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Czasopismo Polskiego Stowarzyszenia
Ekonomistów Środowiska i Zasobów Naturalnych

THEORETICAL AND METHODOLOGICAL PROBLEMS

ENVIRONMENTAL POLICY AND MANAGEMENT

STUDIES AND MATERIALS

GENERAL ENVIRONMENTAL AND SOCIAL PROBLEMS

THEORETICAL AND METHODOLOGICAL PROBLEMS

PROBLEMY TEORETYCZNE I METODYCZNE

Krzysztof **BORYCZKO** • Janusz **RAK**

ANALYSIS AND EVALUATION OF HAZARDS IN EMERGENCY SITUATIONS IN WATER SUPPLY SYSTEMS

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ABSTRACT: The new regulation concerning the quality of drinking water offers a number of delegations on the waterworks inform users about the quality of tap water. The study analysis on the public risk health should be prepared. In the paper the analysis and assessment method of the population and property related to failure occurrence of collective water supply systems is presented. Four categories of factors having impact on the multiplicative risk: purity category or probability of danger occurrence, material damage, loss of population health and security were adopted. On this basis four-parametric risk matrix was developed. In the study also examples of application methods were presented. The method can provide a planning tool in crisis management at the local government level.

KEY WORDS: water supply, risk, risk matrix

Introduction

The Act of 2001 (Ustawa, 2001) on collective water supply and collective sewage disposal gives public health minister a competent to determine by requirements of water quality intended for human consumption. The new regulation (Ustawa, 2015) in came into force on November 28, 2015. Currently, information about the water quality deterioration the water supply company is obliged to transfer within no longer than 7 working days to the sanitary state inspector and mayor or president of the city.

Scope of the information contained in the request for a waiver was extended to:

- reasons why water of the required quality cannot be delivered,
- justifications with an indication of actions to ensure good quality water,
- a study analysis prepared by a research institution conducting studies,
- in the field of public health regarding, the impact of the derogation (concentration and duration) on the health of water consumers.

In addition, an obligation to provide a systematic (every 3 months) detailed report on corrective actions taken and actions planned to be taken in the next reporting period was introduced. Information for consumers about water quality includes data on granted consents to deviation from acceptable water quality parameters. Standard information for residents about water quality should include:

- area covered by water quality research,
- area not covered by water quality research with reasons,
- hazards resulting from lack of water quality research,
- identification of activities that should be taken against contaminated water.

The provisions of the regulation also apply to water from individual water intakes supplying less than 50 people or providing less than 10 m^3/d.

The aim of the paper is to present analysis and assessment method of the population and property related to failure occurrence in collective water supply systems (CWSS). Four categories of factors having impact on the multiplicative risk: probability category of danger occurrence, material damage, loss of population health and security were adopted. On this basis four-parametric risk matrix was developed. In the study also example applications of the methods were presented. The method can provide a planning tool in crisis management at the local government level.

An overview of literature

Risk related to CWSS is the possibility of an event having an impact on safe water supply achievement. According to the international ISO standard (ISO, 2009) the risk assessment consists of its identification, analysis, estimation and evaluation. The Method of Analysis and Assessment of Population and Property Threat requires determining the upper limits of tolerated and controlled risk (Cooper et al., 2005). The goal of risk management is to bring risk level to at least tolerated, and preferably to the "as low as reasonably practicable" ALARP level (Clifton, Ericson, 2005; Pietrucha-Urbanik, Studziński, 2016; Szpak, Tchórzewska-Cieślak, 2015). The novelty of the material and human losses separation method is presented in paper.

In crisis management, a proper risk assessment is the basis for taking actions to effectively and efficiently ensure safety (Boryczko, Piegdon, Eid, 2014; Boryczko, 2016; Rak, Boryczko, 2017). Effective actions should be understood as fully achieving the goals set. In turn, achieving certain results is considered effective.

Risk analysis methods are mainly developed to meet the needs of safety engineering (Vocabulary ISO, 2009). It implies the use of risk assessments in crisis management. The Act on Crisis Management (Ustawa, 2007) obliges the estimation of risk with regard to at least human losses (fatalities, missing persons, injured persons requiring hospitalization and qualified medical aid) and property losses. The classic definition of risk shows that its estimation consists in multiplying the probability or frequency of occurrence of a threat by the losses. Risk estimation requires determining the value of both these factors. The joint consideration of human damages and material losses raises ethical concerns. For this reason, separation should categorize both the risks associated with material losses and human damage. The People and Property Risk Analysis (PPRA) method assumes the adoption of five-stage scales for human damages and material losses (very small, small, medium, large, very large).

The problem of probability estimation

The estimation of danger probability can be made based on modified Bernoulli distribution. Bernoulli's classic formula for the probability of obtaining k successes in n samples is calculated from the formula:

$$P(k) = \binom{n}{k} p^k \cdot q^{n-k}$$

where:

P – the probability of success,

q=1-p – the probability of failure,
k – number of successes,
n – number of samples.

Assuming that:

$$P(A) = 1 - P(A_1)$$

and:

$$P(A_1) = \left(\frac{n}{k}\right) p^k \cdot q^{n-k}$$

and for A_1 event, $n = k$, and $p = 1 - y$, then the formula takes the form:

$$P(A) = 1 - \left[\left(\frac{n}{k}\right) p^k \cdot q^{n-k}\right] = 1 - [1 \cdot (1-y)^n \cdot q^o] = 1 - (1-y)^n$$

where:
y – the frequency of occurrence of hazard A, the value obtained from experience and can be identified with a posteriori probability.

When determining the time perspective, for which the probability of risk is calculated, analysis should take into account time that has elapsed since the last year when threats have occurred. Thus:

$$n = N + (n_1 - n_2)$$

where:
n_1 – the year in which the analysis is carried out,
n_2 – the year in which the last threat occurred,
N – time of prospective analysis.

Table 1 presents the scale of the frequency and probability categories of undesirable event.

Table 1. Categories of frequency and probability of hazard occurrence

Category	Frequency – f	Probability – P
Very small	from once every 100 years up to once every 50 years	0,01–0,02
Small	from once every 50 years up to once every 20 years	0,02–0,05
Average	from once every 20 years up to once every 5 years	0,05–0,2
Large	from once every 5 years up to once every 2 years	0,2–0,5
Very large	from once every 2 years at least once a year	>0,5

Source: author's own work.

Application case of probability estimation

In 2011, the probability of surface water intake contamination was estimated. In 30 years (from 1981), contamination occurred four times, and the last time in 2010. What is the probability of contamination in the perspective of 5 years?

$$n = 5 + (2011 - 2010) = 6$$

$$p = \frac{4}{30} = 0{,}1333$$

$$P(A) = 1 - (1 - p)^n = 1 - (1 - 0{,}1333)^6 = 0{,}57615$$

The probability of water contamination in 2016 with the perspective of the next 5 years was also estimated. The last threat occurred unchanged, i.e. in 2010:

$$n = 5 + (2016 - 2010) = 11$$

$$p = 0{,}1333$$

$$P(A) = 1 - (1 - 0{,}1333)^{11} = 0{,}79272$$

The probability of water contamination in 2011-2016 was 0.57615, and in 2016-2021 it increased to 0.79272.

Problems of estimating material losses

Estimation of material losses resulting from an undesirable event is a complex and multifaceted. The valuation of assets of people, enterprises, real estate, etc. is subject to many researches (Gołębiewski, 2011). At work the interest on local government level income as a measure of losses was assumed.

Table 2. Category of material losses

Category	The amount of material losses – C
Very small	up to 2% of annual income
Small	up to 5% of annual income
Average	up to 15% of annual income
Large	up to 30% of annual income
Very large	over 30% of the annual income or the inability to pass a budget for another year due to exceeding the individual debt ratio

Source: author's own work.

Problems of human losses

The indicator used in analyzes and assessments of accidents at work was adopted. The failure frequency rate indicates the number of undesirable events per 1000 employed. By analogy, the number of undesirable events per 1000 people using the public waterworks was adopted. Three types of human losses were distinguished:

- granting qualified medical help – FM,
- required hospitalization – FH,
- fatal descent – FF.

Table 3 presents the scale of the category of human losses.

Table 3. Category of human losses

Category	Human loss rate		
Very small	FM≤5	FH=0	FF=0
Small	FM≤25	FH≤2	FF=0
Average	FM≤100	FH≤20	FF≤0,05
Large	FM≤250	FH≤100	FF≤0,5
Very large	FM>250	FH>100	FF>0,5

Source: author's own work.

For example the commune (population P=4000 people) uses CWSS. For an undesired event related to secondary water pollution in the water supply network, F_M=20, F_H=0 and FF =0. The number of people who should be given a qualified medical aid is:

$$\frac{P \cdot F_M}{1000} = \frac{4000 \cdot 20}{1000} = 80\ people$$

A four-parameter risk matrix

In the proposed method, the risk is determined by the formula:

$$r = \frac{P \cdot C \cdot F}{O}$$

where:

P – the probability of a threat,
C – material losses,
F – human losses,
O – protection.

Table 4. Four-parameter risk matrix (VS – very small; S – small; A – average; L – large; VL – very large)

	O						O						O				
	no protection						passive protection						active protection				
F	P					F	P					F	P				
	VS = 1						VS = 1						VS = 1				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	1	2	3	4	5	VS = 1	0,5	1	1,5	2	2,5	VS = 1	0,33	0,67	1	1,33	1,67
S = 2	2	4	6	8	10	S = 2	1	2	3	4	5	S = 2	0,67	1,33	2	2,67	3,33
A = 3	3	6	9	12	15	A = 3	1,5	3	4,5	6	7,5	A = 3	1	2	3	4	5
L = 4	4	8	12	16	20	L = 4	2	4	6	8	10	L = 4	1,33	2,67	4	5,33	6,67
VL = 5	5	10	15	20	25	VL = 5	2,5	5	7,5	10	12,5	VL = 5	1,67	3,33	5	6,67	8,33
F	P					F	P					F	P				
	S = 2						S = 2						S = 2				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	2	4	6	8	10	VS = 1	1	2	3	4	5	VS = 1	0,67	1,33	2	2,67	3,33
S = 2	4	8	12	16	20	S = 2	2	4	6	8	10	S = 2	1,33	2,67	4	5,33	6,67
A = 3	6	12	18	24	30	A = 3	3	6	9	12	15	A = 3	2	4	6	8	10
L = 4	8	16	24	32	40	L = 4	4	8	12	16	20	L = 4	2,67	5,33	8	10,67	13,33
VL = 5	10	20	30	40	50	VL = 5	5	10	15	20	25	VL = 5	3,33	6,67	10	13,33	16,67
F	P					F	P					F	P				
	A = 3						A = 3						A = 3				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5

BM = 1	3	6	9	12	15	VS = 1	1,5	3	4,5	6	7,5	VS = 1	1	2	3	4	5
M = 2	6	12	18	24	30	S = 2	3	6	9	12	15	S = 2	2	4	6	8	10
S = 3	9	18	27	36	45	A = 3	4,5	9	13,5	18	22,5	A = 3	3	6	9	12	15
D = 4	12	24	36	48	60	L = 4	6	12	18	24	30	L = 4	4	8	12	16	20
BD = 5	15	30	45	60	75	VL = 5	7,5	15	22,5	30	37,5	VL = 5	5	10	15	20	25
F	P					F	P					F	P				
	L = 4						L = 4						L = 4				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	4	8	12	16	20	VS = 1	2	4	6	8	10	VS = 1	1,33	2,67	4	5,33	6,67
S = 2	8	16	24	32	40	S = 2	4	8	12	16	20	S = 2	2,67	5,33	8	10,67	13,33
A = 3	12	24	36	48	60	A = 3	6	12	18	24	30	A = 3	4	8	12	16	20
L = 4	16	32	48	64	80	L = 4	8	16	24	32	40	L = 4	5,33	10,67	16	21,33	26,67
VL = 5	20	40	60	80	100	VL = 5	10	20	30	40	50	VL = 5	6,67	13,33	20	26,67	33,33
F	P					F	P					F	P				
	VL = 5						VL = 5						VL = 5				
	C						C						C				
	VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5		VS = 1	S = 2	A = 3	L = 4	VL = 5
VS = 1	5	10	15	20	25	VS = 1	2,5	5	7,5	10	12,5	VS = 1	1,67	3,33	5	6,67	8,33
S = 2	10	20	30	40	50	S = 2	5	10	15	20	25	S = 2	3,33	6,67	10	13,33	16,67
A = 3	15	30	45	60	75	A = 3	7,5	15	22,5	30	37,5	A = 3	5	10	15	20	25
L = 4	20	40	60	80	100	L = 4	10	20	30	40	50	L = 4	6,67	13,33	20	26,67	33,33
VL = 5	25	50	75	100	125	VL = 5	12,5	25	37,5	50	62,5	VL = 5	8,33	16,67	25	33,33	41,67

Source: author's own work.

The values of parameters *P*, *C*, *F* are taken according to table 1, 2 and 3. The *O* parameter is set to:

- 1 – no protection,
- 2 – passive protection (monitoring of the CWSS, but without the possibility of immediate reaction to the existing situation),
- 3 – active protection (monitoring of CWSS with the possibility of immediate reaction to the existing emergency event).

Table 4 presents a four-parameter risk matrix, which, based on formula, allows to estimate risk.

The three-grade risk score has been adopted arbitrarily. The individual risk intervals result from the ALARP (As Low As Reasonably Practicable) risk management methodology:

- tolerated risk – from 0.33 to 15,
- controlled risk – from 16 to 45,
- unacceptable risk – from 48 to 125.

Summary

- The methodology of risk analysis and assessment from the author's assumption is simple, with the possibility of easy applying. It can be used for preliminary hazards estimation. The method can be easily adapted to other municipal management systems.
- The People and Property Risk Analysis method presented in the paper is a kind of development of the Preliminary Hazard Analysis method. It allows to analyse human and material losses separately.
- The People and Property Risk Analysis method can be a planning tool in crisis management at the level of local government units.

The contribution of the authors

Krzysztof Boryczko – conception, literature review, acquisition of data, analysis and interpretation of data – 50%
Janusz Rak – conception, literature review, acquisition of data, analysis and interpretation of data – 50%

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Piotr **RYNKOWSKI**

NUMERICAL MODELLING OF HEAT LOSS THROUGH THE COVER IN THE ANAEROBIC DIGESTER

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ABSTRACT: Anaerobic digestion is the biological degradation of biomass in oxygen-free environments. The main product of this process is biogas, rich in CH4 and CO2. Understanding the heat loss characteristic of biogas digester (BD) is important to put these technologies into application. Biogas digester may obtain assumed gas production in cold environmental when the optimal fermentation temperature is maintained. It requires heating system and insulation technologies. Here 2-D axisymmetric steady heat transfer model coupled with surrounding soil was built to calculate heat loss of HBD for a real biogas plant located in north-eastern Poland. A sample to determine the effect of air flow between the membranes of the BD cover on the heat losses has been presented.

KEY WORDS: anaerobic digestion, heat loss

Introduction

Anaerobic digestion is the biological degradation of biomass in oxygen-free environments. Biogas digester has emerged as a successful and promising technology for organic waste management. It has established process for organic wastes. The main product of this process is biogas, rich in CH_4 and CO_2. Biogas digesters (BD) may achieve higher gas production in cold environments by heating and insulation technologies. Understanding the heat loss characteristic of BD is important to put these technologies into application.

Large-scale anaerobic digestion, biogas is burned in cogeneration process to produce electricity, generally for sale and heat. The cogenerated hot water is used by heat exchanger to heat anaerobic digester. In order to maintain the operating temperature in the BD in its optimum from about 40°C to 50°C in the cool climate additional thermal energy is required. Biogas digesters is sensitive to thermal disturbances. Fluctuations of temperatures may lead to decreasing in the biogas yield. The heat transfer phenomena between the biogas digester situated in north-eastern Poland and its surrounding is analysed. The numerical model predicts the heat loss through the cover and the BD for different conditions in the winter season in Poland.

In tropical climate the BD can run efficiently during all year. In cool climate, the temperature in winter is low, what leads to a low biogas production. Several heating technology were introduced to BD and several models for predicting the variations of the digester temperature as a function of climatic conditions were presented (Singh, Singh, Bansal, 1985; Usmani, Tiwari, Chandra, 1996; Perrigault et al., 2012).

Heat transfer phenomena depends on ambient conditions: air temperature, wind speed, solar irradiation intensity, initial ground temperature, etc. Full CFD simulations of anaerobic digesters with non-Newtonian character of the BD are extremely complex. Nowadays CFD simulations of full-scale reactors during the long time require unaffordable computation times. Literature presents 0D thermal models which are much more efficient computationally.

An overview of literature

Singh et al. (1985) proposed a time-dependent, one dimensional model for simulating a solar-heated anaerobic digester. The solar collectors are coupled to a heat exchanger immersed in the digester manure. A fixed dome and floating dome type digesters were analyzed. The model assumed that the

majority heat transfer occurs between the top of the cover and the ambient air.

Usmani et al. (1996) developed an analytical expression for the instantaneous thermal efficiency of a greenhouse-integrated biogas system and the instantaneous thermal loss efficiency factor from the system for given capacity. Gebremedhin et al. (Gebremedhin et al., 2005) established a comprehensive mathematical model that predicts energy requirements to operate a plug-flow anaerobic digester at a specified temperature. The model includes the influence of solar radiation, soil temperature distribution and periodic meteorological conditions on the digester heat transfer to the surrounding soil. Nevertheless, the accuracy of these models was not proved.

Perrigault et al. (2012) used a simple time-dependent thermal model using inputs of solar radiation, wind velocity ambient temperature and digester geometry. The model outputs include temperature of the slurry, the biogas, its holding membrane, wall and cover. The model predicts the influence of geometry and materials on the performance of the digester in cold climate.

Because of the analytical limitations the numerical simulations is a better approach to study the BD heat transfer process. Wu and Bibeau (2006) presented a three-dimensional steady-state model for simulating heat transfer for anaerobic digesters for cold weather conditions. Numerical CFD heat transfer model was used to calculate the heat transfer through the cover, floor and walls. Simulated heat transfer results were compared to a one-dimensional numerical model and validated against experimental data using an operating anaerobic digester.

Yiannopoulos et al. (2008) proposed and developed mathematical model for the prediction of the temperature distribution within the reactor under steady state conditions. The results based on model simulations performed with meteorological data, for latitudes up to 50o suggested that the proposed solar heating system could be a promising and environmentally friendly for anaerobic treatment. Bavutti et al. (2014) focused on summer overheating of BD.

Nowadays, many investigations are focused on small-scale digesters used by families to produce biogas for cooking and heating.

The current study investigates heat transfer phenomena in a large-scale semi-buried agricultural digester located in north-eastern Poland (figure 1). Two-dimensional axisymmetric numerical model was developed to simulate the heat loss as a function of climatic conditions.

Figure 1. Large-scale semi-buried digester located in north-eastern Poland
Source: author's own work.

The anaerobic digester

Anaerobic digester and heat transfer model basic components are shown in figure 2. The biogas plant is located in north-eastern Poland (latitude 52°56'N and longitude 23°15'E). It consists of two anaerobic digesters with diameter 30 m and height 6 m and one anaerobic digester with diameter 32 m and height 8 m. In study, the analyzed reactor has diameter 30 m and height 6 m. The wall is made of reinforced concrete 25 cm thick. The reactor's floor is insulated 8 cm thick polystyrene. The all surface non-buried and buried, for a better thermal insulation, are covered 10 cm thick polystyrene. The reactor's cover is a deformable green EPDM double layer membrane, whose thickness is about 3 mm. The digester is equipped with a mechanical mixing system. Biogas is burned in-site in a cogeneration unit and electricity is delivered to the national grid. Cogenerated hot water is sold and used to heat the digestate through immersed helical-coil heat exchanger. The digestate temperature set point is 40°C.

The reactor is poorly instrumented. The measuring system consisted of the temperature, electricity and heat meter. Part of the data are recorded and part of them are saved manually. The data were obtained from biogas plant manager. The analyzed data are:

- water temperature at the inlet and at the outlet heat exchanger,
- the flow rate of water by the heat exchanger,
- the digestate temperature measured once a day,
- thermal energy generated in a cogeneration unit.

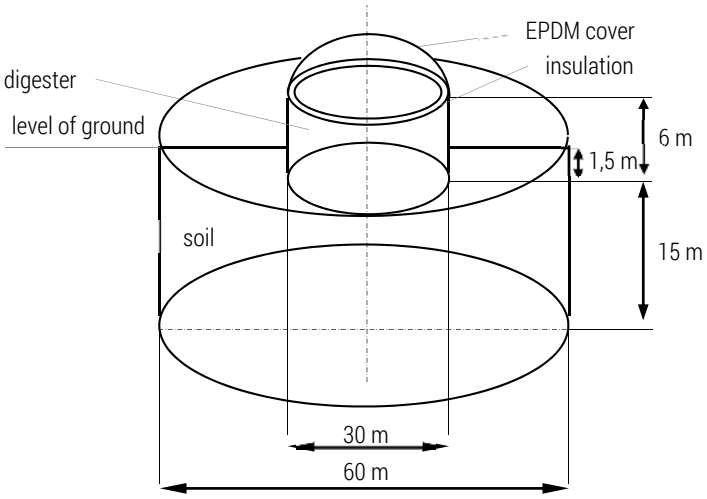

Figure 2. Schematic representation of the anaerobic digester investigated in this study (not to scale)

Source: author's own work.

The manure temperature fluctuations in anaerobic digester during 2016 year is shown in figure 3. The operating temperature fluctuates in a narrow range, between minimum 35,7°C and maximum 43,2°C. During the summer the set point is reached and exceeded in hot days. During the winter the temperature is below set point 40°C. According to the biogas plant manager, during the cool days biogas production is much lower. Therefore, the thermal analysis of the anaerobic digester is required.

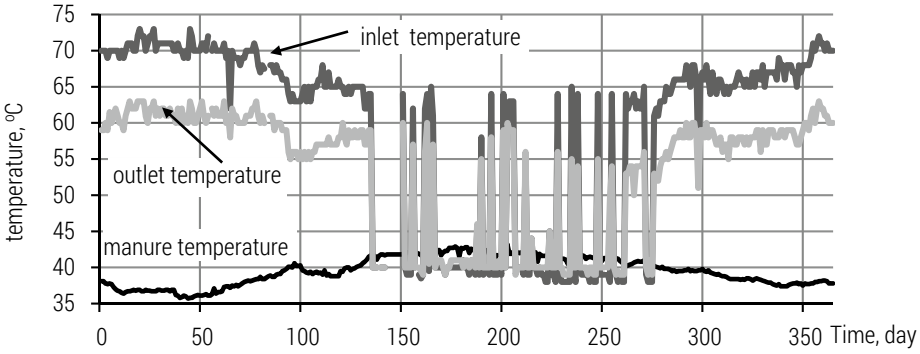

Figure 3. The manure and temperature fluctuations in anaerobic digester and temperature on inlet and outlet of the heat exchanger during 2016 year

Source: the biogas plant data.

Mathematical model

Assumptions

The assumptions used for modelling of the anaerobic digester heat transfer model:

- heat flow through the digester is axisymmetric 2-D and steady,
- the air flow between the membrane is steady,
- the ambient air temperature is constant,
- physical properties of the soil, digester material, insulation material is uniform,
- the effect of moisture transfer and phase transition on the heat transfer of the digester is ignored,
- due to the low value of solar radiation in the location area of digester during the winter season, to simplify the model, the solar radiation and sky effective temperature is neglected.,
- the temperature profile in the soil come from own research,
- according to the biogas plant manager, heat demand for manure heating is 49.4 kW.

Thermal equilibrium equation

The thermal model equations are presented as (figure 4):

$$Q_{manure} + Q_{heating} = Q_{cover} + Q_{wall} + Q_{floor} + Q_{air\text{-}outlet}$$

where:

Q_{manure} – is the heat required to raise temperature of the influent manure to the operating temperature (W),

$Q_{heating}$ – is the heat supplied by the heating system (W),

Q_{cover} – is the heat losses through the digester cover (W),

$Q_{wall\text{-}air}$ and $Q_{wall\text{-}soil}$ – is the heat losses respectively through the digester wall above and below ground level (W),

Q_{floor} – is the heat losses through the digester floor (W),

$Q_{air\text{-}out}$ – is the heat losses through the digester cover by the air flow between the membranes of the cover (W).

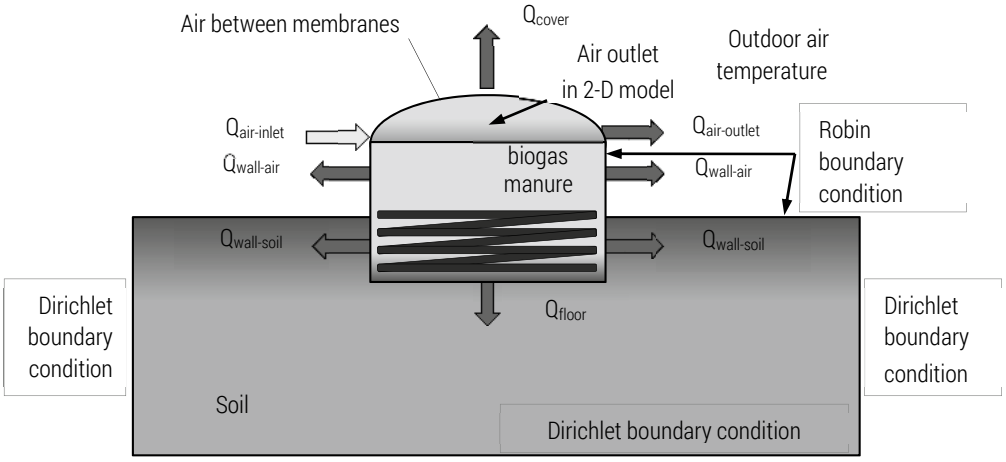

Figure 4. Heat transfer process between anaerobic digester and surrounding with axis of symmetry 2-D axisymmetric steady heat transfer model

Source: author's own work.

Boundary condition

The analysis of 2-D axisymmetric heat transfer problem with Dirichlet, Neumann and Robin boundary conditions. The surface of soil column adopts the Robin boundary condition. The undisturbed ground temperature profile (boundary condition, figure 4) for different depth is presented on figure 5 (Rynkowski, 2017). The manure temperature in biogas digester was obtain from biogas plant data (figure 3).

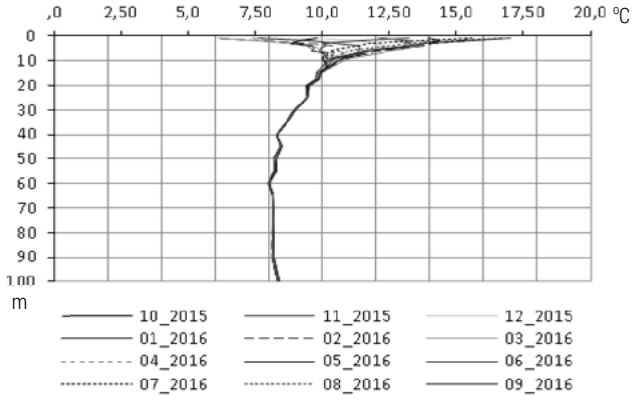

Figure 5. Average undisturbed ground temperature profile

Source: (Rynkowski, 2017).

Between the cover membranes is pumped the outdoor air. According to measurements the velocity of the air is near 4 m/s, diameter of inlet and outlet is 100 mm. Because of 2-D axisymmetric model, it was assumed that the inlet is like in practice, while the outlet is at the central point of upper part the cover (figure 4). Heat loss analysis at different inlet air speeds is considered.

Simulation method

Two-dimensional axisymmetric mesh upper part of model is shown on figure 6. Simple scheme for pressure velocity coupling were solved. The second order upwind scheme were used for energy discretization. The realizable k-ε turbulence model was adopted with scalable wall functions. For each simulation solution was converged before 2000 iterations.

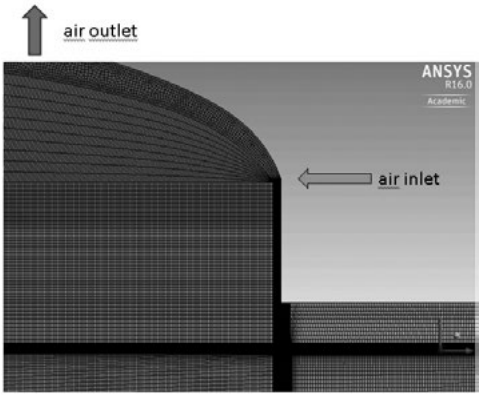

Figure 6. 2-D axisymmetric fragment mesh model with air inlet and outlet points

Source: author's own work.

Table 1. Thermophysical properties of the material

Term	Material	Density kg/m^3	Thermal conductivity coefficient W/(m·K)	Specific heat capacity J/(kg·K)
Soil	Loess	1650	1,00	840
Insulation	Styrofoam	40	0,04	1 460
Wall	Reinforced concrete	2 300	2,30	1 000
Cover	Membrane EPDM	900	0,06	840
Floor	Reinforced concrete	2 500	2,30	840
Biogas (CH_4)	Methane	0,6679	0,0332	2 370
Air (between membranes)	Air	from 1,377 (-22oC) to 1,202 (17oC)	0,0242	1 006

Source: author's own work.

Result and discussion

The model was solved using Fluent R16.0 Academic version. As boundary condition was set average monthly temperatures in the considered location in winter season. The sample of the digestate average temperature distribution for January is presented on figure 7.

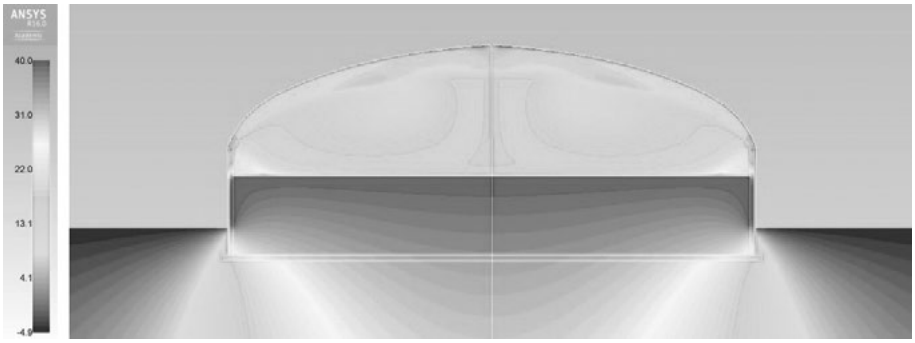

Figure 7. The sample digestate average temperature distribution for January

Source: author's own work.

The monthly average temperatures and heat losses with the average thermal power Q_{HE} of the heat exchanger during the winter season for existing anaerobic digester are presented in table 2. The thermal power of the heat exchanger, taking into account heat demand for manure heating, for heat loss was independently determined.

Table 2. The monthly average temperatures, heat losses to the environment and operating power of the heat exchanger

Month	Monthly temperature [°C]	Q [kW]	QHE [kW]
Calculation temperature	-22,0	58,9	-
January	-4,9	44,7	44,0
February	-2,0	42,3	40,3
March	1,7	39,4	25,4
November	1.6	39,3	30,7
December	-1.3	41,8	39,4

Source: author's own work.

Despite the numerous approximations and assumptions used, the numerical results are in good agreement with real data and observations of heat

exchanger work. In winter, the anaerobic digester temperature remains in a narrow range, between 35,7°C and 39°C (figure 3). Base on table 2 the reason of the temperature drop may be underestimation of the heat exchanger or other reasons related to the operation of the exchanger (pollution of the exchanger causing dropping its efficiency). The manure has a large thermal inertia, so the temperature changes slowly with the time.

The important question is: what is the effect of inlet air flow rate between membranes of the BD cover, on heat loss by the cover of the anaerobic digester? The results of the numerical simulations as the average heat loss in winter months in function of air inlet speed presents figure 8.

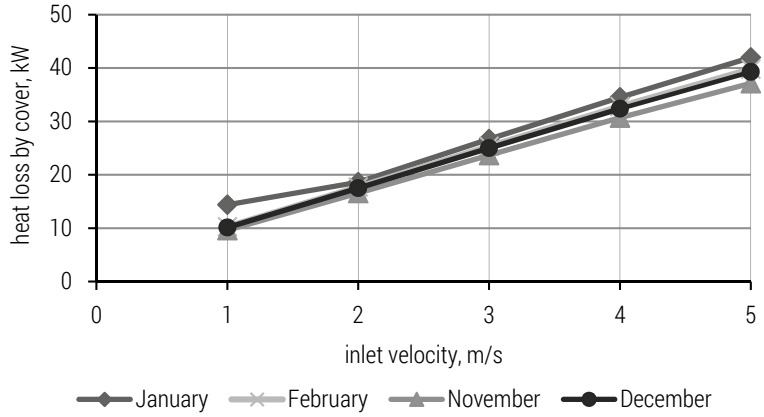

Figure 8. The average heat loss in winter months in function of air inlet speed

Source: author's own work.

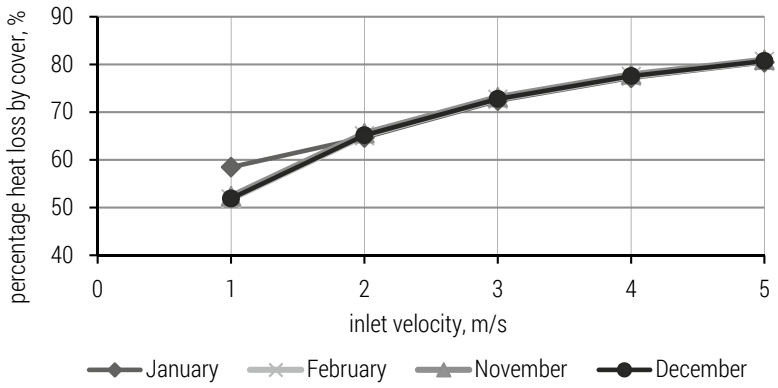

Figure 9. The percentage heat loss in winter months in function of air inlet speed

Source: author's own work.

Conclusion

The results reveal that the heat losses by cover can represent a big part heat loss of the anaerobic digester (figure 8). The heat flux of the cover is the largest, up to four times of the wall. The heat loss of the floor, compering cover, is relatively small, to 1.1 kW for the coldest month, for temperature (-4.9)^{o}C. The numerical experimental results of the heat losses are compared to the heat losses obtained from heat exchanger operating parameters. In each case, for the winter months, the difference between heat losses Q and the operating heat exchanger parameters value Q_{HE} (table 2) are comparatively small. Although, in each case the heat losses are minimal greater than the power of the anaerobic digester the heat exchanger. This can be cause of a local temperature drop of the manure.

Another important question is whether and possibly how the changing of air inlet flow rate between the membranes effect on the heat loss through the dome of digester. The first numerical results show that the influence of that flow is significant. The heat losses by the cover can change in the wide range from about 50% up to near 80% respectively from 1 m/s to 5 m/s in the inlet pipe. These are very large differences that require further analysis. Currently, in real conditions air inlet velocity is about 4 m/s (for 100 mm diameter pipe). For that velocity, the value of the heat loss determined in numerical calculations are similar with real heat loss (table 2).

In engineering problems, a constant value of thermal air resistance is assumed. The air movement is not taken into account at all.

The conclusions from work are:

- the heat loss by the cover in analyzed BD is near 75% of total heat loss (for 4 m/s inlet speed),
- the reason for the manure temperature drop is to low the exchanger's power,
- the heat losses by the cover can change in the wide range from about 50% up to near 80% of total heat loss (from 1 m/s up to 5 m/s in 100 mm inlet pipe).

Further experimental works on this topic are necessary.

Acknowledgements

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ENVIRONMENTAL POLICY AND MANAGEMENT

POLITYKA EKOLOGICZNA I ZARZĄDZANIE ŚRODOWISKIEM

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CARBON EMISSIONS, ENERGY USE, GROSS DOMESTIC PRODUCT AND TOTAL POPULATION IN CHINA

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ABSTRACT: The current study explores the impact of energy consumption, total population, gross domestic product on carbon emissions by utilizing time series data of 1971-2013 for China. Earlier studies concentrated on testing the present form of an environmental Kuznets curve not taking total population in a model. Specifically, this study focuses on analyzing the long run existence of environmental Kuznets curve. The methodology of auto regressive distributed lag model is utilized. The quadratic linkage between national income and emissions of carbon have been detected, confirming the presence of long run linkage between quadratic national income and emissions of carbon. Granger causality test divulge one-way causality between gross domestic product and carbon emissions. The empirical findings also reveal that the energy use and national income are important factors of carbon emanations in the long run. Total population has an insignificant positive influence on emissions of carbon. It is suggested that government should focus to extract that substitute sources of energy which is more environmental friendly.

KEY WORDS: energy consumption, carbon emissions, GDP, granger causality, ARDL, EKC

Introduction

In the early 1980s, the Chinese's government decided to introduce new reforms to establish market economy which brings a greater economic and industrial revolution in China. Today China is the fastest growing economy in the globe. The main reason behind China rapid economic growth is attributed to its huge expansion of the industrial sector. Conversely, economic growth based on industrial expansion may certainly cause to environmental worsen. Meanwhile, China is one of the substantial emitter of carbon dioxide in the world (Environmental Assessment Agency, 2015). Its average carbon emissions are around 6.70 metric tons per capita during 2009-2013 (World Development Report 2016). China's 13th Five-Year plans place many plans and strategies for reducing carbon emission.

Concerns regarding the contrary impacts of environmental variables on economic growth were in conflict with assertions that expansion in gross domestic product would advantage the environment, the creed and belief about environmental quality as a luxury good. Furthermore, masses are ready to pay progressively on this good, wealthy they will (De Bruyn, 2012). Grossman and Krueger (1991) scrutinized nexus between income and environmental quality, discovered an upside-down U-shaped association between gross domestic product and production of a specific contaminant. Panayotou (1993) inferred the association identifying as EKC, later the same relationship was drawn by the famous Economists Simon Kuznets (Kuznets, 1955). Thus, the basic idea behind EKC hypothesis is an upside-down U-shaped relation between variables on environmental contamination and income per capita. It further implies that an expansion in national income will invalidate the environmental influence of the initial phases of economic advancement in long run. The current study, originally, Environmental Kuznet Curve relationships for carbon emissions by including population factor for China, use data from 1971-2013, has been investigated.

This article is divided into five parts. Part two describes the previous studies on EKC. In part three, an analytical framework, empirical model and data used have been discussed. Part four connects the study with empirical results. Conclusions have been drawn in part five.

Literature review

Even though the model of the EKC is a newly established phenomenon, though, a vast literature is available for utilization of the phenomenon (Kuznets, 1955). These studies use variable(s) relating to environmental degradation as responding variable while gross domestic product as the explanatory variable(s) and give different outputs.

A number of studies, lying on the same issue, have been investigated by several researchers after (Grossman, Krueger, 1995) and (Selden, Song, 1995) asserted the expansions and contractions in gross domestic product and the level of environmental degradation develops an inverted U-shaped relationship. Many authors have been tested EKC hypothesis by taking different factors of environmental degradation, for example, municipal waste, carbon emissions, and deforestation. Conversely, the most frequently used variable as a proxy of environmental degradation was sulfur dioxide. In contrast, a U-shaped function for carbon emanation has been described (Heil, Selden, 2001; De Bruyn et al., 1998; Moomaw, Unruh, 1997; Holtz-Eakin, Selden, 1995) by using panel data. Other research also computed findings on the association between gross domestic product and carbon emanations for different nations by using new methods (Kanjilal, Ghosh, 2013; Galeotti et al., 2006; Vollebergh, Kemfert, 2005; Cole, 2005; Martínez-Zarzoso, Bengochea-Morancho, 2004; Dinda, 2004; Stern, 2004).

The another most important factor which plays very significant role in the determinant of carbon emission is energy consumption. There are a lot of studies existed, in passing, after the study conducted by Kraft and Kraft (1978). For instance, (Narayan et al., 2008; Narayan, Singh, 2007; Wolde-Rufael, 2006; Yang, 2000; Masih, Masih, 1996) examine nexus between use of energy and economic growth by employing a variety of procedures for group of counties. Hence, it more appropriate, if take growth of income and use of energy at once in a single multivariate model. Therefore, the current study is utilizing these two linkages, GDP-environment linkage and GDP-environment linkage, in a one model. This method allows the scholar to carry out the rationality of both linkages in a similar structure. For instance, (Halicioglu, 2009; Ang, 2007) introduced this pooled of framework.

In addition to this, the majority of the prevailing literature on the same subject has utilized pooled data for sets of countries in order to develop a linkage between average income per capita and environmental degradation. Contrariwise, time series data apply to only one nation may lead a good general background to examine the linkage. It also allows investigating the cause of strategies about environmental protection, energy policy and other elements during the time (Stern et al., 1996)1996.

There are few studies which use population as a factor of carbon emission. The linkage between population growth and carbon emission has bees discusses in more detail by (Cramer, 1996) and (Shi, 2003). Zhang and Tan (2016) examine the linkage between population factors and carbon emission by taking China as a case study. The findings indicate that population are important factor which bring variations in emission of carbon.

A clear logical for choosing China for our study is that it enacts a noteworthy role in the world energy market. Besides to this, among developing countries, China is important transitional economies that sustain the top figure economic growth, most populated country and the largest contributor of the carbon dioxide emission along with utmost user of energy.

Model specification and econometric methodology

The long-run association between release of carbon dioxide, gross domestic product, use of energy and total population for China is tested by applying the following linear logarithmic quadric form:

$$CE_t = \alpha_0 + \alpha_1 EU_t + \alpha_2 GDP_t + \alpha_3 GDP_t^2 + \alpha_4 TP_t + \varepsilon_t \quad (1)$$

Where: CE_t represents carbon emission per capita, α_0 represent constant, α_1 is coefficient of EU_t, EU_t denotes energy use per capita equivalent to kg of oil, α_2 represents the respective coefficient of GDP_t, GDP_t signify Gross domestic product in current US $, α_4 signify respective coefficient of GDP_t^2, GDP_t^2 shows square of gross domestic product, α_5 shows respective coefficient of TP_t, TP_t is total population and ε_t represents error term.

