significance of the parameters determining the value energy was set at a significance level of less than 0.05 as a linear estimation using the quasi-Newton method.

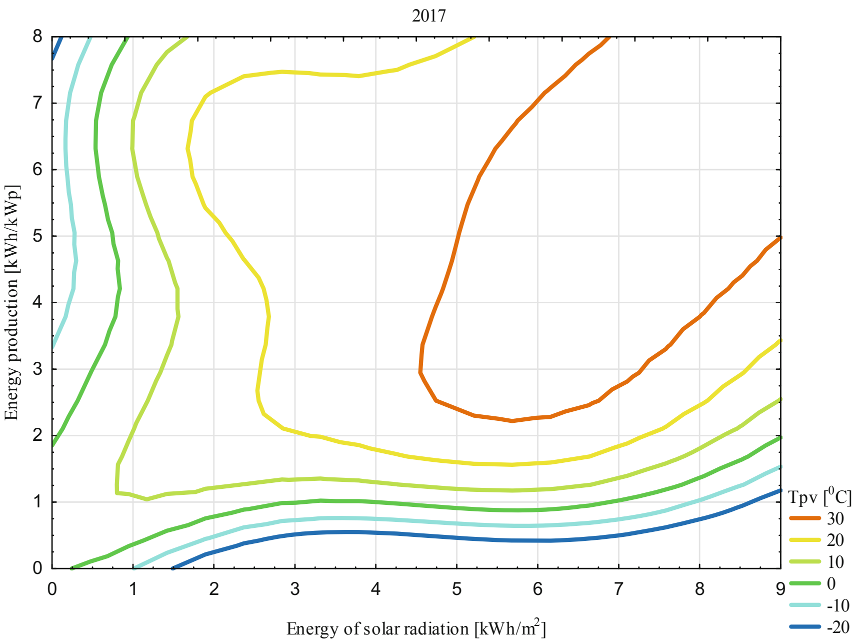

Fig. 4. Characteristics of electricity production dependent on the daily amount of available solar radiation energy and the temperature of the mono PV module (2017)

The most powerful factor influencing the energy yield from photovoltaic modules (E_{pv}) comprises the intensity of solar radiation (E_s). The carried out analyses suggest that on the basis of daily solar radiation energy regression dependencies may be developed in the form of:

$$E_{pv} = 0.132(\pm 0,002) \cdot E_s + 0.036(\pm 0,008) \quad 2016 \tag{1}$$

$$E_{pv} = 0.128(\pm 0,002) \cdot E_s + 0.047(\pm 0,007) \quad 2017 \tag{2}$$

The developed regression models explain the changes in the amount of electric energy generated in monocrystalline PV modules depending on the available solar radiation energy in 92%. Based on such models it may be stated that the increase in the daily availability of solar radiation energy by 1 kWh/m^2 will result in the increase in yield of electric energy by approx. 0.13 kWh/m^2. Thus it demonstrates that the annual average efficiency of energy conversion in monocrystalline PV panels is at the level of 13%. Apart from the intensity of solar radiation, also the operating temperature of PV cells influences the energy yield. The catalogue data for the analysed modules (ET-M672300WW) reveal that their temperature power variation factor is at the level of −0.44%. Increase in the operating temperature of PV cells by1 °C (starting from 25 °C) will result in reduction of the generated power by 0.44%.

Operating temperature of PV cells (t_{pv}) depends on many factors, the most significant ones are considered to be intensity of solar radiation, air temperature (t_z), wind speed and presence of precipitation. The literature presents many comprehensive models enabling to specify their operating temperature. In this paper simple dependencies have been developed allowing for rough estimate of operating temperature of PV cells, according to the intensity of solar radiation and air temperature.

$$t_{pv2016} = 1.356(\pm 0.309) + 1.167(\pm 0.110) \cdot E_s + 1.257(\pm 0.026) \cdot t_z$$
$$\mathrm{R}^2 = 0.95$$

$$t_{pv2017} = 1.696(\pm 0.225) + 2.034(\pm 0.097) \cdot E_s + 0.946(\pm 0.024) \cdot t_z$$
$$\mathrm{R}^2 = 0.96$$

4 Conclusion

1. The carried out analyses suggest that within a year ca. 1130 kWh of solar radiation energy is available per each square metre of surface inclined at an angle of 30$^{\mathrm{o}}$ with the azimuth in southern direction. Most energy, above 50%, is available in the period of only four months of the year, i.e. from May until August.
2. The real amount of electric energy obtained after its conversion into sinusoidal alternating voltage is lower than the theoretically available value by approx. 5–6 kWh/m^2 in the annual period. This disparity has been observed over the summer months. Such a situation derives to a large extent from the change in efficiency of energy conversion in PV panels, depending on the intensity of solar radiation and operating temperature of PV cells.
3. Based on the developed regression models it may be stated that the increase in the daily availability of solar radiation energy by 1 kWh/m^2 will result in the increase in yield of electric energy by approx. 0.13 kWh/m^2. Thus it demonstrates that the annual average efficiency of energy conversion in monocrystalline PV panels is at the level of 13%.

Acknowledgements. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

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Steam Explosion Method – Opportunities for Application in Pretreatment of Lignocellulosic Biomass for Biogas Conversion

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Abstract. The paper presents the results of experiments on the use of an innovative method involving the disruption of lignocellulosic fibers of the substrate used for the production of biogas. Describes and shows the process conditions for the biogas-based substrate obtained from agricultural production, food processing industry, some municipal wastes. On the basis of the literature review, the devices used to produce second generation biogas were discussed. The process of biogas production in this technology assumes the use of lignocellulosic raw materials, which are agricultural, forest, communal or post-crop production residues. Discusses the essence of the process and the results achieved in the bioconversion biogas or ethanol. Presents figures on potential raw material resources dedicated to this technology. The work also includes schemes of solutions used in this technology.

Keywords: Biogas · Lignocellulosic substrates · Steam explosion

1 Introduction

On the basis of Directive 2009/28/EC adopted 23.04.2009 on the promotion and use of energy from renewable sources, a national plan was adopted in Poland (07.12.2010) aiming to promote energy from renewable sources. The plan included a forecast that by 2020 Poland will achieve a level of 15.5% of its gross final energy consumption from renewable sources [1]. The declared percentage of energy yield from renewable sources in terms of gross final energy consumption is highly variable in different EU countries. Malta and Luxembourg declare 10–11%, while Finland has pledged an amount of 38%, Latvia 42%, and Sweden 49% [1]. In the 2030 perspective, according to the adopted directive of the European Parliament, it is assumed that the average percentage of gross final energy consumption should be around 32%. In 2015, the average gross final energy consumption from renewable sources in the EU as a whole was 26.7%, while in Poland it was 13.1%.

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 345–358, 2019.
https://doi.org/10.1007/978-3-030-16542-0_43

According to the General Statistical Office (GSO in Poland) [1] biogas can be divided into the following types, depending on the way that it is obtained:

– biogas from sewage, produced as a result of anaerobic fermentation of sewage slurry
– other biogases:
  • agricultural biogas obtained in a process of anaerobic fermentation of biomass derived from cultivation of energy crops, residues of plant processing, and animal manure
  • biogas obtained in a process of anaerobic fermentation of waste products derived from slaughterhouses, breweries, and other branches of the food sector.

An analysis of the data on energy obtained from biogas indicates that the highest growth in energy in the studied year occurred in the group "other biogases". This growth amounted to a 240% increase in the year 2016 when compared with the year 2012 [1]. Therefore, it can be concluded that the greatest dynamics of growth in the production of biogas comes from the cultivation of energy crops, residue of plant production and animal manures, waste from slaughterhouses, breweries, and other branches of the food sector. Growth in the production of biogas for the years 2010–2020 was forecast somewhat earlier [2].

An increase in the production of biogas should lead to Poland's fulfilment of its commitments to National Indicative Targets and the postulates of the Climate and Energy package (15% of energy consumption from renewable sources by the year 2020). Additionally, an increase in the production of biogas may favourably impact savings in fossil deposits of gas, improve the sustainability of waste management, and substantially limit methane emissions to the atmosphere. The emission of methane to the atmosphere is more harmful due to its impact on the greenhouse effect than the emission of carbon dioxide [3].

For the production of biogas, many substrates are currently used derived from intentional agricultural production, but the search is also being intensified for substrates derived from post-production residues from agricultural production, the agricultural-food industry, as well as certain municipal waste products. These substrates differ in terms of dry matter content, including organic substances, as well as in terms of the amount of biogas generated and the speed of decomposition (speed of generation of biogas). A summary of raw materials used as substrates for the production of biogas along with a description of their basic parameters is presented in Table 1 [4].

Table 1. Characteristics of substrates for methane fermentation [4].

Substrate	Dry matter [%]	Organic dry matter [%]	Biogas yield [m^3] per 1t of organic dry matter	Content of CH_4 in the biogas [%]
Liquid cattle manure	6.5–10.5		175–520	55–65
Liquid pig manure	1.8–8.0		220–637	58–69
Corn silage	20–40	85–97	450–700	50–55
Grass silage	25–50	70–95	550–620	54–55
Slaughterhouse waste				
• flotation tailings from slaughterhouses	14	90	700	
• fat poor flotation tailings	14.4	81.5	375	69
• rumen contents	12–16	85–88	300–600	
• intestines and stomach	16	82	300	
• fatty tissue	37	84	700	
• blood	9.7–18	95–96	410–680	
• chicken slurry	27	67	773	58
• chicken litter	10–29	67–77	300–800	
• chicken manure	32	63–80	250–450	60
• egg waste	25	92	970–980	
	23	80	175–520	
Cattle manure	22			60
	25	68–76	210–300	
Excess sludge	5	80	63	
Potato pulp	6–18	85–96	300–700	58
Dairy waste				
• whey	4–6	80–92	500–900	
• acid whey	5.6	88,8	762	54
• fresh whey	5.6	92.2	746	53
Fruit processing waste				
• fruit waste	60	30	400	
• apple pulp	30	94	330	
• remains from apple processing	22	97.7	566	53
Others (tea leaves, bakery waste, vegetable remains)	5–20	76–90	400	

2 Technologies Used in the Production of Biogas

Methane fermentation depends on many factors, among which the most important are the temperature of the process, the pH of the fermented material, the C/N ratio, and conditions during the mixing process [3]. Due to the fact that methane-producing bacteria are more sensitive to changes in temperature and pH than acetic acid-producing bacteria, the fermentation process should be conducted in conditions which are more favourable for the former's growth and activity [6]. The type of substrate being processed to a great degree determines the selection of biogas production technology. In this regard, currently used technological solutions can be divided by taking into account the following criteria: the temperature at which the process is conducted, the dry matter content in the fermentation chamber, the number of stages of the process, the degree of separation of the individual stages of the process, and the method of dosing the substrate. A classification of biogas production technologies in terms of these criteria is shown in Table 2 [5].