The ARDL depiction of carbon dioxide emissions, energy consumptions, GDP, squared of GDP and total population, can be represented as:

$$\Delta CM_t = \beta_0 + \sum_{i=1}^{m} \beta_{1i} \Delta CM_{t-i} + \sum_{i=0}^{m} \beta_{2i} \Delta EU_{t-i} + \sum_{i=0}^{m} \beta_{3i} \Delta GDP_{t-i} + \sum_{i=0}^{m} \beta_{4i} \Delta GDP_{t-i}^2 + \sum_{i=0}^{m} \beta_{5i} \Delta TP_{t-i} + \beta_6 CM_{t-i} + \beta_7 EU_{t-i} + \beta_8 GDP_{t-i} + \beta_9 GDP_{t-1}^2 + \beta_{10} TP_{t-i} + \upsilon_t \quad (2)$$

Where: ΔCM_t represent change in carbon emission in a t year, β_0 is constant term, β_{1i} is the respective coefficient of ΔCM_{t-i}, ΔCM_{t-i} denoted change in carbon emissions in t-i lagged period, β_{2i} is coefficient of ΔEM_{t-i}, ΔEM_{t-i} represents change in energy use in t-i lagged period, β_{3i} is coefficient of ΔGDP_{t-i}, ΔGDP_{t-i} signify change in gross domestic product in t-i lagged period, β_{4i} is coefficient of ΔGDP_{t-i}^2, ΔGDP_{t-i}^2 represents change in quadratic representation of gross domestic product in t-i lagged period, β_{5i} denoted coefficient of

ΔTP_{t-i}, ΔTP_{t-i} represents change in total population in t-i lagged period, β_6 is coefficient of CM_{t-i}, CM_{t-i} represent carbon emission in t-i lagged period, β_7 is coefficient of EU_{t-i}, EU_{t-i} represent energy use in t-i lagged period, β_8 is coefficient of GDP_{t-i}, GDP_{t-i} represent gross domestic product in t-i lagged period, β_9 is coefficient of GDP^2_{t-1}, GDP^2_{t-1} donates quadratic format of gross domestic product in t-i lagged period, β_{10} represents coefficient of TP_{t-i}, TP_{t-i} denotes total population in t-i and υ_t shows error term.

This technique comprises of following procedures. In first stage of the cointegration approach Fisher (F) or Wald statistics should be estimated. For that reason, a joint significance test that hypothesize of no cointegration, H_0:$\beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = 0$, against the alternative hypothesis, H_1:$\beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10} \neq 0$ carry out for eq. (2). The F-test utilized for this process has a non-standard distribution. Hence, Pesaran et al. (2001) estimate two series of critical values with and without a time trend. One series presume that all given variables are I(0) while other series suppose they are all integrated of order one. Then compare the F-statistic to the upper critical bunds. The null hypothesis is not accepted if estimated F-statistic go beyond the upper critical bounds value. The test become inconclusive if the F-statistics falls into the bounds. Lastly, if the F-statistic is lower than the critical bound value, signifies absent of cointegration.

After construction of long run linkages, eq. (2) is computed by applying an appropriate lag selection criterion namely, SBC or AIC. In the next step of ARDL process, a parameter stability test is possible to run to check the stability in ARDL depiction of the ECM.

Error correction model (EMC) of eq. (3) is constructed in this way:

$$\Delta CM_t = \gamma_0 + \sum_{i=1}^{m} \gamma_{1i} \Delta CM_{t-i} + \sum_{i=0}^{m} \gamma_{2i} \Delta EU_{t-i} + \sum_{i=0}^{m} \gamma_{3i} \Delta GDP_{t-i} + \sum_{i=0}^{m} \gamma_{4i} \Delta GDP^2_{t-i} + \sum_{i=0}^{m} \gamma_{5i} \Delta TP_{t-i} + \lambda ECT_{t-1} + \mu_t \quad (3)$$

In eq. (3), γ_0 represent constant term. While γ_{1i}, γ_{2i}, γ_{3i}, γ_{4i}, γ_{5i} are respective coefficients. λ characterizes the swiftness of adjustment parameter and ECT_{t-1} denotes residuals taken from the eq. (1). The CUSUM and CUSUMSQ are also utilized to scrutinize the goodness of fit for auto regressive distribution model. So, that to use these econometric procedures, time series data on release of carbon dioxide metric tons per capita, Gross Domestic Product in current US dollar, use of energy per capita equivalent to kg of oil along with total population for period 1971 to 2013 are gathered from World Bank website. Eviews 9 are used for data analysis.

To scrutinize the stability of parameters, CUSUM and CUSUM square tests have been performed (figure 1 and 2). Pesaran et al. (Pesaran et al., 2000, 2001) propose that in such model testing for stability of coefficients CUSUM and CUSUMSQ are acceptable. Figure 1 indicates that the graph of CUSUM is significant at the 5% level of significance showing the stability of parameters. Figure 2 signify that the graph of CUSUM of square is signify that the blue line is located within red lines which means all parameters are stable.

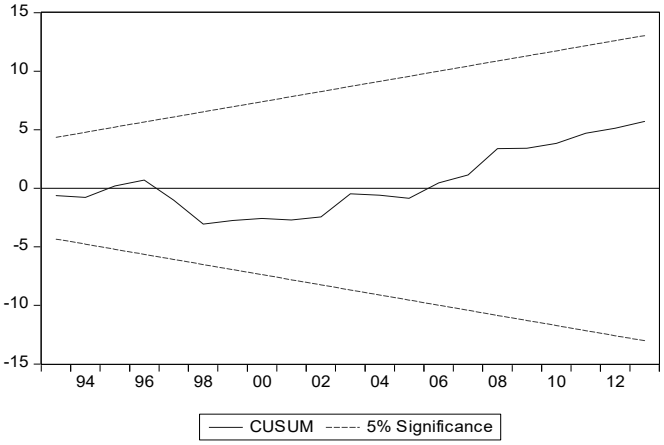

Figure 1. CUSUM

Note: The straight lines in the figure symbolize critical bounds at 5% significance level

Source: author's own work.

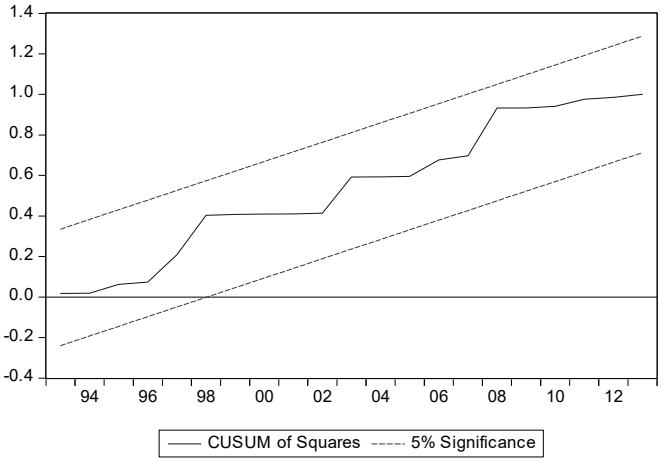

Figure 2. CUSUM of Square

Source: author's own work.

Some diagnosis tests are also run on the short run dynamic model. These tests include ARCH, Breusch-Godfrey Serial Correlation LM Test and Ramsey RESET Test. The final findings of all diagnostic tests verify that short run dynamic model is free of heteroscedasticity and serial correlation. Moreover, Ramsey RESET test identify that there is no specification error in the model.

Empirical findings and discussion

This study utilizes ADF unit root test to inspect stationarity. The outcomes of unit root test are demonstrated in table 1. The findings divulge that all variables are non-stationary at level while become stationary at first difference. Hence, no variable is stationary at second difference.

Table 1. Unit root test

Variable	T-Statistics	P value*
ADF test at level with intercept		
$\ln CM_t$	0.304289	0.9758
$\ln EU_t$	0.974143	0.9955
$\ln GDP_t$	2.489667	1.0000
$\ln GDP_t^2$	2.654390	1.0000
$\ln TP_t$	-0.832336	0.7983
ADF test at first difference with intercept		
$\Delta \ln CE_t$	-3.810335	0.0058**
$\Delta \ln EU_t$	-3.565168	0.0110**
$\Delta \ln GDP_t$	-5.200094	0.0001**
$\Delta \ln GDP_t^2$	-4.823599	0.0003**
$\Delta \ln TP_t$	-2.681757	0.0863***

*MacKinnon (1996) one-sided P values. **,*** 5% and 10% level of significance
Source: author's own work.

To get rid of any serial correlation the ARDL bound testing founded by Pesaran et al. (Pesaran et al., 2001) needs an appropriate lag length in variables. This length has been carefully chosen by taking first difference of conditional error correction version of ARDL. Akaike information criteria is utilized to get maximum lag. Table 2 reports the outputs of VAR lag order selection criteria. The minimum value of AIC shows the maximum lag 5 is appro-

priate lag length for our current model. As to get reliable and unbiased results an appropriate lag order is necessary.

Table 2. VAR lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	81.72637	NA	0.001034	-4.038230	-3.822758	-3.961567
1	86.45742	7.968079	0.000850	-4.234601	-3.976035*	-4.142605
2	87.91583	2.379506	0.000831	-4.258728	-3.957067	-4.151399
3	89.22025	2.059609	0.000820	-4.274750	-3.929995	-4.152089
4	89.94484	1.105959	0.000834	-4.260255	-3.872405	-4.122261
5	93.55964	5.327076*	0.000730*	-4.397876*	-3.966932	-4.244549*

**Lag order selected by the criterion. LR: Sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion*

Source: author's own work.

The presence of long run nexus among the independent and dependent variables of equation (2) by means of ARDL bound test. The finding of bound test of cointegration is shown in table 3. Seeing that the estimated value of F-Statistic is more than the tabulated Pesaran et al. (Pesaran et al., 2001) upper bound value at 5 percent level of significance, hereafter the null hypothesis of no cointegration (H_0:$\beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = 0$) has been rejected at 5 percent level of significance. Consequently, it validates existence of long run association.

Table 3. Bound test of cointegration

Test Statistic	Value	K
F-statistic	4.269633	4
Critical Value Bounds*		
Significance	**I0 Bound**	**I1 Bound**
10%	2.45	3.52
5%	2.86	4.01

*Pesaran et al. (Pesaran et al., 2001) critical values 0.08 percent.

Source: author's own work.

Table 4 signify the long-run coefficients of ARDL (1,5,4,0,2) model. The findings confirm a positive nexus between use of energy and emission of carbon dioxide. The coefficients of both GDP_t and GDP_t^2 validate the presence of

upturned U-relationship between gross domestic product and emissions of carbon. The coefficients of both GDP_t and GDP_t^2 are 2.62 and -0.05, respectively which means that a percent boost in gross domestic product bring a 2.62% upsurge in carbon emissions. The statistically significant negative coefficients of GDP_t^2 infer that the national income rises consistently with the level of carbon emission. This result support the EKC hypothesis which stated that at the initial stage environmental pollution rises with income, but when income goes up to the stabilization point it declines.

The coefficients on total population (TP_t) shows a positive relationship between total population and carbon emanations. But the coefficient of TP_t on CE_t is positive and statistically insignificant. This small coefficient of TP_t signify that a one percent rise in total population leads an increase in CO_2 emission by 0.08 percent.

Table 4. Long-Run coefficients of ARDL (1,5,4,0,2) Model Dependent Variable ln CE_t

Regressor	Coefficient	Standard error	t-ratio
Constant	-46.105408	6.484743	-7.109829*
ln EU_t	2.056343	0.295804	6.951705*
ln GDP_t	2.620768	0.439341	5.965221*
ln GDP_t^2	-0.051541	0.009096	-5.666099*
ln TP_t	0.081186	0.082534	0.983665

*Signify significance level at 5 percent

Source: Author's own work.

As all the variables are stationary at first difference, hence Granger-Causality test can be applying to study the causal association between GDP and CO_2 emission. The Granger causality test findings are depicted in table 5. The findings also signify that in the long run GDP cause CO_2 emission. This result also supports some other studies that investigate the association between GDP and carbon emission, for instance, Jalil and Mahmud (Jalil, Mahmud, 2009) and Zhang and Cheng (Zhang, Cheng, 2009) for China, Muhammad et al. (Muhammad et al., 2010) for Pakistan and Ghosh (Ghosh, 2010) for India.

The error correction representation of the selected ARDL (1, 5, 4, 0, 2) model is depicted in table 6. The results divulge that there exists a positive linkage between use of energy and carbon emissions.

Table 5. Granger causality test findings

Null hypothesis	F-statistic	p-value
ln GDP_t does not Granger Cause ln CE_t	3.80101	0.0318
ln CE_t does not Granger Cause ln GDP_t	1.11160	0.3401
ln GDP_t^2 does not Granger Cause ln CE_t	3.60575	0.0374
ln CE_t does not Granger Cause ln GDP_t^2	1.24678	0.2995

Source: author's own work.

The short run coefficients and error correction term are depicted in table 6. The estimated model utilizes the first difference of the variables (shows short run variations). It is noted that after a temporary shock estimated short-run coefficients depict the conjunction to equilibrium in the long run. The estimated coefficient of the ECM is 49 percent. This reveals that the nearly 49% of the disequilibrium in the preceding year following shocks to the system converge back to the long run equilibrium in the current year. By this ruling, it is deduced that to some extent disequilibrium within the CO_2 emission in the short run is hastily corrected and converged back to equilibrium in the long run.

Table 6. Error Correction Representation of the selected ARDL (1, 5, 4, 0, 2) Model Dependent variable Δ ln CE_t

Regressor	Coefficient	Standard error	t-ratio
Constant	-22.39440	6.979933	-3.208397*
Δ ln EU_t	1.075894	0.122035	8.816265*
Δ ln GDP_t	1.348524	0.405301	3.327215*
Δ ln GDP_t^2	-0.025035	0.007831	-3.196717*
Δ ln TP_t	0.141948	0.076650	1.851894**
$ECM_t(-1)$	-0.485722	0.140774	-3.450363*

*,** shows level of significance at 5% and 10%. Breusch-Godfrey Serial Correlation LM Test (Obs R square) = 0.1741, Autoregressive Conditional Heteroscedasticity Test (Obs R square) = 0.5324, Ramsey RESET Test (F-Statistic) = 1.1436

Source: author's own work.

Conclusions and recommendations

The current study focuses on the relationship among use of energy, gross domestic product, carbon emission and total population for China for the period of 1971-2013. The Environmental Kuznet curve hypothesis has been tested by employing the technique of ARDL. The ADF test reveals that all the variables are stationary at first difference. ARDL Bound test reflects that there exists a long run association among variables. The findings also infer that there is a long run association among gross domestic product, carbon emission, consumption of energy. The long-run coefficients of ARDL model reveal the existence of short-run relation among consumption of energy, carbon emission, gross domestic product and total population. A positive relationship and significant influence of use of energy on carbon emissions have been found. The output of Granger's causality test suggests that there is one-way causality runs through the gross domestic product to carbon emission. The sign of the coefficient of Error Correction term is negative and statistically significant and verifies the existence of long-run nexus among variables. Moreover, the significant value of lagged error correction term depicts that variation in carbon emanations ahead of equilibrium are adjusted by 49 percent within one year. The CUSUM and CUSUMQ procedures are employed on the ARDL model.

The findings of this research are very significant for the environmental policy makers. For that reasons, the countries should extract the substitute sources of energy, for instance, natural gas and solar energy, etc. that there is an environmentally friendly. All the empirical results validate that in high economic growth causes to degradation of the environment and ultimately diminution of natural resources regardless of expanding manner of living. The results of this study are imperative in the environmental policies. Accordingly, it ought to acquire a sustainable economic growth by fewer carbon emissions and using less energy. Additionally, the environmental policy makers may incorporate exogenous impacts, for example, overseas investments to work out energy policies, in addition, to keep up economic growth for worldwide climate forewarning.

The contribution of the authors

The six authors contributed equally to this work.

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Aldona HARASIMOWICZ

GREEN SPACES AS A PART OF THE CITY STRUCTURE

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ABSTRACT: The article describes the role of green areas as an integral element of urban space. The aim of the study is to characterize green spaces in the city and to indicate the most important benefits that these resources generate for both residents and the entire urban system. The method of analyzing the literature of the subject was used to achieve the above objective. The result of this research is an indication of the most important types of urban green spaces and ecological, social and economic values they provide, including identification of a series of connections between the environmental level and social and economic conditions of the cities.

KEY WORDS: urban green spaces, city, urbanization

Introduction

Urbanization affect not only the size and number of cities, but also change the structure of urban areas. One of the dimensions of these changes is the natural environment both in the city itself and outside it. During the systemic changes, as a result of Poland transforming from the command-and-quota economy and shifting towards empowerment, green areas began to disappear on a massive scale, replaced with new developments and increasingly fragmented settlement structures. This process has continued ever since. Throughout this time, approximately 30% of open areas used in a variety of ways have vanished (taken up by the new developments) (Hrehorowicz-Gaber, 2015). Urbanization has negative impacts on the natural environment by exerting pressure on and shrinking green spaces in many cities in Europe, North America, South America, Asia and Africa with the situation in Africa being critical (Abebe, Megento, 2016). Loss of urban green spaces has been recorded in both developing and developed countries, and is dependent on the rate of urban growth often determined by prevailing socio-economic factors (Gairola, Noresah, 2010).

Increased population density and spatial expansion has exerted huge negative impacts on green areas and transforms urban green spaces to impervious landscapes. In recent years, a lot of studies have documented urban growth and consequent loss of urban green spaces (Odindi, Mhangara, 2012). Part of them identify the growth of human settlement on urban fringes as the major cause of loss in green spaces and consequent negative environmental impacts (Yuan et al., 2005). Moreover, urban green spaces in particular have long been recognized as the most critical environmental resource in an urban ecosystem (Gairola, Noresah, 2010).

Urban green spaces play a remarkable role to reduce bad consequences of the rapid rate of urbanization (Li, Pussella, 2017). They have very important part in creating the space of cities because quality of an urban is a result of balanced distribution between buildings, transport infrastructure and green spaces. Besides different types of green areas in the city, their functions and services reveal the impact of quality life (Gülgün et al., 2015). This is why underestimating the importance of green spaces can be dangerous in urban development. The aim of the article is the characterization of urban green spaces based on the literature and indication main benefits appear from their existence for contemporary cities.

What are the green spaces of cities?

The definition of green space has long been argued, and a universally accepted definition of urban green spaces is still lacking. Most developed countries have their own definitions of urban green spaces (Byomkesh et al., 2012). Urban green spaces can be defined as vegetated areas which are found in urban environments and named as semi natural areas in a city (Jim, Chen, 2003). These areas can be covered with natural or man-made vegetation but are present in built-up areas (Li, Pussella, 2017). The term "urban green space" is used to mean formal and informal green sites, and also to refer to "open spaces" that have potential to provide ecological functions (like sports clubs, playing fields, open barren land, etc.) (Qureshi et al., 2010). In reference to green spaces the European Commission (2013) is talking about green infrastructure and defined it as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings.

Green spaces in the city consist of various types of natural elements and usually include parks, forest patches, open spaces, residential gardens of narrow strips of trees along streets (Jim, Chen, 2003). Arabi et al. (2014) grouped urban green spaces into four categories:

- public green spaces, usually called parks, which have been allocated for general public to engage in their activities leisurely,
- semi public green spaces such as open spaces in hospitals, government or private departments etc.,
- private green spaces which are the residential garden units maintained by urban residents,
- street green spaces which are the tree layouts along roadways.

Yang et al. (2017) proposed another way to divide green spaces, they have distinguished six types of such areas: Attached Green Spaces (AGS), Park Green Spaces (PGS), Ecological Green Spaces (EGS), Road Green Spaces (RGS), Other Green Spaces (OGS), and Productive Plantation Green Spaces (PPGS) (figure 1).

From the view of land use and cover, green spaces include woodland, farmland, garden plot, grassland, wetland, and garden green space within the built-up areas (Xu et al., 2011). In other words, urban green spaces include all that have the vegetation and provide a wide range of functions that include air and water purification, mitigation of environmental pollution, carbon sequestration, regulation of micro-climate, habitat for urban wildlife, recreation and spiritual and therapeutic value (Odindi, Mhangara, 2012).

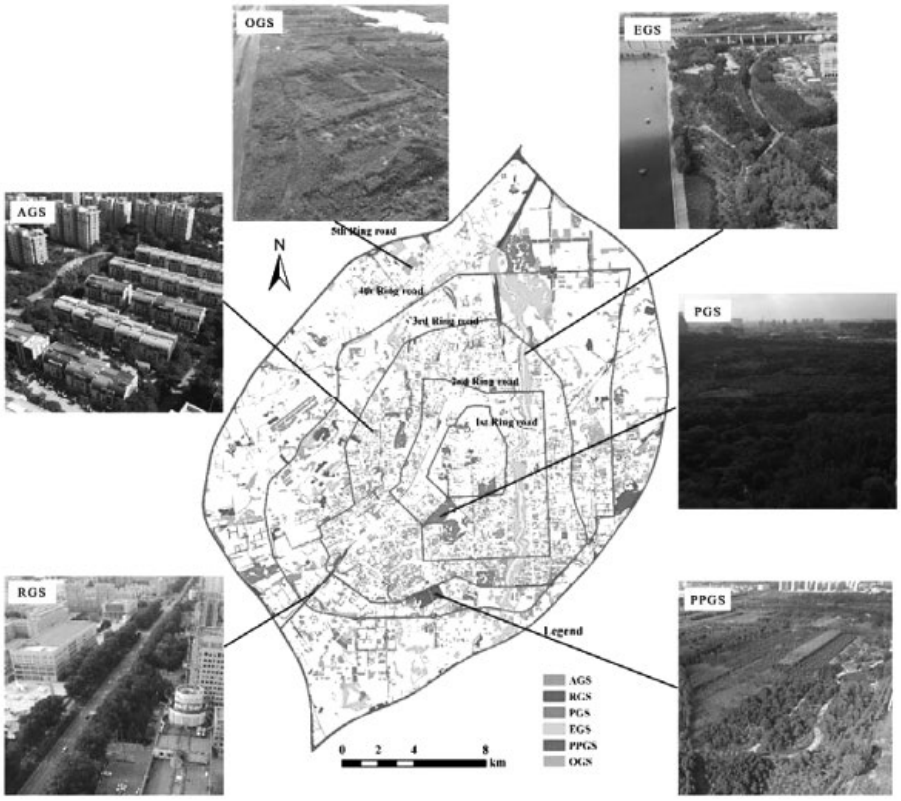

Figure 1. Six types of urban green spaces in Changchun (China)
Source: (Yang et al., 2017).

Urban green spaces have become widely recognized as an important component of the infrastructure in urban areas. Increasing urbanization and development have, however, placed urban green spaces under extreme pressure, threatening their abilities to maintain the basic ecological and social functions upon which human existence depends (Chen et al., 2006). On the other hand, many cities experiencing intensive growth are facing the reduction of green spaces (figure 2, 3, 4), which deepens the existing problems, especially that ecosystem is closely related in other components of urban system – social, economic, cultural or political. For example, Colombo city, the former capital city of Sri Lanka, was nominated as one of the fastest growing urban cities in South Asia by the World Bank in 2013. Yet, Colombo generally has a comparatively, low rate of population growth. Therefore, if the green space reduction rate would be considered.

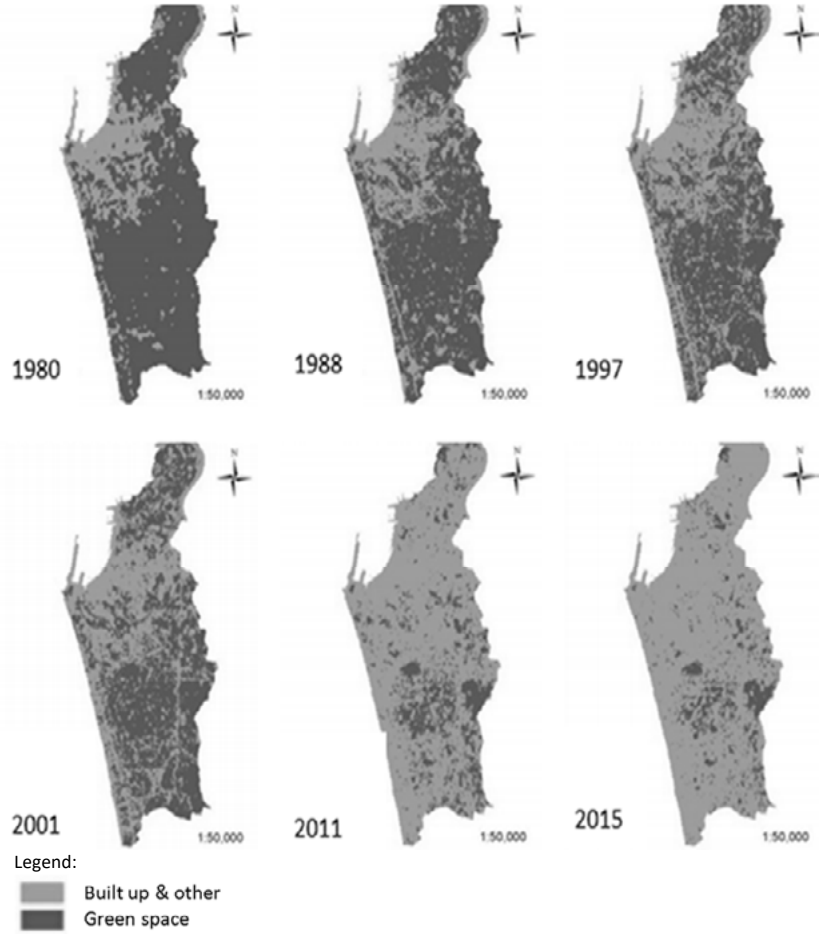

Figure 2. Changes in green spaces in Colombo city, the former capital city of Sri Lanka in 1980, 1988, 1997, 2001 and 2015

Source: (Li, Pussella, 2017).

Colombo could be the worst city with the highest rate of reduction compared with other cities (figure 2) (Li, Pussella, 2017). Addis Ababa hosting nearly 30 percent of the urban population of the Ethiopia was once said "forest city". This unprecedented growth of this city has shrunken green areas in significant scale. The problem is expected to worsen in the coming years due to the massive construction of houses, buildings and roads and the less attention given to green spaces (Abebe, Megento, 2016). In China, however, the distribution of green spaces in cities is not homogeneous. Because green spaces may be insufficient and unequally distributed, conservation of these spaces and their multiple functions is becoming an increasing concern for most Chinese cities (Chen et al., 2006).

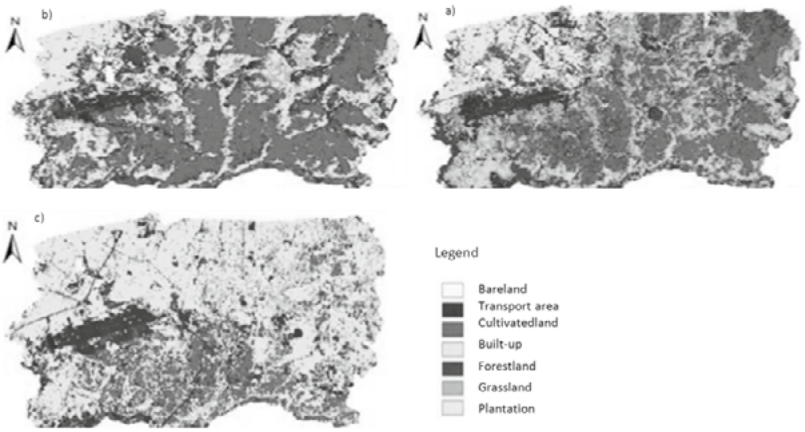

Figure 3. Land use change in 1986 (a), 2000 (b) and 2015 (c) in the city of Addis Ababa, Ethiopia
Source: (Abebe, Megento, 2016).

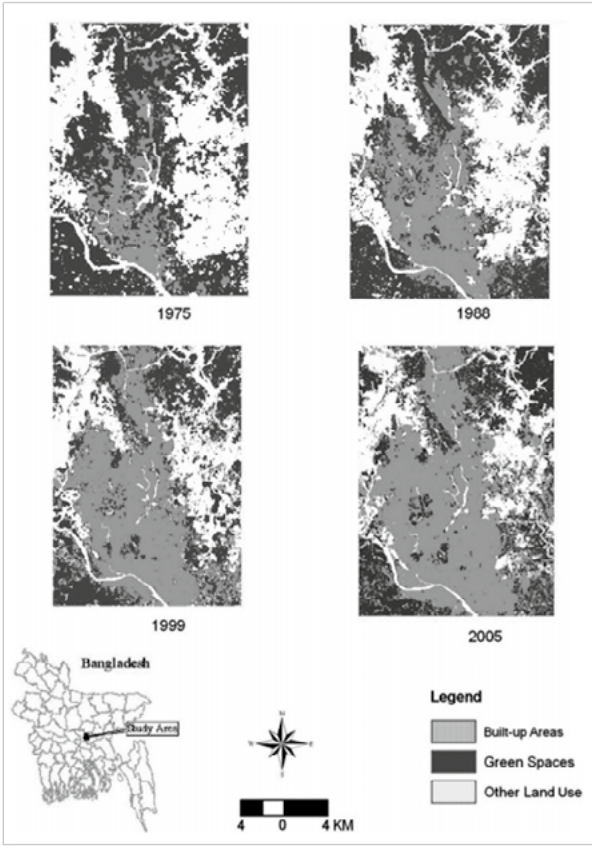

Figure 4. Changes in green spaces in Greater Dhaka the capital of and largest metropolitan area in Bangladesh in 1975, 1988, 1999 and 2005

Source: (Byomkesh et al., 2012).

Parts of urban green spaces

Urban landscape depends on the surrounding area, such as suburban, rural, and bioregional landscapes that are seen in ecological watershed units (Arifin et al., 2009). The largest and most visible parts of green areas in the city space are parks and forests. Urban parks can play an important role in the conservation of biodiversity (Cornelis, Hermy, 2004), they also provide a range of ecosystem services for urban citizens (Heyenga, Savill, 2008). Assessing the accessibility of the urban residents to green spaces, most authors have defined that the urban parks should be within 400 m, it means 5 minutes walking distance, from residencies (Herzele, Wiedemann, 2003). According to the standard which was recommended by National Recreation and Park Association, USA, a space of 0.41 km^2 has to be kept as urban parks for 1000 residents (Nicholls, 2001).

Parks can be designed to perform various functions for city dwellers, so they can be traditional and multifunctional (figure 5). Research shows that urban parks are visited primarily by residents, but it is also an attractive space for visitors from nearby areas and tourists (Schmidt et al., 2016).

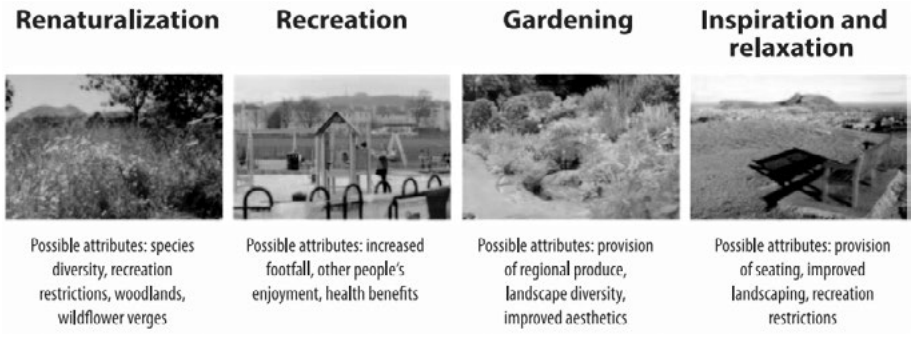

Figure 5. Different types of parks

Source: (Schmidt et al., 2016).

Urban forests play similar role to city space as parks do. General figures for urban open space and urban forests show a wide variance between different European towns and cities. Most woodland is found in the urban fringe. The percentage cover ranges from 1% in Copenhagen to 65% in Stuttgart in the 5 to 10 km ring around the city center (Pauleit et al., 2005). Despite the recognized positive role of forests in metropolitan contexts, a reduction in their functionality has been observed in most urban regions (Tomaoa, 2017). While the percentage of cover of woodlands in Europe's urban areas does not seem to be directly related to their geographic location or the size of urban

areas, four different types of urban woodland (figure 6) could be distinguished (Pauleit et al., 2005):

- closed woodland surrounding the city (e.g. Oslo, Ljubljana),
- woodland islands and belts within the city (e.g. Ljubljana, Munich),
- dispersed woodland within an urban matrix (e.g. Black Country),
- small woodland areas in parks and gardens within the city,
- dispersed woodland in an agricultural matrix around the city (e.g. Florence).

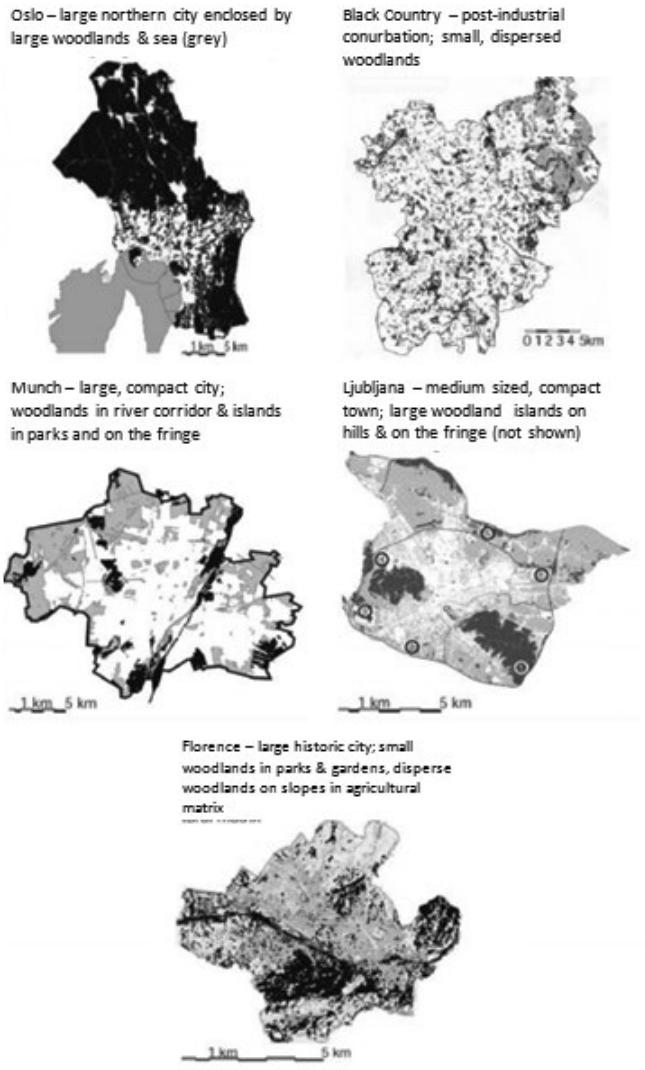

Figure 6. Different types of urban forest (woodlands are shown in black, other open spaces in gray, built-up areas in white)

Source: (Pauleit et al., 2005).

Another element of urban green spaces are private gardens (private green spaces) and roadside green spaces. Private gardens are very heterogeneous in their size and structure and cover a large proportion of urban areas – for example: between 22–7% of the total area of seven UK cities (Loram et al., 2007) or 36% in a small New Zealand city (Mathieu et al., 2007). As a one of the major component of green spaces, privet gardens have vast potential for creating biodiversity benefits (which can varying depends on size and features of gardens) (van Heezik et al., 2012). Roadside green spaces consist of linear corridors between sidewalks (figures 7 and 8). This type of greenery is important not only because its ecological meaning, but it also has aesthetic value. In addition, the design and maintenance of roadside green spaces must comply with the requirements of road safety (e.g. in terms of visibility or roads and pavements contamination).

Figure 7. Roadside green spaces in Jakarta, Indonesia

Source: (Arifin, Nakagoshi, 2011).

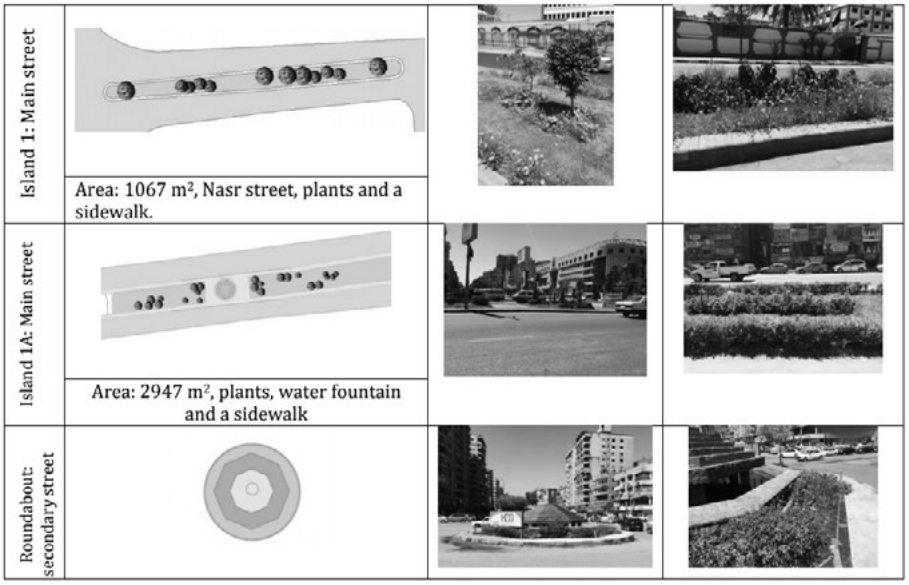

Figure 8. Roadside green spaces in in Naser City, Egipt

Source: (Abd El Aziz, 2016).

In addition to traditional urban green spaces, alternative solutions are now being proposed that increase the spectrum of possibilities for urban nature. This are: vertical gardens, green roofs (figure 9), green terraces (figure 10) and green graffiti (figure 11). Vertical garden structure was invented by French botanist Patrick Blanc and to build them were started in Paris, London, Tokyo and New York since 1988. Vertical garden structure is garden design which consists of vegetations placed on the wall surface. This kind of green elements can improve the air quality of building and can save energy (Gülgün et al, 2015). Roof and terrace gardens are a multifunctional green roof build-up with high water storage. It is suitable for lawns, perennials, and with deeper system substrate, for shrubs and trees. Two types of roof and terrace garden can be distinguished in terms of features and benefit functions: intensive green roof (figure 9 left) which is appropriate to roam or to do various recreational activities, and extensive green roof (figure 9 right) – not suitable both for recreational activities or walking (Gülgün et al, 2015).

Figure 9. Intensive roof garden (left) and extensive roof plantings (right)
Source: (Gülgün et al, 2015).

Figure 10. Green terrace
Source: (Berkooz, 2007).

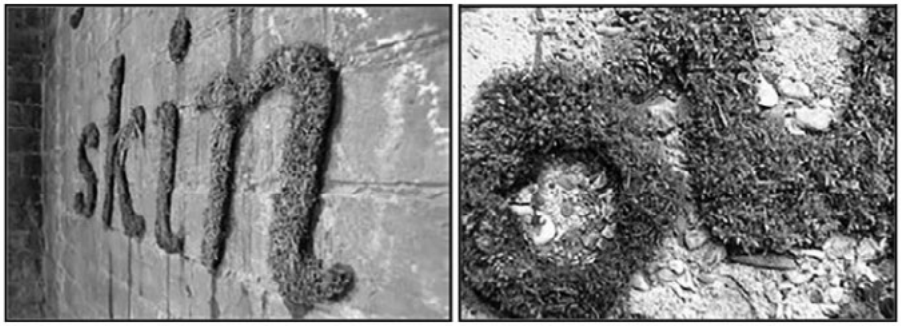

Figure 11. Green graffiti

Source: (Jansen, Ruifrok, 2012).

Roof gardens are becoming more and more popular in urban spaces, for example in U.S. an increasing number of cities now require green roofs in new construction projects – partly to help mitigate global warming. Green roofs slow the flow of rainwater into a storm water system, reduce the energy needed for heating and cooling, and diminish urban heat island effects. More than two million square feet of Chicago's rooftops have been planted with low-growing sedums, native grasses, herbs, and shrubs. Minneapolis, Boston, and other large cities have various "green" requirements as well (Berkooz, 2007).

Benefits of urban green spaces

Green spaces are an inseparable element of the city structure, hence they generate many social, economic and ecological benefits. In the other words, urban green spaces have a constructive role in social, economic and ecological fields and they reduce the negative effects of the urban life (Ignatieva et al., 2011).

Social benefits of existing green spaces are primarily associated with interpersonal relationships and human health. City residents use parks and gardens for restoration and relaxation, exercise and to engage in social interactions. Green spaces within cities are also associated with wider social benefits such as diminished crime, violence, and aggression (Sushinsky et al., 2017). Urban green spaces contribute in a positive manner to maintain public health by facilitating appropriate space for physical exercise to improve physical and psychological well-being, reducing stress, depression and support longevity – their role is seen in improving the quality of life by offering esthetic enjoyment, recreational opportunities, and place for different social

interactions (Li, Pussella, 2017; Loukaitou-Sideris, 2016; Saporito, Casey, 2015; Dinnie et al., 2013; Ozgűner 2011; Irvine et al., 2009; Chiesura, 2004). In this aspects green spaces are especially important – human health and well-being is inextricably linked to experiences of nature and as health problems in cities rise there is a critical need to improve people's access to nature (Sushinsky et al., 2017). The importance of urban parks and green spaces in cities and especially metropolises becomes more evident, when the destructive effects and nonproductive functions of cities in isolation of people from nature, incidence of deceases, psychological pressures caused by crimes in cities and finally the formation of machinery life is realized (Thompson et al., 2002).

Outdoor physical activities in the city are often combined with nature observation, bird watching, photography, or similar directly nature-related activities (Schmidt, 2016). Thus, urban green spaces have also an educational function. Urban green spaces play an important role in the basic education of school children with regard to environment and nature but for academic education and research as well. Urban green spaces are beautiful and therefore have an aesthetic appeal. The presence of urban green spaces in a city increases the quality of life, not only because of their beauty but also because the aesthetic quality of urban green spaces enables people to orient themselves in space and time. Through all this, urban green spaces give neighborhoods their own identity, which makes them more attractive to live in. Urban green spaces can additionally be seen as a compensation for low-quality areas (Rodenburg et al., 2001).

Urban green spaces are important for all residents, but there are particular groups for which they are especially important. For low-income, inner-city seniors in particular, who live in small apartments without private yards and outdoor space, neighborhood parks can offer respite and opportunities for contact with nature, walking, and exercise (Loukaitou-Sideris, 2016). The researchers of 3,144 Tokyo seniors born in 1903, 1908, 1913, and 1918 shown that living in neighborhoods with parks and walkable green spaces positively influenced the longevity of those seniors, independent of age, sex, marital status, income, or baseline functional status (Takano et al., 2002). Rappe et al. (2006) find in their study that self-reported health of older women in a Helsinki nursing home is related positively to more frequent visits to neighborhood parks and green spaces. In addition to seniors, green spaces have special value for children. Green areas plays a significant role in the well-being of children: provide safe play areas for children, have a positive effect on children's cognitive functioning, contribute to their physical, mental, and social development and have an important role in education (Baycan-Levent et al., 2009; Wells, 2000).

One of the most essential issues related to green spaces is the distribution of advantages they generate. Research shows that the benefits of green areas are unevenly distributed. Frequency and manner of using green areas depends on social factors such as age, gender, and education. Socioeconomically disadvantaged areas often have lower quality and quantity of public green spaces, vegetative cover and species richness (Sushinsky et al., 2017). Study proves relationships between racial and economic segregation and differences in exposure to green space between the members of different racial and income groups. Findings generally show that lower-income people and racial minorities live closer to a patch of green space than white people but live in neighborhoods with lower densities of green space (Saporito, Casey, 2015).

Urban expansion significantly affects the natural environment of cities – can causes environmental destruction and pollution. Therefore, green spaces are important from their environmental benefits – they moderate the impact of human activities. Green spaces provide key ecological functions such as carbon storage, producing oxygen, maintenance of air quality, soil conservation, noise buffering, maintain a certain degree of humidity in the atmosphere, regulate rainfall, groundwater protection, reduction of air temperature, form the basis for the conservation of fauna and flora and maintain biodiversity of the city (Bao et al., 2016; Baycan-Levent et al., 2009; Irvine et al., 2009; Chen et al., 2006). Urban green areas contribute to the maintenance of a healthy urban environment by providing clean air, water, and soil, protection against natural hazards, improve the urban climate and maintain the balance of the city's natural urban environment. They preserve the local natural and cultural heritage by providing habitats for a diversity of urban wildlife and conserving a diversity of urban resources (Baycan-Levent et al., 2009).

Economic benefits of urban green spaces are generally connected with market values they generate – in direct and indirect meaning. From an economic perspective, urban greening improves the social wellbeing of city residents in a variety of ways. The greening projects tend to reduce costs related to urban sprawl and infrastructure provision, attract investment, raise property values (Baycan-Levent et al., 2009). Developed areas close to green spaces are the most preferred areas in cities and have higher economic values. Recent research has also shown that green spaces increase the value of nearby area (Biao et al., 2012; Özgüner et al., 2012).

The cities of today have to be lively, offering diverse, integrated functions which attract users, investors and tourists, whilst also enhancing the quality of life of the local residents (Cilliers et al., 2015). Environment quality becomes key for urban competitiveness. Urban green spaces improve urban environmental quality, reduce energy costs, invigorate local economies:

provide employment opportunities, attract businesses and boost urban tourism (Shirazi, Kazmi, 2015; Byomkesh et al., 2012; Odindi, Mhangara, 2012; Baycan-Levent et al., 2009).

Urban green spaces might also deliver products such as fuel, wood, medicine or food and also compost and energy as a result of urban green production (Byomkesh et al., 2012; Rodenburg, et al., 2001). For example, in the American city Ann Arbor (Michigan) many sedums, grasses, and herbs are grown on green roofs, giving economic development (Berkooz, 2007). However, Rodenburg et al. (2001) note that the values of timber production and of picking mushrooms and berries in urban forests are lower than in rural areas. This is because the environmental conditions for growth are limited due to pollution, fragmentation of forests and trampling effects. In addition, the net revenues from timber are usually fairly small if any, because management of areas is relatively expensive due to small-scale management practices.

Despite the many benefits that urban green spaces give, it should be emphasized that they may involve some negative aspects. They can also be a source of crime and therefore be unsafe, especially at night. Urban green space is often seen by some criminals as an attractive place for doing illegal business and the homeless may choose to sleep there. This has to do with the camouflage abilities of urban green space, a park with many bushes and dark places is more dangerous than open space (Rodenburg et al., 2001). Among other inconveniences from green spaces are indicated: causing some allergies, limbs falling from tree sidewalk damaged by tree roots, sap dripping from tree, leaves, flowers, fruits, or seed pods falling from tree, tree roots clogging sewers, insects in tree, darkened streets creating issues of security, unsightly in appearance when not maintained (Chen et al., 2006).

Conclusions

Regardless of the city location, green spaces are today an indispensable element of the "healthy" urban structure. Green areas satisfy a wide spectrum of needs of the entire urban system, especially its residents. Due to their unique benefits, urban green spaces have been recognized as one of the most important components of urban areas (Tian et al., 2012). As Thompson (2002) indicates, in the future, the social and spatial implications of new lifestyles, values, and attitudes toward nature and sustainability will lead to even higher demands for urban green spaces. There is no doubt that urban green areas provide an added value to the urban environment. Therefore, green spaces should be the subject of well thought out planning in cities, so that their quantity, quality, type and distribution contribute to maximizing

the benefits they give and at the same time contributed to the sustainable development of urban areas.

Design and maintenance of urban green spaces should take into account such parameters of the city as population, environmental conditions, climate conditions and different cultural behaviors of immediate residents. As urban expansion and urban population growth are continuous phenomenon, keeping green spaces in accordance with appropriate standards is a challenging task (Li, Pussella, 2017). The two greatest challenges that planners face today in the city are controlling costs and creating more livable spaces in urban areas (through sustainable design) (Abd El Aziz, 2016) and find the good balance between protecting green spaces and developing urban spaces because land use is considered an important factor in urban economic growth and development (Cilliers et al., 2015).

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ACCURACY OF WATER METERS DURING THEIR OPERATION

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ABSTRCT: The article describes the study on water meters after their five-year period of operation. Water meters were tested at a certification stand to check for possible reading errors. The following devices have been included in the study: water meters with a diameter of 20 mm (single-jet, multi-jet and volumetric) as well as single-jet and screw water meters with a diameter of 50 mm. The faulty water meters were disassembled to identify causes of damage specific for various types of water meters. The percentage of faulty water meters differed among individual types of water meters, as well as among single-jet water meters of different manufacturers. The tests carried out should verify the actual errors of water meter readings during and after operation, and check whether the errors vary for different types of water meters. After many years of operational experience, it may be concluded that water meters, if lose their correct metrological properties, they usually show a smaller values than the actual flow. In such cases, faulty water meters cause the apparent water loss. Based on the study the authors found that volumetric water meters had the highest reliability among household water meters while screw water meters among industrial water meters. The studies have confirmed that damaged water meters can contribute to higher apparent water losses.

KEY WORDS: water losses, water meters, faulty water meters

JEL: L1, M2, Q5

Introduction

The objective management, planning and management of a widespread and complex water/sewage infrastructure is possible as a result of a fast and reliable analysis based on the collected data. Nowadays, representatives of a water and sewage sector more and more often reach for tools such as information systems to comprehensively manage the structure. The systems, apart from the geographic information system, contain also a geospatial monitoring system, a hydraulic model system and optimization algorithms.

Particularly important are measurements of water delivery and consumption, because to measure it means to save.

For operators of water networks, water meter economy can also be an important tool for setting directions of modernization and development, not only in the area of water supply metering, but also in utilization of resources and modernization needs (Bergel, Kulig, 2010; Cichoń. Królikowska, 2016).

Optimization of costs and water consumption using smart water meters together with information and communication systems is now becoming a standard for both water users and suppliers. Smart metering is a major technological, business and an organizational challenge, which helps better manage resources and so increase its efficiency.

The water meter carries out its task, i.e. measures a given physical quantity, processes the information obtained from measurements and then makes it available to the user once certain operating conditions and requirements are met. The basic requirement for water meters is their quality, not only at a selection stage but also over the entire lifetime, when the specific metrological characteristics of water meter has to be maintained (Cichoń, 2010; Cichoń, 2013; Tuz, Gwoździej-Mazur, 2012).

Water meters have a certification mark valid for five years, so their readings should remain within the acceptable error limits over this period.

Water meter characteristics

Water meters, installed on a water connection to buildings, are used to set fees between the water supplier and the property owner; in multi-family buildings they help to control water consumption implementing "pay for use" system (Cichoń, Królikowska, 2016; Tuz, 2011).

Mostly mechanical water meters are mounted in installations. They include: wing, screw and volume water meters, equipped with a rotor that is moved by the water flow. Wing water meters (nominal diameter DN 15-40 mm) are used to measure small water volumes. They have a built-in rotor with an

axis perpendicular to a water flow; the rotor is provided with several evenly spaced flat blades (wings). When the water passing through the meter forms one stream, which drives the rotor flowing from one side of the axis, it is a single-jet water meter (figure 1). In multi-jet water meters, the water flow is divided into streams flowing through openings in a special chamber surrounding the rotor. The wing water meters have quite high start-up thresholds and a low dynamic of measurement. They are also quite sensitive to water quality and contamination.

In terms of the working environment of water meter counters, water meters can work as dry-running and wet-running meters.

Screw water meters are used to measure large volumes of water (nominal diameter DN>50 mm). Their rotor is placed perpendicularly to the flowing water, i.e. the rotor axis is parallel to the flow (figure 1).

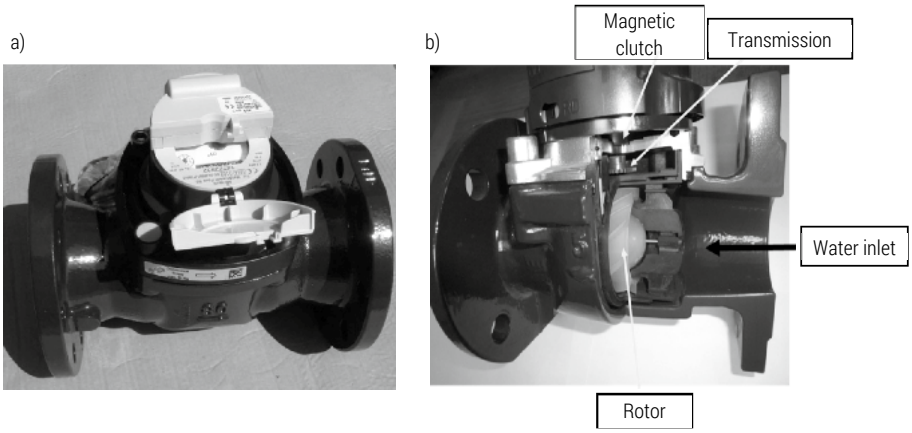

Figure 1. Screw water meter: a) view, b) cross-section

Source: author's own work.

Other options are volumetric water meters, with their very high accuracy, a low start-up threshold, and wide measurement dynamics. Here, water passing through a water meter chamber sets in motion an eccentric piston located there (figure 2).

The chamber is filled and emptied in a cyclic mode. The piston rotates and transfers a portion of water towards the outlet. Then water fills the entire chamber moving the piston until the outlet is exposed and a new inflow of water will be possible. The piston rotations are transferred to the counting system via a mechanical transmission or a magnetic clutch.

Figure 2. Rotor of a volumetric flow meter

Source: author's own work.

Static (digital) water meters represent a measurement technique that does not use moving parts. They measure the water flow rate using sensors and calculate the water volume passing using ultrasonic or electromagnetic waves.

In the case of ultrasonic water meters, two ultrasound heads send signals running simultaneously in opposite directions; one follows the water flow while the other runs just in the opposite way. The time difference measured between these signals is converted to a flow rate and thus to a water volume.

In the electromagnetic flow measurements, according to the Faraday's magnetic induction law, an electromagnetic force is induced in the conductor (water) moving in a magnetic field. The force depends on the magnetic field strength and the water velocity.

Figure 3. Electronic static water meter

Source: author's own work.

Static water meters are maintenance-free. They show low pressure losses compared to mechanical water meters, and any solids present in water have no effect on their metrological parameters or wear and tear. Properly selected water meters can measure both large and small water flows and thus allow to limit losses resulting from incorrect readings, which directly affects the economy of the company.

Static water meters usually provide communication thanks to the special radio modules mounted in them (Koral, 2006). Such provisions allow for remote water consumption readings, controls on their accuracy and delivery of more advanced information on e.g. backflows, leaks or water shortages (Cichoń, Królikowska, 2016; Geresz, 2011; Koral, 2017).

Research need on water meter management in an enterprise

The company, as an element of the water meter management system, purchases and installs water meters according to the manufacturer's recommendations It also conducts periodic readings, checks their condition, controls the accuracy of readings and periodically validates water meters. In case of a water meter failure or inaccuracy of readings, the company makes repairs and accepts complaints from consumers regarding accuracy of readings, according to the conditions specified in the regulations. It is much easier to carry out management tasks when a computer program with a database of recipients, water meters and the amount of water sold is available. Such data can serve as the basis for selecting water meters. Separate measurements, carried out at connections with registration of both water volume and water pressure at the measurement site, can also be useful. Also the pressure at the water meter installation site can affect its selection. If possible, the recipients' data should be supplemented with information on the number of residents using the connection. Such measurements should become the basis for a preliminary selection of a water meter for buildings with a given number of flats and for making decisions on a possible replacement or repair of the water meter. The purchase of more expensive water meters with a higher accuracy should be preceded by a cost/benefit analysis. Due to a cost structure of a water supply and sewage disposal system, obligatory tariff rules and technological conditions of water meter measurements, these devices mostly serve as a tool for cost allocation. Therefore, the device with a similar accuracy class should be used for all residents. The activities carried out by professionals, as part of water meter management in a water and sewage company, are much more in compliance with the requirements set out in standards and regulations. Neither owners of water meters in their households

nor managers of multi-family buildings will ensure a good management of water meters. Housing owners may also alter housing water meters readings; they use some techniques to increase reading errors. In the case of mechanical water meters, these are e.g. devices that reduce a rotor speed of the water meter. It should also be noted that the current fee policy is so structured that the economic effects resulting from a replacement of a faulty water meter quickly disappear after a change of prices and tariff rates. Therefore, the company that takes actions in water meters management, checking and analyzing readings as well as through validation, repair and replacing of water meters with more accurate ones, should carefully monitor related additional expenditures. Systematic legalizations, verification of readings and their analyzes allow to avoid sudden cost increases during the year without limiting activities undertaken as part of water meter management.

The selection of water meters and the rules for their proper installation are aimed to achieve the best metrological properties during their normal operation. However, the assumption is that the metrological parameters of water meters are constant over time, at least within the limits of acceptable errors. The tests carried out should verify the actual errors of water meter readings during and after operation, and check whether the errors vary for different types of water meters. After many years of operational experience, it may be concluded that water meters, if lose their correct metrological properties, they usually show a smaller values than the actual flow. In such cases, faulty water meters cause the apparent water loss.

Methods

Results of the research

The reading errors for various types of water meters manufactured by different producers were analyzed; they were in operation in various water supply systems. The following devices have been included in the study: water meters with a diameter of 20 mm (single-jet, multi-jet and volumetric) as well as single-jet and screw water meters with a diameter of 50 mm. The single-jet and multi-jest water meters with a diameter of 20 mm had the metrological class R80, whereas the volumetric water meters were of the R160 class. The single-jet water meters with a diameter of 50 mm had the metrological class R315. Most water meters have been dismantled due to passing the expiration day, i.e. after a five-year service life. Some water meters were dismantled for various reasons earlier than after 5 years. Several were also dismantled since they did not measure the flow of water at all. In total, 160 water meters were subjected to the study. During the test metrological properties of the water

meters were checked at the certified validation station by comparing the readings of a given water meter with water volumes that actually flowed through it. Each water meter was tested at three characteristic flow rates: at the minimum flow rate Q1, an intermediate flow rate Q2 at a continuous flow rate Q3.

In accordance with the provisions of the Ordinance of the Minister of Economy on the requirements of water meters and the detailed scope of checks performed during legal metrological control of these measuring instruments (Rozporządzenie Ministra Gospodarki z dnia 23 października 2007 r. w sprawie wymagań…), the following error values apply for the initial verification and re-verification of cold water meters, i.e. up to 30°C:

$$\pm 5\% \text{ for } Q_1 \leq Q < Q_2$$

$$\pm 2\% \text{ for } Q_2 \leq Q < Q_4$$

According to the provision of §15 of the Regulation, permissible errors of water meters in use may exceed two times the limit of permissible errors valid for legalization. After metrological tests, water meters were divided into groups in terms of reading errors. The following sets of water meters have been singled out, which:

- met validation requirements (errors ≤±2% or ≤±5% for Q1),
- met the requirements permissible during operation (errors exceed two times the errors permissible during legalization) (errors ≤±4% or ≤±10% for Q1),
- had errors exceeding the permissible limiting errors (errors >±4% or >±10% for Q1),
- did not perform any measurements (error -100%).

Therefore, correct metrological properties had water meters in the first and second group. Of all the water meters tested, 61 units did not meet the requirements, i.e. their reading errors were greater than the permissible errors during operation. In figure 4 the number of water meters in each individual range of reading errors for the minimum flow rate is presented.

In addition to the working water meters, the figure 4 shows also water meters, which reading errors are greater than the permissible limiting errors. It is interesting, that all faulty water meters have an error with the sign "-", which means that their readings were lower than the actual flow. The opposite was not the case with any water meter. Similar were the readings for intermediate (Q2) and continuous (Q3) or nominal (Qn) flow rates. The number of water meters in individual ranges of reading errors is shown in figure 5.

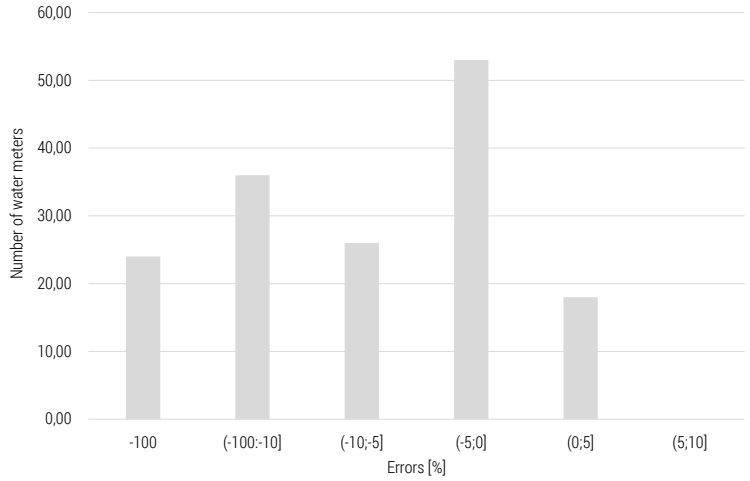

Figure 4. Number of water meters in each range of reading errors at the minimum flow rate

Source: author's own work.

After metrological tests, faulty water meters were dismantled to identify the reasons for such inaccurate readings. The tests showed some failures, characteristic for particular types of water meters.

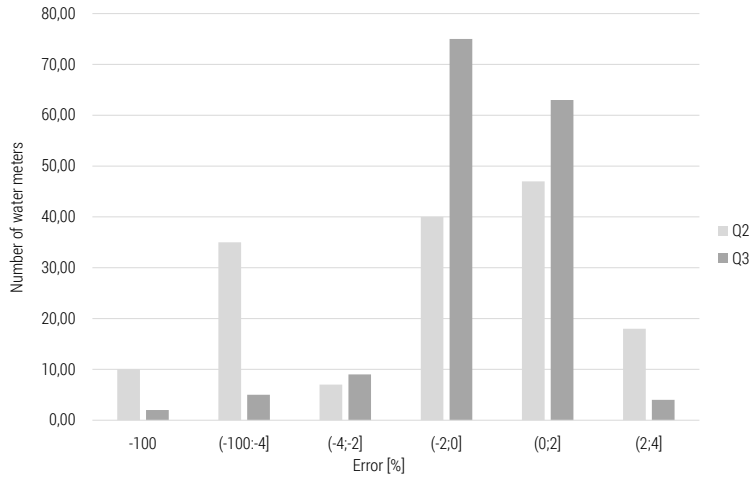

Figure 5. Number of water meters in each range of reading errors at intermediate, continuous or nominal flow rates

Source: author's own work.

In the case of screw water meters, iron particles accumulating on a surface of a magnetic coupling on a rotor side caused the failure. A view and a

microscopic view of these particles is shown in figure 6. The aggregates can cause additional friction on the rotor until it gets blocked.

In the case of single-jet industrial water meters with a diameter of 50 mm, failures are caused by calcium carbonate scaling accumulated on a rotor bearing. The scaling accumulates on the surface of both the axis and the rotor. It increases a bearing surface and its roughness, which in turn increases a bearing friction. Microscopic photos of the bearing surface are shown in figure 7.

In single-jet water meters with a diameter of 20 mm, the most common cause of failure was deformation (flattening) of the rotor axis and calcium carbonate scaling. The microscopic view of the tip of the rotor axis is shown in figure 8.

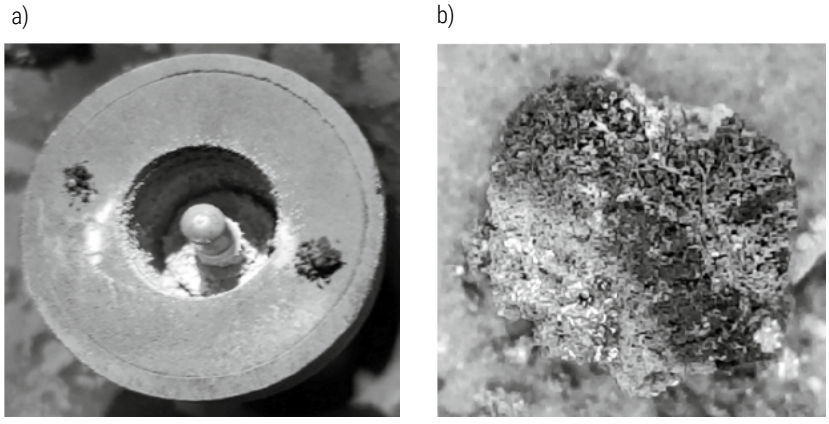

Figure 6. Magnetic coupling of a screw water meter a) view of a magnetic coupling surface with precipitates, b) a microscopic view

Source: author's own work.

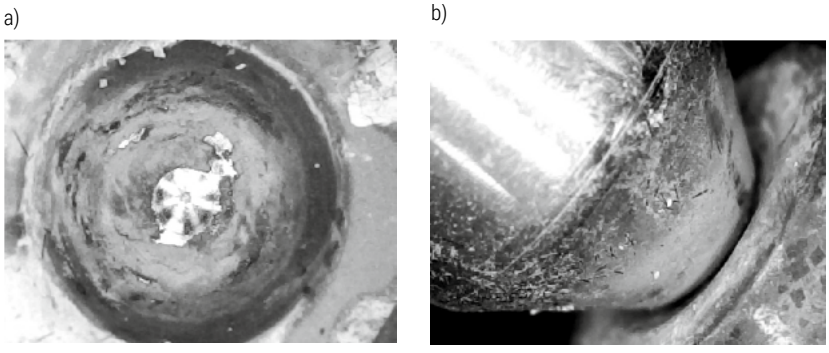

Figure 7. Bearing of the rotor of an industrial single-jet water meter covered with scaling a) microscopic view of a bearing with scaling, b)microscopic view of a bearing profile

Source: author's own work.

Figure 8. Tip of the rotor axis of the single-jet water meter with a diameter of 20 mm
Source: author's own work.

The tip of the rotor axis has become flat (instead of semi-circular) and additionally the contact surface has grown due to calcium carbonate scaling. These changes resulted in a higher friction, and thus an greater reading errors type "–".

Water jet meters that worked at hydrant bases were also tested. In this type of damaged water meters, the impeller axis was worn probably due to too rapid flow changes or excessive flow rates. Figure 9 shows a water meter, which rotor axis was originally 3 mm in diameter and now was less than 0.5 mm.

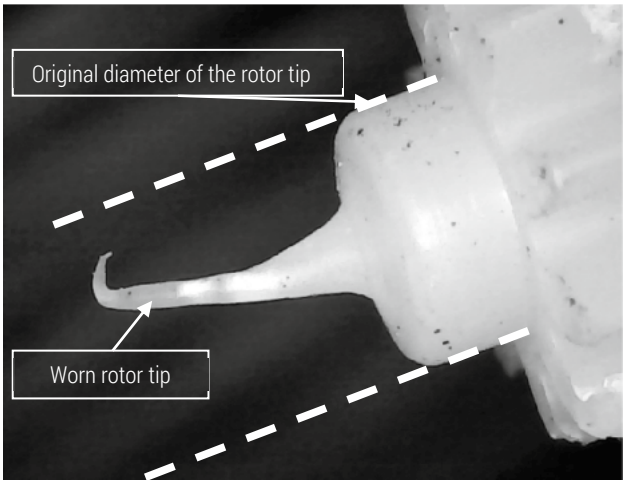

Figure 9. Worn rotor axis of a water meter working at a hydrant base
Source: author's own work.

In the case of volumetric water meters, only one water meter from all units disassembled after 5 years of operation had reading errors exceeding the limit values. In this single case, the water meter showed 7273 m^3, which is rare for water meters with a diameter of 20 mm, because their reading after five years of operation is usually less than 1000 m^3. This water meter has probably also worked at high flow rates and its damage resulted from the worn side surface of the water meter piston. Also, a number of cavities have been found on a surface of a measuring chamber making the piston's sliding surface porous and uneven. The view of the worn side of the piston is shown in figure 10.

The percentage of faulty water meters differed among individual types of water meters, as well as among single-jet water meters of different manufacturers. This applied to counters of various metrological classes in a similar range. It should be noted that the highest efficiency was found in volumetric water meters; only one of them exceeded reading errors after the period of operation. Two other damaged volumetric water meters, dismantled after a short period of operation (as blocked) were also tested. One of them had a broken magnetic clutch while the other was blocked with sediment particles. However, this kind of damage is easy to spot during operation. Screw water meters turned out to be the most reliable among industrial water meters.

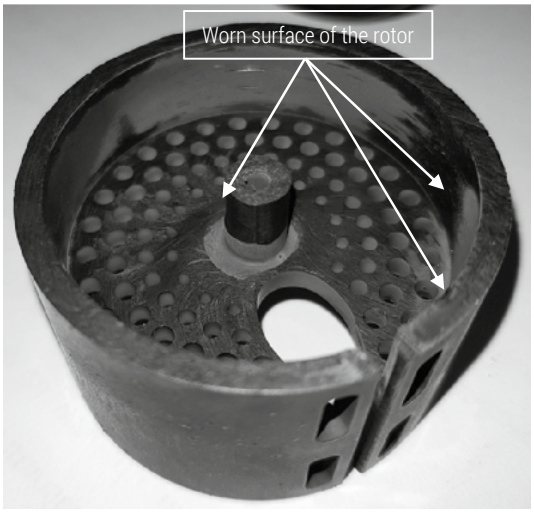

Figure 10. Worn side of the piston in a volumetric water meter

Source: author's own work.

Conclusions

The study confirmed that water meters might lose their metrological properties over time. The authors presented typical faults that may occur in individual types of water meters and cause a higher apparent water loss. Therefore, it is important not only to properly select water meters diameters and a metrological class but also to maintain good metrological properties throughout the entire period of operation. The analysis of faulty readings of water meters during and after their operation is a very important tool, that a water and sewage company may use to select the water meters that are the most reliable throughout their lifetime, in a given water system. Based on the study the authors found that volumetric water meters had the highest reliability among household water meters while screw water meters among industrial water meters. This is also confirmed by many years of research experience in meteorological expertise carried out at a certified validation point.

Readings of the water meter are the basis for calculating water and wastewater fees. It is therefore worth knowing that the device operates correctly, especially now when all efforts are directed to the rational use of water resources.

The contribution of the authors

Tomasz Cichoń – conception, literature review, acquisition of data, analysis and interpretation of data – 50%
Jadwiga Królikowska – conception, literature review, acquisition of data, analysis and interpretation of data – 50%

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Joanna **GWOŹDZIEJ-MAZUR** • Kamil **ŚWIĘTOCHOWSKI** • Bartosz **KAŹMIERCZAK**

ANALYSIS OF WATER LOSSES AND FAILURE FREQUENCY IN AN URBAN-RURAL WATER SUPPLY SYSTEM

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ABSTRACT: This article presents the results of analysis of an urban-rural water supply system. The level of water losses and failure frequency of the water supply system were evaluated. Tests and analyses of the level of water losses were conducted for the years 2010-2016. Tests and analyses of failure frequency were conducted for the years 2013-2016. The guidelines of the International Water Association were applied in calculations. Analyses showed an influence of season on the failure frequency of the urban-rural water supply system. An influence of the number of failures on the volume of water lost in a single failure was also observed. Obtained results were compared with data from domestic literature and the guidelines of standard PN-EN 60300-3-4:2008.

KEY WORDS: water supply system, water losses

Introduction

In 1999, Lambert et al. published the IWA Task Force One guidelines for water balancing and evaluation of water losses in water supply systems. These guidelines set forth a water balance table for water supply systems (table 1) as well as water loss indicators. Among other things, the ILI (Infrastructure Leakage Index) index was established for objective evaluation of water losses and comparison of different water supply systems. ILI slowly began to replace evaluation of water losses in water supply networks employing the water loss percentage index. The guidelines and methodology for evaluating water losses in water supply systems according to the IWA began to function in Polish literature concerning water losses. Every so often, articles are published in which authors evaluate the water losses or failure frequency of various water supply systems (Bergel, 2012; Bergel, Pawelek, 2008; Bergel et al, 2013; Kwietniewski, 2013; Ociepa, Kędzia, 2015). In 1998, Dohnalik reported a mean level of water losses in Poland amounting to 18.6% (Dohnalik, 1998). This became a point of reference for other water supply systems in Poland (Hotloś, 2003). According to numerous authors (Farley et al., 2008; Lambert et al., 2018; Thornton et al., 2008), the percentage index should be departed from in the evaluation of water losses, and the CARL, UARL and ILI indices should be used instead. These indices are defined as (Farley et al., 2008; Lambert et al., 1999; Thornton et al., 2008).

NRW (Non-Revenue Water), unmetered water for which the water company did not receive payment. This quantity arises from the difference between the amount of water pumped into a water supply network and the amount of invoiced water, which is then divided by the amount of water pumped into the water supply network (the former amount).

CARL (Current Annual Volume of Real Losses) is the volume of water lost from the water supply network as a result of leakage in the transmission and distribution systems, tanks and as well as pipe leaks from the point at which water is pumped in to the point of water purchase by a consumer. The value of this index is given in dm^3/day or dm^3/year.

UARL (Unavoidable Annual Real Losses) are the volume of water lose from a water supply system considered to be the amount of water whose loss is unavoidable due to the difficulty of detecting small leaks in water pipelines, economically unfeasible repair, difficult access to the site of the leak, reaction time between the occurrence of a leak and its detection and repair. The volume of water described by the UARL index is a function of the length of the distribution system, the number and length of service lines, and the mean pressure value in the water supply network. The value of this index is given in dm^3/day or dm^3/year.

ILI (Infrastructure Leak Index) is the index recommended by the IWA for evaluation of water losses in a water supply network and planning of undertakings intended to limit the volume of water lost. ILI is defined as the ratio of Current Annual Volume of Real Losses (CARL) to Unavoidable Annual Real Losses (UARL). Values of the ILI index are classified into 4 or 8 categories (Farley et al., 2008; Lambert et al., 1999).

Calculation of failure frequency indices may provide valuable information about the condition of a water supply network. Failure frequency indices can be calculated for an entire water supply network but also for individual groups, i.e. water mains, distributing pipes, service lines, fittings, etc. Index values are expressed as the number of failures per km of pipe and per unit of time within which the number of failures was counted. Acceptable failure frequencies are described in standard PN-EN 60300-3-4. In his article, Bergel gave mean failure frequency values based on tests in 374 water supply systems for water mains, distribution pipes, service lines and systems as a whole (Bergel, 2012).

The literature also defines a unit water loss index that describes the amount of water lost from one service line over the course of the year. The unit loss index is the quotient of real losses divided by the number of service lines. It is also applied for evaluation of water losses in a water supply network (Farley et al., 2008).

Table 1. Water balance in water supply system according to IWA

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
	Water Losses	Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
		Commercial Losses	Unauthorised Consumption	
			Customer Meter Inaccuracies and Data Handling Errors	
		Physical Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows from the Utilities Storage Tanks	
			Leakage on Service Connections up to the Customer Meter	

Source: (Farley et al., 2008).

Material and methods

Tests concerning analysis of water losses and failure frequency were conducted at a water company servicing an urban-rural water supply system. The primary method of acquiring data involved specially prepared input data sheets, which were used as the basis for obtaining information for further analyses. Water loss analysis according to IWA guidelines was conducted for the years 2010-2016. Analysis of the water supply network's failure frequency covered the years 2013-2016. The following formulas were applied in calculations (Farley et al., 2008):

$$\text{Revenue Water} = \text{Billed Authorised Consumption} = \text{Billed Metered Consumption} + \text{Billed Unmetered Consumption} \quad (1)$$

$$\text{NRW} = \text{System Input Volume} - \text{Billed Authorised Consumption} \quad (2)$$

$$\text{CARL} = \text{Non-Revenue} - \text{Unbilled Authorised Consumption Water} - \text{Commercial Losses} \quad (3)$$

$$\text{UARL (litres/day)} = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P \quad (4)$$

where:
Lm – mains length (km),
Nc – number of service connections,
Lp – total length of private pipe, property boundary to customer meter (km),
P – average pressure (m).

$$ILI = CARL/UARL \quad (5)$$

Failure frequency index (Kwietniewski, Rak, 2010):

$$\lambda(\Delta t) = n(\Delta t) / L^{*}\Delta t \quad (6)$$

where:
$\lambda(\Delta t)$ – unit failure intensity [fail·km-1·a-1],
$n(\Delta t)$ – number of failures within time interval Δt,
L – length of pipes tested within time interval Δt (mean length within this interval), km,
Δt – considered time interval, year.

Results

As a result of analyses conducted, values of RW, NRW, CARL, UARL and ILI indices in successive years from 2010 to 2016 were obtained (table 2). The Non-Revenue Water (NRW) index reached its highest level in 2013, amounting to 20.30%, and its lowest value, 14.57%, in 2016. In the same year, ILI reached a value of 1.34, which corresponds to the interval of group A, being ILI<2.00 for

developed countries. This means that further limitation of real losses may be economically unfeasible, and precise analysis of the profitability of decisions made must be conducted (Lambert, 2012). During the considered period, the water supply network achieved a result of ILI<2.00 twice. The ILI's highest values were 2.46 in 2011 and 2.43 in 2013. In other years, the water supply network received a B result, meaning 2.00<ILI<4.00. This means that it is possible to improve the profitability of the water supply network by implementing pressure management, active leak control, etc. (Lambert, 2012).

Table 2. Changes in the values of ILI, UARL, CARL, NRW indices in individual years during the period of 2010-2016

Index	Unit	2010	2011	2012	2013	2014	2015	2016
RW	%	82.80	80.09	80.59	79.70	82.20	80.11	85.43
NRW	%	17.20	19.91	19.41	20.30	17.80	19.89	14.57
CARL	thous. m^3/year	433.79	532.65	525.59	564.00	473.68	545.14	363.08
UARL	thous. m^3/year	208.81	216.65	226.88	232.83	238.76	244.73	270.76
ILI	[-]	2.08	2.46	2.32	2.42	1.98	2.23	1.34

Source: author's own work.

During analyses, the total number of failures over the course of a year during the years 2013-2016 were gathered and presented in a chart (figure 1). These values changed within the range of 0 to 8 failures per month. The most failures were recorded in 2013 – 62 failures. The least failures were recorded in 2014 – 22 failures. The most failures in one month were recorded in January and February 2013 as well as in January 2016 and September 2015. During the analyzed period, only 4 months without failures were registered.

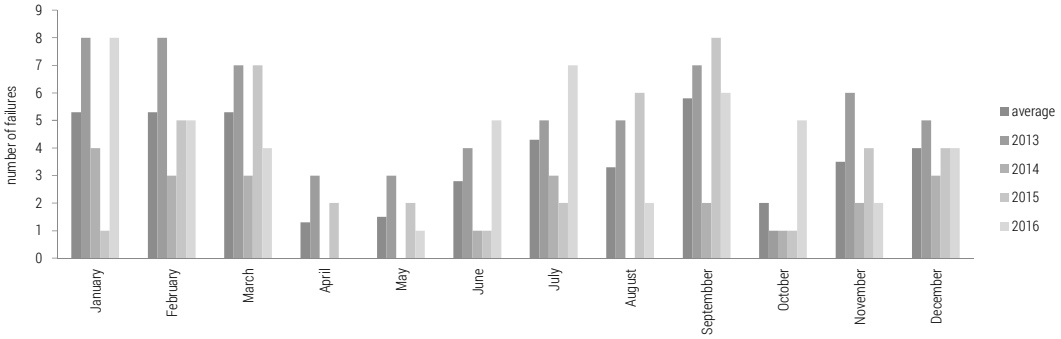

Figure 1. Number of failures in individual months during the years 2013-2016
Source: author's own work.

The months with the highest number of failures are January, February, March and September (table 3). There were 5.3 to 5.8 failures per month on average. The least failures occur in April, May and October. There were 1.3 to 2.0 failures per month on average. The mean number of failure per month amounted to 3.7 during the studied period.

Table 3. Share in annual number of failures

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Mean share of annual failures	11.9%	11.9%	11.9%	2.8%	3.4%	6.3%	9.7%	7.4%	13.1%	4.5%	8.0%	9.1%
Mean number of failures	5.3	5.3	5.3	1.3	1.5	2.8	4.3	3.3	5.8	2.0	3.5	4.0
Share of annual failures in 2013	12.9%	12.9%	11.3%	4.8%	4.8%	6.5%	8.1%	8.1%	11.3%	1.6%	9.7%	8.1%
Share of annual failures in 2014	18.2%	13.6%	13.6%	0.0%	0.0%	4.5%	13.6%	0.0%	9.1%	4.5%	9.1%	13.6%
Share of annual failures in 2015	2.3%	11.6%	16.3%	4.7%	4.7%	2.3%	4.7%	14.0%	18.6%	2.3%	9.3%	9.3%
Share of annual failures in 2016	16.3%	10.2%	8.2%	0.0%	2.0%	10.2%	14.3%	4.1%	12.2%	10.2%	4.1%	8.2%

Source: author's own work.

During the studied period, 0 to 6 service line failures occurred every month, 2.1 failures occurred per month on average during this period. There were 0 to 6 failures on distribution pipes per month. In this group, 1.3 distribution pipe failures occurred per month on average. No water main failures were registered during the period of study. However, 0 to 4 network fitting failures were recorded every month. The mean value of the number of fitting failures amounted to 0.3 failures per month. Values of failure numbers are given in tables 4, 5 and 6.

Table 4. Failures of service lines of the urban-rural water supply network during the years 2013-2016

Year	Sum of service line failures	Minimum monthly value	Maximum monthly value	Mean monthly value	Median
2013	31.0	0.0	5.0	2.6	2.5
2014	14.0	0.0	3.0	1.2	1.0
2015	26.0	0.0	5.0	2.2	2.0
2016	30.0	0.0	6.0	2.5	2.0

Source: author's own work.

Table 5. Failures of distribution pipes of the urban-rural water supply network during the years 2013-2016

Year	Sum of distribution pipe failures	Minimum monthly value	Maximum monthly value	Mean monthly value	Median
2013	23.0	0.0	5.0	1.9	1.5
2014	6.0	0.0	2.0	0.5	0.0
2015	16.0	0.0	6.0	1.3	0.5
2016	16.0	0.0	3.0	1.3	1.5

Source: author's own work.

Table 6. Failures of fittings of the urban-rural water supply network during the years 2013-2016

Year	Sum of fitting failures	Minimum monthly value	Maximum monthly value	Mean monthly value	Median
2013	8.0	0.0	4.0	0.7	0.0
2014	2.0	0.0	1.0	0.2	0.0
2015	1.0	0.0	1.0	0.1	0.0
2016	3.0	0.0	1.0	0.3	0.0

Source: author's own work.

In every year, failure frequency indices of water supply networks for service lines and the distribution network (table 6) were below the recommended value of the failure intensity index according to the European criteria described in PN-EN 60300-3-4:2008. It is worth comparing the obtained failure index values to mean values of these indices in Poland, as described in Bergel's studies (Bergel, 2012). In 2013, the value of the index for service lines and the general index for all pipes was higher than the average national value of the index in individual groups. The value of the failure frequency index for distribution pipes in 2013 was lower than the mean value of this index described by Bergel. In the years that followed in the period of study, obtained index values were lower than mean values in Poland according to Bergel.

Table 7. Failure frequency indices of the urban-rural water supply network during the years 2013-2016

	2013	2014	2015	2016
Service line failure frequency index	0.51	0.22	0.39	0.44
Distribution pipe failure frequency index	0.15	0.04	0.11	0.09
Network failure frequency index	0.29	0.10	0.19	0.19

Source: author's own work.

Assuming that the entire volume of water making up CARL will be lost as a result of the reported failures, the mean loss of water volume due to a single failure can be calculated. The chart (figure 2) presents the results under this assumption. It can be seen that, the greater the number of failures, the lesser the water volume lost as a result of a single failure.

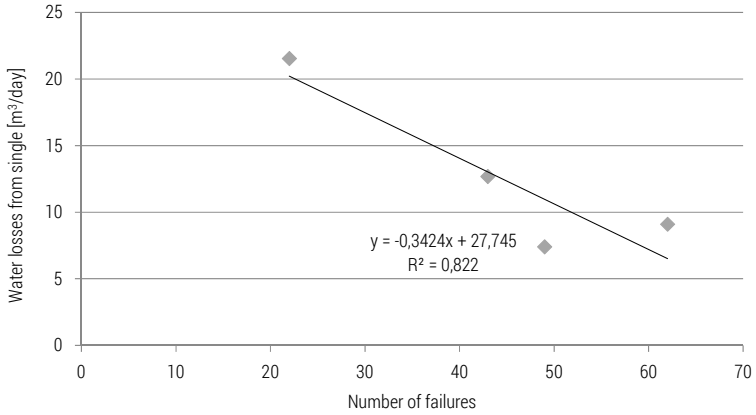

Figure 2. Dependency of water losses per single failure on number of failures

Source: author's own work.

It can be assumed that the total volume of water lost as a result of a failure corresponds to the CARL water volume reduced by the UARL water volume. Under this assumption, the mean water volume lost due to a single failure can be obtained. The chart (figure 3) presents the results under this assumption. It shows that, at the beginning, the mean water volume per single failure decreases as the number of failures grows. Next, the mean water volume per single failure begins to grow.