Table 2. Classification of biogas production technologies [5]

Criterion	Type of technology	Characteristic features
Process temperature	Mesophilic	35–37 °C, most often used
	Thermophilic	55–60 °C, more rarely used, often in the case of processing of substrates of heightened risk, such as slaughterhouse waste or animal litter. A process conducted in these conditions is more sensitive to disturbance, but takes place with greater efficiency
Content of dry matter in the fermentation chamber	Wet fermentation	The content of dry matter in the substrate does not exceed 15%, the fermented material is in liquid form
	Dry fermentation	Substrates with a solid consistency, with a high dry matter content
Number of process stages	Single-stage	The installation has a single fermentation chamber
	Multi-stage	The installation has several serially-joined fermentation chambers
Degree of separation of phases of the fermentation process	Single-phase	Hydrolysis of substrate and methane-production phase take place within a single reactor at an even intensity
	Multi-phase	Hydrolysis of substrate and methane-production phase take place in separate reactors
Method of dosing the substrate	Constant	The substrate is dosed constantly at an even pace, making uninterrupted production of biogas possible
	Periodic	The fermentation chamber is filled and then emptied after the process is completed. The production of biogas is higher at the beginning of the process, becoming lower as time progresses

3 Alternative Substrates for the Production of 2nd Generation Biofuels

The search for alternative substrates for the production of 2nd generation biofuels has been influenced by studies on the use of lignocellulosic materials which are by-products of agricultural production, forest management, municipal waste management, or which are intentionally cultivated for this purpose. The production of biofuels from lignocellulose biomass mainly derived from post-production by-products is not a threat to food production. The use of this type of substrate for the production of 2nd generation biofuels represents serious competition for 1st generation biofuels, which are derived from starch- and sugar-bearing plants which are intentionally cultivated for this purpose. The production of 2nd generation biofuels is still much less practiced than traditional methods, mainly due to limitations on technology and the current state of knowledge [6]. Many microorganisms take part in the bioconversion of difficult-to-access components of lignocellulosic materials in natural conditions. During this process, the biomass is utilised, and the process is aided by elements of the natural environment such as water, solar radiation, changing temperatures, and wind. In natural conditions, these processes last for periods ranging from several months to dozens of years. The length of the process is determined by the resistance of the tissues to external factors, and within this resistance a key role is played by lignin, in close association with the polymers cellulose and hemicellulose. Świątek et al. [6] have shown that the achievement of favourable bioconversion of the lignocellulose substrate into ethanol at a level guaranteeing viability requires pretreatment of the raw material aimed at removal of lignin, interference in the hemicellulose structure, and partial amorphisation of the cellulose. This phase of the process determines the efficiency of subsequent processes. According to [6], lignocellulosic substrates which are potential raw materials for the production of bioethanol can be divided into the following categories: by-products of agricultural production (wheat straw, barley straw, corn stalks, cane sugar pressings, sorghum, rice husks), hard and soft woods, cellulose waste (paper), green plants, and solid municipal waste. Studies are being conducted on the use of these types of lignocellulose biomass as a substrate for the production of biogas. The positive results of these studies involve among other things the use of various types of lignocellulosic raw materials in the production of biogas, an increase in the efficiency of the process and its dynamics, and the facilitation of transport of the biomass to the reactor, as shown in [7–13]. The common area of study of the cited works is the use in these studies of the steam explosion method for the pretreatment of lignocellulosic substrates for bioconversion to biogas.

4 Steam Explosion Method – Efficient Pretreatment of Lignocellulosic Biomass for Biogas Conversion

According to [7–13], this method involves the heating of the lignocellulose biomass in a closed system to a temperature which usually ranges from 160 to 220 °C, resulting in an increase in pressure to about 32 bar. After a retention period of about 5 to 60 min, the pressure is suddenly reduced to normal atmospheric pressure. During this process, there is analogous drop in temperature. This sudden drop in pressure causes the intracellular water to evaporate quickly, causing a phenomenon known as steam explosion or the explosion phase. This steam explosion makes the substrates much better prepared for bioconversion into biogas or ethanol [14].

Kurabi et al. [15], Ruiz et al. [16] Szlachta and Fugol [17] present steam explosion, or in other words thermohydrolysis, as a process of thermal and pressure processing of plant material. When steam is used for the degradation of hemicellulose and the transformation of lignin, thus increasing the hydrolysis potential of the cellulose, two methods can be distinguished. The first of these is the steam explosion method, and the second is steam pretreatment. During steam explosion, the substrate is placed in a large chamber at a temperature of 160–260 °C, under a pressure of 15–30 bar. The lignocellulose material remains in the chamber with the steam for a period ranging from several seconds to several minutes, after which sudden decompression takes place and the pressure drops to the level of atmospheric pressure [15–17]. Steam explosion is conducted in a specialised pressure chamber. The conditions required for this process are temperature and pressure in varying ranges which are strictly dependent on the type of substrate being processed. The steam explosion system was patented as a biomass pretreatment method as early as 1926 by [18], who described it as a pretreatment process for wood. This process involved introducing wood chips into a chamber and heating them to a temperature of 285 °C at a pressure of 3.5 MPa for about 2 min. The pressure was rapidly increased to 7 MPa and maintained for 5 s, after which the chips were expelled through slots to in the chamber to the outside, where they were subject to decompression and exploded in the normal atmospheric pressure, creating a pulp. This method is used in the pretreatment of various types of biomass such as corn stalks, miscanthus, Japanese cedar, willow and birch, and of the post-production by-products of the food industry including citruses, potato pulp, and algae in order to increase the production of bioethanol or methane. The steam explosion method is used for conditioning many types of lignocellulose biomass, and its main advantage is the high yield of sugars with relatively small capital outlays, with a low level of harmfulness to the environment due to the fact that harmful chemicals are not used [20]. Liua et al. [19] used steam explosion pretreatment to destroy the structure of the lignocellulose matrix and facilitate bioconversion. In Fig. 1, a system is presented which consists of a reactor chamber (working capacity 15 dm^3), a reception chamber (working capacity 150 dm^3), and a steam generator (Fig. 1).

During the initial phase, the straw (dry base matter) is loaded from above into the reactor chamber. High-pressure steam supplied by the generator is then introduced into the reactor until the temperature reaches 200 °C (1.6 MPa). After 5 min of being subjected to the effects of the saturated steam, the corn straw is subjected to decompression during transport to the reception chamber with the use of the ball valve. It has been determined that pretreatment with a steam explosion results in a profound transformation of the lignin and severe degradation of the fibrous structure of the majority of the biomass particles.

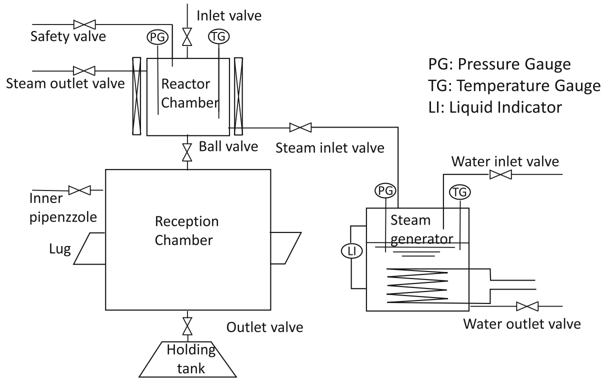

Fig. 1. Diagram of a steam explosion pretreatment reactor [19]

Another solution [20] is a system constructed by Industrieanlagen Planungsgesellschaft for pretreatment of soft woods using steam explosion technology (Fig. 2). Steam at a pressure of 32 bar is generated in an 18 kW generator. A secondary steam chamber between the furnace and reactor provides additional storage space for 23 l of steam. The pretreatment reactor is made of stainless steel (type 1.4571) and has a capacity of 5.8 l (DN100, i.e. an internal diameter of 114.3 mm and internal height of 700 mm) and can be loaded with biomass using a pneumatic ball valve on the top. The

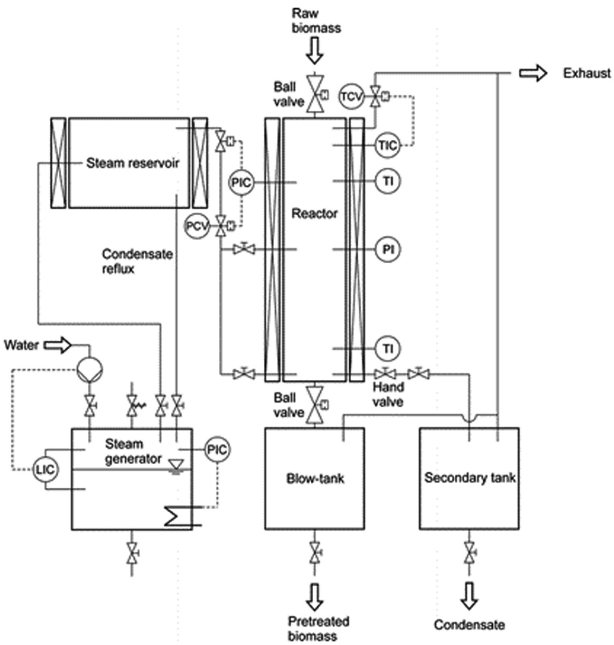

Fig. 2. Diagram of the steam explosion system [20]

saturated steam can be injected into the reactor both at the bottom and halfway up the sides of the reactor. The steam injection is controlled by the pressure settings in the reactor. Air which may collect in the chamber should be expelled to achieve a saturation temperature of the steam appropriate for the applied pressure.

The exhaust valve is controlled by the temperature differential measured at the top of the reactor, where air gathers due to its lower density and temperature relevant to the saturated steam. The ball valve at the bottom of the reactor, on the other hand, is powered by a pneumatic motor operating at a pressure of 10 bar to ensure rapid opening and reduction of pressure as required for the explosion of the steam. The impact of steam explosion pretreatment (T = 235 °C, t = 2.5 min, pressure difference 30 bar) on the structure of spruce wood is shown in Fig. 3.

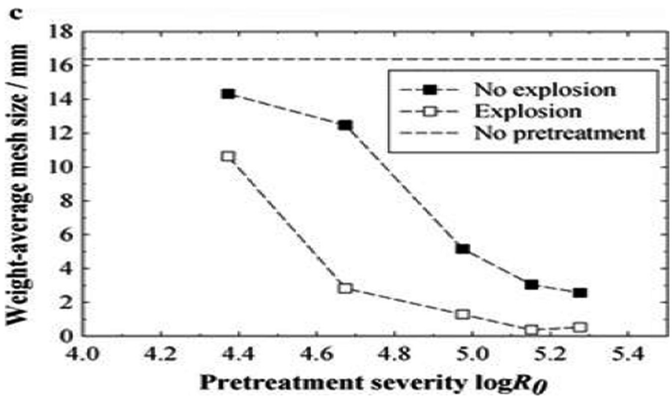

Fig. 3. Impact of steam explosion on structure of biomass [20]

The authors [20] demonstrated that the pretreatment system increases the enzymatic digestibility of the lignocellulose biomass of soft wood.

According to the report [21], the production of biogas or methane from a solid substrate such as wood, straw, or paper may increase substantially thanks to a variety of pretreatment methods. The authors believe that high temperature steam explosion (<200 °C) for a short period (5–10 min) is the best solution for pretreatment of currently used biogas plant input materials in terms of an improvement in gas yield (Fig. 3). In the case of wood and straw, steam explosion pretreatment delivered methane efficiencies of approximately 0.2 m^3 kg^{-1} of raw material and 0.3 m^3 kg^{-1} of raw material respectively. In contrast, straw chemically treated with 8% NaOH (without steam-explosion) delivered lower methane efficiencies, although lower by only about 0.2 m^3 kg^{-1} of raw material. Additionally, steam explosion pretreatment was only effective when a chemical substance (NaOH or both NaOH and H_2O_2) was added to the substrate during processing. Steam explosion with the addition of 2% NaOH and 2% H_2O_2 yielded about 0.5 m^3 kg^{-1} of raw material, whereas methane yield after steam explosion treatment with the addition of only 2% NaOH was about 0.4 m^3 kg^{-1} of raw material (Fig. 4).