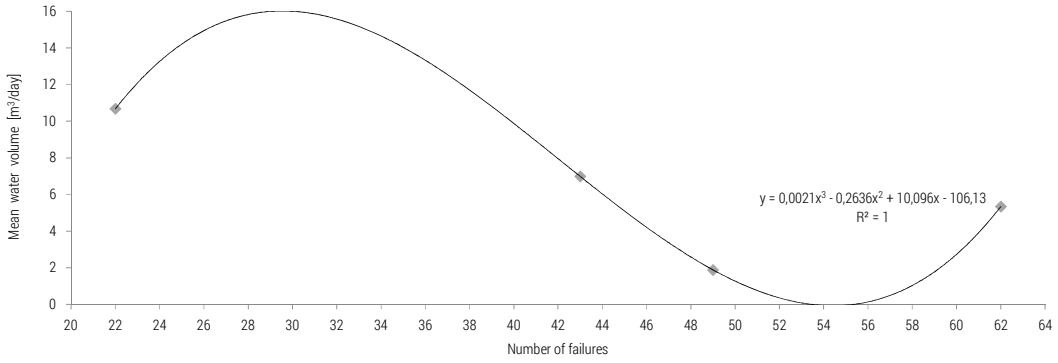

Figure 3. Dependency of water losses per single failure on number of failures accounting for UARL

Source: author's own work.

Real losses, expressed in litres per service line per day, grew as ILI values increased, which can be seen on the chart (figure 4). These values changed within the range of 112.7 to 192.6 liters/connection/day. This result is typical of a B evaluation according to IWA guidelines for pressure group <40 m H_2O. Mean pressure in the analyzed network was evaluated to be 35 m H_2O.

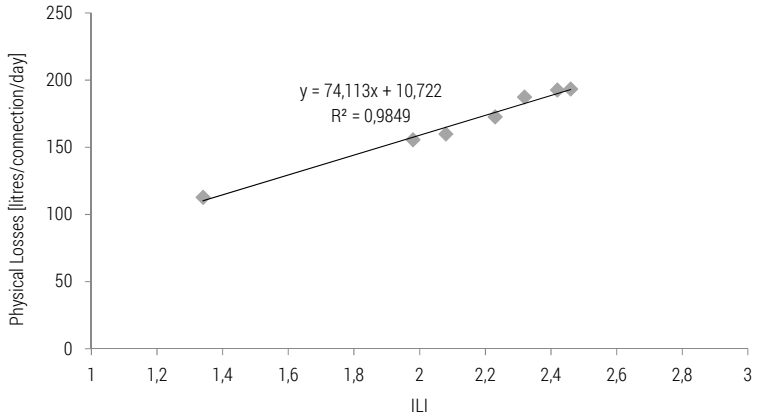

Figure 4. Dependency between Physical Losses per connection per day and ILI
Source: author's own work.

The chart (figure 5) shows how the value of losses from a single service line changed during the analyzed period. This value changed within the range of 100 to 200 liters/connection/day. This value is characterized by a B evaluation for mean pressure in water supply network <40 m.

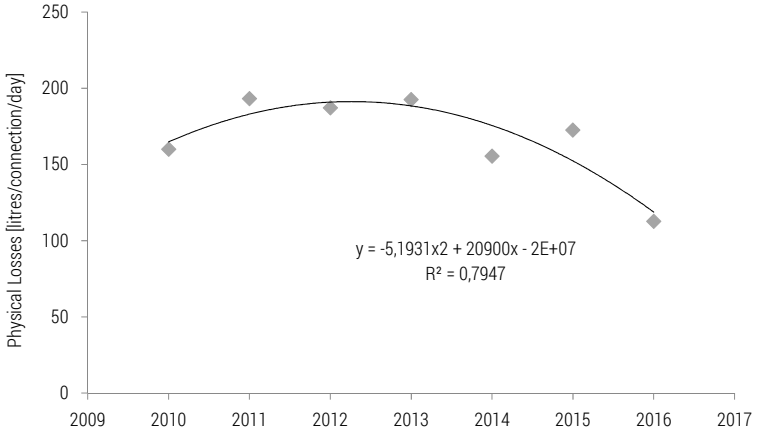

Figure 5. Physical Losses per connection per day in successive years of study
Source: author's own work.

Summary

The analyses conducted provided information on how the level of water losses in the urban-rural water supply system changed over the course of successive years. The urban-rural water supply network received an A or B evaluation in successive years according to the scoring scale recommended by IWA for ILI. NRW fluctuated between 14.57% and 20.30%. The volume of water losses from a single service line over the course of one day is characterized by a B score according to the scoring scale recommended by IWA for the pressure group up to 40 m H_2O throughout the entire period of analysis.

The months characterized by the most failures during the year within the period of study are January, February, March and September. Thanks to this information, it can be determined that intensified inspection of the water supply network should be conducted in precisely these months, e.g. through active leak control. The least failures occur in April, May and October. On this basis, it can be stated that it is not profitable to conduct preventive acoustic inspections of the water supply network in order to find hidden failures during this period.

The most failures were registered on water service lines during the period of study. No water main failures were observed during this period. The failure frequency index of the entire water supply network changed within the range from 0.10 to 0.29 failures/km/year. This is a very good result. The greater the failure frequency index of the network, the greater the ILI. The year 2016 was the exception, in which the failure frequency index was at a level similar to that of 2015, however ILI was nearly half of its 2015 value. This may be owed to the fact that the network increased its length by over 25 km in 2016, which is 10% more than in the previous year.

There was an absence of data about the number of failures in the entire period of study. It would also be interesting to compare the number and type of failures depending on the diameter, material and age of pipes. However the authors were unable to obtain such data from the water company.

In order to conduct precise analyses of the water losses and failure frequency of water supply networks, precise event logs must be kept. IT solutions aiding in the creation and storage of water supply network databases, e.g. GIS-class systems, would also be helpful.

The authors perceive a need to keep datasets and conduct analyses of water losses and failure frequency in networks, which may serve for making economically and technically justified decisions related to the implementation of solutions limiting water losses in the water supply network. It is also worth using several indices during evaluation, e.g. evaluation using ILI followed by verification of unit water loss values. Thanks to such an approach, a water supply system can be reliably evaluated in terms of water losses.

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The contribution of the authors

Joanna Gwoździej-Mazur – concept and objectives, literature review, research – 40%
Kamil Świętochowski – concept and objectives, literature review, research – 40%
Bartosz Kaźmierczak – objectives, literature review, research – 20%

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Mateusz **ROGOWSKI**

USE OF MONITORING SYSTEM OF TOURIST TRAFFIC (MSTT) IN STOŁOWE MTS. NATIONAL PARK FOR VISITORS DESCRIPTION

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ABSTRACT: The development of tourism in valuable natural areas is becoming increasingly dynamic, and therefore this phenomenon requires a more thorough investigation. An increased tourist traffic in a national park entails a range of consequences, which are not irrelevant for the protected nature. The aim of the study is a spatial and quantitative description of tourist traffic in the Stołowe Mountains National Park, basing on the data received from pyro-electric counters in Monitoring System of tourist traffic. The system was created through to cooperation between national park staff and Department of Tourism and Recreation Adam Mickiewicz University in Poznan (Rogowski, Małek, 2016). In the period from 16th September 2016 to 31th August 2017 were 858 346 entries to national park. July and August were the most popular months which accounts for 22% of the total number of entries. All data was presented the visitors flow indicating the most popular areas and regions and the trails sections.

KEY WORDS: tourist flow, monitoring, Stołowe Mountains National Park, infrared traffic counters

Introduction

National parks covering areas with valuable natural assets constitute areas which are highly attractive for tourism, with more and more tourists choosing them as their destination. As a result of all this, dynamic increase in tourist traffic in the national parks located in the mountains that we are currently witnessing leads to an uncontrolled mass tourism, which has a negative impact on the natural environment. This fact may lead to many irreversible effects and conflicts, among which a very important issue from the point of view of the nature itself is the conflict between the need to protect, preserve and make available the natural assets for tourists. This situation has particular implications for the mountain areas with a high natural value, uniqueness and sensitivity, which provides for their attractiveness and popularity of destinations. The aim of the study is a spatial and quantitative description of tourist traffic in the Stołowe Mountains National Park, basing on the data acquired from infrared traffic counters (one's component of MSTT) of period from 16th September 2016 until 31th August 2017.

The Stołowe Mountains, due to their uniqueness and easy availability, are among the areas with a high degree of susceptibility to strong and multi-dimensional impact of tourism. For that reason, an appropriate model should be developed to manage tourism, taking into consideration a proper way to make available precious natural assets and a high tourist traffic in specific spots without causing the degradation of assets. To do this, it is necessary to understand the specificities of the tourist traffic participants, and then, by taking appropriate action, to shape their ecological awareness and sensitivity by making the assets available in the conditions of sustainable development. Within areas which are highly attractive for tourism, like the Stołowe Mountains, the developing tourism with heavy traffic may reach the size of mass tourism. According to Rogowski and Małek (2016), this is the case of two most popular areas of the park, namely Szczeliniec Wielki and Błędne Skały. These areas generate the heaviest tourist traffic, and therefore they should be put under a constant and comprehensive observation.

An overview of literature

Visitor flow monitoring in national parks in Poland is performed basing on different quantitative data. As indicated by Cessford and Muhar (2003), Spychała and Graja-Zwolińska (2014), there are four distinguishable methods of monitoring: direct observation, measurement with sensors, recording of visits, and estimations. In addition, as indicated by Hibner (2014), direct observation

includes direct measurement and the use of cameras and aerial imagery. Infrared traffic counters which serve for automatic traffic count, according to Spychała and Graja-Zwolińska (2014), were used in 14 national parks in Poland. The authors believe that these are among the most effective and useful devices in daily operation of the park. Other advantages include, for example, easy measurement without participation of additional persons, easy use and low risk of failure. Moreover, according to the manufacturer's specifications, the margin of error for quantitative reading is 5%. The data acquired from infrared traffic counters allowed, among others, to describe the tourist traffic in the following national parks: Tatrzański (Fidelus, 2010, 2014; Hibner, 2014; Taczanowska et al., 2014), Babiogórski (Buchwał, Fidelus, 2010), Bieszczadzki (Prędki, 2012) and Stołowe Mountains (Rogowski, 2016). Further analysis of the information allowed determining that motion sensors were installed in the following national parks: Świętokrzyski, Pieniński, Karkonoski and Słowiński.

Research methods

The Monitoring System of tourist traffic (SMTT) was planned, created and installed in 2016 by Rogowski (Department of Tourism and Recreation Adam Mickiewicz University in Poznań) and Małek (Stołowe Mountain National Park). Detailed assumptions for the design of the monitoring system for tourist traffic observation have been presented by Rogowski and Małek (2016) and Rogowski (2017a). The system consists of quantitative and qualitative monitoring and was started 16 September 2016. The qualitative monitoring made up of data coming from tourist surveys, covering two seasons so far (years 2015 and 2016), the results of which have been presented in separate studies (Rogowski, Małek, 2016; Żyto et al., 2017; Rogowski 2017b). The quantitative monitoring gathers data from 38 infrared traffic counters installed on the tourist trails at the park's border and along the public road called "The Road of A Hundred Bends" (Droga Stu Zakrętów). The sensors have been installed most densely in most popular attractions: Błędne Skały "rock-city" (4 sensors) and Szczeliniec Wielki "rock-city" (3 sensors), along the public road (mentioned above) in the area of Fort Karola, Narożnik and Białe Skały (5 sensors) Radkowskie Skały and Skalne Grzyby (2 sensors each). The scope of data includes hourly, daily, weekly, monthly and annual reports, taking into account the direction of traffic: entries (IN), exits (OUT) and passings (IN+OUT). Each day approximately 912 automatic measurements are made. Data is downloaded from the devices via "Bluetooth" technology through an application on a mobile device. Data was analysed in a spreadsheet using the statistical measurements.

Results of the research

The tourist traffic in the Stołowe Mountains National Park is distinguished for its strong concentration in time and space. In the period from 16th September 2016 to 31th August 2017, 858 346 entries (IN) were recorded. The greatest number of entries is observed in the summer months (July 191 517 and August 189 833, which accounts for 22% of the total number of entries) and in the spring (May: 162 840 – 19%, and June: 130 953 – 15%) (figure 1). These months generate 80% of the total number of entries to the park, and therefore this period may be defined as a high tourist season. Lower values are recorded in October and April (30-50 thousand tourists), so these months may be considered a medium tourist season. September is a transition period between a high and a medium season, as 44 thousand entries were recorded in the second half of that month. The lowest tourist traffic has been recorded in the remaining autumn and winter months – from November to March (approximately 9-10 thousand tourists), and therefore this period may be referred to as a low tourist season.

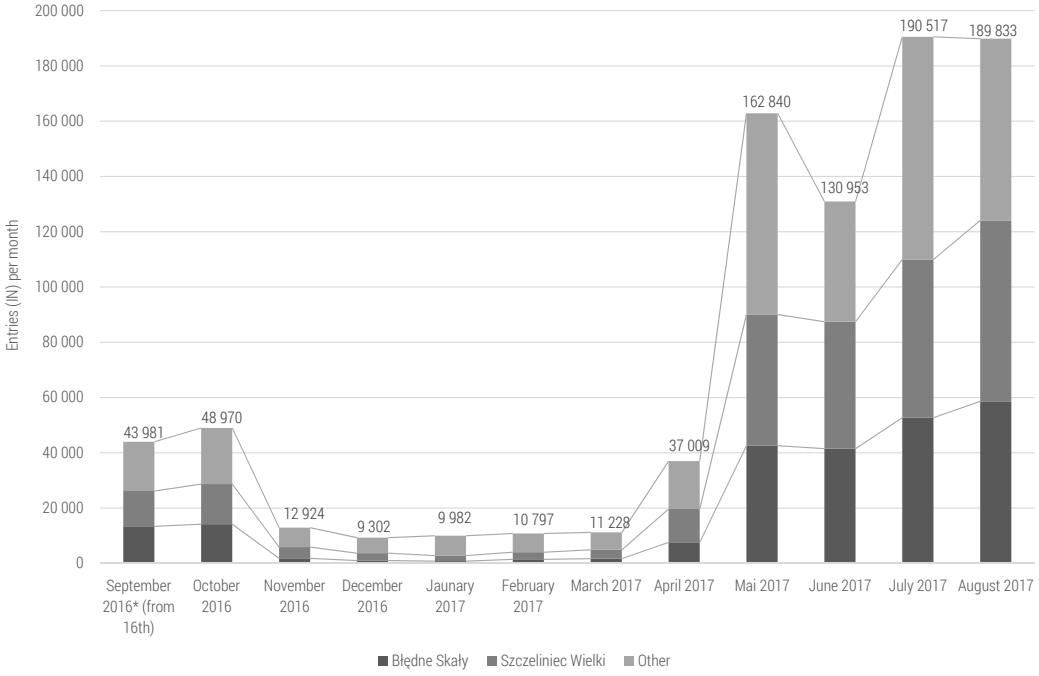

Figure 1. Tourist entries (IN) in a monthly scale to the Stołowe Mountains National Park and on the tourist routes in Szczeliniec Wielki and Błędne Skały (from 16th September 2016 to 31th August 2017)

Source: (Rogowski, 2017a).

A short-term increase in tourist traffic is observed on consecutive days free from work related to bank holidays and the so-called "long weekends" (table 1).

Table 1. The size of the tourist traffic (IN) in selected holiday periods

Period	Number of entries (IN)	Percentage of monthly entries (IN)
11-13 November 2016 (Independence Day)	5.632	44%
24-31 December 2016 (Christmas and New Year's Eve)	5.786	62%
14-17 April 2017 (Easter)	7.182	19%
29-30 April 2017 (beginning of the 1st of May weekend)	13.027	35%
1-3 May 2017 (1st of May – 3rd of May National Holiday)	31.451	19%
15-18 June 2017 (Corpus Christi Holiday)	27.690	64%
12-15 August 2017 (Assumption of the Blessed Virgin Mary)	40.774	21%

Source: author's own work.

Holiday periods generate from 19% to 64% of the total monthly number of entries to the park, an example of which may be Christmas with the New Year and the so-called "long weekend" in May and in June. In these periods, tourist traffic is the highest in a given month. Due to a high occurrence of such periods, in most of the analysed months such dynamic and short increases can be observed. In addition, a peak season of school excursions may be indicated (16-25 May 2017) with almost 65.6 thousand entries to the park, which accounts for nearly a half of the total number of entries in the given month.

The analysis of the number of entries to the park in the consecutive days of the period in question shows that the increased popularity of the specific month goes together with a greater variation in the number of daily entries (figure 2). Months with the highest footfall have the widest distribution of data, and for those with the lowest – the distribution is more focused. An exception is April, which belongs to the low season, but due to the sequence of days free from work, on 30 April a dynamic increase in the tourist traffic was recorded. In the period under analysis, most tourists entered the park on the following days: 18 July (14 722), 1 May (13 148), 2 May (13 092), 14 August (12 241), 13 August (11 221), 15 August (10 496) and 15 Jun (10 082).

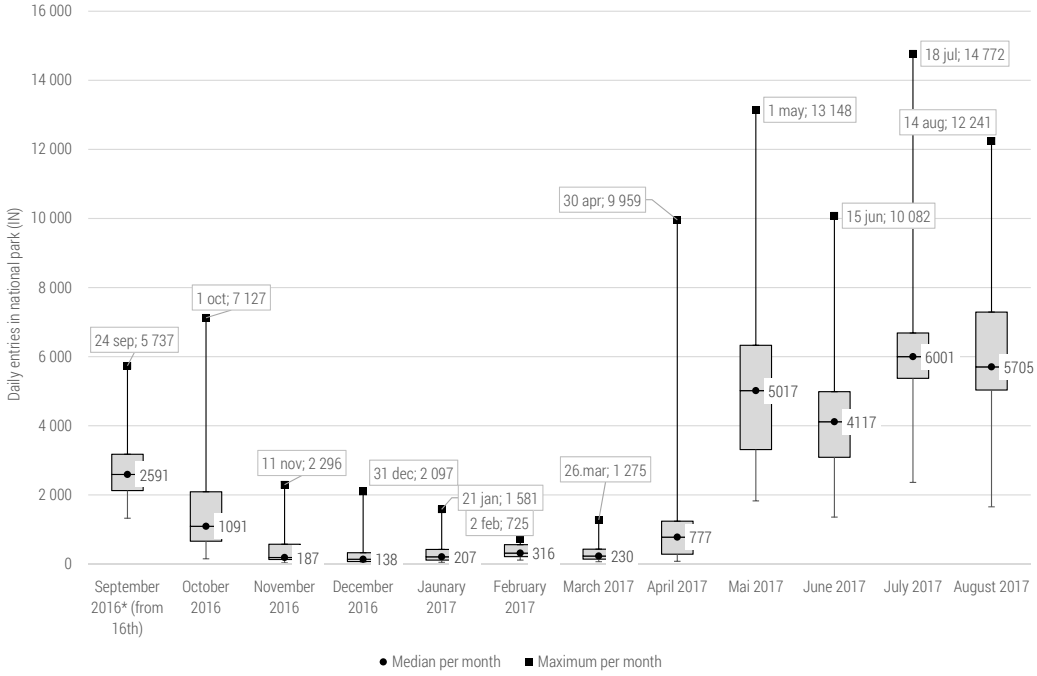

Figure 2. Daily tourist entries (IN) to the Stołowe Mountains National Park (from 16th September 2016 to 31th August 2017)

Source: author's own work.

Spatial concentration of the tourist traffic was related to the main attractions, because approximately half of the tourists trails the routes in Szczeliniec Wielki and Błędne Skały. In the summer months the rate is as high as 2/3 of tourists (June 2017 – 67%, August 2017 – 65%, July 2017 – 58%), whereas outside the tourist season the percentage drops to 1/3 of the value (January 2017 – 28%, February 2017 – 37%, December 2016 – 40%). Such differences be caused by official closing of the tourist trails in Szczeliniec Wielki and Błędne Skały and the fact that the entries to the park are also generated by the local community inhabiting the towns near the park. This factor is not driven by seasons.

The count of entries (IN) allows to indicate the attractions visited most frequently, which undoubtedly include: Szczeliniec Wielki (269 958) and Błędne Skały (237 411). However, as shown in Tab. 2 the greatest number of entries (IN) was recorded on the route to Szczeliniec Wielki from the side of Karłów (365 627). The remaining areas are less popular, as evidenced by the following data (IN): Narożnik (18 194), Radkowskie Skały (14 917), Karol's Fort (8 061) and Białe Skały (4 047). The number of entries (IN) compared

for particular sensors allows to determine the popularity of certain areas of the park. The most popular regions include the areas of: Szczeliniec area (422 273), Skalniak – Błędne Skały area (258 336), Skalne Grzyby area (27 464), Narożnik – Białe Skały area (23 549), Karola's Fort area (20 925) and Radkowskie Rocks area (14 917).

Location of the sensors, most of which were installed in the most popular areas of the national park, also allows to determine approximate tourist traffic loads for some sections of the routes. This may be presented for the network of tourist routes located in the area of Szczeliniec Wielki "rock-city" (table 2, figure 3) and Błędne Skały "rock-city" (table 3, figure 4).

Table 2. Tourist traffic loads (IN+OUT) for measuring points in the area of Szczeliniec Wielki "rock-city"

Measuring points	Number of entries (IN)	Number of exits (OUT)	Load (IN+OUT)
Szczeliniec Wielki – tourist route	269 958	21 571	291 529
Karłów	365 627	324 819	690 446
Parking area at the bottom of Szczeliniec	34 638	17 880	52 518
Parking area near Pośna Waterfalls – green route	15 648	12 686	28 334
Parking area near Pośna Waterfalls – blue route	4 470	5 858	10 328
Radków Baza – yellow route	1 168	1 261	3 229

Source: author's own work.

In the period under analysis, the greatest number of passings (IN+OUT) was recorded at the measuring point in Karłów (690 446), which accounts both for entries to and exits from Szczeliniec Wielki. This is the most popular place in the park for tourists. From there, most tourists go to the fork of the routes between Szczeliniec Mały and Szczeliniec Wielki. Then, most people continue the route to Szczeliniec Wielki, but some go down north to the parking area at the foot of Szczeliniec. This is, at the same time, an alternative way for the blue tourist route running via the western foot of Szczeliniec Mały. The fork mentioned above is also reached by tourists from the parking area at the foot of Szczeliniec, Pasterka and Radków. As a result, the final section of the approach to the mountain shelter "Pod Szczelińcem" has the heaviest tourist traffic load in the whole park. On mesa of Szczeliniec Wielki, a tourist route is running from the mountain shelter, and 76% of the tourists who reached the shelter decided go that route. From that group, 93% of persons decided to go down to Karłów – according to the principles of tourist traffic specified at the mesa – whereas 7% returned to the shelter taking the same way, which is contrary to the park's regulations.

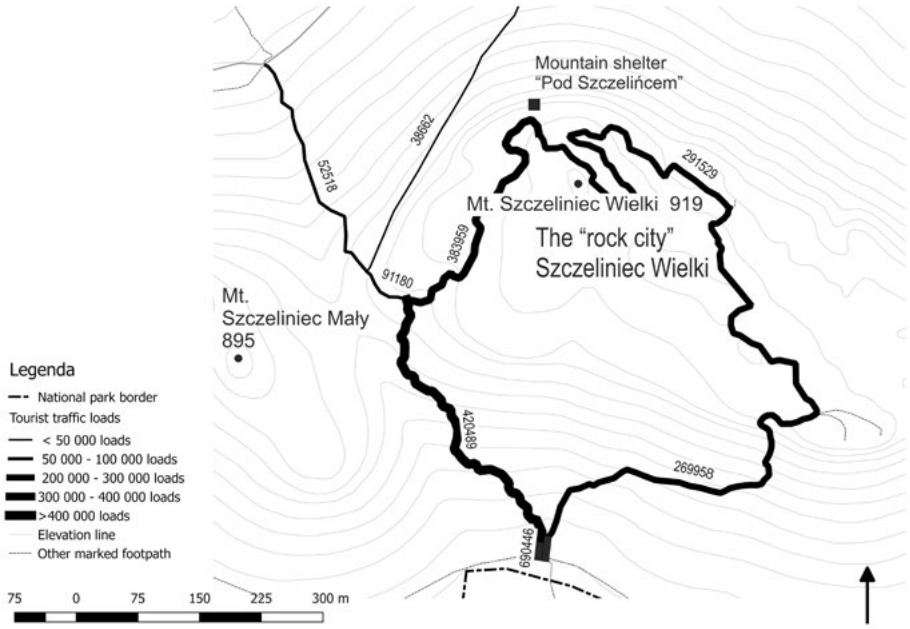

Figure 3. Tourist traffic loads (IN+OUT) for specific sections of the routes in the area of Szczeliniec Wielki "rock-city"

Source: author's own work.

In the trail network in the area of Błędne Skały, the most heavily loaded section is the one between the upper parking area and the entrance to the tourist route, and then the tourist route itself in Błędne Skały (340 851 passes IN+OUT). From that group, 70% of tourist decided enter to trail on Błędne Skały "rock city". The access traffic for that place has an uneven distribution. Approximately half of tourists drive to the upper car park and return from there. Other tourists go on foot. Most of them get there from the lower parking area, "YMCA", and from the side of Bukowina Kłodzka. A secondary access is the climb route from the north, from Ostra Góra, and from the side of Skalniak, although in this case these are only estimates, because there is no such sensor in that place. After leaving the tourist route in Błędne Skały, tourists can choose between two return routes: one along the state border and the other running around the rock labyrinth from the south. As a result, the return traffic is distributed between both return routes (table 3, figure 4).

Table 3. Tourist traffic loads (IN+OUT) for measuring points in the area of Błędne Skały "rock-city"

Measuring points	Number of entries (IN)	Number of exits (OUT)	Load (IN+OUT)
Błędne Skały – tourist route	237 411	8 616	246 027
Błędne Skały – return route	84 591	3 552	88 143
"YMCA" parking area	25 894	21 990	47 884
Błędne Skały – green route	18 849	11 043	29 892
Ostra Góra	8 569	7 545	16 114
Jakubowice	3 482	3 017	6 499
Zielona Droga – state border	1 963	1 777	3 740

Source: author's own work.

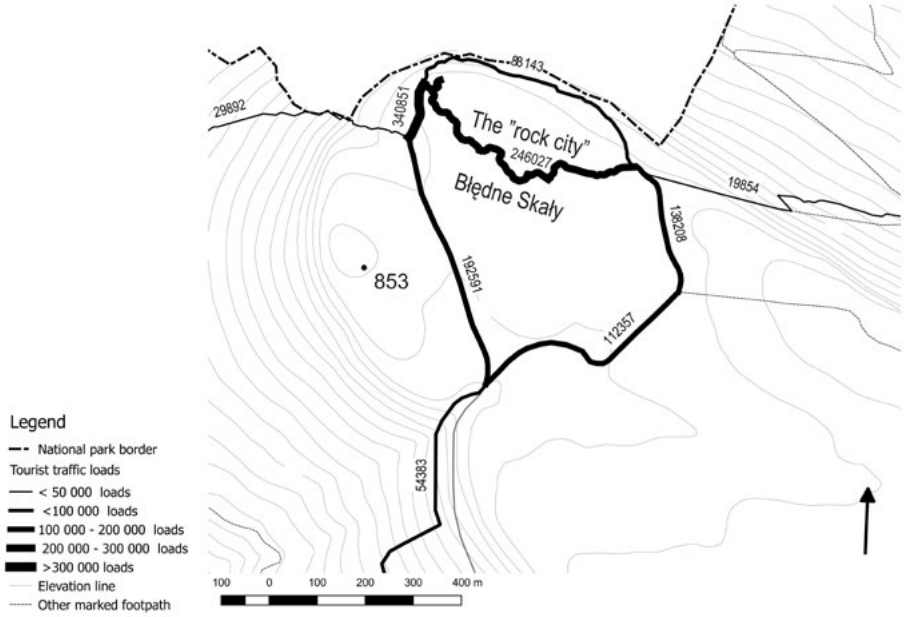

Figure 4. Tourist traffic loads (IN+OUT) for specific sections of the routes in the area of Błędne Skały "rock-city"

Source: author's own work.

Conclusions

The Monitoring System of tourist traffic (MSTT) which serves to gather data regarding the number of passings allows to developing a detailed and comprehensive description of the tourist traffic in the Stołowe Mountains National Park, both in terms of quantity and space. This is an extremely important tool in the current functioning of the park and tourist traffic management, and it is compatible with the idea of sustainable tourism defined in World Conference of Sustainable Tourism (Charter..., 1995).

The monitoring data allows determining tourist footfall in selected locations in the park, directions where the tourists go and loads on route sections. Footfall, if determined, allows to indicate a high and low tourist season, an exact number of visitors to the most popular attractions and regions of the park, and to specify the tourist traffic loads in those locations. The most important findings include the following:

- an estimated number of tourists entering the Stołowe Mountains National Park within twelve months (from 16th September 2016 until 31th August 2017), which is as many as 858 346 entries, and this allows to verify the current data obtained solely on the basis of the tickets sold for the tourist routes to Szczeliniec Wielki and Błędne Skały "rock-cites",
- determination of the share in the amount of entries to the park for two most popular months (July and August, per approximately 190 thousand), which is as much as 40% of the counted entries; May is third in the row, and this is the month when visitors come mainly in groups as part of tourism organised by schools,
- indication of the occurring phenomenon which involves a dynamic increase in the tourist traffic in the periods of consecutive days free from work, in particular during the so-called long weekend in June and the period of Christmas and New Year,
- indication of two most popular attractions of the park – Szczeliniec Wielki and Błędne Skały – generating half of the tourist traffic, and in the summer months it reaches as much as 2/3 of the total tourist traffic,
- indication of the routes which are most loaded with the tourist traffic (by comparing entries – IN and exits – OUT), which includes the climb route from Karłów to the mountain shelter "Pod Szczelińcem" and the section from the upper parking area near Błędne Skały to the entrance on the tourist route, and also tourist routes in Szczeliniec and Błędne Skały.

Quantitative data from infrared traffic counters may be useful in many works and studies. After determining the indicators of volume and throughput, it is possible to see the periods when those indicators are exceeded, because the phenomenon of mass tourism increases, as also observed by the

park's staff. That fact may cause many threats to the natural environment and for that reason it is very important to provide diagnosis for this state of the matters. Currently, the working values of the tourist volumes and throughput for the most popular sections of routes are being determined, which will be verified further against opinions of the national park staff, ticket sellers and tourists themselves. As a result, the method for determining the tourist throughput and volume will be developed, taking into account the opinions of all the stakeholders. That fact may provide the basis for the discussion on the ways to re-organise the tourist traffic management in specific hours on the tourist routes in Szczeliniec Wielki and Błędne Skały "rock-cites". The cause is a relation to excessive numbers of entries and decreased satisfaction drawn from experiencing nature among tourists. In addition, taking into consideration the social participation in generating tourist traffic, the plans are to provide, on an ongoing basis, current information about the entries on the tourist routes on Szczeliniec Wielki and Błędne Skały "rock-cites", so that tourists themselves can decide whether to go on the route at a specific time.

The data collected in the following months will allow to creating a model of forecasting the size and variability of tourist traffic. In addition, by aggregating the acquired results with the data characteristic for other phenomena, we could answer the question which factors drive the size and variability of tourist traffic. An example may be meteorological data, the aggregation of which will allow determining the degree of interrelation between the tourist traffic and the current weather. Further works envisage also relocating some of the infrared traffic counters to other sections of the routes, in order to examine more thoroughly the tourist traffic loads in those areas. In addition, further plans include investigating a phenomenon of illegal dispersion of tourists outside the routes, by relocating the devices to paths and ways not made available for tourism.

Acknowledgements

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Dariusz ANDRAKA • Joanna TOMASZEWSKA

APPLICATION AND DIGITAL IMPLEMENTATION GIS DATA TO COMPUTER MODELING OF THE SANITARY SEWAGE NETWORK IN PODLASKIE VOIVODSHIP

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ABSTRCT: The paper presents the results of computer modelling of sanitary sewerage networks in selected towns of the Podlasie Voivodship.The calculation process of the design and operation of the sewerage network is labor-intensive and time-consuming, and it becomes necessary to use information technologies in the design process. Computer-aided design streamlines the entire process and enables a more accurate analysis of the work of the designed system. Nowadays, there is a growing interest in computer modelling. The concept of computer modelling is the construction and study of models that map reality or only a fragment of it. In practice, this is the main procedure used for research seeking to determine the behaviour of operational reality in given conditions. Computer models give the possibility to verify design assumptions and network operating conditions. Thanks to them, there is an opportunity to control real flows during operation.

KEY WORDS: computer modelling of sewage networks

JEL: C63, C88

Introduction

The paper presents the results of computer modelling of sanitary sewerage network in Łapy. It is a fragment of research carried out in sewerage networks in selected towns of the Podlasie Voivodeship (Łapy, Sokółka, Michałowo, Supraśl, Czarna Białostocka). The sewer networks selected for research are represented by characteristic systems built in the communes of north-eastern Poland.

The calculation process of the sewerage network design is labor-intensive and time-consuming, especially for large sewer systems. Therefore, it becomes necessary to use information technologies in the design process. Computer-aided design streamlines the entire process and enables a more accurate analysis of the work of the designed system. Nowadays, there is a growing interest in the use of computer modelling in municipal enterprises. The concept of computer modelling includes building and researching models that mimic the actual work of the network or just a fragment of it. Computer models give the opportunity to verify project assumptions and simulate network operating conditions. Thanks to the appropriate amount and quality of the output data, computational methods are real and real (Dziedziela, 2010; Dziobak, Mrowiec, 1999; Sołtys, Stec, 2014).

The Geographic Information System (GIS) is the basic tool for collecting and processing spatial information. GIS improves the management of large amounts of data related to computer models. Thanks to this technology, it is possible to combine databases with visualization and spatial analysis (Nowatorska, 2009). At work, QGIS was used to process digital spatial data. It is a popular and fully functional platform type GIS, which also gives the possibility of combining processed data with software, e.g. for modelling sewer networks (Kędzia, Ociepa, 2015).

Storm Water Management Model (SWMM) was used for the modelling process of the tested sewer networks. SWMM was developed by the US Environmental Protection Agency (US EPA). The program is made available under an open source license. It is a fully functional tool for making computer models of sewage networks (Nowakowska, Kotowski, 2017).

Research object

Sewage system in Łapy – Population 16000 (http://www.lapy.pl). In the city and commune of Łapy, the sewerage network has 10 villages (out of 24 in the commune) and the whole city of Łapy. The commune is canalized in 87% in relation to the number of households. In the municipality of Łapy, the

length of the sanitary sewage system is 83.2 km, draining sewage from the village of Łapy and the villages of Łapy Szołajdy, Łapy Dębowina, Gąsówka Osse, Uhowo, Łapy Pluśniaki, Łapy Korczaki, Łapy Łynki, Gąsówka Oleksin, Gąsówka Stara and Łapy Kołpaki. Wastewater is directed to a sewage treatment plant with a design capacity of Qdśr=10000 m^3/d located in the village of Łapy. The treatment plant applies mechanical and biological treatment with two-stage biological treatment based on the activated sludge method and final or simultaneous phosphorus precipitation using a PDC coagulant. Sludge treatment and its final disposal is carried out through the use of compaction, fermentation, mechanical dewatering and hygienization processes using lime. The Receiver of treated wastewater is the Awissa River (Brzosko, Danowski, 2010; http://www.lapy.pl).

Results of the research

The preparation of the model began with the implementation of a situation and altitude plan in the QGIS program. The map was made on the basis of the cadastral information of the Białystok poviat located on the website http://bialystok.geoportal2.pl and digital foundations obtained for scientific purposes from the Poviat Office for Geodesy and Cartography in Bialystok.

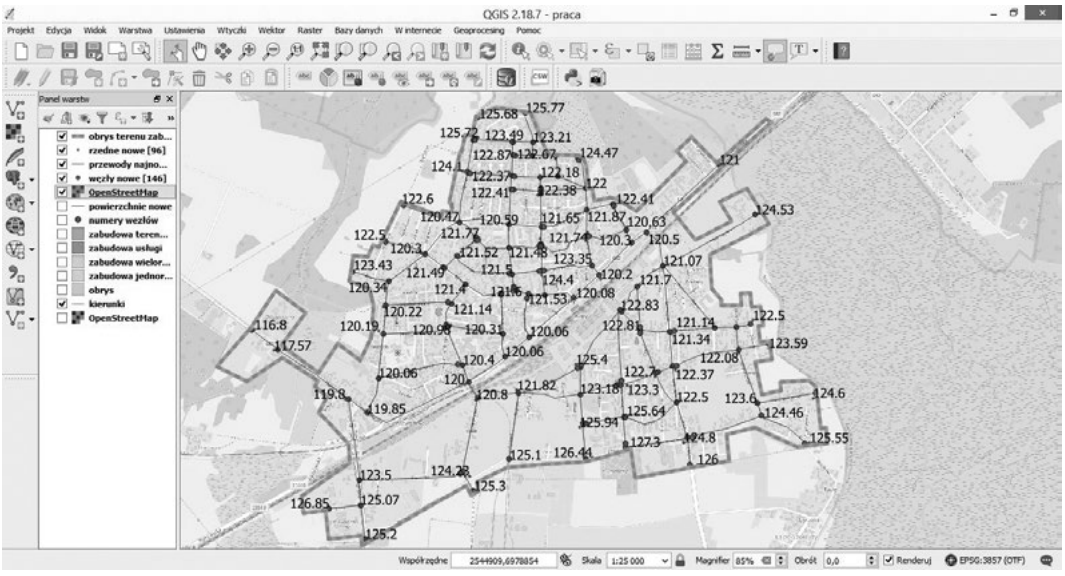

Figure 1. Sewage network of the city of Łapy with elevated land elevations in the QGIS program

Source: (Tomaszewska, 2017, p. 50; Nowotarska, 2009).

In the work, three variants of computer simulations of the tested sewage network were made. The first variant presents the existing state of the sewerage network in Łapy, based on data and completed with calculations. In the next variant, the changes of selected wire diameters and the effect of these changes on selected network parameters were simulated. In the third variant, changes were made to the depressions of selected sewage wells.

Variant 1

After simulation of a computer sewage system in the SWMM program, longitudinal profiles were generated and it was found that there are places in the tested network in which overfilling of manholes may occur.

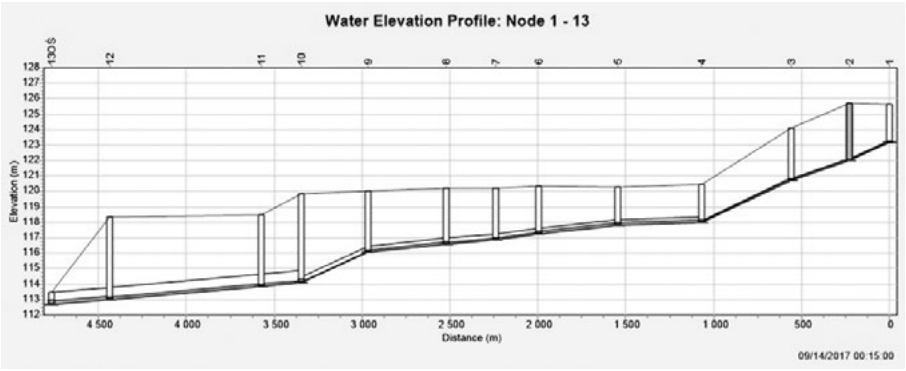

Figure 2. Longitudinal profile of a part of a sewage system in Łapy, showing the location of a full sewage weell, made in the SWMM program

Source: author's own work.

In the modeled variant 1, the simulation of wastewater flow velocity on its individual sections was started. It was found that the tested models of the wastewater velocity rates range from 0.01 m/s to 0.13 m/s.

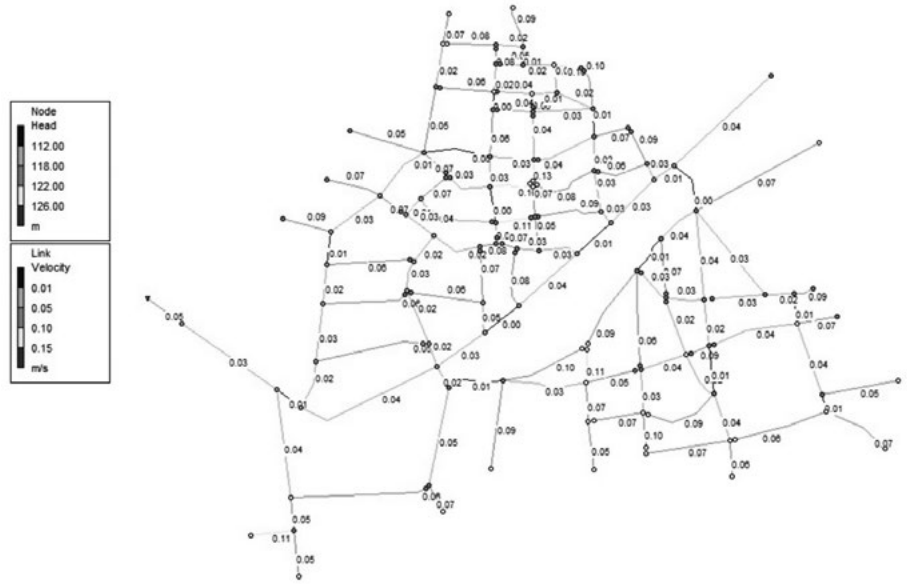

Figure 3. Results of modeling the speed of sewage flow in the first variant

Source: (Tomaszewska, 2017, p. 84).

Variant 2 – A model with the simulation of diameters change

In order to eliminate the overflow of sewage well, simulations were made to increase the diameters in selected sections of the analyzed networks.

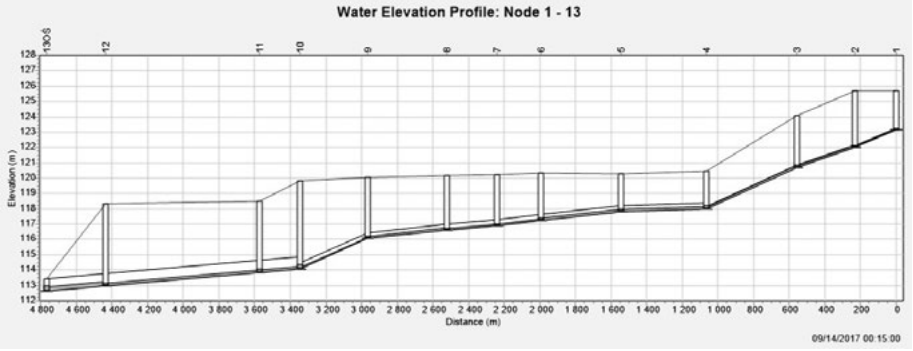

Figure 4. Longitudinal profile of a part of a sewage network in Łapy after increasing the diameters of selected sections of the network, made in the SWMM program

Source: author's own work.

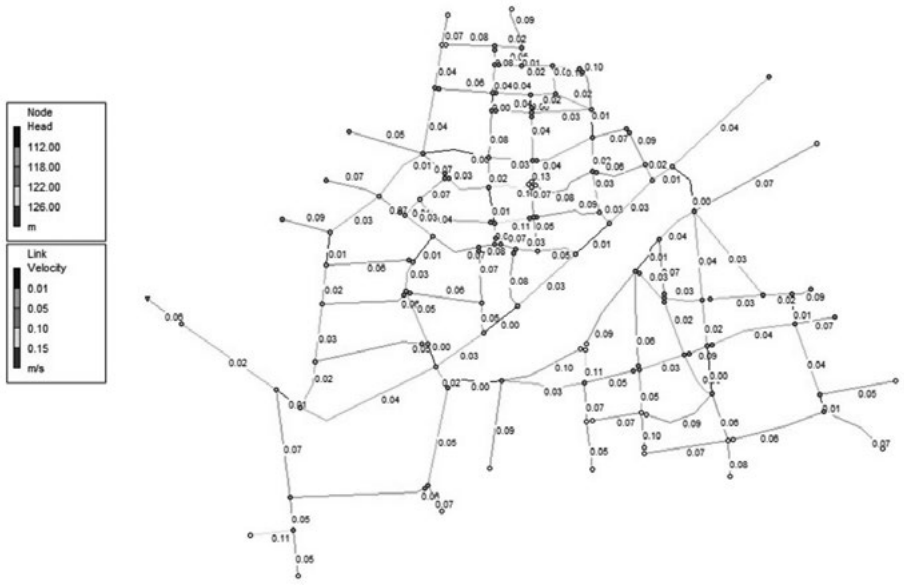

Figure 5. Results of modeling the speed of sewage flow in the second variant after changing the diameters of selected conduits

Source: (Tomaszewska, 2017, p. 85).

Variant 3 – A model with the simulation of changes in the hollows of selected sewer manholes

In the next simulation, in order to eliminate overflows of sewer manholes, the channel cavities were changed. As a result of such activities, the overcrowding has been liquidated.

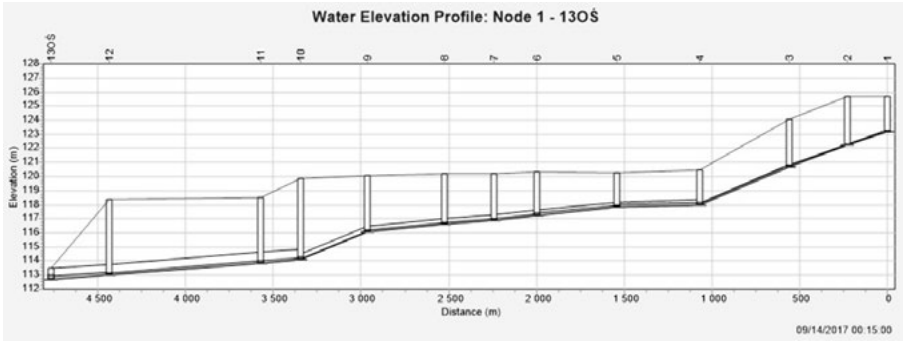

Figure 6. Longitudinal profile of a fragment of the sewage system in Łapy after changing the hollows of selected sewage wells, made in the SWMM program

Source: author's own work.

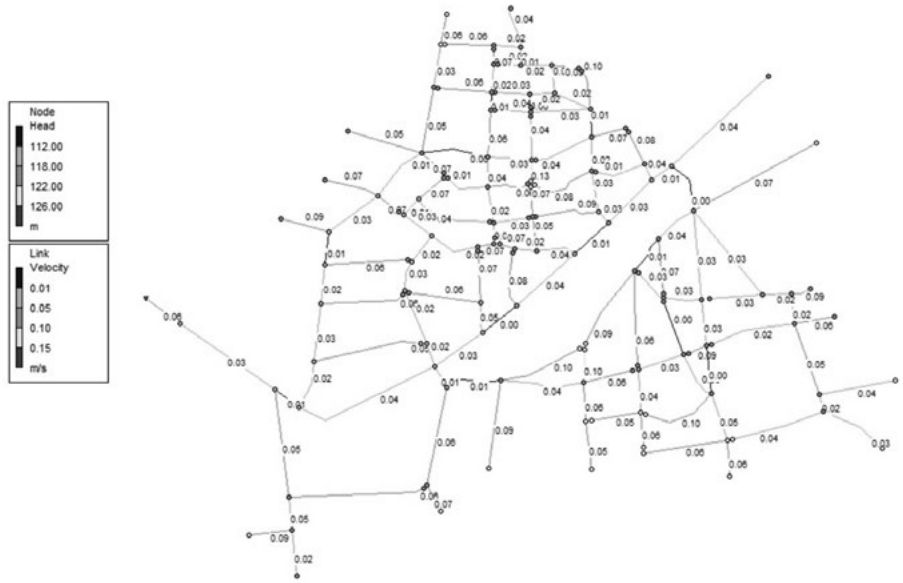

Figure 7. The results of modeling the speed of sewage flow in the third variant after the hollows of selected sewage wells

Source: (Tomaszewska, 2017, p. 86).

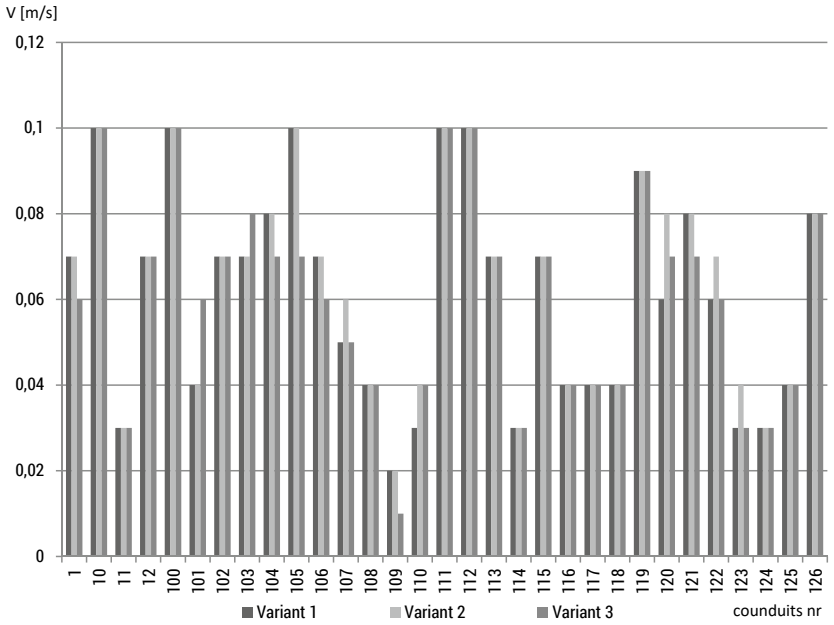

Figure 8. Part of the modeling of flow velocity in selected pipes of the modeled sewage network of the city of Łapy

Source: author's own work.

As a result of the simulation, the SWMM program found a solution to the problem of the possibility of sewage wells overflow in the sewer networks under investigation. When comparing the simulation results, it was found to what extent the change in pipe diameters or pit wells influences the flow velocity of the sewage in the lines of the tested networks.

Conclusions

Computer modelling of sewage networks is becoming more and more common, which results from the continuous development of technology in environmental engineering in recent years. Computer simulations give the possibility of mapping detailed conditions prevailing in the analyzed network. Under real conditions, obtaining such data is complicated and time-consuming. Simulations allow the selection of the most favorable variant of the designed sewerage network.

In order to carry out the simulation, techniques for processing digital geodetic data in the QGIS program were combined with computer modelling of selected parameters of sewage networks in the SWMM program.

The use of computer models in the design stage gives the opportunity to verify the design assumptions. It allows to check whether the designed network is able to drain the assumed amount of sewage and what the actual flows in the channels look like (Sołtys, Stec, 2014). Because of the computer models of sewer networks, you can: check the parameters of the network, plan changes in the network, assess the efficiency of operation, detect errors in the network and analyze the current work of the network.

The analyzed sewage network was checked for correctness of the pipe diameters and the sewage flow rate in the sewers. In places where the diameters have been chosen incorrectly, the sewer manholes were overfilled and the stretched sectional flow depended in a time unit. After the detection and elimination of errors, the simulation ran smoothly.

Because of the simulations and the results generated, the following conclusions can be made:

- computer modelling is a highly effective way to simulate the operation of the sewerage network,
- when designing a sewerage network, special attention should be paid to the selection of diameters, because too small diameters of pipes cause the creation of transfers in sewer wells and slow down the flow without causing significant changes on further sections of the network,
- carried out simulations allow to state that in the analyzed gravitational sewage system, the diameters used cause too low rates of sewage flow.

Acknowledgements

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The contribution of the authors

Wojciech Kruszyński – conception, literature review, acquisition of data, analysis and interpretation of data – 30%
Jacek Dawidowicz – acquisition of data, analysis and interpretation of data – 25%
Darisz Andraka – acquisition of data, analysis and interpretation of data – 25%
Joanna Tomaszewska – literature review, acquisition of data, analysis of data – 20%

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STUDIES AND MATERIALS

STUDIA I MATERIAŁY

Anna KRZYSZTOFEK

ENVIRONMENTAL RESPONSIBILITY OF RESPECT INDEX COMPANIES

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ABSTRCT: The aim of the article is to explain one of the three areas of CSR environmental responsibility. The CSR initiatives aimed at the environment, which are implemented by selected Respect Index companies, will be presented, 5 companies with a similar profile of activity in the industrial sector were selected for the survey. The subject of the study was the analysis of reports, briefs prepared by companies and information from websites. The subject of the study are selected listed companies, which were included in the 10th edition of the Respect Index. Adequate research methods were necessary to achieve the objective of this article. The methods of analysis of literature, analysis of reports, briefs, the comparison method and the observation method were applied.

Companies perceive the problems of the natural environment and that care for its condition is a priority for them. The main objective of the activities carried out by the companies in the field of environmental protection is the implementation of business strategies, promotion of an appropriate image, as well as promotion of ecology and effective waste management. The analysis of environmental practices shows that environmental education is one of the most popular measures taken. Not only children, but also consumers, customers, residents of large cities, and representatives of specific industries are the targets of the activities.

KEY WORDS: Environmental Corporate Social Responsibility, corporate social responsibility, Respect Index, enterprise

Introduction

For more than a decade, more specifically since 2009, when the Respect Index was established, enterprises in Poland began to pay attention to conducting their business in a responsible manner. Since then, there has been a growing interest in the concept of business management, based on conscious action oriented not only towards financial profit, but also on the broadly understood social and environmental interests. There is a growing trend in the field of companies implementing the *Corporate Social Responsibility* (Krzysztofek, 2012, p. 109-119) (CSR) concept.

According to the definition of CSR commonly used in Europe, CSR is *"a concept by which enterprises, at the stage of strategy development, take into account social, ethical, environmental interests and relations with the entities functioning in their environment"* (Adamczyk, 2009, p. 9). The basic premise of this theory is to base the company's success on its long-term, sustainable development resulting from taking into account three dimensions: the economic, the ecological and the social dimension. None of them should be overlooked, as only their harmonious combination gives the desired effect, i.e. keeping themselves on the market (Rok, 2001, p. 262-263).

Social responsibility is inseparably associated with the concept of environmental responsibility. In this area of responsibility, there are different manners, methods and tools to reduce the environmental impact of an organization. These also include innovations that allow the use of alternative and environmentally friendly solutions (http://odpowiedzialnybiznes.pl). It is therefore more and more often said that companies should be involved not only in providing quality products and services and guaranteeing a profit to stakeholders, but also in environmental activities (Kryk, 2003, p. 264-266).

The aim of the article is to explain one of the three areas of CSR environmental responsibility. The CSR initiatives aimed at the environment, which are implemented by selected Respect Index companies, will be presented. The subject of the study was the analysis of reports, briefs prepared by companies and information from websites. The subject of the study are selected listed companies, which were included in the 10th edition of the Respect Index. Adequate research methods were necessary to achieve the objective of this article. The methods of analysis of literature, analysis of reports, briefs, the comparison method and the observation method were applied.

The area of ecological responsibility of enterprises

Enterprises operating on the market should observe the principles of social responsibility and create a business based on the 3xE system, i.e. Ethics, Economics and Ecology. Here we are dealing with the concept of *Environmental Corporate Social Responsibility* – ECSR, also known as *Environmental Corporate Responsibility* – ECR. It can be considered from two points of view (Jabłoński, 2013, p. 141):

- as a result of the development of the concept of social responsibility, then introduction of pro-ecological assumptions into this concept,
- the implementation of the idea of sustainable development at the level of the economic ecosystem and at the level of the enterprise itself is conducive to the development of the ECSR concept.

The ecological area of social responsibility results from the fact that management of modern enterprise must take into account environmental protection – very important from the social point of view (Koneczna, Henclik, 2010, p. 485-492). Environmental responsibility manifested through preventing the pollution of water, soil and air. This includes segregation and recycling, the use of appropriate materials and substances, as well as the installation of filters and treatment plants.

Environmental responsibility requires compliance with a number of principles and standards. This concerns in particular the observance of environmental protection regulations and the implementation of measures in the area of ecology (Jabłoński, Jabłoński, Primus, Spytkowska, 2010, p. 7; Łuczka-Bakuła, 2010, p. 293-306).

The assumptions of the ECSR concept are as follows (Jabłoński, Jabłoński, Primus, Spytkowska, 2010, p. 9; Łuczka-Bakuła, 2010, p. 425-434):

- it allows for increasing the company's value through the use of ecological criteria to meet the needs of the stakeholders,
- it is a platform for building an effective business model aimed at environmental needs,
- it triggers eco-innovations that stimulate the long-term growth of the company,
- it ensures a balance of business needs between shareholders and other environmental stakeholders,
- it makes it possible for the company to use resources efficiently in the context of the environmental criteria adopted,
- it is the interface between the internal and external environment of the entity,
- it is a guarantee of effective reporting of compliance with standards of conduct to stakeholders (e.g. in the context of environmental protection),

- it is a platform for effective use of the company's intellectual capital in terms of increasing social capital among various stakeholder groups,
- it allows for reduction of the business risk of the company.

Factors that lead to greater concern for the environment are as follows (Kaczmarek, 2011, p. 507):

- the emergence of environmental standards and regulations,
- the increase in consumer sensitivity to environmental issues and the resulting bottom-up pressure on businesses to take care of the environment,
- technological progress contributing to the development of environmentally friendly technologies.

The implementation of environmental responsibility is based on the following assumptions:

- building a sustainable business model as a platform for dialog between stakeholders (Jabłoński , 2008, p. 19),
- a redefinition of business value to include an analysis of the needs of stakeholders in the direction of building a sustainable value for an environmentally responsible organization (Laszlo, 2008, p. 159-205),
- setting sustainable value objectives based on *Sustainability Business* principles (Burchell, 2008, p. 111-118),
- redefinition of the role of stakeholders and their relations with business by determining the impact of the company's activities on the value for stakeholders and determining the influence of stakeholders on the value for shareholders (Adamczyk, 2011, p. 89-96).

Respect Index

The Respect Index is the first index of responsible companies in Central and Eastern Europe. The name Respect Index is an acronym for words that indicate the nature of the index, namely: Responsibility, Ecology, Sustainability, Participation, Environment, Community, Transparency.

The Respect Index now has 10 editions – so far, 41 different companies have participated in it, each with a high level of social responsibility each year. The main criteria used in the evaluation process are the following categories (ESG) (http://www.odpowiedzialni.gpw.pl):

1. Environmental:

- environment management,
- reduction of environmental impact,
- biodiversity,
- environmental aspects of products/services.

2. Social:
- OHS,
- human resources management,
- relations with suppliers,
- dialog with stakeholders,
- social reporting.

3. Governance:
- strategic management,
- code of conduct,
- risk management,
- fraud risk management,
- internal audit and control system,
- customer relations.

More and more companies from the Respect Index report non-financial data, but still not all entities do so. As of 1 January 2017, all listed companies that employ more than 500 people and have a balance sheet total of more than EUR 20 million or a net turnover of more than EUR 40 million are obliged to report non-financial data in connection with the entry into force of the EU Directive 2014/95/EU on the disclosure of non-financial data (Krzysztofek, 2016, p. 336-337).

Methodology – selection of companies to be examined

The following criteria were applied in the process of selecting companies for the case study:

1. The company is included in the Respect Index.
2. Companies that appear in each edition of the Respect Index up to the 10th edition.
3. Preparation of reports (integrated annual report, corporate social responsibility report, environmental report) based on the guidelines of the *Global Reporting Initiative*.
4. The industrial sector.

The individual elements of the study considered in the study proceedings are presented in figure 1.

The funnel method was used to select companies. Selection of the sample was deliberate.

Due to limited access to companies and their employees and managers, it was assumed that the basic research method would be the analysis of the content of company documents. The analysis will be carried out using secondary sources of information concerning the analyzed companies: inte-

grated annual, social and environmental reports, codes of ethics, as well as regulations, strategies and their own websites, where they publish information about the company: establishment history, mission, scope of activity, etc.

	Criterion	Number of companies
Level 1	The company is included in the Respect Index.	10th edition 41 companies
Level 2	Companies that appear in each edition of the Respect Index up to the 10th edition.	9 companies
Level 3	Preparation of reports based on the guidelines of the *Global Reporting Initiative*.	7 companies
Level 4	The industrial sector.	5 companies

Figure 1. Case selection procedure

Source: author's own work.

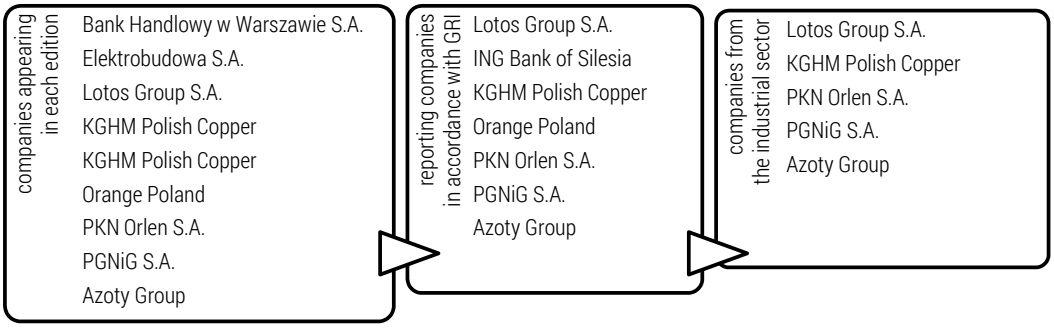

Figure 2. Selection of companies for the study

Source: author's own work.

Table 1. Reports prepared by industrial sector companies

	Companies	Type of report for 2015
1.	Lotos Group S.A.	Integrated Annual Report 2015
2.	KGHM Polish Copper	Integrated Report 2015
3.	PKN ORLEN S.A.	Integrated Report Grupy ORLEN 2015
4.	PGNiG S.A.	Annual Report 2015
5.	Azoty Group	Integrated Report Grupy Azoty za rok 2015

Source: author's own work based on data from the Respect Index companies and reports.

Five companies with a similar profile of activity in the industrial sector were selected for the survey: Lotos Group S.A. (Grupa Lotos S.A.), KGHM Polish Copper (KGHM Polska Miedź S.A.), PKN Orlen S.A., PGNiG S.A. and Azoty Group (Grupa Azoty S.A.) The telecommunications company Orange Poland (Orange Polska S.A.) and ING Bank of Silesia (ING Bank Śląski S.A.) were excluded from the survey. The integrated reports of these entities for the years 2010-2016 were analyzed.

Environmental responsibility – case study

The next chapter is devoted to environmental initiatives taken by the companies. Examples of ongoing projects and programmes undertaken by companies in the context of the implementation of the ECSR concept will be discussed. Table 2 below presents the practices related to the environmental activities of the five companies implemented in 2010-2016.

In accordance with the declaration contained in the mission statement of the company, Lotos Group (Grupa Lotos S.A.) strives to conduct and develop its activity in all areas in a sustainable manner, respecting the environmental conditions specified by the law and observing the principles of corporate social responsibility. The Company takes into account the impact on the neighborhood-both the environment and people living in the vicinity of the plant (http://odpowiedzialny.lotos.pl). In recent years, it has implemented a number of ecology-related programmes (Zintegrowany Raport Roczny, 2015; Grupa Kapitałowa LOTOS, p. 13-60; Zintegrowany Raport Roczny, 2014; Grupa Kapitałowa LOTOS, p. 22-249):

1) Maritime Education Programme – education of young people from Gdańsk on the maritime history of the city, ecology and protection of the Baltic Sea and acquainting them with sailing.
2) Protecting the biodiversity of the Baltic Sea – activities aimed at helping to halt the process of extinction of the most endangered species of the Baltic Sea.
3) The use of natural gas for heating and technological purposes in Lotos Group – the refinery's process furnaces were partially fueled with medium pressure natural gas.
4) The inventory of natural resources in the area of the refinery of Lotos Group and its surroundings – it covered the areas of the gminas of Gdańsk and Pruszcz Gdański and made it possible to identify the most valuable and the most sensitive components of nature in the vicinity of the refinery.
5) Destination Baltic Sea – the project combines two Lotos programmes to help Baltic nature and to protect the Sobieszewsko Island.

Table 2. Company practices implemented in the years 2010-2016

Lotos Group S.A.	KGHM Polish Co	PKN ORLEN S.A.	PGNiG S.A.	Azoty Group
1. Maritime Education Programme 2. Protecting the biodiversity of the Baltic Sea 3. The use of natural gas for heating and technological purposes in Grupa Lotos S. A. 4. The inventory of natural resources in the area of the refinery of Grupa Lotos and its surroundings 5. Destination Baltic Sea 6. Eco Academy 7. Industrial water purification in Lotos Group using an innovative straw installation	1. Health Promotion and Prevention of Environmental Risks Programme 2. Efficiency Programme 3. Soil liming 4. Development of the Obora sand plant 5. 20 consultation sessions with local communities 6. EKO-Zdrowie Programme	1. Reconstruction of the peregrine falcon population 2. Compensatory planting of trees and shrubs 3. ORLEN for Eagles 4. Ecological education 5. Cleaning the Wodąca Valley 6. Ecological education and information in the field of local community environmental protection 7. Eco Volunteering	1. Heat by nature 2. Pro-ecological office solutions 3. The promotional campaign Natural Gas from PGNiG is money for you 2013 4. Ecological education and promotion of activities in the field of environmental protection 5. Pro-ecological projects in Primary Schools in the Podkarpackie Voivodeship	1. A Tree for a Bottle 2. Ecological Academy of Skills 3. Catch the Hare 4. Together we take care of safety 5. Dialog Forum with the local community 6. Employee Volunteering Competition

Source: author's own work based on Integrated Company Reports.

6) Eco Academy – checking the knowledge of compliance with regulations and practical solutions concerning environmental protection at 28 petrol stations operated in a franchise model.
7) Industrial water purification in Lotos Group using an innovative straw installation – purified water on the Motława River.

KGHM Polish Copper (KGHM Polska Miedź S.A.), as one of the largest enterprises in Lower Silesia, does not want to and cannot evade responsibility for the state of the natural environment. Activities implemented by the company related to ecology include (Raport Zintegrowany za rok 2015, KGHM Polska Miedź, p. 41-130; Raport zintegrowany KGHM Polska Miedź S.A. za rok 2014, p. 51-107; http://kghm.com):

1) Health Promotion and Prevention of Environmental Risks Programme – addressed to children aged from 1 to 16 who live in the vicinity of the smelters owned by the Company.
2) Efficiency Programme – minimizing the company's environmental impact.
3) Soil liming – soil research in the Jerzmanowa Gmina and the rural Głogów Gmina.
4) Development of the Obora sand plant – revitalization of the mining area for recreational and treatment purposes with the use of renewable energy and the brine from the mines.
5) Establishment of the Polska Miedź Foundation in 2003 – donations i.e. for health protection and promotion, education, culture, dissemination of physical culture and sport, ecology, protection of natural heritage, public safety, etc.
6) 20 consultation sessions with local communities – an agreement was signed allowing the company to expand the Żelazny Most Mining Waste Management Facility.
7) EKO-Zdrowie Programme – encouraging residents to take part in free sports activities and medical examinations.

Polish Oil Company Orlen (Polski Koncern Naftowy Orlen S.A.), operates in accordance with the principle of sustainable development, with due respect for environmental conditions specified by the law and in accordance with the principles of corporate social responsibility, paying attention to present and future environmental impacts (http://www.orlen.pl). Implementation of business strategies with the highest environmental neutrality, promotion of the Orlen Group's green image, effective waste management and consolidation and reinforcement of competences in the area of environmental services. Since 2009, it has been implementing the Responsibility and Care Programme. Projects implemented by the company related to environmental protection include (http://raportzintegrowany2015.orlen.pl):

1) Reconstruction of the peregrine falcon population – installation of breeding shelters on two chimneys of the Production Plant in Płock, where chicks of endangered species are born.
2) Compensatory planting of trees and shrubs – the company's employees plant shrubs and trees in Płock.
3) ORLEN for Eagles – protection of Polish eagles, rare and extinct species.
4) Ecological education – collecting waste at places designated by city offices. Workers and their families participate in these activities.
5) Cleaning the Wodąca Valley – pro-environment activities of the employees of the station in the Małopolska region.
6) Ecological education and information in the field of local community environmental protection – promotion of knowledge on ecology, i.e. cooperation with universities, lectures at meetings of the City/Powiat Council, monitoring of the current state of the environment.
7) Eco Volunteering – employees participate in cyclical projects organized under the slogan "We have energy. We help".

Polish Oil and Gas Company (Polskie Górnictwo Naftowe i Gazownictwo S.A.) since 2007, it has been preparing comprehensive annual environmental reports, and since 2008, environmental issues have been included in PGNiG's social reports. The data contained in them are compiled into thematic groups related respectively to a specific type of environmental impact and to a specific element of the environment. In recent years, the company has implemented a number of environmental protection programmes (*Zrównoważony rozwój i odpowiedzialny biznes w PGNiG wrzesień 2014 r.*; *Raport Społeczny GK PGNiG 2014,* p. 34-40; http://www.pgnig.pl):

1) Heat by nature – Christmas tree collection. Trees processed into biomass are used in heat and power plants to produce heat and electricity.
2) Pro-ecological office solutions – 2 pro-ecological solutions were implemented: waste segregation and purchase of ecological office materials.
3) The promotional campaign Natural Gas from PGNiG is money for you 2013 – thanks to the campaign, nearly 1,350 customers were reached and over 600 residents were contacted directly. The participants received information materials on natural gas.
4) Ecological education and promotion of activities in the field of environmental protection:
   - inter-school Ekolandia competition – competition of 9 schools on environmental protection knowledge,
   - the "Pre-schoolers' Advice Regarding Waste" contest – an art competition for children aged 3-6,
   - rescue exercises on the premises of the Wierzbno Expedition Terminal,
   - training courses for managers on safety, HSE and auditing,

- Voivodeship Celebrations of the Environmental Protection Day,
- stopping the degradation of the Lake Czerniakowskie reservoir,
- participating in an action promoting a healthy lifestyle under the slogan: Green road to work.

5) Pro-ecological projects in Primary Schools in the Podkarpackie Voivodeship:
- ecological week "Getting intimate with nature",
- the ecological project entitled "Christmas Painted with Ecology".

Azoty Group (Grupa Azoty S.A.) in 2014, for the first time it published the Integrated Report, in which, in addition to the economic results for 2013, social and environmental initiatives were widely described. The report is one of the elements of CSR promotion activities (http://www.grupaazoty.com). The company implements environmental programs based on participation in the international programme of the chemical industry "Responsibility and Care". It voluntarily declares to gradually reduce the burden on the environment and improve the safety of employees through the implementation of the projects (Roczny raport na temat kwestii środowiskowych i społecznych za 2014 r. Grupa Azoty S.A.; Roczny raport na temat kwestii środowiskowych i społecznych za 2015 r. Grupa Azoty S.A.; Integrated Report of Grupa Azoty for the year 2015):

1) Co-organizer, partner of conferences related to environmental issues.
2) A Tree for a Bottle 2015 – a competition involving collecting as many empty PET bottles as possible that will be recycled. In return, the facilities receive tree and shrub cuttings and the winners receive prizes.
3) Ecological Academy of Skills – an action addressed to teachers of local schools, mainly with natural and chemical specialties.
4) Catch the Hare – a photo competition for employees of companies participating in the Responsibility and Care Programme, and for the last four years – their children as well.
5) Together we take care of safety – an educational campaign for children and youths from the Puławy Powiat.
6) Dialog Forum with the local community – a meeting attended by nearly 50 representatives of the educational community. They were introduced to "Social and sponsorship policy" and "Policy of cooperation with schools and universities for the development of intellectual capital" in the company.
7) Employee Volunteering Competition – gives employees a lot of freedom in choosing the goal of pro-social activities, and ten best projects are provided with financial support for up to 5 thousand PLN.

The conducted research indicates that companies perceive the problems of the natural environment and that care for its condition is a priority for them. The main objective of the activities carried out by the companies in the field of environmental protection is the implementation of business strate-

gies, promotion of an appropriate image, as well as promotion of ecology and effective waste management.

The analysis of environmental practices shows that environmental education is one of the most popular measures taken. Not only children, but also consumers, customers, residents of large cities, and representatives of specific industries are the targets of the activities. Companies are eager to engage in pro-environmental programmes, which are often long-term and extensive measures, which also include environmental education. Biodiversity initiatives are particularly important, as they often support endangered species. The subject of waste and the policy of its re-use is important. It not only permeates actions aimed at the community, but also actions in the eco office category (Raport odpowiedzialny biznes w Polsce 2015, p. 70).

Summary

Human health and the condition of the planet depend to a large extent on the natural environment in which they live, the rational use of raw materials, especially non-renewable ones. More and more people are saying that companies should engage not only in the provision of products and services of appropriate quality, but also in matters related to the protection of the natural environment. Being ecological is becoming more and more fashionable and environmental protection measures are becoming more and more popular. All these circumstances led to an increased search for the foundations for the development of the ecological concept of Ecological Corporate Social Responsibility by the companies. The dissemination of knowledge about ECSR resulted in pro-social and pro-ecological attitudes among listed companies.

The companies are taking up a number of initiatives in the field of environmental protection and have started to implement programmes addressed to the society – especially in the field of environmental education. Practices are dominated by a corrective approach – they are looking for solutions to fix what they have previously "broken". They use modern technologies and solutions to reduce the negative impact on the environment, undertake numerous eco-investments. They also notice the surroundings, especially the animals, in their neighborhood.

There are many arguments in favour of introducing CSR practices in the company. Active involvement in pro-social and pro-ecological activities improves their image, which contributes to increasing their value and improving their competitive position on the market. More and more investors, suppliers, end users, business partners, co-workers and customers are paying attention to the fact that a company cares about the environment.

Treating environmental objectives as important components of the company's policy and their practical implementation results in employee satisfaction, and it increases the support and trust of local communities and current and potential customers.

One of the main obstacles to environmental projects is the lack of awareness of the benefits of CSR and the tools that can be used by employees at all levels. Moreover, there is also a lack of institutional financial support. The ECSR concept consistently implemented by companies can contribute to improving competitiveness and building a lasting advantage over competitors.

It can be expected that the following years will bring even more good practices implemented by the companies towards their stakeholders in concern for the planet. Caring for the natural environment is important for businesses and stakeholders, but also for future generations – to safeguard and strengthen the resources that will be needed in the future. The development of enterprises, regardless of the level at which it is implemented, must not take place at the expense of the natural environment. Voluntary undertaking of activities aimed at nature conservation by enterprises and incorporating this issue into the strategy is an expression of concern for the quality of air, soil and water, as well as an expression of great responsibility and maturity.

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THE EVALUATION OF THE PUBLIC PERCEPTION OF THE IMPLEMENTATION OF "RAJGRÓD FW6 POLSKA WIND FARM"

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ABSTRACT: Renewable energy sources play a key role. The Polish legal system takes into account public participation in the investment process. This also applies to the construction of a wind power plant. In Poland, there is still opposition from local communities to the choice of location and the implementation of an investment project involving the construction of a wind power plant. The aim of this article is to assess the public perception of the construction of a wind farm located in the municipality of Rajgród. The survey of the local community opinion was conducted on the basis of a questionnaire carried out through a direct interview. By using the conditional valuation method (CVM), which uses the ready-to-pay (WTP) techniques, residents' preferences regarding participation in investment financing costs were also examined. Surveys carried out show that the inhabitants of the commune support renewable energy sources and some of the respondents are willing to partially subsidize them. The research has shown that there is a correlation between the age, education and income of the respondents and the amount of co-financing declared by them for the construction of a wind farm in the commune of Rajgród. The largest group of people willing to finance the investment were people in the age groups 26-40 and 41-65. The declared willingness to finance the investment was 1,86 EUR (10% of people) and 2,33 EUR (15% of people). These were people aged between 41-65 with their income of over 232,56 EUR. Only 2% of the respondents declared the amount of 1,16 EUR and they were people over 65 years of age with an average monthly income of about 116,28 EUR.

KEY WORDS: wind farms, social perception of investments, opinion pool

Introduction

Today, humanity is facing global warming and climate change. Therefore, renewable energy sources play a key role, not only in solving the problems of dwindling natural resources, but also in reducing greenhouse gas emissions. Wind is one of the key sources of renewable energy for the energy sector (Krawiec, 2010).

The world fossil reserves are limited and gradually becoming depleted. Different sources give the approximate year of depletion of natural resources. According to the data of the Institute of Systematic Research of the Polish Academy of Sciences, oil resources will be used up around 2050, hard coal after 2020, and gas after 2060. Today, more and more countries in the world are seeing the potential of renewable sources of energy, reducing their dependence on fossil fuels. Wind power is already being used in more than 80 countries in Asia, Europe, the Americas, Australia and even Africa. Wind energy has considerable potential to be used. It is estimated that from a technical point of view, the world's usable wind energy resources are 53,000 TW-h/year, i.e. three times the world's energy consumption. Wind energy is currently expected to account for 12% of global electricity production by 2020 (Lewandowski, 2013).

The conditions for the use of renewable energy sources are still subject to changes in Polish law and in the financing system. In Poland, there is still opposition from local communities to the choice of location and the implementation of an investment project involving the construction of a wind power plant. Therefore, there is still a conflict resulting from the need to improve air quality by reducing emissions of gases and dust from the combustion of conventional fuels and the potential impact of wind farms on the deterioration of the comfort of life of the local inhabitants (Jakóbowski, 2016).

The Polish legal system takes into account public participation in the investment process. This also applies to the construction of a wind power plant. Therefore, it is also worth getting to know the opinion of the local community before taking action. It is important to interview the local population in order to determine whether the local community, and in particular the owners of the plots selected for the construction of wind farms, are willing to lease the land and whether the owners of neighbouring plots will allow for the implementation of the connection infrastructure if the project requires it. Site inspections are also part of the process of assessing the acceptance of the planned investment. These activities make it possible to estimate the risk of local social protests against the construction of wind farms, and if such a risk occurs, to develop a project for its prevention.

The aim of this article is to assess the public perception of the construction of a wind farm located in the municipality of Rajgród. The survey of the local community opinion was conducted on the basis of a survey carried out through a direct interview. By using the conditional valuation method (CVM), which uses the ready-to-pay (WTP) survey, residents' preferences regarding participation in investment financing costs were also examined.

Energy technology in Poland and worldwide

Today's energy policy strategy is to reduce conventional energy production in favour of green energy. Reducing greenhouse gas emissions is a global problem. The action to reduce greenhouse gas emissions aims at reducing their negative environmental impact, combating climate change, and it is one of the ways to achieve sustainable development (Jakóbowski, 2016).

Globally, the share of conventional energy in global energy production continues to decline. The ever-increasing prices of fuels and the ever-increasing pollution of the natural environment are becoming a global problem. The solution to this problem may be the use of unconventional (renewable) energy sources, including wind energy (Krawiec, 2010).

The public has now realized the importance of the natural environment and that recovering lost environmental assets is a long-term process, which can sometimes be no longer possible (Jakóbowski, 2016).

According to some data from 2016, which can be found at the Global Carbon Atlas online platform, China is the largest producer of carbon dioxide, the second largest is the United States and the third one is India (www.globalcarbonatlas.org).

The principles of the Chinese government, announced in February 2016, assume a reduction in coal production by 500 million tons by 2020. The energy revolution also aims to achieve the level of 15% of renewable energy in total production of energy by 2020. According to data from the Global Wind Economic Council of 10 February 2016, in China, the installed capacity of the wind turbines is 145 105 MW. This country has become a leader in the development of wind farms, which has installed more than 30 GW of power over the course of a year. The production of energy by wind turbines not only involves reduced emissions of pollutants into the air, but it is also profitable. Modern Chinese technologies have contributed to an increase in innovation in the energy sector.

In August 2015, the *Clean Power Plan* project was implemented in the United States to reduce air pollution from the energy sector. The plan set out to reduce the level of carbon dioxide emissions from power plants by 32%

compared to the year 2005 by 2030. The Americans have the fastest growing sources of renewable energy. There is also an increase in the number of wind turbines installed. According to the American Wind Energy Association (AWEA), 4,300,000 turbines (37 wind farms) have been installed in the USA with a total capacity of 5 GW.

The Indian government has also drawn attention to the need for sustainable energy development. The result is the installation of facilities producing about 50,000 MW from renewable energy sources. However, this represents only 11% of the generated power. India's energy policy indicates that by 2022, the capacity from renewable energy sources will have been 74.4 GW. This concept will reduce carbon dioxide emissions by 20-25%. Currently, the share of wind energy in this country is about 10%.

The European Union's energy policy aims to ensure energy security, protect the environment, including the fight against climate change, and build a strong energy market based on the harmony of its member states.

According to data from the Global Wind Economic Council (GWEC) of February the 10th, 2016, the share of wind energy in the total energy volume in the countries of the European Union is still increasing. It is the following for some selected countries: Denmark – 40%, Portugal and Ireland – over 20%, Spain and Cyprus – about 20%, Germany – 16%. It should also be mentioned that Denmark is the largest producer of wind turbines and it plans to increase the share of wind energy in the overall electricity balance to 50% by 2030 (www.gwec.net).

In Poland, research into wind energy resources is carried out by the Institute of Meteorology and Water Management. At the of 2012, the annual growth of rate of installed wind power capacity was 880 MW (54%), and in 2013 – 893 MW (38%). In 2013, Poland was ranked 8th in terms of attractiveness for the wind energy market. According to data collected in 2013 by the Global Wind Energy Council, the share of energy produced from wind turbines amounted to 3.6% of all electricity produced (*Stan energetyki wiatrowej w Polsce w 2015 roku*, 2016).

As far as the Polish energy policy is concerned, its fundamental objectives are were defined in the Energy Law Act of 10 April 1997 (Prawo energetyczne, 1997). In addition, Poland, becoming a member of the EU, has assumed obligation related to the sustainable development of energy policy based on alternative energy sources. Since 1999, the country has had a non-governmental organization Polish Wind Energy Association (PWEA). The mission of the Association is to support the development of wind energy as a clean source of energy. The members of PWEA are companies that operate on the Polish wind power market and turbine manufacturers from Poland and abroad. In Poland, at the end of 2015, the capacity of the installed power

plants amounted to 4 978 MW. Wind power plants produced in 2015 10 041 GWh of electricity, which accounted for approx. 6.21% of total electrical energy production in the country (Maj et al., 2016).

According to the report of PWEA about 80% of wind investments belong to the so-called independent energy producers. Only 19% of the installed capacity is held by state-owned companies (PGE Renewable Energy – 529 MW, Tauron Ecoenergy – 200.75 MW, Energy – 185 MW, and ENEA – 56 MW) (Niedziółka, 2012).

Wind energy in the public opinion

The Act of 3 October 2008 on the provision of environmental information and its protection, public participation in environmental protection and impact assessments on the environment (Ustawa o udostępnianiu informacji o środowisku…, 2008) refers to the right of the public to submit comments and requests when decisions are taken and when documents are drawn up (articles 33-43). In addition, the authorities conducting the proceedings, concerning the planned investment, have the obligation to inform about it and give reasons for their decisions. Every investment can have a potential impact on the development and possible improvement of the living standards of the local community. The public's interest in the project may result in its acceptance, which may result in their support for the implementation of the investment project. However, the public often has some concerns about the planned investment, which can lead to numerous protests.

The society considers the positive effects of the investment the following things: the additional revenue for landowners, the improvement of road quality and the increase in revenue in municipalities' budgets (that is the property tax). Investments related to the construction of wind power plants are often accompanied by protests from nature conservationists as well as local communities. According to nature conservationists, the construction of wind farms may have a negative impact on the natural environment (in particular on the avifauna and landscape). On the other hand, the protests of local community's concern mainly the impact on their health (noise emission), the deterioration of the landscape quality, as well as the decline in the value of land that could be used for construction or recreation purposes in the vicinity of the power plant. In most cases, these concerns result from the public's ignorance of the real impact of wind farms on the environment.

When constructing wind farms, it is very important that the investor consults the local authorities. It is worth getting acquainted with the plans of a village, commune and district development in order to get acquainted with

the needs of the local community. For this purpose, the project design, the scale of the project and a report on the environmental impact of the project should be presented to the inhabitants. Some of the local population's fears are due to ignorance, so it is necessary to provide the local community with as much information as possible about the planned project and wind power industry, i.e. to carry out the so-called educational process. It includes, among other things, promotional campaigns and information meetings aimed at raising people's awareness of wind energy (Niecikowski at al., 2008).

In Poland, public acceptance studies for the construction of wind farms were carried out. Respondents in communes where the farms were located stated that their concerns about wind energy proved to be unfounded. The presence of wind farms did not adversely affect their health, they did not feel annoying noise, they did not complain about bad mood and they did not notice a negative impact of these investments on the natural environment.

In 2011, employees of the Department of Public Health of the Pomeranian Medical University in Szczecin, commissioned by the Polish Wind Energy Association, conducted research on the acceptance of wind energy and other renewable energy sources by adult Poles. The research was carried out all over Poland by means of a diagnostic survey using a questionnaire, taking into account the following characteristics of respondents: income, education, age, gender and the place of residence. The conclusions of the study were as follows:

- the obtained results indicate that the research participants perceive the benefits of wind energy in the following areas: ecology, human health, and the technological progress of the country,
- despite the dynamic development of wind energy, stereotypes and myths about it continue to exist (*Akceptacja dorosłych Polaków dla energetyki wiatrowej i innych odnawialnych źródeł energii*, 2011).