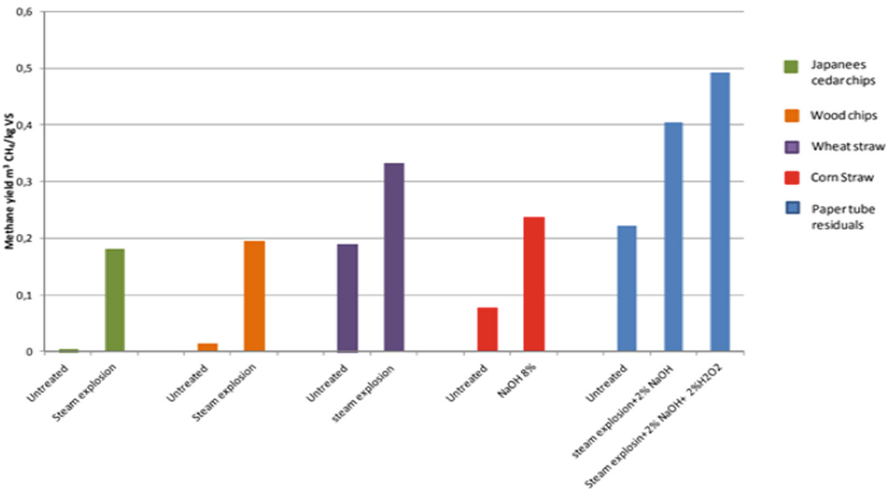

Fig. 4. Efficiency of methane yield depending on substrate pretreatment method [21]

A method and device for accelerating decomposition of lignocellulose biomass has been developed at the University of Warmia and Mazury in Olsztyn which involves the use of thermochemical processes. The reactor in which the process is carried out has a capacity of 3 dm^3. Processing of the biomass takes place at high temperatures and under a saturation pressure appropriate to the temperature of the input material. The pretreatment process begins with submerging the biomass in water, after which 10–20 min of hydrolysis takes place with the addition of acid or lye. Hydrolysis is completed with a rapid reduction in pressure. During this phase, the water explosively changes into steam and then nearly instantly condenses. Rapid state transitions mean that local pressure changes can achieve several hundred bar. The shockwaves resulting from vaporisation and condensation destroy the wood cell walls. The greatest degree of destruction of cellulose and hemicellulose in the cells of the biomass can be achieved by using hydrolysis within a temperature range of 200 to 230 °C, in the presence of sulphuric acid (VI) and with explosive expansion of the steam [22].

The steam explosion method can be used for conditioning many types of lignocellulose biomass, and its great advantage is that it yields large amounts of sugars with relatively low capital outlays and very little harm to the natural environment due to the fact that dangerous chemicals are not used. During steam explosion treatment, part of the hemicellulose becomes hydrolysed into acids which may act as catalysts for the further hydrolysis of the hemicellulose.

For the pretreatment of lignocellulose biomass suitable for use in the production of 2nd generation biofuels, the following processes are most commonly used: physical, physicochemical, chemical, and biological. The advantages and disadvantages of these methods are presented in Table 3.

Table 3. Advantages and disadvantages of the use of various pretreatment methods for Lignocellulosic substrates [23]

Pretreatment method	Advantages	Disadvantages
Mechanical grinding	Reduction of the crystalline structures of the cellulose	Energy use exceeds produced energy
Steam explosion	Degradation of hemicellulose, transformation of lignin, high viability	Destruction of some of the xylans, incomplete rupture of the lignin-carbohydrate matrix, creation of inhibitors
AFEX	Increase of bioactive surface, removal of lignin and cellulose, absence of inhibitors	No effect on substrates with high lignin content
Action of carbon dioxide	Increase of bioactive surface, viability, absence of inhibitors	No impact on lignin and hemicellulose
Acid method	Hydrolysis of hemicellulose into xylose and other sugars, change in the lignin structure	High costs, possibility of occurrence of corrosion, formation of inhibitors
Alkali method	Removal of lignin and hemicellulose, increase of bioactive surface	Long processing time
Biological method	Degradation of lignin and hemicellulose, low energy usage	Very slow process of hydrolysis

Bruni et al. [24] has stated that biofibre and the remains of the biomass separated from the fermented liquid manure, when subjected to steam processing at 180 °C for 15 min (without the addition of acid or pre-soaking) obtained increases in methane efficiency of 29% when compared with biofibre not treated with heat. According to [25], a plant which also sees an increase in methane yield when subjected to heat processing is the rush family. Methane yield from rushes subjected to steam explosion was 24% higher than in the case of rushes not pretreated. The process conditions were as follows: steam pressure 1.72 MPa, time in the pressure chamber 8.14 min, residual moisture 11%. Steam explosion pretreatment is considered to be one of the most effective technologies for the pretreatment of substrates such as wood or agricultural by-products, including lignocellulosic substrates, both at the laboratory scale and in reality. It is estimated that with properly selected parameters and process factors, steam explosion may allow for a high level of biogas production to be achieved; e.g. straw subjected to the steam explosion process allows for up to 600 m^3 of biogas to be obtained from 1 tonne of dry straw (with 85% raw material). Unfortunately, during the steam explosion process, inhibitors may be formed, encouraged by the high pressure and temperature, and compounds such as furfural and phenols may be formed from the decomposition of sugars and lignin. This results in a decrease in the biomethane efficiency of substrate subjected to heat processing [26].

The process of steam explosion has been commercialised, and is being successfully used in Masonite factories for the production of wooden doors and windows for homes [27]. The Italian Agency for New Technologies, Energy, and Environment [28] is using an experimental reactor which allows 300 kg h^{-1} of material to be processed. The Cambi Company [29] is using the thermohydrolysis phenomenon to process waste water residues and biodegradable waste. [30, 31] have also presented information suggesting that the use of pretreatment of lignocellulose biomass involving steam explosion brings favourable results in the preparation of biomass for the production of biofuel pellets in order to increase their fuel value, density, and pelletisation characteristics.

5 Potential Residual Lignocellulose Biomass in Poland Suitable for Use in the Production of 2nd Generation Biofuels

The potential residual lignocellulose biomass in Poland has been calculated based on data from the Main Statistical Office (GSO) [32]. Using statistical data on areas of cultivation of the analysed plants and their harvests as well as formulas expressing the ratio between harvest yield and straw yield [33–35], the amount of straw potentially available for use for energy purposes has been estimated. Moreover, using the previously mentioned source, the total amount of unused meadow grasses and wood waste from by-products of the orchard industry has also been estimated. This estimated potential for lignocellulose biomass in Poland is:

- Straw mass from basic grains with admixtures (2016r.) 25.9 mln tonnes. of this amount, after taking into consideration needs for fodder and animal bedding, a surplus of about 12.4 mln tonnes remains for use
- Corn stalk mass remaining after cultivation for grain, about 5.6 mln tonnes
- Straw mass remaining after cultivation of oilseeds, about 2.0 mln tonnes
- Unused meadow grasses (as hay), about 2.4 mln tonnes
- Waste wood from the cultivation of orchards, about 122,000 m^3
- Additionally, a partial change from production of corn for grain to production for silage can be considered (in 2016, the area under cultivation for grain was 595405 ha, while that for silage was 602185 ha).

Therefore, the estimated potential for lignocellulose biomass in Poland derived from field production of plant matter of the types taken into consideration and which may be used for biofuel production is about 22.4 mln tonnes.

6 Conclusion

The percentage of biogas in the structure of the renewable energy sector both in the EU (7.60%) and in Poland (2.88%) is very modest when compared to solid biofuels. An increase in the production of biogas should aid Poland to achieve the adopted targets. Moreover, an increase in the production of biogas may favourably impact savings in usage of fossil deposits of this type of fuel, improve the sustainability of the economy of post-production waste products, and significantly reduce emissions of methane into the atmosphere. Currently for the production of biogas, many substrate are used which are intentionally cultivated for this purpose, though increasingly frequently substrates are being explored which are the residual products of agricultural and agricultural-food production, as well as certain types of municipal waste. The search for alternative substrates for the production of 2nd generation biogas is shaping the course of studies on the use of lignocellulosic substrates which are residual by-products of agricultural production, forest management, municipal waste, or dedicated cultivation. The production of biofuels from lignocellulose biomass, mainly derived from post-production residuals, is not detrimental to food production. The production of 2nd generation biofuels is still, however, lagging far behind traditional production due to technical limitations and the current state of knowledge. The estimated potential of lignocellulose biomass in Poland derived from field production which can be used in the production of biofuels is large, amounting to about 22.4 mln tonnes. A solution for this conundrum is seen in the use of the steam explosion method for pretreating the lignocellulosic substrate for conversion to biogas. The advantage of this method is the yield of high amounts of sugars with small capital outlays and minimum harm to the natural environment due the fact that the method does not use harmful chemicals. The use of this method in the production of biogas results in an increase in the efficiency of the process, its dynamics, and facilitation of the transport of the biomass to the reactor.

Acknowledgements. This research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

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Electrooxidation of Sesame Oil in Acid Electrolyte

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Abstract. The energy industry is based mainly on coal, crude oil, natural gas or nuclear energy. However, in recent years renewable energy sources have also become increasingly used. One of the devices that uses renewable energy sources is a fuel cell (FC). The fuel cell can be powered by hydrogen, methanol, hydrazine or other substrates. Commercial fuel cells use mainly hydrogen, methanol or hydrazine. Due to the fact that water is the only by-product, hydrogen is the considered to be the best fuel for fuel cells. Problems with hydrogen storage cause, however, that new fuels for FCs are very desirable. Vegetable oil seems to be such substance, application of which as fuel in FCs is possible. But in the first place, it is necessary to determine possibilities of electrooxidation of this fuel. The paper presents the research on sesame oil electrooxidation. The work shows results of electrooxidation of sesame oil emulsion on a smooth platinum electrode in acid electrolyte. The maximum stable current density reached in the tests was 5 mA cm^{-2}.

Keywords: Electrooxidation · Biofuel · Fuel cell · Environmental engineering · Renewable energy source

1 Introduction

In the past decades, alternative devices using renewable energy sources have been developing very fast. A fuel cell (FC) is one of these devices. The fuel cell is a type of a galvanic cell. However, whereas in a regular battery the energy is stored, in the FC the fuel and oxidant have to be supplied externally [1, 2]. In the FC the chemical energy of fuel is converted directly into electrical energy, without intermediate states [2–4]. FCs are characterized by high efficiency, silent operation and zero or low influence on the environment [2, 5].

The commercial fuel cells are powered mainly by hydrogen, methanol or hydrazine [6, 7]. Due to the fact that water is the only by-product, hydrogen is considered to be the best fuel for fuel cells [2, 5, 8]. Thus, FCs are most often powered by hydrogen. However, there is a problem with cheap storage and cheap production of this fuel [9–11]. Recently, more and more new renewable fuels have been researched and applied [12, 13]. One of these fuels can be vegetable oil, e.g. canola oil, which is often used as raw material to biodiesel fuel production [12, 14]. Recycled vegetable oil can be also used as fuel [15, 16]. The previous authors' research has shown a possibility of direct

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 359–366, 2019.
https://doi.org/10.1007/978-3-030-16542-0_44

electricity production from canola or coconut oil [16–19]. The possibility of electrooxidation of sesame oil is shown in this paper.

Sesame oil is obtained from sesame seeds. This oil is mainly used in salad or cooking, also in cosmetics, soaps, paints and lubricants [20–22]. It can be used as a base substrate for production of biodiesel as well, e.g. by transesterification of sesame seed oil with methanol in the presence of NaOH as catalyst [23–25]. An internal combustion engine (diesel engine) fuelled with sesame biodiesel in terms of fuel efficiency, consumption and power has equal parameters compared to the one fuelled with mineral diesel. Moreover, it was noted that the environmental performance of biodiesel produced from sesame oil was superior to that of standard mineral diesel. Sesame oil can be blended with diesel fuel in different concentrations, e.g. B20%, B10% or B5%. It should be noted, that there is no noticeable change in engine power output even at 100% sesame biodiesel [26]. However, of importance is the question whether it is possible to use sesame oil for the direct production of electricity, bypassing the combustion process, e.g. in a FC. This paper presents the research on sesame oil electrooxidation on smooth platinum electrode in acid electrolyte, which allows for assessing the possibility of using sesame oil as fuel for FCs.

Current density (obtained in FCs) is the most important parameter that characterizes a FC and fuel for FCs [1, 2, 27, 28]. Theoretically, this parameter can be calculated from Butler-Volmer equation, but calculations often are not consistent with test results in real conditions [27, 28]. Therefore, the choice of fuel must be made by experimental methods. For this reason, this paper presents analysis of electrooxidation of sesame oil, which may contribute to design and building of a FC powered by this oil in the future.

2 Materials and Methods

Based on earlier studies a decision was made to add oil to the electrolyte. Due to hydrophobic properties of sesame oil it is difficult to mix it with water, therefore in order to add sesame oil to the electrolyte (aqueous solution of H_2SO_4) it is necessary to use a detergent [29]. As a detergent Syntanol DS-10 was used – it is a mixture of primary oxygen-ethylene-glycol ethers of fatty alcohol of C_{10}–C_{18} fraction [30]. This detergent is characterized mainly by high superficial activity [30, 31]. Moreover, Syntanol DS-10 is an environmental friendly detergent because it is fully degradable by bacteria [32].

First, an emulsion of sesame oil was prepared for measurements. The emulsion was obtained by mixing oil, detergent and water, in 1:1:2 proportions. A mechanical stirrer was for this purpose with speed of mixing set at 1200 rpm [33–35]. Emulsion stabilization time was 3 h.

Measurements were performed by the method of polarizing curves, using a smooth platinum electrode. The surface of working electrode (platinum electrode) was 6.28 cm^2. Platinum was chosen due to its excellent catalytic properties [27]. Saturated calomel electrode (SCE) was used as a reference electrode [36]. Measurements were carried out in a glass reactor, with acid electrolyte (H_2SO_4). The range of temperatures of measurements was 298–328K. The experimental set-up was equipped with AMEL potentiostat (System 5000), controlled by a computer with CorrWare software.

The scheme (Fig. 1) shows the scheme of the experimental set-up for electrooxidation of sesame oil emulsion (direct electricity production from sesame oil). The Fig. 2 shows the scheme of the reactor (glass vessel) applied for measurements.

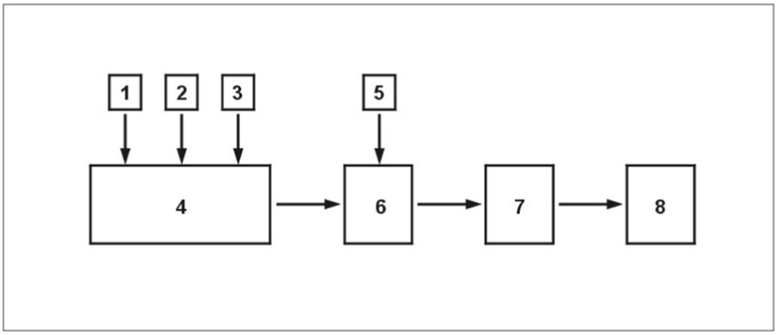

Fig. 1. Scheme of the research position: 1 – sesame oil, 2 – water, 3 – detergent, 4 – sesame oil emulsion preparation, 5 – electrolyte preparation, 6 – reactor (glass vessel), 7 – potentiostat, 8 – data analysis.

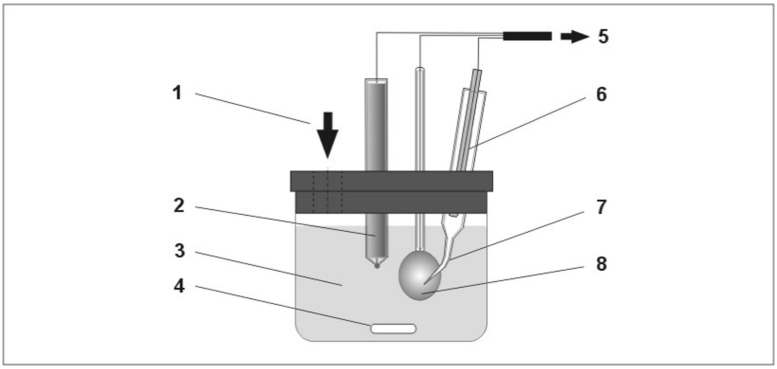

Fig. 2. Scheme of the reactor (glass vessel) for measurements of sesame oil emulsion electrooxidation: 1 – sesame oil emulsion, 2 – auxiliary electrode, 3 – electrolyte (aqueous solution of H_2SO_4) with sesame oil emulsion, 4 – stirrer bar, 5 – to potentiostat 6 – reference electrode, 7 – Haber-Luggin capillary, 8 – working (Pt) electrode.

First, before electrooxidation of sesame oil emulsion, measurements of electrooxidation of pure Syntanol DS-10 were carried out. Next, electrooxidation measurements of sesame oil emulsion were performed, for various concentrations of the oil (0.0025%, 0.0050%, 0.0100%, 0.0250%, and 0.0500% of working reactor volume) at temperatures ranging from 298–328K. The comparison of results from Syntanol DS-10 electrooxidation and sesame oil emulsion electrooxidation allowed for determining whether the electricity is generated from the electrooxidation of sesame oil or only from the detergent.

3 Results

The Fig. 3 shows the electrooxidation of emulsion at temperature 298K.

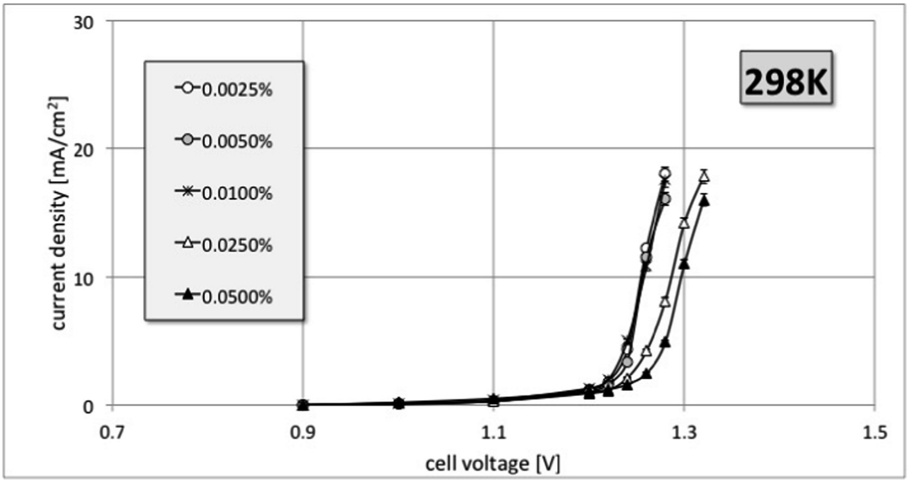

Fig. 3. Polarization curves of emulsion electrooxidation - 0.1n H_2SO_4, 298K – sesame oil concentration: 0.0025%–0.0500%

The Fig. 4 shows the electrooxidation of emulsion at temperature 308K.

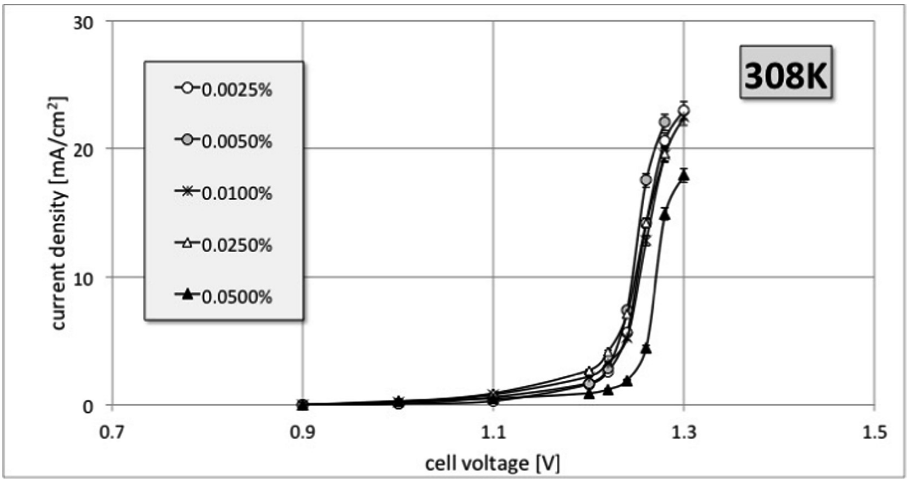

Fig. 4. Polarization curves of emulsion electrooxidation - 0.1n H_2SO_4, 308K – sesame oil concentration: 0.0025%–0.0500%

The Fig. 5 shows the electrooxidation of emulsion at temperature 318K.

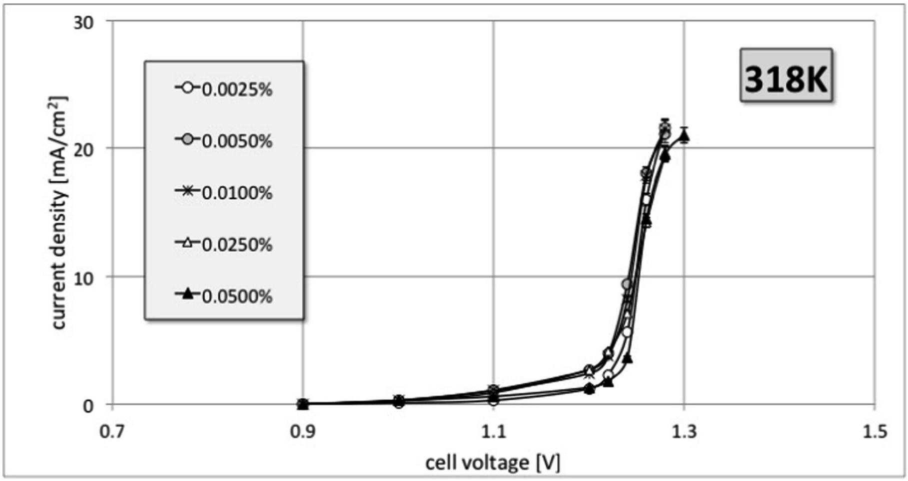

Fig. 5. Polarization curves of emulsion electrooxidation - 0.1n H_2SO_4, 318K – sesame oil concentration: 0.0025%–0.0500%

The Fig. 6 shows the electrooxidation of emulsion at temperature 328K.