In 2012, Veolia Environment commissioned the Millward Brown SMG/KRC Institute to conduct a public acceptance survey for wind farms. The aim of the survey was to verify public acceptance of wind farms in areas where investments had already been made. Whereby, half of them were built by 2007 (10 wind farms, which were the only ones existing at that time). The aim was to compare the results of new and existing investments over a longer period of time. The conclusions of the study were as follows:

- residents of the areas where wind farms are located are positively disposed to this type of investments, and most of them would again give their consent to the construction of a wind farm,
- 1/3 of the residents were afraid of starting up a wind farm, and the most frequent concerns were: noise (70%), negative impact on health (49%) and the deterioration of life comfort (32%),

- the vast majority of the residents (78%) stated that the presence of a wind farm did not adversely affect their health, 63% did not feel the noise caused by the operation of the turbines, and 61% did not feel the negative impact of a wind farm on the environment,
- 73% of the respondents were of the opinion that the launch of the wind farm brought some environmental benefits (63% of the respondents indicated the benefits of increasing the tourist attractiveness of the area, and 57% of the increase of the commune's tax revenues paid by the investor) (*Poziom akceptacji społecznej dla farm wiatrowych, 2012).*

In 2013, a survey was conducted in order to obtain information on the attitude of the inhabitants of the Warmińsko-Mazurskie Voivodeship towards wind energy. One of the most important assumptions of the study was to investigate the differentiation of the level of support for wind energy depending on whether you live in the commune with or without wind power plants. Such a survey design was to show the experience of the inhabitants of Warmia and Mazury with wind energy to date and to diagnose the character of the inhabitants' attitudes towards wind farms, and in particular their impact on the nearest environment: landscape, the health of the inhabitants, the development of tourism, the natural environment, and power management of particular communes. The conclusions of the study were as follows:

- the vast majority of the inhabitants (78%) of the Warmińsko-Mazurskie Voivodeship see the potential of wind energy investment for their region (the most frequently indicated benefits are: environmental protection, the increase in a commune's income from taxes paid by the investor and the decrease of unemployment),
- the research has shown that the inhabitants of communes with wind farms, in comparison to the general population of the region, see much more benefits associated with the construction of wind farms,
- the vast majority of respondents (87%) were of the opinion that wind power plants are a good source of energy,
- the majority of respondents (75%) agreed that a wind farm should be established in their commune, whereas in communes with power plants this percentage was 82% (*Energetyka wiatrowa*, 2013).

Characteristics of "Rajgród Wind Farm FW6 Polska"

Raigród commune is situated in the north-eastern part of Grajewo county in Podlaskie Voivodeship. Rajgród commune has an agricultural and tourist character. The area of the commune is 20716 ha, of which 5879 ha are forests and 1254 ha are waters. The areas used for agricultural purposes account for 58% of the total area of the commune. The majority of soils used for agricultural purposes are classified as IV (45%) and V (23%) of the bonus class. Classes V and VI soils constitute a significant percentage – 28% of the commune's area. Forests, which constitute 28.37% of the commune's area, both public and private, are managed and supervised by Rajgród Forest Inspectorate. From the southeast the commune borders with the Biebrza National Park forest complex. Slightly more than 6% of the commune area is covered by water. These are mainly areas connected with Rajgrodzkie Lake and the Jegrznia river. Rajgrodzkie Lake, with the total area of 1514 ha, is crossed by the border of voivodships and within the boundaries of Rajgród commune there are 1000 ha of its area. Within the administrative boundaries of the commune there is the entire eastern bay, part of the main reservoir (the biggest depth is 52 m) and most of the picturesque southern bay. From the eastern bay flows the Jegrznia river, which after numerous meanderings flows into Dręstwo Lake (the lake itself is not located in the commune, and the border with the neighbouring commune Bargłów Kościelny runs along a part of the coastline), then it flows out and falls into the vast area of Czerwone Bagna. The Kuwasy canal, which together with some smaller canals and drainage ditches forms a network of surface waters in the agricultural part of the commune, originates from the southern bay. There are 10 holiday resorts by the lakes. The seat of the commune authorities is the town of Rajgród, located on the eastern bay of Rajgrodzkie Lake. There are 5969 people living in the commune, and in the town of Rajgród there are 1799 people. Apart from Rajdród, the commune consists of the following villages: Bełda, Biebrza, Bukowo, Czarna Wieś, Ciszewo, Danowo, Karczewo, Kołaki, Kosiły, Kosówka, Kozłówka, Kuligi, Łazarze, Miecze, Orzechówka, Pieńczykowo, Pieńczykówek, Przestrzele, Rybczyzna, Rydzewo, Skrodzkie, Sołki, Stoczek, Turczyn, Tworki, Wojdy, Woźna Wieś, Wólka Mała, Wólka Piotrowska. The effect of the attractive location of the commune is the development of ecological agriculture and agritourist. In the whole commune there are 390 business entities, 13 of which belong to the public ownership sector, and the remaining 377 are private entities (www.umrajgrod.pl).

The investment of the wind farm was carried out in the area of Rajgród commune, in 7 villages, such as Turczyn, Bukowo, Kołaki, Kosiły, Karwowo, Skrodzkie and Wólka Piotrowska. The wind farm was established in the area

of the commune about 10 km south-west of Rajgród. The land on which the farm was built is an irregular area with numerous small glacial hills and closed valleys. The area in which turbines are located is rural. The land was used for arable farming. The predominant vegetation is cultivated vegetation and the plants that grow on the meadows. There are also some roadside and mid-field trees and bushes. In the adjacent areas on the northern side of the wind farm there are forest complexes.

This area has a network of paved roads. In order to construct access roads to particular turbines and shunting yards, changes in terrain were planned during the investment planning process so as to meet the design requirements for new transport systems. In the village of Turczyn two trees were cut down, which collided with the scope of the access road. The resulting internal roads are made of a hardened surface with a variable roughness of 4 m in width.

The analysed area for wind farm development is fully covered by the local spatial development plan. The building and architectural design takes into account the assumptions of the local plan. The owners of the land, which constitutes the area for the investment, are natural persons (agricultural land) and the management of the commune and the town of Rajgród (the area of communal roads). The investment has not changed the current purpose of the areas located in the vicinity. Wind turbines were distributed irregularly as their optimal location was taken into account. Considering the guidelines of the local spatial development plan and the existing standards "Rajgród wind farm FW6 Polska" meets the location guidelines (The Municipal Office in Rajgród).

The construction of "Rajgród Wind Farm FW6" involved the construction of 11 repetitive wind turbines, including the main power supply point (GPZ), network connection with the transformer station through underground power cables, and internal access roads with a manoeuvring area.

The wind farm is an object consisting of a reinforced concrete foundation, a tower and a three-pane wind turbine with a horizontal axis of rotation. The turbine consists of a gondola and a rotor. The maximum height of the wind turbine tower, counted to the rotor axis, is 125 m. The diameter at the base of the tower is approx. 4.8 m. The energy produced is transmitted via underground cable lines to the main power supply (GPZ). The entrance to the interior of the building is led by technological stairs, which are located on the side of access roads. The facility is equipped with SWT-2.3-108 turbines with a total capacity of 25.3 MW and a nacelle rotation system. A wind turbine (WTG) consists of a tower and a nacelle which consists of a rotor and a measuring system. The rotor consists of blades connected by a hub. The blades are moved by wind and transmit power to the hub, which is connected to the

drive shaft, which increases the speed of the axis. The mechanical energy is transferred from the gearbox to the electric generator, which converts it into electricity that is then transferred to the output of the power grid. In addition, the facility is equipped with devices regulating the parameters of turbines in order to obtain acceptable levels of noise. In addition, the nacelle casing has a weather protection function. The core of the tower is located in a reinforced concrete foundation of 20 cm above ground level. The tower of the wind turbine is made of steel segments. The rotor wings have a housing protecting the interior girder, which is the structure of the wing. In addition, the power plant was equipped with a daily signposting of an air obstacle. This marking is in the form of five painted strips of equal width which are perpendicular to the axis of the wing from the outside. Out of five lanes, three are red and two white and they cover 1/3 of the length of the wing. A wind turbine operates both during the day and at night (*Farma wiatrowa Rajgród FW6 Polska*, 2013).

The method of researching the public perception of investments

Among the inhabitants of 7 villages, covered by the investment of the construction of a wind farm in the commune of Rajgród, surveys were conducted using the direct interview method, in order to test the knowledge of their inhabitants about renewable energy sources and their attitude towards the implementation of "Rajgród wind farm FW6 Polska".

The research tool was a survey questionnaire containing 12 questions. The first part, consisting of 4 questions, concerned the general knowledge of the inhabitants about renewable energy sources. Residents were asked whether they knew what renewable Energy sources were and whether they supported their use, as well as if they believed that wind farms had a negative impact on the environment. The second part of the questionnaire, containing 8 questions, made it possible to examine the attitude of the respondents to the construction of a wind farm in the commune of Rajgród. Respondents were asked about the benefits the commune and they themselves would have from building a wind farm and whether its construction would have an impact on their lives and health. The preferences of the inhabitants with regard to participation in the cost of investment financing were also examined. The last part of the questionnaire included a metric in which the respondents were asked about their gender, age, income and education.

To assess the social perception of investment financing costs, the Contingent Valuation Method (CVM) was used, based on the Willingness to Pay (WTP) study (Graczyk, 2005). Each respondent, after receiving a question-

naire, could determine the amount of money they would be willing to spend on the construction of a wind farm.

The survey was conducted on a group of respondents who were the inhabitants of rural areas covered by the impact of the analyzed investment, 60 people (60% of whom were women and 40% men) representing households agreed to fill in the questionnaire. The majority of the respondents were aged 26-40 (37%) and 41-65 (38%). Most of the respondents had secondary or vocational education (28% in each of the analyzed groups).

The analysis of the results of the survey for the reception of the „Rajgród wind farm FW6 Polska" investment project

The research has shown that regardless of age and level of education of the commune inhabitants, all the respondents know, what renewable energy sources are. They also understand the need to use renewable sources for energy purposes. The support for the implementation of wind farms decreases in the situation of constructing facilities in the respondent's area of residence.

On the basis of the questionnaire, the opinion of the inhabitants was also examined in relation to the negative impact of wind power plants on the environment. The vast majority of respondents, i.e. 67% stated that wind farms do not have a negative impact on the environment, as the energy generated comes from renewable energy sources. The remaining 33% were against the construction of power plants, claiming that wind farms have a negative impact on the environment, as well as being a nuisance for people and animals (noise emitted by wind turbines) and contribute to the mortality of birds and bats. These were people aged 18-26 (18% of the respondents) and 26-40 (15% of the respondents) with secondary education.

When asked about the benefits of building a wind power plant in the commune, 63% of respondents said that the commune has financial benefits from the investment, especially concerning the property tax. The largest group were people aged 26-40 (25% of the respondents) with secondary education and 41-65 (23% of the respondents) with vocational and university education. On the other hand, 29% of the respondents indicated that the benefit is the improvement of the technical condition of road infrastructure in rural areas. The largest group were people aged 41-65 (12% of the respondents) with primary and vocational education and 26-40 (10% of the respondents) with secondary education. On the other hand, 8% of the inhabitants stated that thanks to the investment the commune increased its prestige in relation to other communes and in relation to the county. These were

people aged 18-25 (3% of the respondents) with University education and aged 41-65 (5% of the respondents) with primary education (figure 1 and 2).

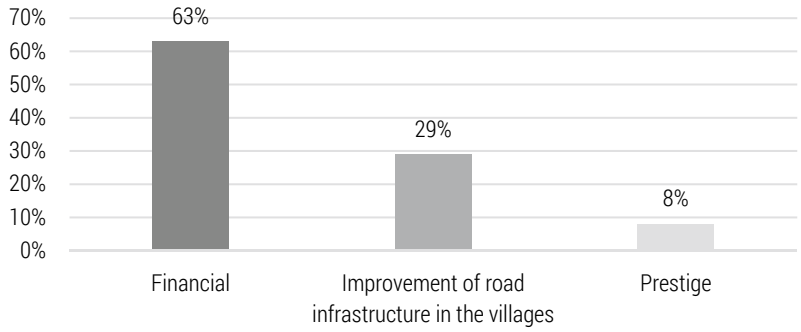

Figure 1. The benefits for the commune of Rajgród from a construction of a wind farm

Source: author's own work.

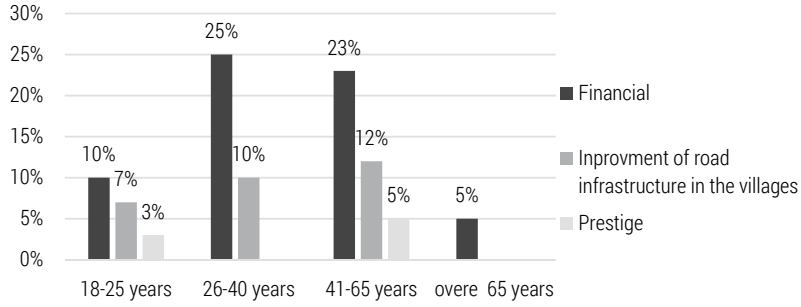

Figure 2. The benefits for the commune from the construction of a wind farm and the age of respondents

Source: author's own work.

In the survey 88% of the respondents stated that the investment will bring more benefits. The largest group were people aged 41-65 (35% of the respondents) with income over 1000 PLN and aged 26-40 (22% of the respondents) with income between 500 and 1000 PLN. They, first of all, pointed out all the financial benefits to farmers who rent land for the investment. Additionally, the statements mention the improvement of communal roads used by the inhabitants of particular villages. Only 12% of the respondents said that the investments have not brought any benefits to them. These were people aged 26-40 with an average monthly income of about 500 PLN (figure 3).

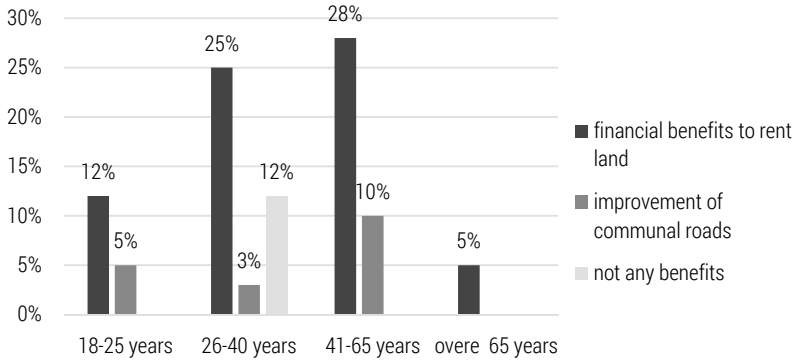

Figure 3. The benefits from the building of a wind farm for the inhabitants of the commune of Rajgród

Source: author's own work.

Preferences to participate in investment financing costs were also examined. The majority of respondents (68%) were against its co-financing. The largest group were people aged 41-65 (27% of the respondents) with incomes over 232,56 EUR and 26-40 (25% of the respondents) with incomes up to 232,56 EUR. On the other hand, in the 18-25 age group 12% of respondents did not want to participate in financing investments, while in the 65+ age group – 3% of people with an average monthly income of about 116,28 EUR. The respondents claimed that EU programs or the investors themselves should provide financing for the construction of the wind farm. On the other hand, those who agreed to co-finance the investment (33%) stated that they were ready to declare small amounts of money. The largest group of these people were persons aged 26-40 and 41-65 (respectively 12% of the respondents), while people aged 18-25 constituted 8% of the respondents, and persons aged 65 ±1% of the respondents.

Among all the respondents, the largest number of them, i.e. 15%, declared that they were able to co-finance the construction of a wind farm with the amount of 2,33 EUR. They were people aged 26-40 and 41-65. And the smallest amount of investment co-financing was 1,16 EUR declared by 2% of the respondents aged over 65. The maximum amount of co-financing among the respondents was 3,49 EUR, declared by 3% of the respondents aged 18-25 (figure 4 and 5). It was a one-time declaration of the surveyed financing of investments related to renewable energy sources, including wind farms.

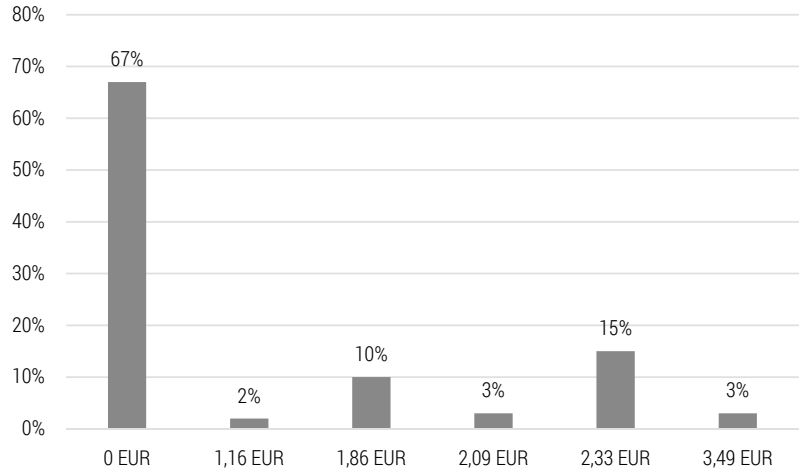

Figure 4. Respondents' declared amounts for the construction of a wind farm in the commune

Source: author's own work.

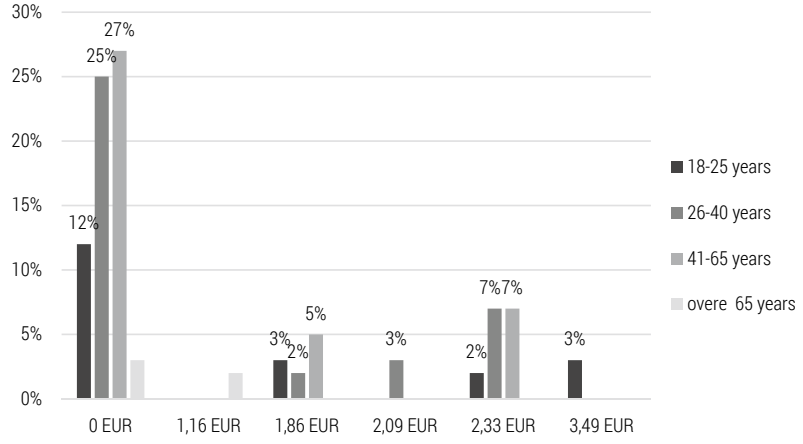

Figure 5. The relationship between the age of respondents and the amount of co-financing for the investment

Source: author's own work.

It was also examined the relationship between the level of education and the readiness of respondents to finance the construction of a wind farm in the commune. In the group not willing to pay, the majority of the respondents (23%) were people with university and vocational education (22%). People declaring their readiness to finance investments are those with secondary education (16% of people) (figure 6).

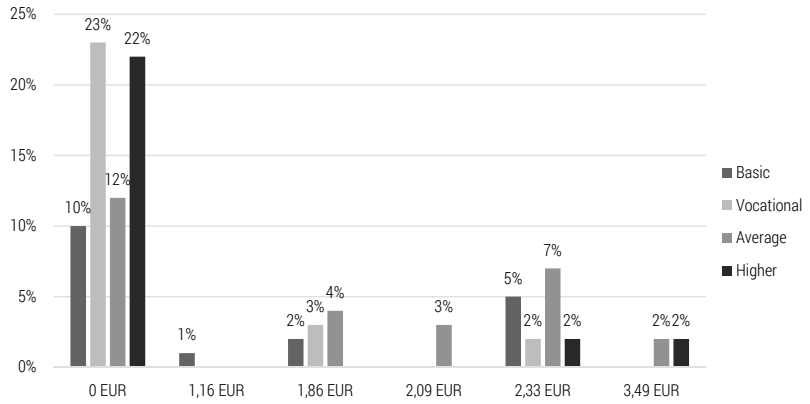

Figure 6. The level of education of the respondents declaring their willingness to pay

Source: author's own work.

Another issue was to check the relationship between the declaration of co-financing and the average monthly income of the respondents (figure 7).

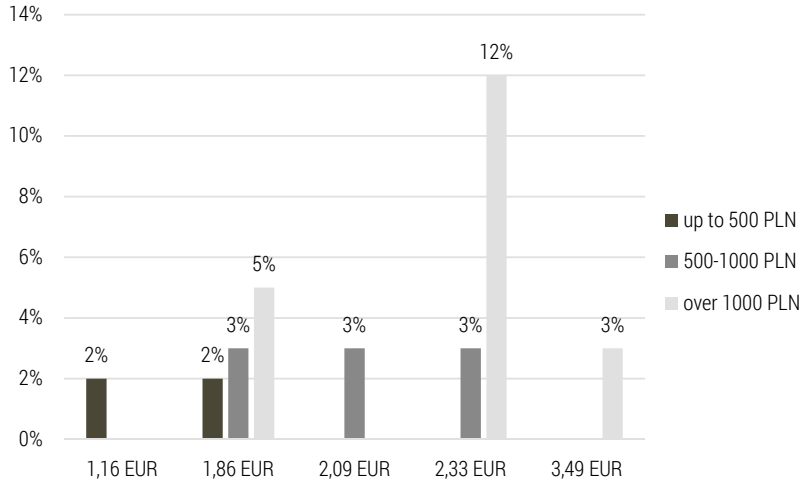

Figure 7. Average monthly income per person of respondents declaring their willingness to co-finance the construction of a wind farm in the commune

Source: author's own work.

The research has shown that there is a relation between the income and the amount of investment co-financing declared by the respondents. The highest amount of 3,49 EUR was declared by 3% of the respondents, while 2,33 EUR would be ready to be paid by 12% of the respondents. These people indicated income of above 232,56 EUR. On the other hand, the smallest

amount of 1,16 EUR was declared by 2% of the respondents with their incomes below 116,28 EUR.

When asked about the impact of the wind farm location on their lives, 55% of the respondents said that the wind farm located in the commune does not directly affect their lives. On the other hand, 45% of the respondents complained about the noise and changes in the landscape. The inconvenience of a wind farm, or its absence, is related to the distance of the wind farm from the place of residence of individual respondents.

The last question concerned comments and objections concerning the construction of the wind farm in the area of the commune of Rajgród. Most respondents did not object it, but 15% of the residents pointed out that the distances between the turbines and residential buildings were too short, claiming that a longer distance would be more appropriate due to the nuisance of the noise emitted by the turbines.

In summary, all respondents support the use of renewable energy sources. The majority of the respondents support investing in wind farms in their commune. The positive attitude of the commune inhabitants towards the construction of a wind power plant is also related to the distance between them and the wind turbines.

Conclusions

On the basis of the conducted analysis, the following conclusions can be drawn concerning the public perception of the implementation of wind power projects:

1. The residents are familiar with the concept of renewable energy and understand its importance for the energy industry development at local and national level.
2. Local communities point to financial benefits resulting from the location of wind farms in the area of the commune.
3. The residents understand the importance of renewable energy for the environment and are concerned about the risks and nuisance that windmills can pose to humans and animals.
4. The inhabitants of the commune support renewable energy sources. Most of the respondents accept wind farms in their commune, and 33% of the respondents are willing to partially subsidize them.
5. The research has shown that there is a correlation between the age, education and income of the respondents and the amount of co-financing declared by them for the construction of a wind farm in the commune of

Rajgród. The largest group of people willing to finance the investment were people in the age groups 26-40 and 41-65.

6. The declared readiness of the respondents to finance the investment was at the level of 8 PLN (10% of people) and 10 PLN (15% of people). These were people aged 41-65 with their income of over 1000 PLN. Only 2% of the respondents declared the amount of 5 PLN and they were people over 65 years of age with an average monthly income of about 500 PLN.
7. People with low incomes were unwilling to finance investments or declaring low amounts. In the group not willing to pay, the majority of respondents were people with university and vocational education. On the other hand, those who declare their readiness to finance investments are mostly people with secondary education.

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The contribution of the authors

Krystyna Rauba – literature review – 60%; acquisition of data – 20%; analysis and interpretation of data – 70%
Agata Zimińska – literature review – 40%; acquisition of data – 80%; analysis and interpretation of data – 30%

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Iwona SKOCZKO • Ewa SZATYŁOWICZ

ANALYSIS AND ASSESSMENT OF AIR QUALITY IN THE CITY OF BIALYSTOK IN 2012-2017

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ABSTRACT: The aim of the research was to assess the state of air pollution with mentioned pollution for the area of the city of Bialystok. The analysis was carried out using data from 2 air monitoring stations. The stations are owned by the Provincial Inspectorate for Environmental Protection in Bialystok. The work also compared the air quality in Bialystok with the air quality in the main voivodship cities with a similar population: Olsztyn, Lublin, Bydgoszcz and two of the largest urban agglomerations in the country: Warsaw and Wroclaw. It was found that the quality of air in the city of Bialystok compared to the analyzed cities is the best. In addition, it was observed that increased concentrations of PM10 and PM2.5 suspended dust occur in Bialystok in the months of X-III, due to the low emission from combustion of fuels.

KEY WORDS: air quality, air monitoring, NOx, PM2.5, PM10

JEL: Q52, Q53

Introduction

Air pollution is a local, pan-European and hemisphere problem. Air pollution is the most harmful and dangerous of all pollution, because it is mobile and can contaminate virtually all environmental components in large areas. The sources of air pollution are mainly anthropogenic emissions from the municipal and housing sector, transport and industry (Cembrzyńska et al., 2012; Pasela et al., 2017). We mainly deal with a large concentration of the above sources in urban-industrial agglomerations. Therefore, urban areas are particularly vulnerable to air pollution with dust and gases such as sulphur oxides, nitrogen oxides and car-bon monoxide.

The air quality in Poland is monitored as part of State Environ-mental Monitoring (SEM) and the responsibility for its maintenance lies with the Inspectorate for Environmental Protection. The city of Bialystok constitutes one zone from 46 SEM zones, where the air quality is assessed – Bialystok Agglomeration. The city has exceptional land-scape and environmental values, it is located in the functional area "Green Lungs of Poland". Over 32% of the city area is occupied by green areas. Due to the above-mentioned exceptional location of the city, it was decided to assess the air quality and to determine the trends of changes in individual gaseous pollutants in the last six years in the city of Bialystok. The aim of the study was to analyze and evaluate the results of gaseous pollutants measurements: NO_x, NO_2, SO_2, CO and suspended dust PM10 and PM2.5 obtained from urban background measurement stations in the city of Bialystok in 2012–2017. The work also compares the air quality in Bialystok with the air quality in the main provincial cities with similar population: Olsztyn, Lublin, Bydgoszcz and in two of the largest urban agglomerations in the country: Warsaw and Wroclaw.

Material and Methods

In the assessment of air quality, the analysis was limited to the results of measurements of total nitrogen oxides (NO_x), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon monoxide (CO) concentration as well as particulate matter PM10 and PM2.5. The results of measurements of gas air pollutants concentrations averaged over the year and the frequency of exceeding the 1- and 24-hour admissible levels specified in the Regulation of the Minister of Environment (Journal of Laws, pos. 1031) in 2012-2017, were obtained from the information service of the Main Inspectorate of Environmental Protection. The Provincial Inspector for Environmental Protection in Bialystok is

responsible for monitoring and assessment of air quality in the Bialystok agglomeration (over 250 000 inhabitants). The air quality monitoring system in Bialystok consists of 3 stationary measurement stations. Two of them are characterized by the measurement of urban background: at Waszyngton Street 16 (1) and at Warszawska Street 75A (2). Data regarding the analyzed background stations are presented in table 1.

Table 1. Basic information about urban background measurement stations in Bialystok

	Name	National station code	Station classification	Location		Type of measurements	Measured parameters
				coordinates	address		
1	Bialystok – Miejska	PdBialWaszyn	background	Φ 53,126689 λ 23,155869	Waszyngton Street 16	A, M*	NO_x, SO_2, CO, PM2.5, PM10
2	Bialystok – Warszawska	PdBialWarsza	background	Φ53,129306 λ 23,181744	Warszawska Street 75A	A, M*	PM2.5, PM10

* A – automatic measurement, M – manual measurement
Source: www.powietrze.gios.gov.pl [20-01-2018].

Characteristics of air pollution were elaborated by calculating averages: annual pollutant concentrations for both years and the entire analyzed period (2012-2017). The number of exceedances of normalized mean hour values in the analyzed period at each station was also calculated. In addition, from the set of PM10 and PM2.5 suspended particulates concentrations at the analyzed Bialystok-Miejska and Bialystok-Warszawska stations, in the period 2012-2017, monthly averages for the whole period were calculated to extract months with an increased concentration of particulate matter. Concentrations of gaseous and dust pollutants in the city of Bialystok were compared with those in cities: Lublin, Olsztyn, Bydgoszcz, Wroclaw and Warsaw in the same research period of 2012-2017.

Results and discussion

Tables 2 and 3 summarize the values of annual average concentrations (C_{year}), average annual minimum values (Min_{year}), average annual maximum values (Max_{year}) for the sum of nitrogen oxides (NO_x), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO) (for CO, also the average annual maximum 8-hour concentration) and particulate suspended matter PM10 and PM2.5, exceedances of the allowable levels of 1-hour NO_2 (AL_{h1}) and 24-hour PM10 and sulfur dioxide (AL_{h24}) and 50% percentile of total NO_x, NO_2, CO, PM2.5 at 2 air quality monitoring stations in 2012-2017 in Bialystok.

Table 2. List of statistical parameters for NO_x, NO_2, SO_2, CO concentrations at the Bialystok-Miejska measurement station

Station	Parameter	2012	2013	2014	2015	2016	2017	Average 2012-2017
NO_x concentration [µg/m³]								
Bialystok -Miejska	C_{year}	19.4	18.2	18.8	20.2	18.1	16.6	18.6
	Min_{year}	0.0	0.0	0.9	0.9	0.0	0.7	-
	Max_{rok}	469.4	470.5	327.0	530.3	353.5	675.0	-
	$S50_{PERC}$	13.4	13.3	12.8	13.7	12.8	12.2	-
NO_2 concentration [µg/m³]								-
Bialystok -Miejska	S_{year}	14.5	14.4	13.7	14.9	13.4	13.1	14.0
	Min_{year}	0.0	0.0	0.9	1.0	0.5	0.7	-
	Max_{year}	153.3	107.4	94.3	111.9	96.9	93.6	-
	$S50_{PERC}$	11.6	11.6	10.7	11.7	10.7	10.4	-
	AL_{h1}	0	0	0	0	0	0	-
SO_2 concentration [µg/m³]								-
Bialystok -Miejska	S_{year}	3.3	10.9	4.3	4.1	3.2	3.5	4.9
	S_{winer}	4.1	5.5	7.4	5.2	3.7	3.8	-
	Min_{year}	0.0	1.8	0.0	0.0	0.0	0	-
	Max_{year}	89.1	103.6	83.6	30.3	26.4	37.9	-
	ALD_{h24}	0	0	0	0	0	0	-
CO concentration [µg/m³]								-
Bialystok -Miejska	S_{year}	0.3	0.3	0.3	0.4	0.4	0.3	0.3
	Min_{year}	0.0	0.0	0.1	0.2	0.1	0.1	-
	Max_{year}	4.0	5.1	2.9	4.1	2.4	2.1	-
	Max_{h8}	2.9	2.6	2.0	2.8	1.9	1.6	-
	$S50_{PERC}$	0.3	0.3	0.3	0.4	0.3	0.3	-

Source: www.powietrze.gios.gov.pl [20-01-2018].

The analyzes show that the average annual values of the concentration of total nitrogen oxides NO_x in 2012-2017 at the Bialystok-Miejska station range from 16.6 µg/m³ in 2017 to 20.2 µg/m³ in 2015. Minimum concentrations in the examined period oscillate between 0.0 and 0.9 µg/m³, while the maximum concentration in the analyzed period was recorded in 2017 and amounted to 675.0 µg/m³.

In the case of nitrogen dioxide NO_2, it was found that the average annual concentration values in the analyzed years 2012-2017 did not exceed the admissible annual value of 40 μg/m^3 (Journal of Laws on 2012, pos. 1031) and fluctuated from 13.1 to 14.9 μg/m^3 (table 2). In period 2012-2017, there were also no days exceeding the permissible 1-hour NO_2 limits. The minimum NO_2 concentrations in the analyzed time interval ranged from 0.0 to 1.0 μg/m^3, while the maximum observed concentrations ranged from 153.3 μg/m^3 in 2012 to 93.6 μg/m^3 in 2017. In period 2012-2017, a significant downward trend was observed in the case of maximum NO_2 concentrations. Nitrogen dioxide (NO_2) is commonly found in the work environment and in the municipal environment, resulting from the combustion of organic substances containing nitrogen, detonation of explosives, electrochemical treatment of metals and operation of diesel engines (Kostrz, Satora, 2017).

Analysis of annual average SO_2 concentrations in 2012-2017 indicates that in 6 years the SO_2 concentration remains at a similar level, and only in 2013, there was much higher annual average concentration compared to the remaining years from the analysis period. The average annual concentration of SO_2 in 2013 was 10.9 μg/m^3. In Bialystok, there are no exceedances of permissible concentration of sulfur dioxide (SO_2). Concentration of sulfur dioxide (SO_2) are dependent on the season of the year and associated emission factor, which are local individual heating sources, therefore the average concentration in the year from the winter period were separately calculated. It was observed that the winter average value in most years is slightly higher than average for the entire calendar year. Sulfur dioxide enters atmospheric air as a result of the process of burning the hard coal, when organic and inorganic sulfur compounds decompose and pass into the exhaust gases (Kostrz, Satora, 2017).

Concentration of carbon monoxide (CO) observed in the years 2012-2017 remained at the same level of 0.3-0.4 μg/m^3. The maximum 8-hour concentration of carbon monoxide in the period under study did not exceed the applicable standards.

Table 3. List of statistical parameters regarding suspended PM10 and PM2.5 concentrations at the Bialystok-Miejska and Bialystok-Warszawska measuring stations

Station	Parameter	2012	2013	2014	2015	2016	2017	Average 2012-2017
PM10 concentration [µg/m^3]								
Bialystok -Miejska	$_{Cyear}$	27.8	22.9	24.9	24.9	19.8	21.0	23.6
	Min_{year}	6.6	3.8	5.9	6.1	3.3	2.7	-
	Max_{year}	142.6	75.2	69.7	91.0	65.2	129.7	-
	AL_{h24}	26	8	10	26	2	8	-
Bialystok-Warszawska	S_{year}	30.9	26.9	30.0	29.2	23.9	23.3	27.4
	Min_{year}	0.0	0.0	0.0	0,0	0.0	0.0	-
	Max_{year}	485.0	385.6	402.6	362.6	294.1	309.2	-
	LD_{S24}	38	20	37	46	15	13	-
PM2.5 concentration [µg/m^3]								
Bialystok -Miejska	S_{year}	24.7	20.5	19.6	19.3	19.0	16.9	20.0
	Min_{year}	0.0	0.0	0.0	0.0	0.0	0.0	-
	Max_{year}	430.0	456.0	246.0	261.0	185.0	200.6	-
	$S50_{PERC}$	18.0	17.0	15.1	14.,0	15.0	11.9	-
Bialystok -Warszawska	C_{year}	22.3	19.3	21.9	21.2	17.5	17.6	19.9
	Min_{year}	4.6	2.5	4.5	3.4	1.7	1.2	-
	Max_{year}	139.2	88.2	88.3	106.5	71.1	134.2	-

Source: www.powietrze.gios.gov.pl [20-01-2018].

Table 3 presents results for suspended particulate matter PM10 and PM2.5. The tests showed that values of 24-hour concentrations of suspended dust PM10 above the LD_{24} standard = 50 µg/m^3 were above the frequency of exceeding the permissible level in the calendar year for 24-hour concentrations of particulate matter PM10 determined at 35 times. This took place in 2012, 2014, 2015 at the Bialystok-Warszawska station. The overruns in the above-mentioned years were respectively: 2012 – 38 times, 2014 – 37 times and 2015 – 46 times. At the Bialystok-Miejska measurement station, in 2012-2017, the exceedance of the permissible frequency of exceeding the level from the Regulation was not noted. Comparing the annual mean concentrations of PM10 with the levels recommended by the World Health Organization, to which the EU adheres, it was found that in all years from the period 2012-2017, the average annual concentration of PM10 was close to or exceeded the recommended level of 20 µg/m^3 at both stations. The mean

concentrations from the 6-year analysis period were respectively 23.6 μg/m^3 at the Bialystok-Miejska station and 27.4 μg/m^3 at the Bialystok-Warszawska station. At the Bialystok-Warszawska station, slightly higher average annual concentrations of PM10 and maximum annual concentrations were observed than at the Bialystok-Miejska station. Specific meteorological conditions contribute to the occurrence of high maximum concentrations of PM10, which, along with the unfavorable ventilation conditions characteristic of compact urban buildings, cause frequent, especially during winter inversion, occurrence of extremely high concentrations of particulate matter called *"smog episodes"* (Cembrzyńska et al., 2012). In Bialystok, the highest maximum concentration of PM10 in 2012-2017 was recorded at the Bialystok-Warszawska station in 2012 and it amounted to 485 μg/m^3. In Wroclaw, in the winter season of 2009-2012, the average concentration of PM2.5 in the air was exceeded by an average of 25% from the established national standard (Sówka et al., 2015).

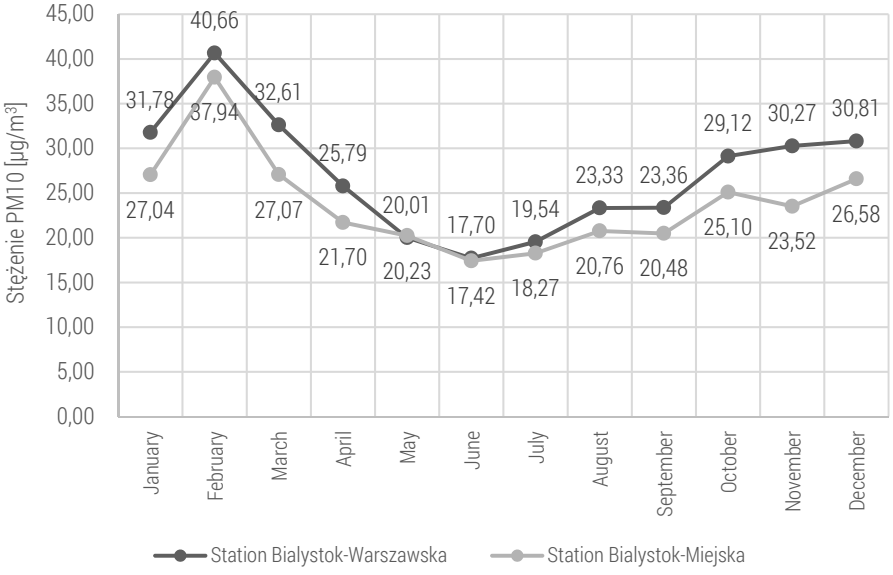


Figure 1. The annual course of the average monthly PM10 [μg/m^3] in Bialystok in 2012-2017

Source: author's own work based on www.powietrze.gios.gov.pl [20-01-2018].

Figure 1 shows the annual course of the average monthly PM10 concentration in Bialystok in 2012-2017, based on which it was observed that the monthly values in the annual course, similar as in the case of PM2.5 (figure 3), are the lowest between April and September, while the largest ones fall

between October and March. Such dependence results, among others, from the start of the heating season due to the lowering of air temperatures in the winter months. Slightly lower concentrations were observed at the Bialystok-Miejska station. The average PM10 for the heating season (X-III) was 30.23 μg/m³ at the Bialystok-Warszawska station, and at the Bialystok-Miejska station – 27.87 μg/m³. In the case of summer season, i.e. non-heating period (IV-IX), the average PM10 at the Bialystok-Warszawska station was equal to 23.16 μg/m³, while at the Bialystok-Miejska station, 19.81 μg/m³. At both stations in winter season, the PM10 concentration was higher by around 20% as compared to the summer season.

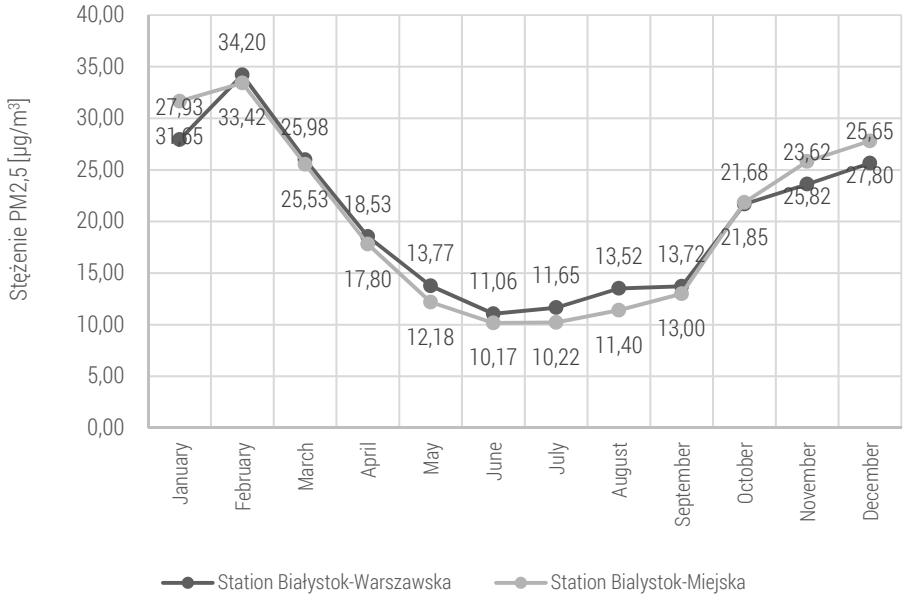
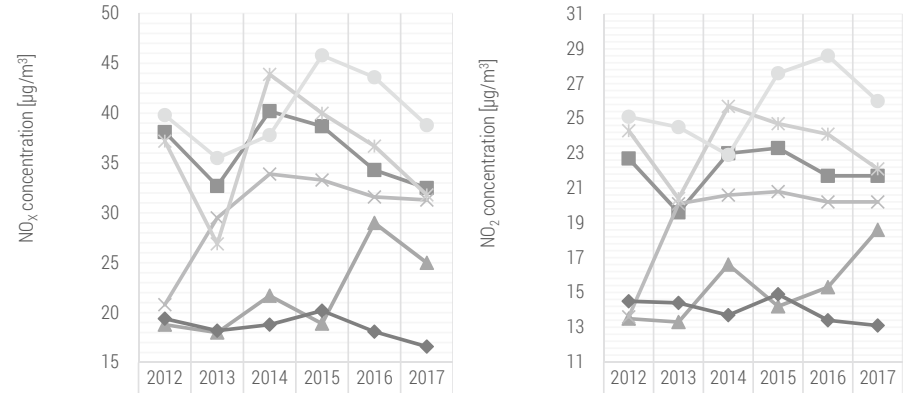


Figure 2. The annual course of the average monthly PM2.5 [μg/m³] in Bialystok in 2012-2017
Source: author's own work based on www.powietrze.gios.gov.pl [20-01-2018].

The analysis results of air pollution with suspended dust PM2.5, taking into account the annual course of the average monthly concentration at both city background measurement stations in Bialystok (figure 2), show identical trends as in the case of PM10. There is a significant decrease in the mean monthly PM2.5 in months IV-IX. The average PM2.5 in months X-III was 26.51 μg/m³ at the Bialystok-Warszawska station, while at the Bialystok-Miejska station, it was 27.68 μg/m³. In months IV-IX, the average PM2.5 at Bialystok-Warszawska station was equal to 13.71 μg/m³, whereas at Bialystok-Miejska station – 12.46 μg/m³. At both stations in winter season, the concentration of PM2.5 was higher by about 45-50% as compared to the summer season.

The obtained high values of suspended particulate matter concentrations PM10 and PM2.5 in the winter season (figures 1 and 2) are mainly associated with low emissions from the municipal and housing sector. The use of hard coal in Poland for heating buildings contributes to the creation of dust, the share of which in the total amount of emitted dust is from about 55% to 85%. Dust that occurs in cities comes from the combustion of coal for energy purposes (generation of energy and heat for technological and municipal needs) (Widawski, 2015; Pasela et al., 2017). According to GUS data, the consumption of fuels in the Podlasie province in 2016 was classified as follows: hard coal – 1785 thousand tons, which accounted for approximately 64%, natural gas – 828 thousand TJ – 30%, liquid gas (without vehicles, stationary consumption) – 110,000 tons – 4%, light heating oil – 63 thousand tons – 2%, heavy fuel oil – 3 thousand tons – 0.1%. Summing up, the highest dust concentration values were observed in Bialystok in winter season, which indicates the main source of dust, which is low emissions from the municipal and living sector.

For the comprehensive comparison of air quality in the city of Bialystok (about 297 thousand inhabitants) with other urban agglomerations, three main provincial cities with a similar number of inhabitants were selected: Lublin (about 340,000 residents), Olsztyn (about 180,000 residents) and Bydgoszcz (around 355,000 inhabitants) and 2 cities from the largest urban agglomerations in Wroclaw (about 638,000 inhabitants) and Warsaw (about 1,758 thousand residents). Data for the comparison of concentrations of individual pollutants came from the GIOŚ Database. Urban background measurement stations were selected where measurements of the same pollutants as at the Bialystok-Miejska station were made. Measurement stations in individual cities were: Lublin Obywatelska Street 13, Olsztyn Puszkin Street 16, Bydgoszcz, Warszawska Street 10, Warsaw, Kondratowicz Street 8, Wroclaw, J. Conrad-Korzeniowski Street 18, Wroclaw, Na Grobli Street. Figures 3a and 3b present comparison of the average annual concentrations of the sum of nitrogen oxides and nitrogen dioxide in the city of Bialystok and selected cities. The city of Bialystok is characterized by the lowest average annual concentrations of the nitrogen oxides sum and nitrogen dioxide during the analysis period of 2012-2017. In all analyzed cities, since 2015, a downward trend in NO_x and NO_2 has been observed. The capital city of Warsaw was characterized by the highest average annual concentrations of analyzed pollutants.



	2012	2013	2014	2015	2016	2017
Lublin	38,1	32,7	40,2	38,7	34,3	32,5
Olsztyn	18,8	18	21,7	18,9	29	25
Bydgoszcz	20,8	29,5	33,9	33,3	31,6	31,3
Wroclaw	37,2	26,9	43,9	40	36,7	31,8
Warszaw	39,8	35,5	37,8	45,8	43,6	38,8
Bialystok	19,4	18,2	18,8	20,2	18,1	16,6

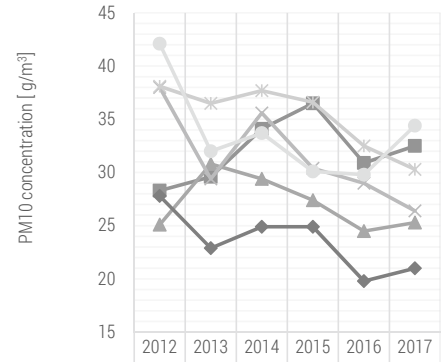
	2012	2013	2014	2015	2016	2017
Lublin	22,7	19,6	23	23,3	21,7	21,7
Olsztyn	13,5	13,3	16,6	14,2	15,3	18,6
Bydgoszcz	13,6	20,1	20,6	20,8	20,2	20,2
Wroclaw	24,3	20,4	25,7	24,7	24,1	22,1
Warszaw	25,1	24,5	22,9	27,6	28,6	26
Bialystok	14,5	14,4	13,7	14,9	13,4	13,1

Figure 3. Comparison of changes in average annual concentration a) sum of nitrogen oxides NO_x, b) NO_2 nitrogen dioxide in 2012-2017 in selected cities

Source: author's own work based on www.powietrze.gios.gov.pl [20-01-2018].

Analysis of average annual suspended particulate PM10 and PM2.5 (figure 4a and 4b) concentrations values indicates that, within six years, a downward trend in airborne dust concentrations in all analyzed cities was observed as compared to 2012. The city of Bialystok, in terms of the PM10 and PM2.5 analysis, was classified as a city with the lowest pollution in the analyzed period.

In conclusion, it can be stated that the air quality in the city of Bialystok is at a good level. The city is characterized by lower average annual concentrations of gaseous pollutants and suspended particulate matter as compared to the cities of similar size and function (provincial cities): Lublin, Olsztyn and Bydgoszcz. Also, in comparison to one of the largest urban agglomerations such as Wroclaw and Warsaw, the average annual concentrations of gaseous and particulate pollutants in the city of Bialystok are significantly lower. However, levels of suspended particulates PM10 and PM2.5 recommended by the WHO are exceeded in Bialystok.



	2012	2013	2014	2015	2016	2017
Lublin	28,3	29,6	34,1	36,5	30,9	32,5
Olsztyn	25,1	30,8	29,4	27,4	24,5	25,3
Bydgoszcz	38	29,4	35,6	30,4	29	26,4
Wroclaw	38,1	36,5	37,7	36,6	32,5	30,3
Warszaw	42,1	32	33,7	30,1	29,8	34,4
Bialystok	27,8	22,9	24,9	24,9	19,8	21

	2012	2013	2014	2015	2016	2017
Lublin	22,4	21,4	23	21,3	19	20,7
Olsztyn	18,2	28,9	22,6	20	15,3	18
Bydgoszcz	22,1	23,4	24,6	23,1	22,8	21,2
Wroclaw	26,8	27,8	23,1	22,9	22,5	20,7
Warszaw	25,6	23,6	25,5	23,6	21,8	21,4
Bialystok	24,7	20,5	19,6	19,3	19	16,9

Figure 4. Comparison of changes in average annual concentration of a) PM10, b) PM2.5 in 2012-2017 in selected cities

Source: author's own work based on http://powietrze.gios.gov.pl/pjp/archives [20-01-2018].

Conclusions

1. In the analyzed period of 2012-2017, average annual values of NO_2 and SO_2 concentrations on the analyzed Bialystok-Miejska station were not exceeded.
2. The average annual value of particulate matter concentration at the analyzed urban background measurement stations in Bialystok in 2012-2017 was respectively for PM10 23.6 μg/m^3 at the Bialystok-Miejska station, while at Bialystok-Warszawska station 27.4 μg/m^3 and analogously 20,0 and 19.9 μg/m^3 for PM2.5.
3. Increased PM10 and PM2.5 concentrations above the average for the period 2012-2017 were observed in the winter season (October-March) on both measuring stations, which indicates that the main source of dust is low emissions from the municipal and housing sector.
4. The air quality in the city of Bialystok is slightly lower compared to other cities with similar population and function. During the period 2012-2017, a slight decrease in the majority of gaseous and particulate pollutants in the city of Bialystok was observed.

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The contribution of the authors

Iwona Skoczko – 50%
Ewa Szatyłowicz – 50%

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THE INFLUCENCE OF THERMAL BRIDGES ON THE OPERATION OF UNDERFLOOR HEATING SYSTEM

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ABSTRACT: The work determines the influence of the presence of thermal bridges within the pipes of underfloor heating on its performance: thermal efficiency, surface temperature and heat losses. Three types of building partitions with thermal bridges are considered: the external wall, the external wall with the insulated and uninsulated balcony slab. The analysis was made for variable heat resistance of thermal insulation and floor finishing layer, variable pipe spacing, temperature of the heating medium and outside air. The calculation was carried out with the use of computer software using boundary element method (BEM). It was found that considering three types of thermal bridges in the floor heating model does not significantly affect the thermal efficiency of the floor heating and its average surface temperature. The effect of considering the thermal bridges on the amount of heat losses to the room below was observed.

KEY WORDS: thermal efficiency, surface temperature, heat losses, surface heating systems

Introduction

Radiant floor heating is widely used in residential buildings, industrial, sports and medical objects. It has a special application in buildings with large cubic capacity and heights, in rooms with large glazing and with high infiltration rate, in which traditional heating systems based on convection radiators are uneconomical (Raimundo et. al, 1995). The floor heating heats and provides the optimal air temperature only in the zone of human residence (up to a height of 2 m), therefore there is no need to heat the entire airspace.

In the design process of surface heating systems, apart from the hydraulic calculations, pipe dimensioning and determination of thermal efficiency, one of the most important issues is the design of building partitions which are integrated with them. A surface heating should be designed in this way to minimize the amount of heat loss to the environment on its other side. In accordance with the applicable guidelines for the design of surface heating systems (set of standards PN-EN 1264 and PN-EN ISO 11855), heat losses to the room below the floor heating slab are taken into account in the thermal efficiency calculations. Heat losses affect the mass flow of the heating medium. In the design process are not taken into account heat losses through building partitions adjacent to the radiator plate and through the connection points of the building partitions, i.e. thermal bridges.

The analysis of the influence of thermal bridges on the performance of surface heating systems, including floor heating, was not the object of many research works. The heat losses of a floor heating located in the slab-on-ground floor, below and above the ground level with regard to the external wall, were examined in (Chuangchid, Krarti, 2001; Weitzmann et. al, 2005; Żukowski, 2009). The value of the linear heat transfer coefficient for connection of the heated ground floor slab and the external wall was calculated in (Weitzmann et. al, 2005). It has been shown that the thermal energy losses through foundations constitute a significant part of total heat losses in single-family buildings with surface heating systems and their impact should not be neglected in the design process of buildings (Chuangchid, Krarti, 2001; Weitzmann et. al, 2005). The issue of the influence of a floor heating located in the inter-floor ceiling on the value of heat losses through the external partition and the value of linear heat transfer coefficient for three types of thermal bridges was analyzed in work (Werner-Juszczuk, 2015). The analysis included the connection of the external wall with the ceiling, the connection of the external wall with insulated balcony slab and the connection of a door with the balcony slab. The calculations were carried out for variable pipe spacing, water temperature and constant temperature of external, internal

air, thermal resistance of the finishing layer, the insulation of the external wall and insulation below the floor heating pipes.

This paper deals with the analysis of the influence of thermal bridges on the operating parameters of a floor heating, i.e. thermal efficiency, surface temperature and heat losses to the room below. The analysis of the heat exchange process in the floor heating plate adjacent to the external wall was performed, taking into account the impact of three thermal bridges: connection of the external wall with the inter-floor ceiling and connection of the external wall with an insulated and uninsulated balcony slab.

The calculations were made with the computer software using the boundary element method (BEM).

Research methods

Assumptions regarding the construction of floor heating and building partitions:

- type A of a floor heating,
- pipe PE-Xc, 18x2 mm, λ = 0.35 W/(m·K),
- thermal resistance of the floor covering $R_{\lambda,b}$ = 0.05; 0.1; 0.15 (m^2·K/W),
- the screed thickness above the pipes 45 mm,
- pipe spacing W = 0.1; 0.15; 0.2; 0.25 m,
- supply temperature of the heating medium T_V = 30, 35, 40, 45, 50°C,
- cooling rate of the heating medium 5 K,
- the average flow speed of the heating medium 0.4 m/s,
- the inside air temperature in room with the floor heating and below this room $T_i = T_e$ = 20°C,
- the thickness of the edge insulation 8 mm, λ = 0.042 W/(m·K),
- distance between the pipes and edge insulation 50 mm,
- outside air temperature T_a = –20°C, –10°C, 0°C,
- heat transfer coefficient of the external wall U = 0.20; 0.23; 0.25 W/(m^2·K) (maximum values meeting standards (WT, 2013) for buildings built after 1.01.2014, 2017, 2021),
- thermal conduction coefficient and dimensions of building materials according to table 1.

The following building structures are taken into consideration:

- the inter-floor ceiling with the floor heating (figure 1),
- the connection of external wall with floor heating slab (figure 2) – the thermal bridge I,

- the connection of external wall with the uninsulated balcony slab and floor heating plate (figure 3) – the thermal bridge II,
- the connection of external wall with the insulated balcony slab and floor heating plate (figure 4) – the thermal bridge III.

Table 1. Description of the elements of building structures

No.	Element	λ [W/(m·K)]	Dimension [m]	No.	Element	λ [W/(m·K)]	Dimension [m]
1	reinforced concrete slab	1.7	0.15	8	thermal insulation	0.042	variable
2	thermal insulation	0.04	0.03	9	plaster	0.8	0.02
3	screed	1.2	0.066	10	reinforced concrete beam	1.7	0.25x0.25
4	plaster	0.82	0.015	11	thermal insulation	0.042	0.05
5	floor covering	variable	variable	12	screed	1.2	0.04
6	edge thermal insulation	0.042	0.008	13	thermal insulation	0.042	0.05
7	silicate brick hollow	0.8	0.25	14	balcony reinforced concrete slab	1.7	0.12

Source: author's own work.

The dimensions of thermal bridges were adopted, maintaining the minimum required dimensions specified in PN–EN ISO 10211, that is 1.5 m in the vertical axis and a minimum of 1.5 m in the horizontal axis depending on the pipe spacing (figure 1–4).

The heat transfer coefficients on the surfaces of floor heating are determined from formulas (1) and (2):

- the upper surface of floor heating slab:

$$\alpha = 8.92 \cdot (T_{F,m} - T_i)^{0.1} \quad (1)$$

- the bottom surface of the floor heating slab:

$$\alpha = 1.163 \cdot (T_{F,m,e} - T_i)^{1/3} + 0.025 \cdot (T_{F,m,e} - T_i) + 0.055 \cdot T_e + 4.05 \quad (2)$$

where:

$T_{F,m}$ – the mean temperature of the upper surface of floor heating slab [°C],
$T_{F,m,e}$ – the mean temperature of the bottom surface of floor heating slab [°C].

The heat transfer resistance on the surfaces of other building partitions was derived from PN–EN ISO 6946. The heat exchange process at the water – pipe interface was described according to formulas presented in work (Werner-Juszczuk, 2016).

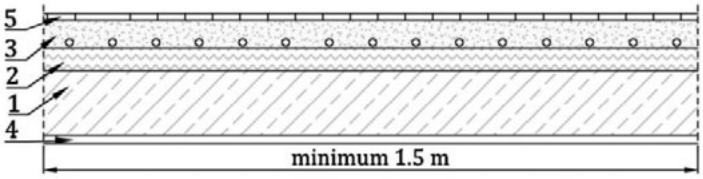

Figure 1. Scheme of inter-floor ceiling with the floor heating (markings according to table 1)

Source: author's own work.

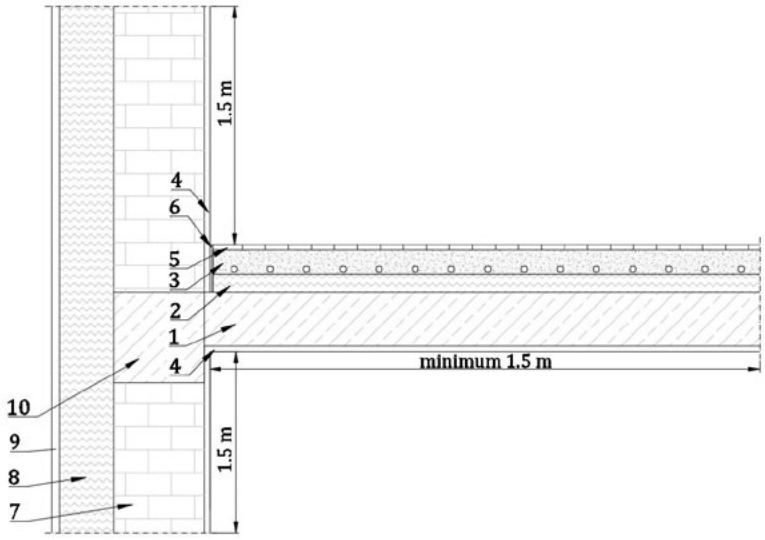

Figure 2. Scheme of thermal bridge I – the connection of external wall and floor heating slab (markings according to table 1)

Source: author's own work.

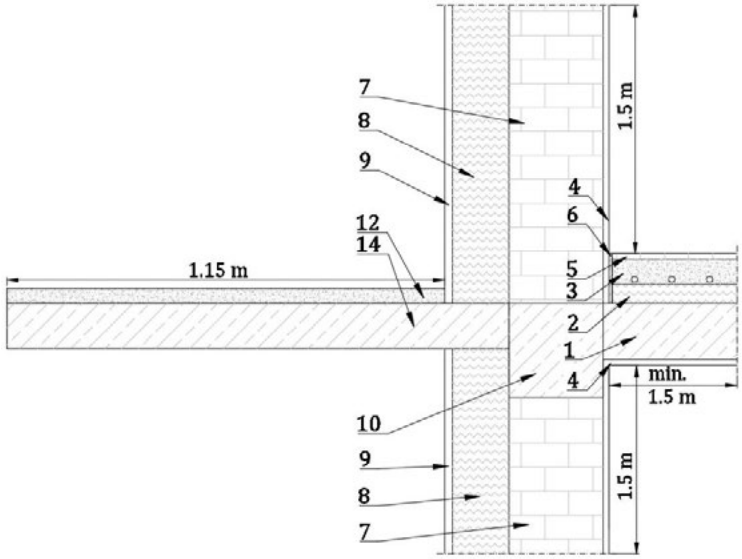

Figure 3. Scheme of thermal bridge II – connection of the external wall with the uninsulated balcony slab and floor heating plate (markings according to table 1)

Source: author's own work.

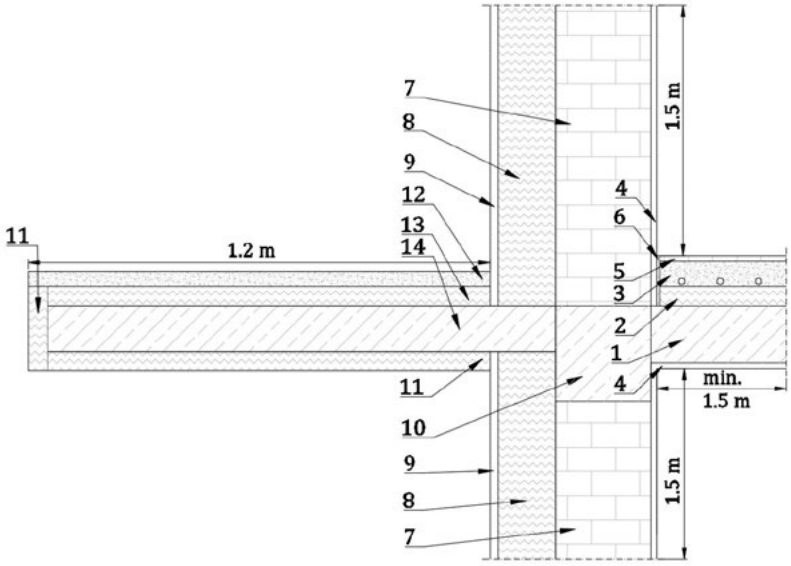

Figure 4. Scheme of thermal bridge III – connection of the external wall with the insulated balcony slab and floor heating plate (markings according to table 1)

Source: author's own work.

Influence of thermal bridges on the thermal efficiency and surface temperature of floor heating system

The results of numerical calculations of heat transfer in the floor heating slab and in the floor heating slab adjacent to the external wall with three analysed thermal bridges, were compared.

It was found that after taking into account the influence of thermal bridges, the thermal efficiency q_i of the floor heating is almost unchanged. The heat flux density q_i after considering the external wall with thermal bridges varies by 1.1-3.5%, depending on the pipe spacing and the thermal resistance of the finishing layer, which corresponds to 0.5-2 W/m^2. Even consideration the most disadvantageous thermal bridge, i.e. the external wall with the uninsulated balcony slab (bridge II), contributes to a small decrease in the thermal efficiency q_i (figure 5).

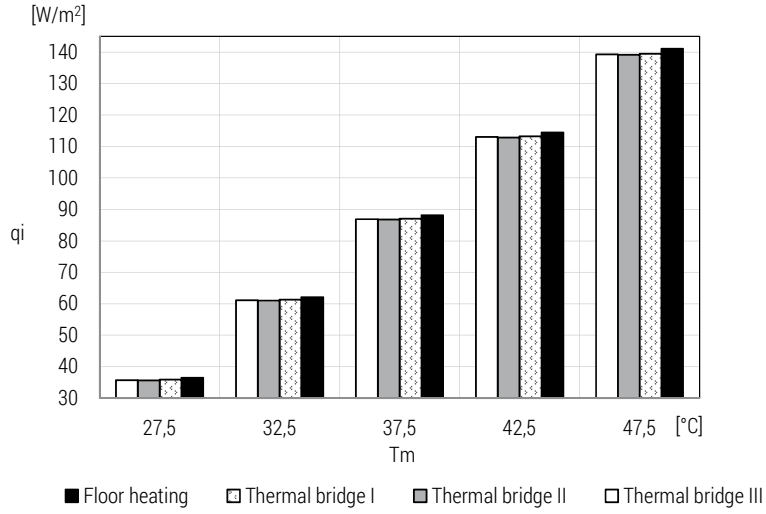

Figure 5. Thermal efficiency q_i of floor heating after considering the influence of thermal bridges for various heat medium temperature T_m (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m^2·K)/W; U = 0.25 W/(m^2·K); T_a = −20°C)

Source: author's own work.

The average surface temperature $T_{F,m}$ of the floor heating after considering in calculation model the external wall with three analyzed thermal bridges is reduced (figure 6). Differences between the surface temperature of the floor heating plate with and without thermal bridge equal from 0.04 K to 0.15 K, depending on the pipe spacing and the thermal resistance of the finishing layer. Therefore, it was found that the influence of thermal bridges on the surface temperature of the floor heating system is negligibly small.

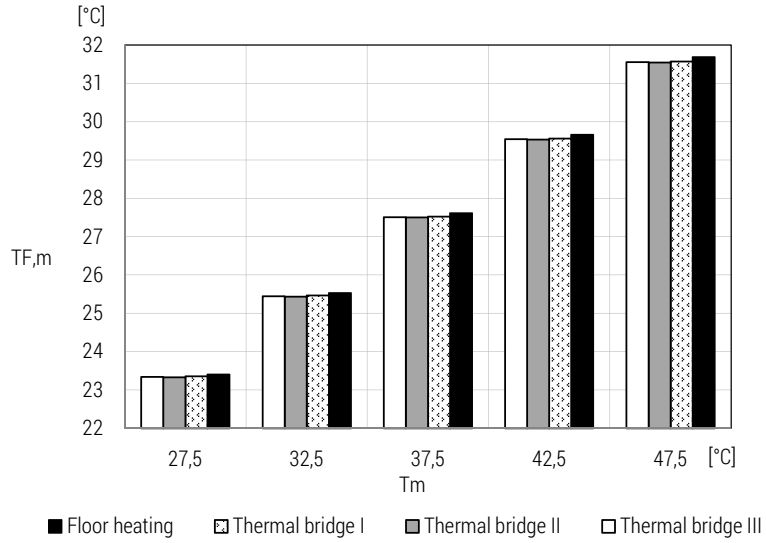

Figure 6. Average surface temperature $T_{F,m}$ of floor heating, after considering the influence of thermal bridges for various heat medium temperature T_m (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W; U = 0.25 W/(m²·K); T_a = −20°C)

Source: author's own work.

On the basis of comparison of the temperature field in the floor heating slab and in the slab adjacent to the external wall, it was found that the presence of three analyzed thermal bridges slightly affects the isothermal distribution. An example of the temperature field in the floor heating plate before and after taking into account the external wall with thermal bridges is presented in figures 7-10. Due to the large size of analyzed building structures, only details are presented, not entire structures.

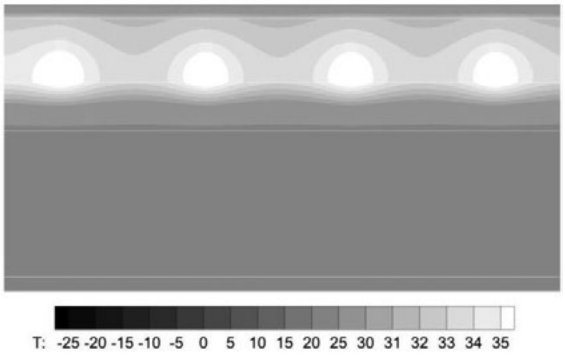

Figure 7. Temperature distribution in floor heating slab (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

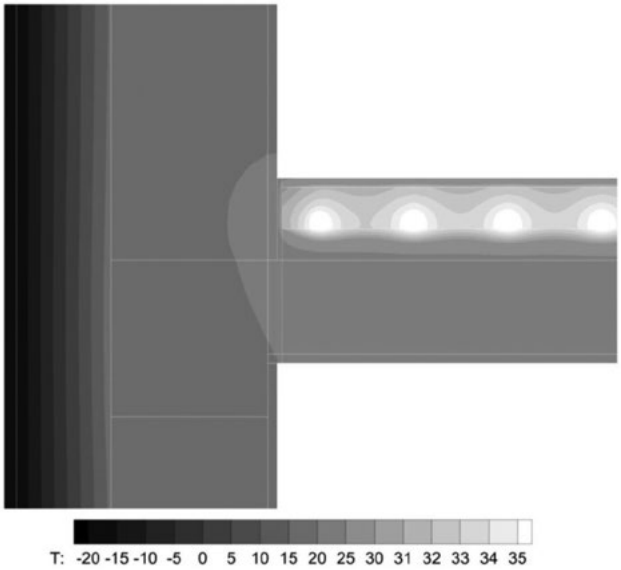

Figure 8. Temperature distribution in thermal bridge I (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

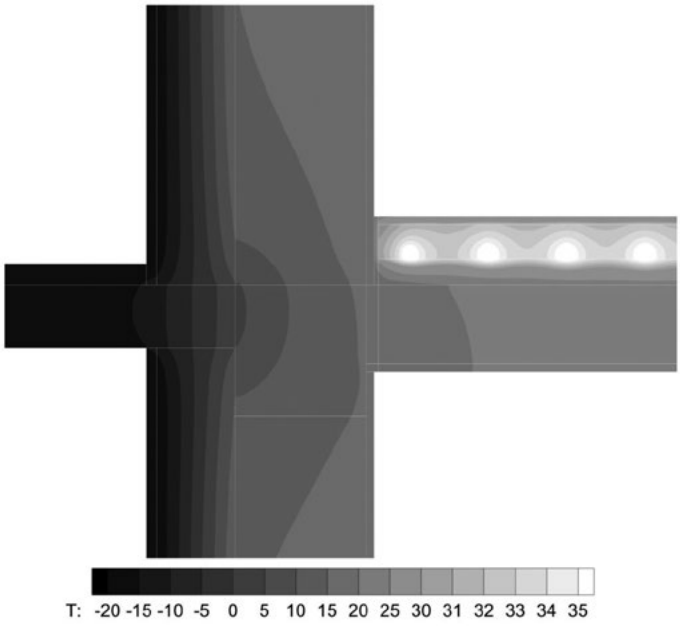

Figure 9. Temperature distribution in thermal bridge II (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

It is shown in figures 8-10, that consideration in calculation model the external wall (bridge I), uninsulated (bridge II) and insulated (bridge III) balcony slab affects the reduction of temperature in the area of the first and second pipe located at the external wall, despite the use of the edge insulation of thickness 8 mm. The distribution of isotherms for next pipes almost does not change.

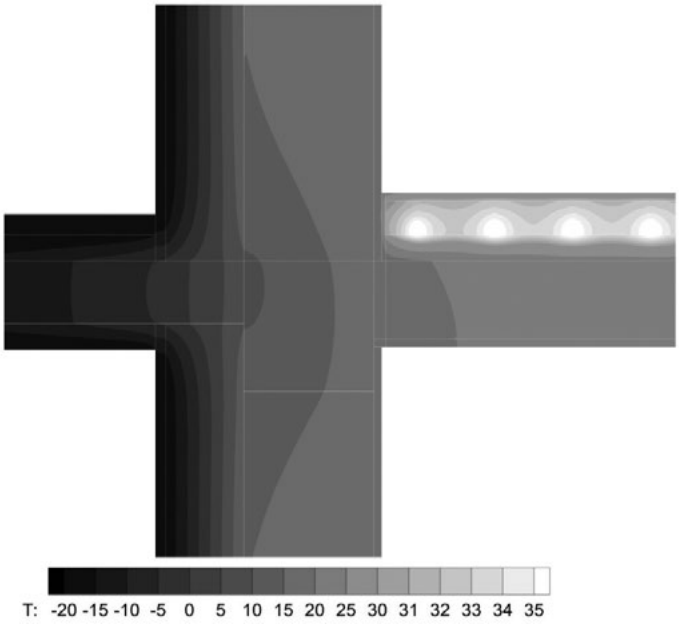

Figure 10. Temperature distribution in thermal bridge III (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

After taking into account various values of overall heat transfer coefficient U of the external wall adjacent to the floor heating slab, it was found that the change in the U does not cause a significant change in the thermal efficiency of the floor heating q_i (figure 11).

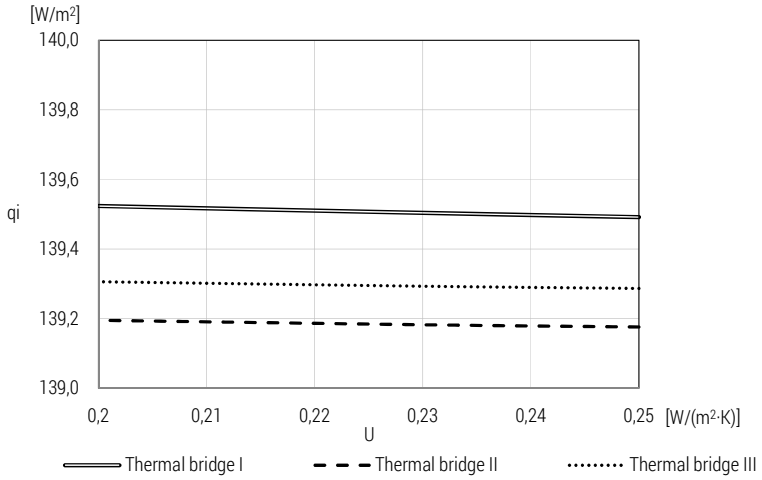

Figure 11. Dependence of thermal efficiency qi of a floor heating on the heat transfer coefficient of the external wall U including the influence of thermal bridges (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W)

Source: author's own work.

Influence of thermal bridges on the heat losses in floor heating system

After considering the floor heating slab interaction with an external wall with three thermal bridges, a decrease in the density of the heat flux emitted to the room below q_e was observed (figure 12). Decrease of q_e value depends on the type of thermal bridge, the pipe spacing, the temperature of the heating medium and the thermal resistance of the finishing layer. The smallest decrease was observed for the thermal bridge I, i.e. the connection of the ceiling with the external wall. For thermal bridge I the value q_e decreases by 1.3 W/m² to 2.4 W/m², which is from 28% to 9% of the heat flux density q_e of the floor heating without considering the influence of thermal bridge. For the II bridge, i.e. the connection of a uninsulated balcony slab with the external wall, the heat flux density q_e decreases by 22–83% which corresponds to 5.6 W/m² to 3.8 W/m². For the III bridge, i.e. the connection of insulated balcony slab with the external wall, the fall is from 19% to 66% (4.6 W/m² to 3.4 W/m²).

The reduction of the floor heating heat losses q_e to the room below, after considering the influence of external wall with thermal bridges, is associated with heat losses through the external wall. Due to the higher temperature difference between the room with the floor heating and the external environment in relation to the temperature difference between the rooms on both sides of the floor heating slab, a more intensive heat exchange appears, which

results in increased heat losses through the external wall while reducing heat losses to the room below.

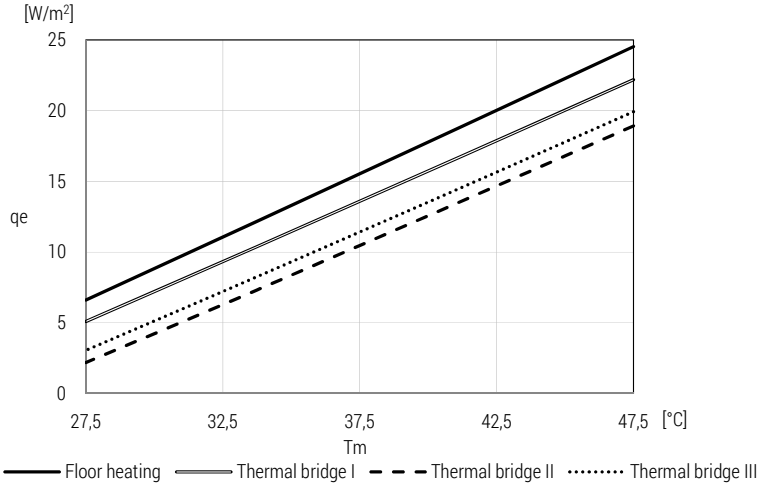

Figure 12. Dependence of the heat losses q_e of a floor heating on the heat medium temperature including the influence of thermal bridges (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W)

Source: author's own work.

Analysis of the heat losses q_e for three heat transfer coefficient U of the external wall adjacent to the floor heating slab, indicates that the increase in the U value causes the decrease in q_e by a maximum of 0.5 W/m² (figure 13).

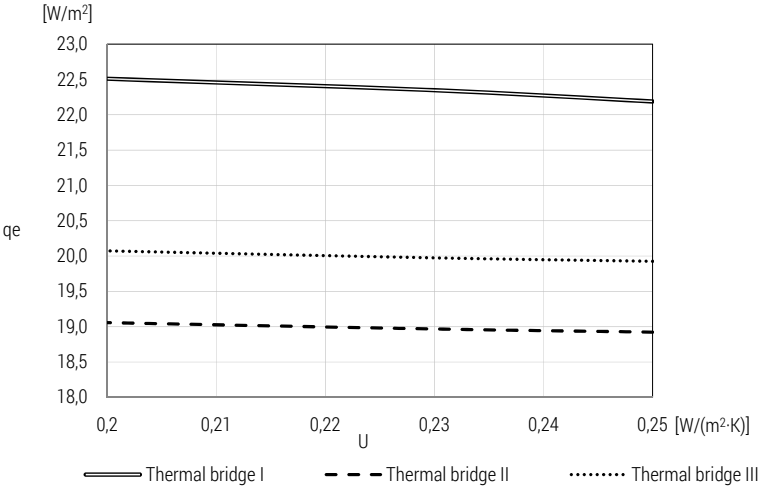

Figure 13. Dependence of floor heating heat losses q_e on the heat transfer coefficient U of the external wall with thermal bridges (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W)

Source: author's own work.

Conclusions

Consideration in the floor heating calculation model the influence of three types of thermal bridges, i.e. the connection of the external wall with the inter-floor ceiling, the connection of the insulated and uninsulated balcony slab with the external wall, does not significantly affect the calculated thermal efficiency of the floor heating and its average surface temperature. The maximum change in the density of the heat flux emitted from the radiator surface is 3.5% which corresponds to 2 W/m^2, and the maximum temperature change is 0.15 K. The results refer to the external air temperature in the range -20°C–0°C and the overall heat transfer coefficient of external wall U in the range of 0.20-0.25 W/(m^2·K), meeting the current requirements specified in the Technical Conditions (WT, 2013).

Taking into consideration the influence of three types of thermal bridge causes the decrease in heat losses to the room below the floor heating slab by a value of about 1 W/m^2 to 6 W/m^2, which accounts for a 9% to 83% of heat losses of floor heating slab considered separately.

The distribution of isotherms in the three analysed structures adjacent to the floor heating plate indicates the minimal impact of the external wall with thermal bridges on the temperature field inside the floor heating slab. Only in the case of pipes running directly at the external wall, a drop in temperature due to thermal bridges is observed. Therefore, it can be concluded that the 8 mm thick edge insulation layer, recommended by producers of surface heating systems, is sufficient to minimize the impact of the three analysed thermal bridges on the thermal performance of a floor heating.

Acknowledgements

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Monika **KOLENDO**

DAILY WATER DEMAND VARIATIONS IN THE BIALYSTOK WATER DISTRIBUTION SYSTEM IN LIGHT OF CHOSEN ECONOMIC AND ENVIRONMENTAL CONDITIONS

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ABSTRACT: The study presents the analysis of water consumption in Bialystok in north-eastern Poland in the years 2007–2013. It has been shown in the study that demand for water during a week is varying and it fluctuates. A detailed analysis of water consumption on individual days of the week and public holidays is presented. Individual consumption per capita and daily water consumption irregularity coefficients were estimated. In the analysed period, the highest average daily water demand was recorded on Saturdays (43,129 m^3), and the lowest on Sundays (37,712 m^3). Moreover, the impact of economic and environmental factors on the process under study has been characterized in the study. In Bialystok, the price of water increased by 42% in the years 2007-2013, with the inflation rate in the country at 119.2% in those years. It is also presented the influence of maximum daily temperature and precipitation sum on daily water consumption on working days and Saturdays, as well as separately, on Sundays and public holidays.

KEY WORDS: water demand irregularity, daily water use, air temperature, rainfalls, water price

Introduction

The analysis of water consumption is one of the elementary issues in planning, design, and operation of water supply systems. It is aimed at capturing the relationships and typical regularities of the process under examination (Siwon et al., 2006). The analysis of the amount of water squashed into the water supply system in urban areas is particularly important in the light of the downward trend in the amount of water used, which continues over the years (Klos, 2013). The observed downward trend is the result of transformations taking place in the technical, social and economic spheres of life (Babel at al., 2014; Their, 2015).

The factors determining the above-mentioned changes include: the reduction of failure rate, gradual network modernization and its monitoring with the use of IT systems (Trębicka, 2013). Decreasing water consumption is also a consequence of a significant increase in the price of water in recent years. What is more, decreasing water use is also results of an increase in the population's salary, which, among other things, makes it possible to have access to water-saving household appliances (Arbues et al., 2003). Demographic factors, i.e. population numbers and migrations of the population related to, among others, with holiday season, also affect water consumption (Hotlos, 2013; Studziński at al., 2014).

In addition, environmental factors also influence the level of both annual, monthly and daily demand, i.e. the variability of meteorological conditions, in particular air temperature (average and maximum) and the sum of precipitation (House-Peter, Chang, 2011; Yasar et al., 2012). The research and analysis of the influence of meteorological factors on the variability of water intake has been conducted for years. However, due to the distinctive characteristics of the water distribution system and different local climatic conditions, it is advisable to conduct such research in each water supply system (Hotlos, 2013).

The aim of this paper is to describe the characteristics of daily demand for water on particular days of the week, as well as the irregularity of the examined process with the indication of the regularity having a considerable influence on the amount of water pumped into the water supply system. Unit consumption per an inhabitant was estimated and coefficients of irregularity of daily water consumption were determined. The above-mentioned characteristics were the starting point for the analysis of economic and environmental factors influencing the daily demand for water in Bialystok urban water supply network. The analysis considered the price increase for water supply and sewage disposal as well as two climatic factors, i.e. the maximum daily air temperature and the daily sum of precipitation.

Daily water use in Bialystok

Bialystok, with a population of about 300 thousand inhabitants, is the largest city in north-eastern Poland. The city functions as the administrative, economic, scientific and cultural centre of the Podlasie Voivodship. Bialystok is the largest academic and scientific hub in the region. The city offers education opportunities for about 43 thousand students. The leading industries in the city's economy are: food processing, electrical engineering, machine industry, plastic processing, textiles, wood building materials (https://en.um.bialystok.pl/274-charakterystyka/default.aspx).

Based on data obtained from Wodociągi Białostockie Sp. z o. o. (Water Supply Pipelines of Bialystok Ltd.) for the years 2007-2013, daily volume of water pumped into the water mains of Bialystok was analyzed. In this paper, the example time series of the daily water demand (for the years 2007 and 2013) are shown in figures 1 and 2. The following regularities should be indicated when characterizing the time series of the analyzed process for particular years. The first characteristic feature is the noticeable seasonality per week (s=7). In all the characterized years, at the beginning of the year, roughly to about 90-100 days, there is a very similar distribution of demand for water with only the mentioned seasonality of the week observed. Then, about between 90th and 100th day, there is a temporary (1-2 days) dramatic drop in water consumption, which is a consequence of moveable Easter holidays.

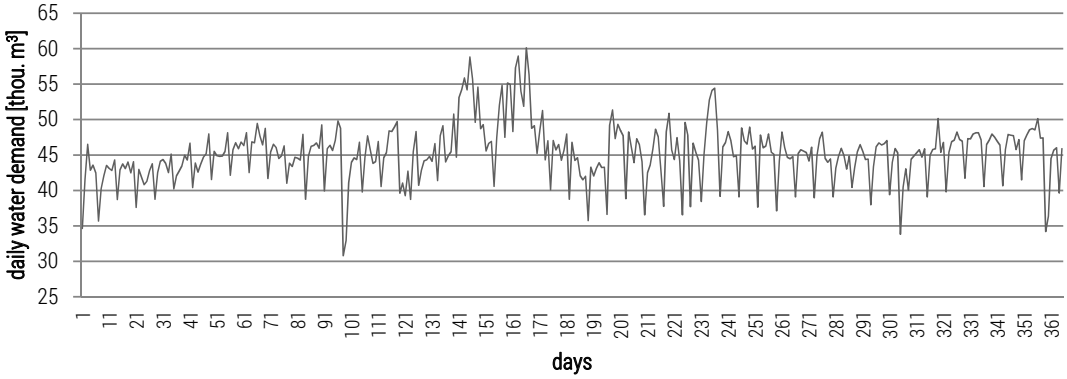

Figure 1. Daily water demand in 2007

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

Subsequently, in most of the analyzed time series, a significant deviation from regular seasonality is also observed between 121 and 123th day of the year. These are public holidays, on 1-3 May, where the demand for water is decreasing. In the following months, there is a certain irregularity. The period

from May to August is characterized by an increase in water consumption in relation to the remaining months and, it is worth noting that each year the course of the chart line differs slightly. Weekly seasonality is impaired by other factors. According to the author's earlier research (Kolendo, 2016a; Kolendo, 2016b), weather conditions played a significant role during that period, which will also be analyzed later in this paper.