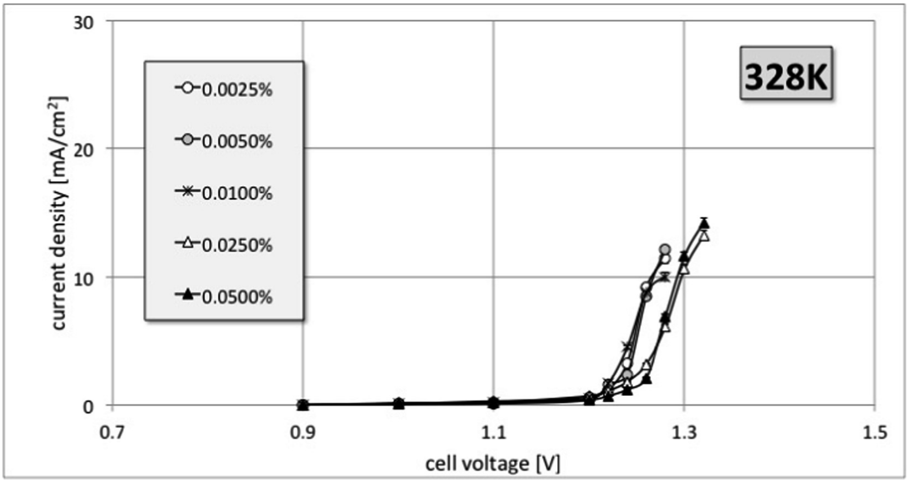

Fig. 6. Polarization curves of emulsion electrooxidation - 0.1n H_2SO_4, 328K – sesame oil concentration: 0.0025%–0.0500%

The potential of a working electrode was established in 20 min and was poorly reproducible. Real stationary potential was in the range of 0.51–1.14 V – this current-free potential depended on the concentration of sesame oil.

4 Conclusion

Despite obtaining low current density, the research data have shown that electrooxidation of sesame oil is the right direction of research. The electrooxidation of sesame oil emulsion occurred for all temperatures (298–328K) and for all tested concentrations of oil. The highest stable current density was obtained at the temperature 318K and it was equal to 5 mA cm^{-2}. The current density of about 1–3 mA cm^{-2} was obtained for all other analysed concentrations. Above the temperature 328K the current density begins to drop. Comparing the current density values above 328K for the Syntanol DS-10 electrooxidation and electrooxidation of sesame oil emulsions, it can be noted that in this temperature range electrooxidation of the detergent occurs in the first place, and only later electrooxidation of sesame oil. The presented results for sesame oil electrooxidation are close to data obtained during electrooxidation measurements of emulsions made of canola oil, waste canola oil or coconut oil [16–18]. Moreover, the data of sesame oil electrooxidation are also similar to electrooxidation of crude oil, diesel fuel or waste engine oil from agricultural machinery [33–35].

The possibility of electrooxidation of sesame oil emulsion (oil concentrations in the range 0.0025–0.0500%) on a smooth platinum electrode in acid electrolyte (0.1n H_2SO_4) in temperatures varying from 298 to 328K was shown in this paper. Thus, it can be stated that the electricity production from sesame oil without the process of combustion is feasible.

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Alternative Vehicle Fuel Management: Impact on Energy Security Indicators

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Abstract. Land transport consumes primarily oil products. Their use effects on climate change. A tendency of crude oil price increasing, uneven allocation, and exhaustibility forces to look for alternatives. Alternative vehicle fuel can to reduce energy dependence and meet ecological requirement. The aim of the study was to reveal the basic principles of the alternative vehicle fuel management and its influence on energy security indicators. The fundamental objectives and principles of alternative fuel management were reviewed. The energy security indicators which are affected by the use of alternative fuels were considered. The primary goal of the alternative vehicle fuel management is profit optimization and strengthens the energy security indicators. The energy security indicators can be improved by the use of indigenous fuels (both renewable and non-renewable) and by increasing the diversification of energy resource supplies.

Keywords: Alternative fuel management · Energy security · Indicator · Energy market · Environment

1 Introduction

Scientific and technical progress in the developed countries has been accompanied by acceleration in the growth rate of energy consumption. In 2016, primary world energy consumption exceeds 13 276 billion tons of oil equivalent. Most of it is crude oil (up to 4418 billion tons or 33.28%) [4]. Transport mainly uses petroleum fuels. Therefore the overall trends in the oil market should be considered.

At the moment the total estimated reserves of hydrocarbon fuels of the planet exceed 12,5 trillion tons, most of which is coal. Crude oil accounts for about 21% [4]. The world energy market is divided unevenly by the production and consumption.

One of the most important tasks is the forecast of extraction of energy resources. The first man who started researching the problem of energy resources scientifically was King Hubbert. He formulated the basic principle of peak theory. It describes depletion of fossil resources [34]:

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 367–374, 2019.
https://doi.org/10.1007/978-3-030-16542-0_45

– production starts from zero;
– production increases to its maximum level (which is called a peak), which can never be bridged;
– after passing the peak, there comes the fall of production until the resource is exhausted.

Standard Hubbert curve has the form of a bell. For example, in Ukraine a crude oil production curve complies with the Hubbert peak theory (Fig. 1) [24, 28]. The modern tendency can be described as follows. Crude oil holds a dominant position despite there was a decrease in its share. There has been an increase in natural gas' market share. Renewable energy utilization' share has increased [4].

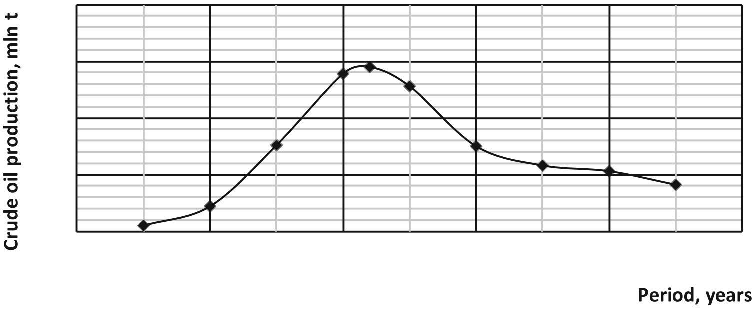

Fig. 1. Crude oil production history in Ukraine (adapted from [19])

Today the dominant global trend is the growth of the cost of fossil energy resources. Therefore, the mid 1990s renewable energy resources in general and biofuels in particular were started to develop. It is caused by two main reasons. The first reason is the environmental protection and reduced greenhouse gas emissions. The second one is to ensure energy independence of energy-importing countries [18].

As a result of the world crude oil reserve reduction, there is a tendency of the crude oil price increase. This makes transport, and hence the economy of each country, dependent on the availability of crude oil. Therefore, energy security for the transport sector is often equated with crude oil security and totally national energy security.

That is why the most important problem for the transport sector is the replacement of petroleum fuels by non-petroleum ones, i.e. alternative fuels. By 2020 the European Union is going to transform about a quarter of the entire European vehicle fleet to alternative fuels: compressed natural gas (CNG), biogas, hydrogen (fuel cells), liquefied petroleum gas (LPG), and biofuels. Each country has its own national features [11].

To produce and utilise alternative vehicle fuels, alternative vehicle fuel management should be applied. The aim of the paper was to reveal the basic principles of the alternative vehicle fuel management and impact of its application on energy security indicators.

2 Materials and Methods

Although the energy security concept is old, its indicators and definition have been studying last decades [1, 20]. The energy security concept has received great attention and has been the subject of many studies within different fields of science [14, 22, 29]. In the 21st century publications on energy security have emerged as being of great importance [33]. Many reasons for this growing interest are the following: increased energy prices [29], the growing dependence on energy [15, 16], the global energy supply crisis [2], climate issues [3, 19], etc.

The first available record of a definition of energy security was made by Willrich [32]. He defined energy security as: 'Assurance of sufficient energy supplies to permit the national economy to function in a politically acceptable manner.' Afterwards many scientists tried to make own definitions by including a certain parameters in the definition [7, 10, 13]. They offered a number of indicators to measure energy security. In our study we used the most widespread indicators [6, 12].

Total Primary Energy Supply Self Sufficiency ratio (*TPESR*) is an important measurement of the strength in energy security. It indicates of how dependant the country on internal sources is. It is calculated as

$$TPESR = \frac{IP}{TPES} \cdot 100\%$$

where *IP* is the indigenous production; *TPES* is the total primary energy supply.

Usually, the Reserve/production ratio (*RPR*) is used as an indicator to show the remaining amount of fossil energy resources

$$RPR = \frac{PR}{PP}\ \text{years},$$

where *PR* is the proven reserves of energy resources; *PP* is the primary energy production.

For biofuels Reserve-to-Production Ratio is equal to infinity.

Energy intensity (*EI*) is an important indicator to compare national economies. It is calculated as

$$EI = \frac{TPES}{GDP}\ \text{toe/mln EUR},$$

where *TPES* is the total primary energy supply, toe; *GDP* is the gross domestic product, mln EUR.

National energy dependency for different energy sources is found as

$$ED = \frac{ERI}{GIE},$$

where *ERI* is the import for different energy resources; *GIE* is the gross inland energy.

Sectoral indicators give information about share of alternative fuels (resources). For example, shares of alternative fuel in transport is equal to

$$SB = \frac{BC}{PDC} \cdot 100\,\%,$$

where BC is the alternative fuels consumption; PDC is the petrol & diesel fuel consumption.

To design optimum diversity strategies, the diversity must to be measured. To reach the above Herfindahl-Hirschman Index (HHI) and Shannon-Wiener Index (SWI) may be used. The SWI and HHI can be calculated as [11, 20, 21, 26]

$$SWI = -\sum_{i=1}^{n} (p_i \cdot \ln p_i), \;\; HHI = \sum_{i=1}^{n} p_i^2.$$

where p_i is the share of i^{th} alternative energy resource; n is the amount of energy resources.

The optimal value of SWI should exceed 2 [26].

Energy price is a widespread indicator. The price of crude oil has fluctuated but has a gradual rise. It directly affects the formation of vehicle fuel prices and impacts on alternative fuels too [31].

Detailed data collection has been carried out. Literature, statistics and websites were used. The further calculations were made based on information collected.

3 Results

3.1 Alternative Fuel Management: Basic Principles

Both conventional and alternative fuels can be used by transport. Traditional fuels are fuels of oil origin. They include diesel fuel, gasoline, kerosene, etc. Alternative fuels are fuels of non-oil origin. They include biodiesel, bioethanol, biogas, compressed natural gas, liquefied petroleum gas, etc. Their use can improve both environmental and economic indicators of economic activity. Alternative energy sources are divided into non-renewable and renewable ones.

Non-renewable alternative energy sources are natural resources and materials that can be used by humans for energy production. Firstly, they can be classified as fossil fuels and their by-products: coal and brown coal, shale, peat, natural and petroleum gas. They are also wastes of some industries: metallurgy, chemical and thermochemical processing of carbon and hydrocarbons, etc.

Renewable alternative energy sources are the sources of continuously existing or recurrent environmental flows of energy: solar, wind, thermal energy of the Earth, of the seas and oceans, rivers, biomass (plants and animals). To produce renewable fuels, renewable resources (vegetable oil, animal fats, biomass, wood, agricultural and household wastes, etc.) can be used.

To reduce fuel costs and strengthen energy security, the use of non-petroleum fuels are increasing worldwide. Therefore, an effective control system for alternative fuel utilization is needed.

We propose the following definition of alternative vehicle fuel management "Alternative vehicle fuel management is the activity aimed at the effective use of alternative fuels to maximize profits (minimization of costs), improve ecological features, and strengthen the competitive positions and energy security indicators".

The subject of Alternative Vehicle Fuel Management is the patterns and trends of production and use of the alternative fuels, including renewable, the principles of production control as an energy ecology-friendly system in the whole system of social reproduction. Alternative fuel management may be considered as a part of energy management, fleet management, and fuel management.

Fleet management is aimed at the efficiency in fleet operations. Many transport companies rely on fleet managers to maximize profitability, and mitigate risks of their operating activity [30]. Fleet management carries out a range of functions, including fuel management. Fuel management systems are used to maintain, control and monitor fuel consumption and its stock, as a means of business. It is designed to effectively measure and manage the use of fuel within the transportation. Since there are traditional and alternative fuels, it is logical that the alternative fuel management can be an integral part of fuel management and vehicle management in general.

The main goal of energy management is to maximize profits through minimizing manufacturing costs, particularly for energy resources. Meanwhile, both environmental and economic parameters of the production should not be deteriorated. An important role is played by the use of alternative fuels, including renewable energy. On this basis, the main tasks of alternative fuel management can be formulated as follows:

- reducing utilization of traditional fuels;
- development of new types of alternative fuels which have advantages over conventional fuels;
- adaptation of vehicles for the use of alternative fuels;
- development of competitive technologies to produce alternative fuels, including renewable fuels;
- search for new and environmentally friendly ways to increase the return on investments in the alternative fuel producing.

The main results, which are planned to achieve by alternative fuel management, can be divided into four groups: economic, environmental, ensuring the competitiveness and strengthening national energy security.

3.2 Impact on Energy Security Indicators

Imports of crude oil and other fossil hydrocarbon energy resources have a direct impact on energy security and the balance of the national economy. So it should be reduced to minimum acceptable levels to ensure energy, economic and political security. Fuel imports from one source must not exceed 30% of the total energy balance. An important role in this is the use of alternative fuels, including renewable ones.

Alternative fuel utilization has been increasing last decades. The world's energy infrastructure has begun to change towards alternative fuels for the last 20 years. There were companies that are engaged in the of alternative fuel management activity [25].

Biofuels plays an important role. The use of biofuels in the transport across the EU has primarily been driven by concerns around climate change issues. But only indigenous biofuels production can allow countries to improve their energy security by reducing their dependence on imported oil. In the USA the share of non-conventional fuels is 8,1% and biofuels – 5,1%. In the EU market penetration is 5,5% for bioethanol and 7,3% for biodiesel [8]. In Brazil market penetration is higher: 45% for bioethanol and 7,9% for biodiesel [5]. It improves sectoral indicators, national energy dependence and Total Primary Energy Supply Self Sufficiency Ratio.

Because of diversification strategy, in the EU countries the HHI value and the SWI value were improved. According to our calculations (on the basis of [9]), from 2000 to 2015 there has been a rise in SWI from 1,141 to 1,169 and in HHI from 0,369 to 0,387.

The most widespread alternative fuel in the world is compressed natural gas. From 1996 to 2018, the number of natural gas vehicles (NGV) has increased from 850 thousand to 25 million [23]. This is a result of its economical attractiveness. It is important to note that imported gaseous fuels are unlikely to improve the energy security indicators except the diversification one.

Thus in Ukraine in 2017 the share of gaseous fuels was around 31% [27]. But Ukraine imported natural gas and liquefied petroleum gas, so it improves diversification and cost indicators only. Pakistan is short of crude oil reserves too. In 1980s Pakistan launched CNG programs and today its NGV fleet takes 4th position in the world [23]. Currently its CNG industry annually consumes around 3,4 billion natural gas (nearly 8% of national gas production) [4, 17]. The share of compressed natural gas in transport is 23,1%. The utilization of this fuel improves TPESP and national energy dependency. The SWI for the above countries is: Ukraine – 1,06 and Pakistan – 1,01.

Alternative fuel management can make transport systems less vulnerable to fuel supply and fuel costs fluctuation. It encounters many problems (imperfect standards, immature technologies and unnoticed potential benefits). Despite these constraints, alternative fuel management is growing in the world.

The implementation of the alternative fuel management strategy will improve the energy security indicators of any country (Table 1).

Table 1. Impact of alternative fuel management strategy on energy security indicators

Indicator	Positive impact
Total Primary Energy Supply self sufficiency ratio (*TPESR*)	An increase of indigenous fuel production
Reserve/production ratio (*RPR*)	For biofuels Reserve-to-Production Ratio is equal to infinity
Energy intensity	Alternative fuel utilization reduces transportation costs and it results in increase *GDP*
National energy dependency	A decrease of import
shares of alternative fuel in transport	Increase share of alternative fuels and decrease import
Diversification	The more sources of fuels the higher Shannon-Wiener Index

4 Conclusion

There is a steady tendency of gradual growth in fossil fuel prices worldwide. This stimulates the search for acceptable alternatives. The alternative fuel management has been proved as an effective tool for improving energy security indicators. The motivations for starting its programs are the following: conventional fuel costs, environmental regulations, energy supply diversification, etc. The definition of alternative vehicle fuel management had been proposed.

The key findings from this study are as follows: biofuels are reducing greenhouse gas emissions and to improving energy security; petroleum fuels dominate on the transport and, therefore, energy security is currently equated with “crude oil security”; energy security indicators can be improved by increased use of indigenous fuel supplies and by implementation of the diversification strategy of supplies; alternative fuels could be used to supply the transport sector and contribute to improving the energy security indicators.

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Renewable Energy Sources Are also the Condition of the Evaluation of Land Applicability for Construction Purposes

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Abstract. Intensive development of new technologies gives the possibility of using alternative, renewable energy sources and is one of the decisive factors that affects the economic development of each country. Successive activities aimed at implementing the principles of environmental protection strengthen Poland's economic position against the background of highly developed European countries. The implementation of investments that maintain the principles of sustainable development have a major impact on socio-economic development in the regional and local dimensions. Striving to achieve the principle of sustainable development both in urban areas and outside these areas is of key importance.

The aim of the work is to demonstrate that a necessary condition that must be considered at the stage of assessing the suitability of land for construction purposes is to check the availability and the possibility of using alternative, renewable sources of energy.

In order to verify the necessity of using alternative sources of energy, tests were carried out illustrating the computational demand for an exemplary building usable area, for non-renewable primary energy necessary for proper functioning.

The research results show that the location of real estate considered in the aspect of microclimatic and geological conditions is an important feature that determines the suitability of the area for construction purposes. This feature also affects the value of the property and should be included in the process of estimating the land designated for construction.

Keywords: Real estate management · Renewable energy sources · Real estate value · Spatial planning

1 Introduction

The intensive development of modern technologies gives the possibility of using alternative, renewable energy sources and is one of the key factors affecting the economic development of each country.

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 375–380, 2019.
https://doi.org/10.1007/978-3-030-16542-0_46

Successively introduced and implemented measures implementing the principles of environmental protection strengthen the economic position of Poland against the background of high-level European countries. The EU assistance funds obtained enable the implementation of highly capital-intensive investments that have a very positive impact on the health of residents and improve the quality of life. Each of the implemented investments, which maintains the principles of sustainable development, has a fundamental impact on the economic development on the local and regional level. The key meaning is striving to achieve the principle of sustainable development both in urbanized areas and outside these areas. EU regulations emphasize that sustainable management of environmental resources is important in real estate management in three areas: environmental protection, environmental pollution and land reclamation. It should be noted that spatial planning is a very important element of real estate management and at the same time is the main tool for environmental protection and shaping [1, 2].

A renewable energy source can be defined as - non-fossil energy source including wind energy, solar radiation energy, aerothermal energy, geothermal energy, hydrothermal energy, hydro energy, wave energy, currents and tides, energy obtained from biomass, biogas, agricultural biogas and bioliquids [10].

The binding legal regulations in the European Union countries, including Poland, set requirements regarding the permissible maximum value of the EP (Primary Energy) indicator, among others, for newly designed production or storage buildings. This indicator determines the annual computational demand of the building for non-renewable primary energy, necessary for heating, ventilation, cooling, domestic hot water preparation and lighting. The maximum value of this indicator is calculated using the formula [2, 5]:

$$EP = EP_{H+W} + \Delta EP_C + \Delta EP_L \left[\frac{\mathrm{kWh}}{\mathrm{m}^2 \cdot \mathrm{year}}\right]$$

where:

EP_{H+W} – partial maximum value of the EP indicator for heating, ventilation and domestic hot water preparation,
ΔEP_C – partial maximum value of the EP indicator for the cooling needs,
ΔEP_L – partial maximum value of the EP indicator for lighting.

Tables 1, 2 and 3 present partial maximum values of individual indices for a production and storage building [6].

Table 1. EP_{H+W} for a production and storage building.

EP_{H+W}	
From 01.01.2017 year*	From 01.01.2021 year*
90	70

* Regulation of the Minister of Infrastructure of April 12, 2002 on technical conditions that should be met by buildings and their location. Journal of Laws 2015, item 1422, in Polish, 2015.

Source: own research based on [6]

Table 2. ΔEPC for production and storage building.

ΔEP_C	
From 01.01.2017 year*	From 01.01.2021 year*
$\Delta EP_C = 25 \cdot \frac{A_{fC}}{A_f}$	
A_f – heated usable area of the building [m^2],	
A_{fC} – cooled usable area of the building [m^2],	
* Regulation of the Minister of Infrastructure of April 12, 2002 on technical conditions that should be met by buildings and their location. Journal of Laws 2015, item 1422, in Polish, 2015. When the building has a cooling system, otherwise $\Delta EP_C = 0$.	

Source: own research based on [6]

Table 3. ΔEP_L for production and storage building depending on the t_0.

ΔEP_L depending on the $t_0 \left[\frac{h}{year}\right]$	
From 01.01.2017 year*	From 01.01.2021 year*
for $t_0 < 2500$; $\Delta EP_L = 50$	for $t_0 < 2500$; $\Delta EP_L = 25$
for $t_0 \geq 2500$; $\Delta EP_L = 100$	for $t_0 \geq 2500$; $\Delta EP_L = 50$
* Regulation of the Minister of Infrastructure of April 12, 2002 on technical conditions that should be met by buildings and their location. Journal of Laws 2015, item 1422, in Polish, 2015. Including built-in lighting, otherwise $\Delta EP_L = 0$	

Source: own research based on [6]

2 Area and Method of Research

In order to confirm the necessity of using alternative energy sources, computational examinations illustrating the demand for the newly installed building usable area were carried out, on non-renewable primary energy necessary for correct and compliant with applicable regulations.

The annual calculation index of the building's demand for non-renewable primary energy determines how much energy from non-renewable energy raw materials can be used in accordance with applicable regulations for heating, ventilation, cooling, hot water preparation and lighting of a given building.

In the case when we directly use raw materials from non-renewable sources for energy production, then the energy consumption is multiplied by the coefficient of non-renewable primary energy (w_i) on the creation and delivery of the energy carrier. This means that the energy obtained from these raw materials requires the use of additional energy needed for extraction and delivery to the building. However, the use of renewable energy sources such as solar energy, geothermal energy, wind energy causes that an workload factor is equal 0.0, which means that to obtain 1 kWh of energy from this source, 0.0 kWh of non-renewable energy will be used [4].

Table 4 presents the annual computational demand for the newly-developed usable floor space of a production or storage building for non-renewable primary energy necessary for heating, ventilation, cooling, domestic hot water preparation and lighting.

Table 4. EP for an exemplary production and storage building.

Individual partial maximum values of the EP indicator	EP	
	From 01.01.2017 year	From 01.01.2021 year
EP_{H+W}	90	70
$\Delta EP_C = 25 \cdot \frac{100}{1000}$	2.5	2.5
ΔEP_L (for $t_0 \geq 2500$)	100	50
The total annual value of the EP indicator	**192.5**	**122.5**
A_f – heated usable area of the building = 1 000 m^2,		
A_{fC} – cooled usable area of the building = 100 m^2.		

Source: own research based on [4]

For design and research purposes, it was assumed that the area designated for the construction of a production or storage building has access to the infrastructure in the form of a system power grid. The system's electro-ergonomic energy, which is the main source of energy, has the most inferior value (w_i = 3.0) of the non-renewable primary energy input coefficient [5]. Table 5 presents the calculated values of the EP indicator using some of the proposed alternative renewable energy sources, i.e. solar, wind, thermal, biomass and biogas, and the calculated value of EP in case of using electricity from the system's power grid.

Table 5. EP indicator when using alternative energy sources.

No.	Way of powering the building with energy	A renewable energy source	w_i	Energy consumption	EP
1	Energy production	Solar energy	0.0	**60*** $\left[\frac{kWh}{m^2 \cdot year}\right]$	0.0
2		Wind energy	0.0		0.0
3		Geothermal energy	0.0		0.0
4		Biomass	0.2		12.0
5		Biogas	0.5		30.0
6	**Electrical grid**	**Electricity**	**3.0**		**180.0**

* Adopted calculation energy consumption for heating, ventilation, cooling, domestic hot water preparation and lighting.

Source: own research based on [4]

In the analyzed case, the EP index was exceeded by almost 50% from the admissible value, which will apply from January 1, 2021. In view of the above, in the case of the planned research facility, it is necessary to take steps to obtain a building permit, to lower its value through the use of alternative energy carriers from renewable sources. Accessibility to renewable energy sources gives the opportunity to increase the share of renewable energy in the energy demand of the building, while the use of appropriate quality building materials and equipment as a building provides the opportunity to reduce computational energy consumption for heating, ventilation, cooling, hot water preparation and lighting.

3 Conclusion

Computational research carried out shows that the value of the primary energy index is important in the investment process. This indicator is a parameter that determines the compliance of the energy demand of a building with the applicable regulations. This paper shows that an attempt to design a building using electricity as the only source of power supply is an unacceptable solution and if it is impossible to reduce the primary energy index by using renewable energy sources disqualifies the area as an investment area [7, 8].

The necessity to use alternative, renewable energy sources at the stage of building design is also one of the elements assessing the suitability of land for construction purposes in the investment process. On the other hand, the location of the real estate, and thus the microclimatic and geological conditions prevailing on it, are not negligible in the case of assessing the suitability of the area for construction purposes. This feature affects the value of the property and should be taken into account in the process of estimating the land designated for construction.

The state administration bodies should carry out activities aimed at conducting surveys depicting the occurring, most advantageous alternative sources of renewable energy in a given area. This information should be made available at the following levels of spatial planning described below, as this information is important in the local and regional dimension. The current spatial planning system in Poland has been shaped in three stages. The first level is the spatial concept of the country's development, taking into account the principles of sustainable development and the actions necessary to achieve it based on natural, cultural, social and economic conditions. The second level is the voivodship spatial development plan. This plan takes into account the arrangements for spatial development of the country, analyzes and studies as well as developed concepts and programs, as well as landscape audits.

The third level is a municipal spatial development plan. The municipal plan determines the purpose of the commune's areas and the manner of their development and development. In the absence of communal spatial development plans, the function of the area is determined on the basis of a study of the conditions and directions of the spatial development of the commune. The study takes into account the findings of the concept of spatial development of the country and the establishment of a spatial development plan for the voivodeship [3, 9].

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Vegetation of Permanent Pastures as a Biomass Source for Energy Purposes

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Abstract. The study aimed at determining applicability of permanent pasture (meadow) vegetation for energy purposes. The possibility of using mowed, air-dried and collected biomass as solid fuel was considered. Botanical composition of the sward and the yield size were determined on the studied area. For individual species found in the sward, analysis of chemical composition, ash content, volatile matter, solid carbon, higher heating value and calorific value were determined. Sward of the studied pasture was dominated by: True fox sedge *Carex vulpina* L and tufted hairgrass *Deschampsia caespitosa* L. Hay yield was 66.3 dt ha^{-1}. Mean higher heating value of the collected plant material was 16.54 MJ kg^{-1}, calorific value was 15.26 MJ kg^{-1}. Ash constituted 6.54%. Vegetation of the studied meadow was characterized by elevated potassium, sodium and calcium content relative to energy crop biomass.

Keywords: Meadow biomass · Energy purposes · Direct combustion

1 Introduction

In recent years, a rather considerable restriction or abandoning of exploitation of significant portion of pastures has been observed in Poland. On average, this state concerns 20% of their area [1]. This results in an ongoing degradation and loss of productive and environmental potential of these areas. Use of vegetation of these areas for energy purposes may be one of the methods for limiting this phenomenon. According to the Institute for Land Reclamation and Grassland Farmig expertise performed for the Ministry of Agriculture and Rural Development, depending on the level of production intensification, from 2.3 to approx. 3.4 M tons of biomass originating from pastures can be annually used for energy purposes, of which 40% from unused meadows. Biomass as fuel material or substrate for biogas production can be further

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 381–389, 2019.
https://doi.org/10.1007/978-3-030-16542-0_47

obtained from pastures subject to agro-environmental program, introducing obligation to perform harvest of at least one swath per year.

The presented study aimed at determining usability of biomass from permanent meadow as solid fuel, through determination of botanical composition of the sward, analysis of chemical composition of selected plant species and determination of their higher heating value and calorific value.

2 Materials and Methods

The study covered an area of a natural meadow, located at the bank of the Rudawa river near Balice (50°05′13″N 19°47′32″E), located within the Zabierzów commune. Part of this pasture constitutes a zone of indirect protection around potable water intake from the Rudawa river. The study was carried out in the first ten days of July. Botanical composition of the sward was determined using botanical and weight method acc. to Stebler and Schrötera (1887), as modified by Filipek [7]. Based on the obtained values, percentage share of individual species in the yield weight was determined from the examined pasture. During botanical analyses, vegetation samples to determine higher heating value and calorific value and chemical composition were also obtained. Higher heating value and calorific value were determined using KL-12Mn calorimeter, following the PN-ISO 1928:2002 standard [22]. In order to determine the general content of ash components, the plant material was incinerated in chamber furnace at temperature of 450 ± 10 °C for 12 h, and the residues were diluted in (1:2) (v/v) nitric acid. Total sulfur content was determined following mineralization of sample in concentrated nitric acid and binding of sulfate sulfur $Mg(NO_3)_2$. Quantitative determination of components in the obtained solutions was performed using inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer Optima 7300 DV) [23]. Nitrogen and carbon content was determined in a Carbon Nitrogen Sulfur analyzer (Vario MAX Cube by Elementar) [5].

3 Results and Discussion

Botanical composition of sward and percentage contribution of individual recorded species is presented in Table 1. The conducted botanical and weight analysis demonstrates that the studied meadow is dominated by true fox sedge and tufted hairgrass. These two species were dominant in the sward and their total share in the yield weight exceeded 30%, thus determining the floristic type. The lowest share in the sward characterized the creeping buttercup. Botanical composition of the studied pasture is characteristic of riparian meadows, formed on soils with higher moisture content, with average fertility and slight acidity [12]. Considering usability of plant assemblages of permanent pastures for energy purposes, their yielding in determined habitat conditions is significant [25]. The analyzed plant assemblage has developed on a locality characterized by higher soil moisture. This is demonstrated by its location, apart from the vegetation. Mean yield of air dry plant mass from the analyzed meadow from one swath that can be harvested was 66.3 dt ha^{-1}. Thus, it is slightly higher than mean hay yields from Polish meadows, which, according to Polish Central Statistical Office (GUS), remained at the level of 44.5 dt ha^{-1} in the period 2006–2010 [8]. However, the usability of plant biomass for energy purposes, through conversion into heat by means of direct combustion, is not determined solely by the yield size, but also its technical parameters such as higher heating value and calorific value. Mean higher heating value of the studied material remained at the level of 16.54 MJ kg^{-1}. This parameter did not exhibit statistically significant differentiation between plant species determined for sward (Table 2). Slightly higher higher heating values, ranging from 17.1 to 19.5 MJ kg^{-1} were obtained in the study of Murawski et al. [19], who studied sward of extensively used meadows. Similar values of the discussed parameter, from 17.08 to 19.17 MJ kg^{-1} are furthermore provided in the study of Harkot et al. [9] who analyzed possibilities of utilizing meadow sward for energy purposes. Values of higher heating value for meadow vegetation obtained in the presented study as well as obtained in other studies do not differ significantly from those concerning biomass of plants generally considered energy crops, such as giant miscanthus (*Miscanthus* × *giganteus*), Virginia mallow (*Sida hermaphrodita* (L.) Rusby) and basket willow (*Salix viminalis* L.). In the case of giant miscanthus (*Miscanthus* × *giganteus*) the higher heating value according to various sources ranges from 16.55 to 19.80 MJ kg^{-1} [2], for Virginia mallow (*Sida hermaphrodita* (L.) Rusby) it ranges from 16.5 to 19.5 MJ kg^{-1} [20], while for willow biomass (*Salix viminalis* L.), depending on the cultivated clone, age of shoots, agrotechnical factors, ranges from 18.3 to 18.7 MJ kg^{-1} [6].

Table 1. Mean values of air dry weight of individual species selected in the sward with their percentage share in the yield.

Species	Mean of air dry weight from the surface of 1000 cm^2 (g)	Mean of air dry mass yield (dt ha^{-1})	The average share of the species in the weight of the yield (%)
Deschampsia caespitosa L.	10.60	10.60	16.0
Carex echinata Murray	7.63	7.63	11.5
Carex vulpina L.	13.10	13.10	19.8
Carex pilosa Scop.	3.73	3.73	5.6
Ranunculus repens L.	2.22	2.22	3.4
Festuca rubra L.	5.83	5.83	8.8
Holcus lanatus L.	5.40	5.40	8.1
Centaurea jacea L.	9.00	9.00	13.6
Molinia caerulea (L.) Moench	5.95	5.95	9.0
Agrostis gigantea Roth	2.80	2.80	4.2

Source: own work

Calorific value constitutes the key parameter for the assessment of biomass utilized for energy purposes. It mainly depends on the moisture content and chemical composition of the fuel. In the case of biomass it is normally lower than for fossil fuels and it ranges from 5 to 8 MJ kg^{-1} for biomass with 50–60% moisture content to 15–17 MJ kg^{-1} for pre-dried material (moisture 15–20%) and approx. 20 MJ kg^{-1} for completely dry [21]. Calorific value for the studied plant material in dry state did not exhibit statistically significant variation and was on average 15.26 MJ kg^{-1}. Higher values of the parameter (from 17.08 to 19.11 MJ kg^{-1}) also concerning meadow vegetation were obtained by Harkot et al. [9]. Compared to the biomass of popular energy crops, calorific value of plants from the analyzed meadow is slightly lower. According to literature data, the value of the parameter for dry willow wood (Salix viminalis L.) is on average 18.50 MJ kg^{-1} [13, 18], for giant miscanthus shoots (Miscanthus × giganteus) it ranges from 16.63 to 16.79 MJ kg^{-1} [15] and in the case of Virginia mallow (Sida hermaphrodita (L.) Rusby), from 16.6 to 16.80 MJ kg^{-1} [15].

Amount of remaining ash constitutes another significant parameter for solid fuel assessment, apart from higher heating value and calorific value. The fuel quality reduces with the increase of its contribution. High ash content in fuel is undesirable, as it results in issues with combustion automation [4] and difficulties associated with management of residues after combustion. In the studied material, ash constituted 6.54% of the share on average and no differences in its content between individual species was found. According to the study of Čubars and Poišana [4] ash content in dried meadow grasses is approximately 7%, however certain differences associated with botanical composition of the sward may occur. Vassilev et al. [27] provide that herbaceous and agricultural mass contain 8% of ash o average, and in the case of rye straw this value amounts to 4.7% [26]. Biomass of energy crops has the following share of ash components: willow wood from 1.8 to 2.2% depending on the shoot age [10], above-ground mass of giant miscanthus (Miscanthus × giganteus) approx. 1.2% [15] Viriginia mallow shoots (Sida hermaphrodita (L.) Rusby) from 2.8 to 5.2% [14].

Share of bound (solid) carbon in the analyzed material was 15.74% on average.

Content of volatile matter means the loss of fuel weight occurring during its thermal destruction in anoxic conditions. The degree of coalification is determined based on the content of volatile matter, determining the value in use of an organic substance. The higher content of volatile matter in the fuel, the easier the ignition and the faster is the combustion. Natural solid fuels with the lowest degree of coalification - biofuels - the content of volatile matter is high and ranges from 60 to 80% [17]. The share of volatile matter in the studied meadow biomass, following the literature reports was also high and it amounted to 77.7% on average, without the trend to differentiate between individual species (Table 2). Biomass of such plants as the Virginia mallow (Sida hermaphrodita (L.) Rusby) and giant miscanthus (Miscanthus × giganteus) is characterized by even higher share of volatile matter, according to Krički et al. [15] amounting to 84.9 and 88.8%, respectively. For willow wood, this value remains at the level of 79.9% [18].

Chemical composition of biomass as solid fuel determines the value of its two most important technical parameters, that is higher heating value and calorific value. The influence of the content of certain elements in the fuel on the type and properties of combustion products formed is of no lower significance. These shall be considered in two aspects: in terms of durability of the devices, on which the combustion process is performed and the environmental burden.

Carbon is the main biomass component, and the energy accumulated in it is released during the combustion process. This element determines the calorific value of biomass. The studied material on average contained 428 g $kgd.w.^{-1}$ of carbon (Table 3). Differences in its content between individual species were statistically insignificant. Slightly higher content of the component (460–480 g $kgd.w.^{-1}$) was determined by Harkot et al. in the hay from once-cut meadow [9]. However, the content of carbon in the analyzed material should be considered as rather high, as according to Jagustyn et al. [11], its content in 'agro' biomass may range from 272–591 g $kgd.w.^{-1}$. Biomass of energy crops: willow (Salix viminalis L.), mallow (Sida hermaphrodita (L.) Rusby) and miscanthus (Miscanthus × giganteus) on average contains this component at the level of 504.5; 491.4 and 496.4 g $kgd.w^{\cdot -1}$, respectively [16].

Table 2. Mean ash, volatile matter, bound carbon for individual species distinguished in the sward and their higher and lower heating value in dry state.

Species	Ash dry A_d (%)	Volatile parts dry V_d (%)	Bound carbon dry C_{fd} (%)	Higher heating value dry HHV (MJ kg^{-1})	Lower heating value dry LHV (MJ kg^{-1})
Deschampsia caespitosa L.	6.91	76.50	16.58	16.64	15.36
Carex echinata Murray	6.85	76.86	16.30	17.09	15.81
Carex vulpina L.	5.29	80.28	14.43	17.03	15.73
Carex pilosa Scop.	5.30	78.19	16.50	16.19	14.89
Ranunculus repens L.	6.85	75.92	17.22	16.53	15.25
Festuca rubra L.	10.19	70.85	18.96	16.52	15.29
Holcus lanatus L.	8.38	74.99	16.63	16.66	15.40
Centaurea jacea L.	6.30	79.39	14.31	16.85	15.57
Molinia caerulea (L.) Moench	4.14	83.34	12.51	15.32	14.01
Agrostis gigantea Roth	5.19	80.87	13.94	16.58	15.28

Source: own work

From ecological viewpoint, nitrogen and sulfur contribute to the increase of greenhouse gas emissions and are taken into consideration every time fuels are characterized. Moreover, sulfur has strong corrosive action. Sulfur content was on average 1.57 g $kgd.w.^{-1}$ (Table 3) and it can be considered to be rather low, as according to Jagustyn et al. [11], content of this element in 'agro' biomass may range from 0.3 to 6.7 g $kgd.w.^{-1}$. In terms of sulfur content, differences between species were insignificant. In the study carried out by Harkot et al. [9] the content of sulfur in meadow biomass ranged from 1.4 to 2.7 g $kgd.w.^{-1}$. On the other hand, mean sulfur content in the biomass of energy crops (willow (Salix viminalis L.), mallow (Sida hermaphrodita (L.) Rusby) and miscanthus (Miscanthus × giganteus)) is slightly lower, according to Król et al. [16] it amounts to 0.3; 1.2 and 0.9 g $kgd.w.^{-1}$ respectively.

The content of nitrogen in the collected plants did not exhibit significant differentiation as well. On average, it was present at the level of 10.4 g $kgd.w.^{-1}$ (Table 3).

In the biomass of agricultural origin, the N content may range from 0.8 to 14 g kgd.w.$^{-1}$ [17], while in the plants of willow (Salix viminalis L.), mallow (Sida hermaphrodita (L.) Rusby) and miscanthus (Miscanthus × giganteus) it ranges from 0.8 to 8.8 g kgd.w.$^{-1}$ [16].

Table 3. Carbon, nitrogen, sulfur content in plant material.

Species	N	C	S
	g kgd.m.$^{-1}$		
Deschampsia caespitosa L.	10.8 ± 0.02	430 ± 0.03	1.12 ± 0.04
Carex echinata Murray	9.84 ± 0.03	427 ± 0.02	1.10 ± 0.02
Carex vulpina L.	11.4 ± 0.02	442 ± 0.02	1.45 ± 0.02
Carex pilosa Scop.	11.0 ± 0.01	434 ± 0.02	2.03 ± 0.05
Ranunculus repens L.	10.7 ± 0.01	433 ± 0.01	2.95 ± 0.02
Festuca rubra L.	13.7 ± 0.01	407 ± 0.05	2.14 ± 0.08
Holcus lanatus L.	9.65 ± 0.09	415 ± 0.02	1.59 ± 0.18
Centaurea jacea L.	10.0 ± 0.07	425 ± 0.05	1.11 ± 0.01
Molinia caerulea (L.) Moench	8.13 ± 0.02	437 ± 0.03	0.97 ± 0.01
Agrostis gigantea Roth	8.95 ± 0.03	434 ± 0.01	1.22 ± 0.08

±standard deviation, n = 2
Source: own work

The properties of mineral substance during combustion are largely influenced by the presence of alkaline metals such as Na, K, Ca and S. Sodium and potassium evaporate in high temperatures, and then by reacting with other combustion products form low melt compounds accumulating on the operating areas of furnaces, other elements associated with the phenomenon, such as sulfur, accelerate high-temperature corrosion [11].

The analyzed biomass of individual species did not exhibit differentiation in terms of sodium, potassium and calcium content. The mean content of these elements was 0.28; 11.80 and 7.92 g kgd.w.$^{-1}$, respectively (Table 4). Potassium stands out particularly well here due to its high content. However, it is not a special case, as numerous authors have reported high share of this element, especially in agricultural biomass. Potassium content determined by Stępień and Pawluczuk [24] in meadow vegetation ranged from 0.3–9.3 g kgd.w.$^{-1}$. Wesołowski et al. [28] who analyzed chemical composition of plant assemblages of shoreline of a water body provide the potassium content at the level of 25.4 g kgd.w.$^{-1}$. Moilanen [18] provides K content of barley straw at the level of over 12 g kgd.w.$^{-1}$.

The calcium, potassium and sodium content in the analyzed plant species was slightly higher than the values provided by Borkowska and Lipiński [3] for biomass of long-term energy crops (willow (Salix viminalis L.), mallow (Sida hermaphrodita (L.) Rusby) and miscanthus (Miscanthus × giganteus)) in which the mean content of these elements is 5.01; 3.37 and 0.10 g kgd.w.$^{-1}$, respectively.

Table 4. Macronutrient content in plant material.

Species	Na	K	Ca
	g kgd.w.$^{-1}$		
Deschampsia caespitosa L.	0.114 ± 0.04	12.8 ± 0.10	6.25 ± 0.13
Carex echinata Murray	0.066 ± 0.005	11.0 ± 0.07	6.84 ± 0.09
Carex vulpina L.	0.071 ± 0.000	12.8 ± 0.00	5.14 ± 0.05
Carex pilosa Scop.	0.058 ± 0.005	12.3 ± 0.29	6.34 ± 0.28
Ranunculus repens L.	0.083 ± 0.001	13.6 ± 0.07	8.32 ± 0.03
Festuca rubra L.	1.917 ± 0.014	16.1 ± 0.08	20.4 ± 0.11
Holcus lanatus L.	0.118 ± 0.003	15.3 ± 0.17	4.99 ± 0.12
Centaurea jacea L.	0.076 ± 0.001	10.3 ± 0.10	5.14 ± 0.04
Molinia caerulea (L.) Moench	0.085 ± 0.001	8.45 ± 0.14	2.63 ± 0.06
Agrostis gigantea Roth	0.208 ± 0.005	5.32 ± 0.08	13.1 ± 0.14

±standard deviation, n = 2
Source: own work

4 Conclusions

1. In terms of botanical composition, the studied pasture belongs to riparian meadows type true fox sedge and tufted hairgrass.
2. Air dry yield of plant mass from the studied meadow remains at the level of 66.3 dt ha^{-1} and it is slightly higher than mean yielding level for meadows in Poland.
3. Mean higher heating value for the studied material was 16.54 MJ kg^{-1}, and calorific value was on average 15.26 MJ kg^{-1}.
4. Higher heating value of the analyzed vegetation was similar to the value of the parameter obtained for energy crops: giant miscanthus (*Miscanthus* × *giganteus*) and Virginia mallow (*Sida hermaphrodita* (L.) Rusby).
5. The content of volatile matter in the studied biomass was 77.7%, thus it was lower relative to energy crops such as basket willow, Virginia mallow and giant miscanthus.
6. Biomass of the studied meadow was characterized by higher sodium, potassium and calcium content relative to energy crops ((willow (*Salix viminalis* L.), mallow (*Sida hermaphrodita* (L.) Rusby) and miscanthus (*Miscanthus* × *giganteus*)).
7. A significant contribution of areas covered with permanent grassy and herbaceous vegetation emphasizes the need for further this type research.

Acknowledgements. This research was financed by Ministry of Science and Higher Education of the Republic of Poland.

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Author Index

A. Krakowiak-Bal and M. Vaverkova (Eds.): *Infrastructure and Environment*, pp. 391–392, 2019.
https://doi.org/10.1007/978-3-030-16542-0