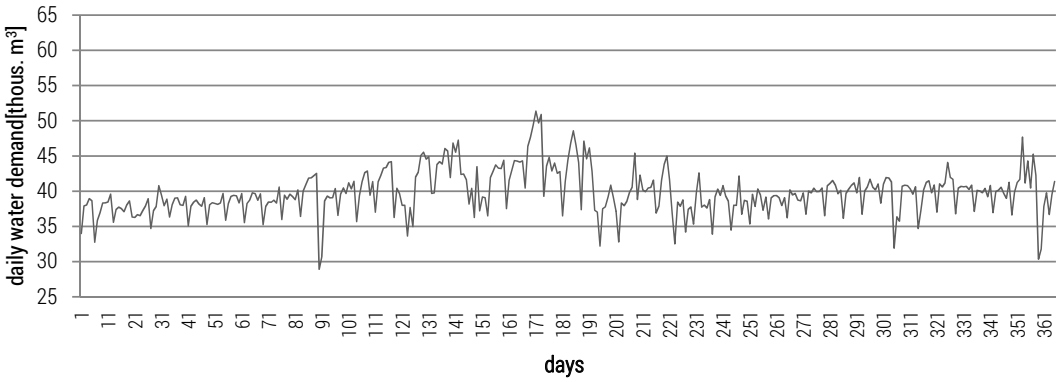

Figure 2. Daily water demand in 2013

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

When analyzing further elements of time series of the daily water demand, from about September (that is from 244th element of the series) a clear weekly regularity is noticeable, like that observed at the beginning of the year. Therefore, the influence of random factors, such as weather conditions, is decreasing. By the end of the year, therefore, until the end of the annual daily water consumption series, a deviation from the average values is recorded on 305th day of the year (1 November). Significant deviations from the average level of the time series also occur at the end of the year. At first, there is a significant increase in water consumption on the 357 and 358 days of the year, followed by a sharp decline. The lowest levels are recorded on the 359 day or 25 December (Christmas Day). This is a very characteristic moment in the analyzed series. This regularity shall be repeated in all the years of characterization. The detailed development of the time series from 22 to 31 December of the years 2007-2013 is presented in figure 3.

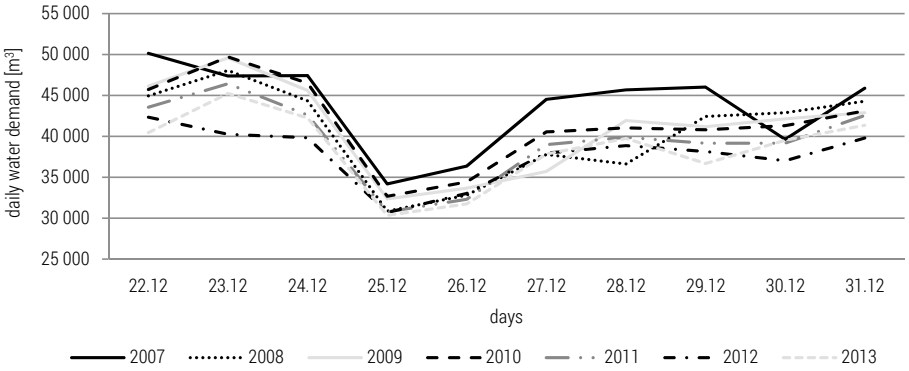

Figure 3. Daily water demand between 22.12 and 31.12 in each year

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

The analysis of the time series of the daily water demand in the years 2007-2013 allows us to determine a day characterized by maximum and minimum water consumption. Minimum daily water consumption in the period from 2007 to 2013 was recorded on March 31, 2013, on Easter Sunday. On that day 28,904 m^3 of water was pumped into the water supply system. The maximum daily water consumption was on 15 June 2007, on Friday, and amounted to 60,111 m^3. This confirms that the smallest water partitions occur on public holidays, while the largest partitions occur on summer days.

Mean daily water demand and its irregularity

As it was presented in the works (Kolendo, 2016a; Kolendo, 2016b), in which the time series of annual and monthly water demand were analyzed, there is a clear decreasing trend in water consumption in Bialystok. The above-mentioned process is also observed by analyzing daily water demand.

The difference between the average daily water consumption in 2013 and 2007 is 5446 m^3/d, which represents 12% of the average in 2007. The population is quasi-fixed, so the q_i indicator showing water consumption per capita is also decreasing. It is worth noting that with lower water consumption the irregularity of water consumption is also decreasing. Although this is not a linear trend, it can generally be stated that smaller fluctuations in water consumption were observed in the time of lower water demand (table 1).

Table 1. Water demand in 2007-2013 and its irregularity

Year	$Q_{dśr}$ [m³/d]	Population [no. of individuals]	q_i [m³/M*d]	Q_{dmax} [m³/d]	Q_{dmin} [m³/d]	N_d
2007	45 227	307 315	0,147	60 111	29 327	1,33
2008	43 741	307 638	0,142	57 056	26 176	1,30
2009	42 470	308 439	0,138	53 709	21 339	1,26
2010	42 096	308 432	0,136	52 730	21 801	1,25
2011	41 484	308 997	0,134	53 516	22 738	1,29
2012	40 356	309 864	0,130	49 835	19 701	1,23
2013	39 781	310 466	0,128	51 377	22 473	1,29

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

Table 2 shows the average water production per a weekday over the period of the years 2007-2013. On each day of the week, there is a declining trend, with the biggest decrease in average water consumption between 2007 and 2013 was recorded on Fridays (nearly 14%).

Table 2. Water production in particular days in years 2007-2013

Day	Water production [m³]							Mean [m³]
	2007	2008	2009	2010	2011	2012	2013	
Monday	45 441	43 608	42 846	42 051	41 387	40 358	39 856	42 225
Tuesday	45 995	44 903	43 740	43 035	42 284	41 235	40 319	43 071
Wednesday	46 145	45 191	43 994	43 191	43 011	41 097	40 838	43 358
Thursday	46 019	44 976	43 206	43 077	42 591	40 875	40 652	43 057
Friday	46 151	44 319	42 513	42 781	41 846	40 732	39 863	42 601
Saturday	46 803	44 331	43 347	43 099	42 198	41 425	40 719	43 129
Sunday	40 029	38 812	37 628	37 426	37 057	36 839	36 210	37 712

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

The highest average daily water demand in the analyzed period is on Saturday (43 189 m³) and the smallest is on Sunday (37 712 m³). However, it should be emphasized that the average amount of water pumped into the water supply system from Monday to Saturday varies slightly between days (table 2). This finding is also confirmed by the small standard deviation values for all days (from 3 233 to 3 549 m³).

Economic and environmental aspects

The author's previous research shows that many factors influence the demand for water in years, months and subsequent days (Kolendo, 2016a; Kolendo, 2016b). One of the economic aspects, conditioning especially the decreasing tendency of the characterized process that has been observed for years, is the price for water supply and sewage discharge. In the years between 2001 and 2013, Pearson's correlation coefficient for the annual sum of water pumped into the water mains and the price for water supply and sewage disposal in Bialystok was -0.95 (Kolendo, 2016a), which highlights the strong correlation of these variables.

According to the research conducted by the Supreme Chamber of Control in 2016, charging the costs of water supply and sewage disposal in Poland to household budgets, expressed in percentage of the total budget, is one of the highest in the European Union and has already reached a level above which the EU principle of price availability of services will be violated (http://multiconsult-polska.com/ceny-wody-w-polsce-najwyzsze-w-eu).

In the area served by Water Supply Pipelines of Bialystok Ltd., there was also a significant increase in the prices of the service. Table 2 presents a comparison of inflation in Poland according to data from the Central Statistical Office and price increases for water supply services and sewage disposal in Bialystok in the years 2007-2013. The following analysis is based on price levels and inflation in 2007, where it is at the level of 100 percentage points. According to the analysis, the increase in the price of water in the analyzed period, amounting to 142%, is more than double the inflation rate in (119.2%). Similar dependences were noted, among others, in Dębica (Rak et al., 2007), Stalowa Wola (Studziński et al., 2014) and in most of the provincial cities (http://multiconsult-polska.com/ceny-wody-w-polsce-najwyzsze-w-eu).

Meteorological factors also influence the variability of the overall water abstraction and consumption by its users of the urban water supply system (Arbues et al., 2003; House-Peters, Chang, 2011; Hotloś, 2013; Kolendo, 2016a), including to the greatest extent the air temperature and the intensity of rainfall. To determine the causal link of increased fluctuations in water consumption in the period from May to August and to capture certain regularities, the values of daily water demand (in m^3) were compared with meteorological parameters, i.e. the maximum daily temperature (in °C) and daily sum of rainfall (in mm). Meteorological data for Bialystok station (WMO index – 12295) were obtained OGIMET service (www.ogimet.com), due to the large amount of data, detailed analysis and characterization of the influence of meteorological factors was performed for data of 2013.

Table 3. Inflation in Poland and changes of water prices in Bialystok in 2007-2013

Year	Inflation [%]	Changes of water prices in Bialystok [%]
2007	100	100
2008	104,2	106
2009	107,7	120
2010	110,3	126
2011	114,6	135
2012	118,3	142
2013	119,2	142

Source: author's own work based on data from Central Statistical Office of Poland and Municipal Water and Sewage Company in Bialystok.

Many studies have shown that the impact of meteorological conditions on water consumption is recorded only in the spring and summer months (from May to August) (Hotloś, 2013; Kolendo, 2016b), which is also confirmed by the "disturbed" seasonal cyclicity of water consumption as seen in figures 1 and 2. In the present study both the influence on the process of average daily temperature and maximum daily temperature was considered. A much larger correlation was noted considering the maximum daily value of this factor. In addition, the greater influence of the change in the maximum daily temperature changes occurs at higher values of this parameter, i.e. in warmer months (it should be specified in which).

Water demand is also affected by the migration of the population (a school year, an academic year, holidays, public holidays). Therefore, to make the assessment to be more accurate, it was decided to consider the analysis of water demand in each month from May to August as separate periods and not as a single spring/summer season in total. Despite generally higher air temperature in July and August, water consumption is lower. The factors other than meteorological, such as students' departure from the city or the population's departure during the holiday season, have an impact here.

The studies were also conducted considering the variability of water intake in the weekly cycle. Due to the relatively balanced water consumption from Monday to Saturday these days were treated as one group, while Sunday and public holidays were analyzed separately.

As shown in the table below (table 4), the average maximum air temperature in the indicated four months ranges from 20.1°C to 24.5°C. From Monday to Saturday in all the analyzed periods, the influence of the maximum daily temperature is quite strongly correlated with the daily water consumption ($r \in <0,62;0,75>$). As the air temperature increases, the demand for water

also increases. Water consumption on Sundays and other public holidays is considerably lower (by 12-15%) than on weekdays and Saturdays. This is a consequence of the reduction in water consumption by residents, industry and public institutions. On Sunday and public holidays, the relationship between water intake and temperature is similar, although correlation rates are in most cases lower than on the remaining days, and in July even inconsistent with general knowledge. This is due to the fact that the analyzed data series for these days are small and it is difficult to draw general conclusions based on a few observations in the group.

Table 4. Mean water use, meteorological parameters and correlation coefficient

Month	Days	Mean water use [m³]	Mean maksimum temp [°C].	Rainfalls [mm]	Correlation coefficient [*]	
					Temperature [°C]	Rainfalls [mm]
May	Monday-Saturday	42 877,46	21,28	80,10	0,70	-0,37
	Sunday and Holidays	37 651,14	20,06	24,00	0,63	-0,64
June	Monday-Saturday	44 634,92	23,33	30,40	0,62	-0,17
	Sunday and Holidays	38 051,20	23,14	33,10	0,89	-0,10
July	Monday-Saturday	41 526,48	23,49	63,10	0,69	-0,26
	Sunday and Holidays	35 298,25	24,53	26,60	-0,64	-0,64
August	Monday-Saturday	39 676,42	23,58	64,10	0,75	-0,40
	Sunday and Holidays	34 563,80	23,80	0,00	0,74	-

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok and OGIMET.

The precipitation or lack of rainfall have also some impact on the daily water demand. The occurrence of prolonged rain-free periods in the spring-summer period causes an increase in water consumption, for example used to water public greenery, allotment gardens or to sprinkle streets and squares.

Figure 4 shows that during precipitation of more than 10 mm, water consumption is decreasing, but it is difficult to present the statistical impact of total precipitation on water consumption. In the conducted analysis (table 4) for most of the analyzed data sets, there are no statistically significant dependencies. This is due to the sizeable number of rain-free days or days with rainfall below 10 mm, which represents 93% of working days and Saturdays in the period between May and August 2013.

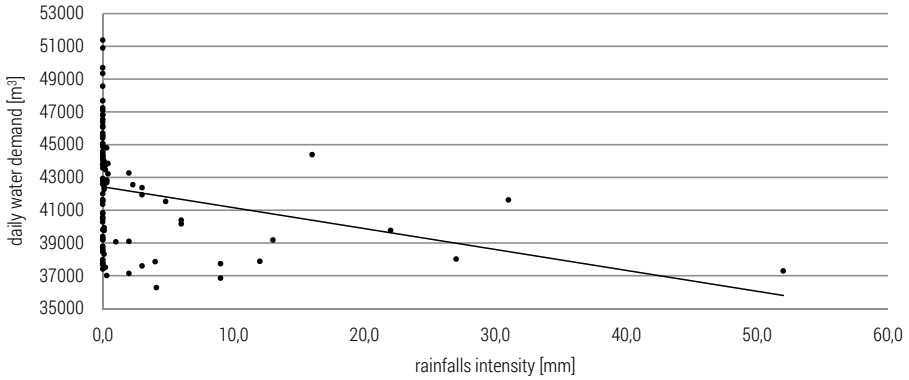

Figure 4. Daily water demand and rainfalls intensity (working days and Saturdays, 2013)

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok and OGIMET.

Conclusions

The paper indicates that the process of daily demand for water in Bialystok municipal water supply system is characterized by a weekly seasonality, which is disturbed several times during the year by the occurrence of public holidays, and in the period from May to August a significant contribution of random factor was also noted. In 2007-2013, the highest average daily demand for water was recorded on Saturdays (943 129 m^3), while the lowest demand for water was recorded on Sundays (37 712 m^3). Analysis conducted in Spain also show clear difference in the demand profile for the different days; namely, Saturdays are clearly different from Sundays (Herrera et al., 2010).

The quantity of water pumped daily into the water mains is determined, among others, by changes in water prices and local climatic conditions. The decreasing tendency, which has been going on for many years, is the result of a significant increase in the price of water, which in the years 2007-2013 was twice as high as the national inflation rate. Moreover, based on the collected data, the influence of population variability on water abstraction has been demonstrated. This process became visible in July and August, when water consumption is decreasing due to the departure of residents and students from Bialystok during their holidays and holiday breaks.

The statistical analysis of 2013 data shows that in the months from May to August there is a significant correlation between water consumption and maximum daily air temperature. The largest correlations were obtained on weekdays and Saturdays in May and August (r=0.70 and 0.79 respectively). The large variety of factors influencing the amount of water pumped into the

water mains and the overwhelming number of rain-free days mean that the influence of the amount of rainfall is sometimes imperceptible. A significant impact maximum daily air temperature and occurrence of rainfalls on daily water demand present also international studies (Bougadis et al., 2005; Yasar et al., 2012; Babel et al., 2014).

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Marcin **DĘBOWSKI** • Marcin **ZIELIŃSKI** • Magda **DUDEK** • Paulina **RUSANOWSKA**

USE OF THE WASTE FRACTION FROM BIOETHANOL PRODUCTION FROM SUGAR BEETS FOR THE PRODUCTION OF CHLORELLA VULGARIS SPECIES MICROALGAE BIOMASS

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ABSTRACT: The objective of this study was to determine the possibility of using a liquid waste fraction generated in the process of bioethanol production from sugar beets for biomass production from Chlorella vulgaris microalgae. The process of microalgae culture was conducted in three variants differing in the volume of the liquid phase fed to the technological system. The highest technological effects in biomass growth were noted in the experimental variants in which the distillery stillage constituted 5% and 7% of culture medium volume. Concentration of biomass achieved in these variants reached 1416±45.30 mgo.d.m./dm3 and 1458.3±54.52 $mg_{o.d.m.}/dm^3$, respectively. Increasing the content of the liquid waste fraction in the medium to 10% caused significant growth inhibition of biomass of algae from the species Chlorella vulraris. The use of such a culture medium for microalgae biomass production requires its pre-treatment to remove organic compounds, color and turbidity.

KEY WORDS: microalgae, bioethanol production, photobioreactors, *Chlorella vulgaris*

Introduction

Nowadays, the development and wide-scale implementation of clean, effective, and renewable technologies for energy production become a challenge to scientists and a priority to operators and administrators of energetic systems. It is commonly believed that this goal may in part be achieved through stimulating the development of unconventional methods for energy production based on the use of biomass of various characteristics and origin (Goyal et al., 2008; Börjesson, Berglund, 2006). This concept has however been undermined by some analyses. For example, Fargione et al. (2008) and Searchinger et al. (2008) demonstrated that irrational management of resources of typical energy crops may in fact lead to a negative balance of the volume of greenhouse gases emitted to the atmosphere. In addition, intensive exploitation of arable lands for the culture of crops intended for biofules production is suggested to have adverse impacts on the global food supply and on a significant increase in food prices (Johansson, Azar, 2007).

Therefore, a real need emerges for alternative sources of biomass whose use for energetic purposes would be justified considering both economic and ecological concerns. Taking into account their very high photosynthetic effectiveness, high rate of biomass growth, resistance to various contaminants and possibility of management of area which cannot be used for any other purposes, algae seem to be a perfect alternative to typical energy crops (Shen et al., 2009; Smith et al., 2010).

One of the key elements determining cost-effectiveness of algae biomass production is the use of an inexpensive and available source of nutrients. Many studies conducted so far have investigated possibilities of using wastewater with high concentrations of nitrogen and phosphorus for this purpose (Wang et al., 2008; Li et al., 2008). Dynamic development of bioenergetic systems based on methane fermentation processes in many cases poses difficulties in the management of post-fermentation sludge. After dehydration, the solid phase is applied as a fertilizer or used in co-combustion processes (Holm-Nielsen et al., 2009). In turn, neutralization of the liquid phase is difficult owing to its considerable volume and high concentration of contaminants. The same case is with the currently popular systems for wastewater treatment under anaerobic conditions which allow for efficient biodegradation of organic compounds but not for the removal of biogenes. This fact excludes the possibility of direct discharge of this wastewater to the natural environment (Rajeshwari et al., 2000).

Considering the characteristics of effluents from bioethanol production and algae demands for nutrients, its seems that a substrate of this type may

represent a source of biogenes and microelements. Algae use may affect intensive growth of biomass and allow for simultaneous neutralization of contaminants. Mùnoz et al. (2004) demonstrated that during the photosynthetic process, algae released from 1.50 to 1.92 kg $O_2 \cdot kg^{-1}$ of the produced biomass and that the rate of oxidation achieved during organic contaminants degradation ranged from 0.48 to 1.85 kg $O_2 \cdot m^{-3} \cdot d^{-1}$. Research works conducted so far have proved that a high concentration of CO_2 in the effluents intensifies algae growth, which has a direct effect upon the effectiveness of contaminants degradation (Lundquist, 2008). In systems based on saline water, the use of wastewater or effluents enables balancing the molecular ratio of carbon, nitrogen and phosphorus (C:N:P = 106:16:1), the so-called Redfield's ratio (Lundquist, 2008).

The objective of this study was to determine the possibility of using a liquid waste fraction generated in the process of bioethanol production from sugar beets for biomass production from *Chlorella vulgaris* microalgae.

Research methods

The liquid waste fraction of distillery stillage from the process of alcoholic fermentation of sugar beets served as the culture medium in the experiment. Mean concentrations of the analyzed components in the material after centrifugation (Rotina 380, 3 min., 9000 rpm) and filtration through a blotted paper filter were presented in table 1.

Table 1. Characteristics of the liquid phase of distillery stillage

Parameter	Unit	Value
COD	mgO_2/dm^3	7800±270
$N_{tot.}$	mg/dm^3	257±24.0
NO_3^-	mg/dm^3	130.33±3.06
NO_3^--N	mg/dm^3	29.37±0.65
NO_2^-	mg/dm^3	0.23±0.037
NO_2^--N	mg/dm^3	0.07±0.012
$P_{tot.}$	mg/dm^3	208±2.0
PO_4^{3-}	mg/dm^3	147.33±5.51

Source: author's own work.

Characteristics of the experimental material excluded the possibility of *Chlorella vulgaris* biomass culture with a crude substrate. Therefore the centrifuged fraction had to be diluted to increase culture medium transparency and to decrease concentrations of organic compounds. The process of microalgae culture was conducted in three variants differing in the volume of the liquid phase fed to the technological system: variant 1 – control, in which the culture medium was prepared based on deionized water and pure chemical reagents (table 2); variant 2 – in which the load of the liquid waste fraction fed to the exploited photobioreactors reached 5%, variant 3 – in which the liquid waste fraction load reached 7% load, and variant 4 – in which the liquid waste fraction load reached 10% of the total volume of the culture medium. Increased percentage of the effluent in the culture medium caused complete growth inhibition of microalgae from the genus *Chlorella vulgaris*. Considering the necessity of using a high dilution rate of the tested liquid waste fraction, the concentration of biogens potentially assimilable by the microalgae biomass in the culture medium was too low. It was , therefore, necessary to introduce external sources of nitrogen compounds (table 2).

Table 2. Composition of the synthetic medium used to culture *Chlorella vulgaris*

Component	Unit	Value
$NaNO_3$	g/dm^3	25.0
$CaCl_2 \cdot 2H_2O$	g/dm^3	2.5
$MgSO_4 \cdot 7\ H_2O$	g/dm^3	7.5
$K_2HPO_4 \cdot 3\ H_2O$	g/dm^3	7.5
KH_2PO_4	g/dm^3	17.5
NaCl	g/dm^3	2.5
VB12	mL/dm^3	1.0
VB1	mL/dm^3	1.0
Microelements	mL/dm^3	6.0
Na_2EDTA	mg/dm^3	0.75
$FeCl_3 \cdot 6\ H_2O$	mg/dm^3	97.0
$MnCl_2 \cdot 4\ H_2O$	mg/dm^3	41.0
$ZnCl_2$	mg/dm^3	5.0
$CoCl_2 \cdot 6\ H_2O$	mg/dm^3	2.0
$NaMoO_4 \cdot 2\ H_2O$	mg/dm^3	4.0

Source: author's own work.

Biomass of microalgae of the *Chlorella vulgaris* species was used in the study. The tested culture of algae originated from the Culture Collection of Baltic Algae (CCBA) deposited at the Institute of Oceanography of the University of Gdańsk. These microalgae are widely used in multiple research areas including both pharmacology, dietetics and cosmetology but also in energetic technologies as potential sources of biomass. The culture used in our study was characterized by high resistance to varying environmental conditions and applicability for the culture in media with various physicochemical characteristics. The initial concentration of microalgae in photobioreactors was ca. 50 $mg_{o.d.m.}/dm^3$.

Chlorella vulgaris biomass was grown in vertical tubular reactors with active volume of 2.5 dm^3 (figure 1), under conditions of 24 lighting (intensity of light reaching the photobioreactor's surface was ca. 5.0 klux). The proper process of algae biomass proliferation was ensured by providing indispensable technological conditions concerning culture medium composition and temperature conditions (23°C). Contents of columns were continuously aerated with compressed air delivered from the reactors' bottoms with Mistral 200 peristaltic pumps having the efficiency of 200 dm^3/h. This technological treatment allowed providing carbon dioxide to the system and effective stirring of algae cultures.

Technical parameters of a single experimental installation were as follows:

Total height	H_{tot} = 72 cm
Active height	H_{act} = 66 cm
Internal diameter	D_{int} = 7 cm
Active volume of tank	V_{act} = 2.4 dm^3

Taxonomic analysis of the cultured biomass of algae was conducted under microscope magnifications of: 1.25×10×40 or 1.25×10×10, using an MF 346 biological microscope with Optech 2MP camera and additionally using a BBE Alage OnLine Analyser by Moldaenke. Microalgae biomass used as the inoculum of the exploited bioreactors was subjected to qualitative analyses which included determinations of contents of: dry matter (d.m.), organic dry matter (o.d.m.), and mineral dry matter (m.d.m.), with the gravimetric method acc. to the Polish Standard (PN–75/C–04616.01). Quantification of individual components in the culture medium and characteristics of the tested liquid waste fraction were carried out in samples after filtration using Hach Lange cuvette tests and a UV/VIS DR 5000 spectrophotometer. Light intensity was measured using an HI 97500 luxometer by HANNA.

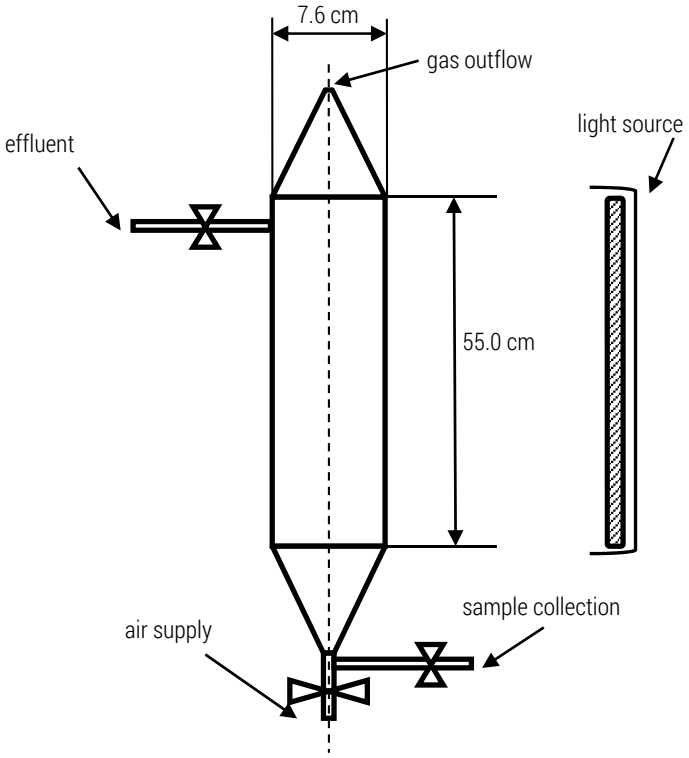

Figure 1. Scheme of a photobioreactor used in the study
Source: author's own work.

Statistical analysis of the results and computation of determination coefficients R^2 were made in STATISTICA package 10.0 PL. All physicochemical analyses were carried out in three replications. The hypothesis on distribution of each analyzed variable was verified with the Shapiro-Wilk W test. One-way analysis of variance (ANOVA) was conducted to determine the significance of differences between mean values. Homogeneity of variance in groups was checked with Levene's test, whereas HSD Tukey's test was used to determine the significance of differences between the analyzed variables. Differences were found significant at $p = 0.05$.

Results

The study aimed to determine the feasibility of using a liquid waste fraction from alcoholic fermentation of sugar beets in the process of culture and proliferation of biomass of *Chlorella vulgaris* microalgae.

The rate of biomass growth in photobioreactors and effectiveness of biogens consumption by the algae were monitored throughout the culture period. The highest technological effects were determined in the control variant in which microalgae were cultured on the medium prepared from deionized water and chemical reagents. The final concentration of microorganisms was 2527.33±170.01 $mg_{o.d.m.}/dm^3$ (figure 2), while the effectiveness of nitrogen and phosphorus compounds removal from the culture medium accounted for 76% (figures 3 and 4), and the coefficient of biomass growth for 247.40 $mg/dm^3 \cdot d$ (table 3).

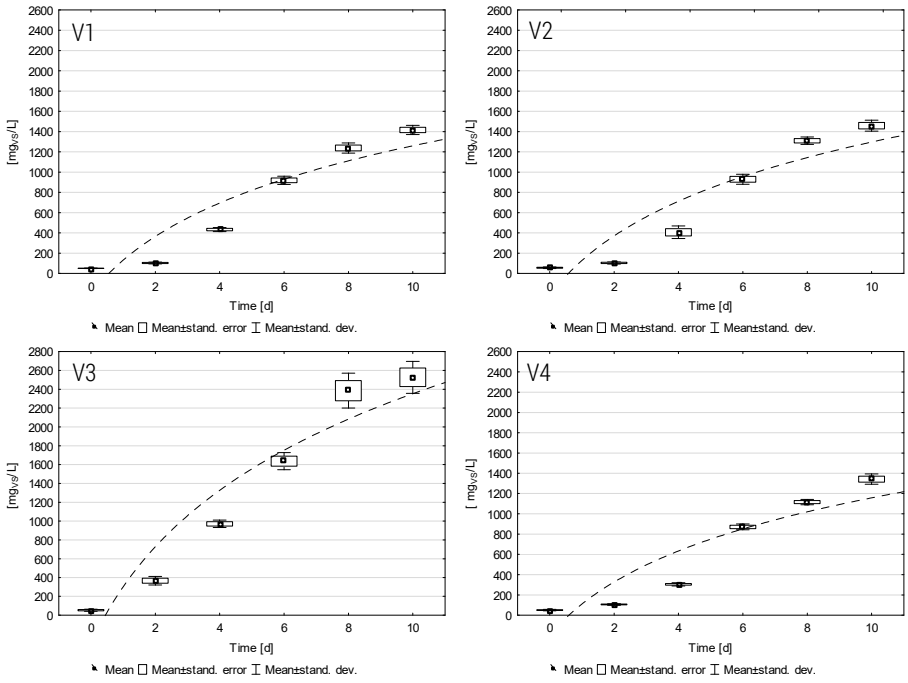

Figure 2. Changes in organic dry matter concentration in the culture medium in the subsequent experimental variants

Source: author's own work.

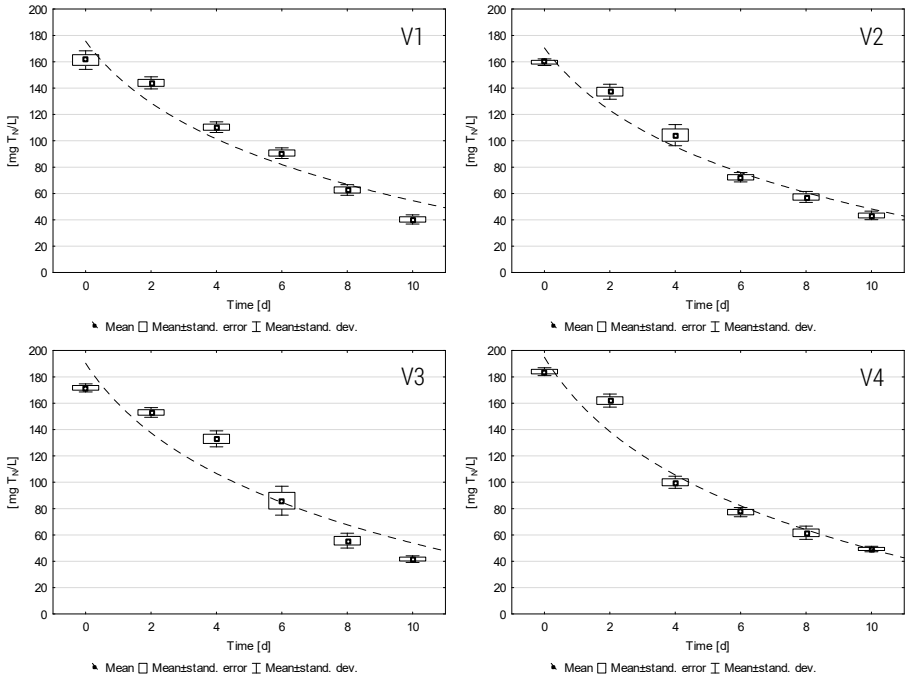

Figure 3. Changes in total nitrogen concentration in the culture medium in the subsequent experimental variants

Source: author's own work.

In variants established to test the liquid phase of distillery stillage in the process of microalgae biomass proliferation, the concentrations of produced biomass were significantly lower. In variant 2, the concentration of *Chlorella vulgaris* was at 1416 ±45.30 $mg_{o.d.m.}/dm^3$ and the effectiveness of nitrogen compounds removal reached 73% (figure 2 and 3). In variant 3 the respective value was at 1458.3 ±54.52 $mg_{o.d.m.}/dm^3$ (figure 2). Similar was also the effectiveness of nitrogen compounds consumption by microalgae which reached on average 76% at the end of the culture (figure 3). Variant 2 and 3 were characterized by a high effectiveness of phosphorus compounds removal from the culture medium, i.e. 91%-92% for each variant (figure 4). The rate of biomass growth was 136.50 $mg/dm^3 \cdot d$ in variant 2 and 140.20 $mg/dm^3 \cdot d$ in variant 3 (table 3). Poorer technological effects were observed in variant 4. The concentration of produced biomass was at 1343.0 ±50.59 $mg_{o.d.m.}/dm^3$ and biomass growth coefficient at 129.20 $mg/dm^3 \cdot d$ (figure 2, table 3). Effectiveness of denitrification reached 73% (figure 3). In turn, effectiveness of phosphorus compounds removal reached barely 63% and their concentration in the culture medium after completed culture accounted for 6.87 ±0.21 mg $P_{tot.}/dm^3$ (figure 4).

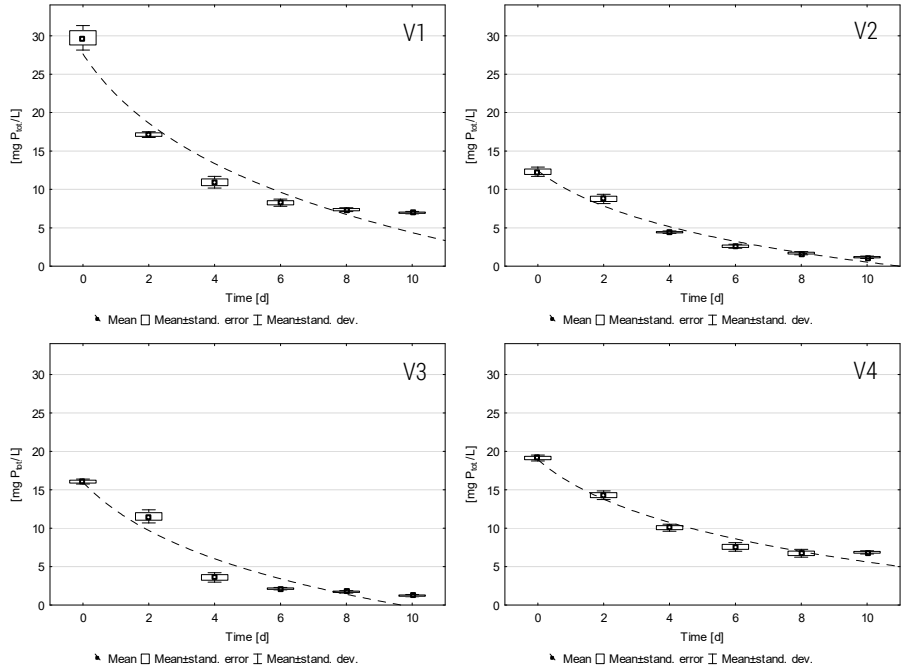

Figure 4. Changes in total phosphorus concentration in the culture medium in the subsequent experimental variants

Source: author's own work.

Discussion

Many literature reports suggest the feasibility of using liquid wastes of various type in the process of microalgae biomass production (Mùnoz, Guieysse, 2006). Their use as a culture medium may directly contribute to reduction of costs incurred on the supply of water and nutrient substances indispensable for the effective growth of microalgae biomass (Wang et al., 2010). Experimental works conducted so far have proved that high concentration of CO_2 in wastewater and effluents intensifies algae biomass growth, which has a direct impact on the effectiveness of contaminants degradation (Lundquist, 2008). In this study, we analyzed the possibility of using a liquid waste phase from bioethanol production from sugar beets in the process of microalgae biomass production.

In the case of using waste substrates, of outmost significance is the choice of an appropriate species characterized by relatively high resistance to substances likely to occur in the applied wastes. It was proved that such requirements were met by the species of *Chlorella sp.* and *Scenedesmus sp*. genera.

Algae from the genus *Chlorella sp.* are resistant to effects of heavy metals, owing to which they may be used in treatment processes of industrial wastewater (Mùnoz et al., 2003). Literature works provides examples of using algae from the genus *Chlorella sp.* in biodegradation of so noxious wastewater like: landfill leachate (Lin et al., 2007), wastewater from the timber and paper industry (Yewalkar et al., 2007), from textile industry (Acuner, Dilek, 2004), from phenolic industry (Essam et al., 2007) or from the production of ethanol and citric acid (Valderramaa et al., 2002). *Chlorella sp.* is used for the treatment of wastewater containing organic compounds, e.g. effluents from fermentation tanks (Ogbonna et al., 2000), or from dairy processing plants (Bernal et al., 2008). Other investigations proved that *Chlorella pyrenoidosa* may be cultured based on effluent from a fermentation tank and contribute to effective removal of organic contaminants and biogenes. In this study, microalgae biomass concentration in the reactor reached 1.25 g d.m./dm^3. It was also found that the effectiveness of contaminants removal by *Chlorella pyrenoidosa* reached 78.76% for nitrogen, 94.78% for phosphorus and 98.34% for COD since day 6 to day 8 of the culture (Su et al., 2012). Considering the aforementioned results, we tested biomass of *Chlorella vulgaris* in our study.

The phenomenon of *Chlorella sp.* growth inhibition in the subsequent experimental variants could be due to a high concentration of organic compounds in the culture medium. Wang et al. (2010) analyzed the possibility of using effluent from bovine manure fermentation as a source of nutrients for *Chlorella sp.* They demonstrated that the effectiveness of biomass production, content of lipids in algae cells and effectiveness of contaminants removal were correlated with the dilution rate of the post-fermentation effluents. Other investigations proved the initial concentration of COD originating from wastewater treatment plant in the culture medium to be the factor determining growth rate of biomass of microalgae from the genus *Scenedesmus sp*. (Uggetti et al., 2014). High concentrations of organic compounds increase the growth of bacterial biomass competitive to microalgae (Szwaja et al., 2016). Bacteria use nutrients from the culture medium, which additionally reduces the effectiveness of microalgae biomass growth.

Another reason may be restricted access of light resulting from turbidity and coloration of the liquid waste fraction generated in the process of bioethanol production from sugar beets. Feeding high doses of this substrate to photobioreactors had a direct effect on reduced light permeability of the medium.

Table 3. Analysis of the culture medium and algae biomass

Variant	Day of culture	COD	T_N	$P_{tot.}$	NO^{3-}	NO^{3-}-N	NO^{2-}	NO^{2-}-N	PO_4^{3-}	d.m.	m.d.m.	o.d.m.	Biomass growth coefficient
		mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³·d
V1	0	41.1±2.74	161.33±7.02	29.13±1.60	77.2±5.5	14.4±0.7	0.038±0.12	0.011±0.01	101±4.38	265±52.12	205±25.41	53.33±11.24	247.40
	2	57.8±4.62	144.0±4.58	17.13±0.38	649±12.1	147±12.4	0.791±0.13	0.241±0.02	41.4±1.29	684±104.89	284±12.35	366.67±45.54	
	4	36.7±7.52	110.0±4.04	10.93±0.75	382±11.0	86.4±5.4..	1.37±0.22	0.417±0.09	32.1±2.47	1298±214.84	275±12.47	971.0±39.51	
	6	74.5±6.94	90.67±4.04	8.27±0.47	648±14.8	146±12.5	1.87±0.20	0.569±0.15	23.0±3.21	1884±389.32	220±24.62	1636.33±91.05	
	8	81.2±8.98	62.67±4.05	7.37±0.25	394±14.3	112±8.62	2.57±0.24	0.846±0.18	24.6±2.15	2699±264.52	275±24.34	2386.0±185.98	
	10	83.8±5.84	40.33±3.51	6.97±0.15	368±9.5	83.1±9.5	3.88±0.35	1.18±0.28	25.3±1.98	2857±285.41	290±13.25	2527.33±170.0	
V2	0	2212±62.0	159.67±2.52	12.3±0.61	85.14±10.2	13.56±2.6	0.05±0.005	1.21±0.06	37.4±2.5	252±47.34	199±24.6	51±2.0	136.50
	2	1238±24.0	137.33±5.68	8.77±0.60	274.25±22.5	121.3±15.4	0.284±0.006	1.78±0.07	9.6±3.1	322±38.41	215±41.3	104±8.89	
	4	353±14.6	104.33±8.02	4.43±0.15	155±14.2	35.9±8.6	6.79±0.6	2.07±0.9	16.5±2.5	723±62.47	287±28.6	433±19.67	
	6	553±26.3	72.33±3.51	2.6±0.26	47.1±8.6	10.6±3.6	20.2±2.4	6.15±1.4	9.32±1.9	1564±51.4	607±15.7	919±40.73	
	8	608±19.4	57.33±4.16	1.7±0.2	81.4±4.9	18.4±2.4	21.6±6.2	6.59±1.6	8.5±0.7	1897±47.2	679±61.3	1238±49.16	
	10	616±31.0	43.33±3.21	1.17±0.15	92.9±12.4	21.0±3.7	22.1±3.7	6.74±2.0	22.1±4.6	2112±28.4	702±22.2	1416±45.30	

V3	0	4330±74.6	171.67±3.05	16.07±0.32	82.71±124	17.22±7.6	0.07±0.06	0.83±0.07	50.21±5.8	212±12.4	154±14.9	56±8.19	140.2
	2	2870±51.2	153.0±3.61	11.53±0.85	185.43±14.6	136.24±12.6	0.412±0.04	0.94±0.04	12.47±0.8	347±33.1	244±21.5	104±10.54	
	4	611±24.6	133.0±6.08	3.6±0.62	29.5±8.4	6.66±1.7	3.85±0.6	1.17±0.06	16.32±2.4	887±62.4	420±23.4	407±62.65	
	6	803±18.6	86.0±11.0	2.13±0.15	3.31±0.5	0.75±0.05	0.31±0.01	0.01±0.01	19.24±2.6	1578±42.7	626±24.7	929±49.44	
	8	882±24.6	55.67±5.68	1.73±0.15	4.0±1.3	0.90±0.04	0.56±0.08	0.17±0.01	13.62±2.9	2010±24.6	695±33.5	1310±36.76	
	10	889±19.7	41.67±2.52	1.23±0.15	4.30±0.98	0.97±0.07	0.45±0.05	0.14±0.04	24.4±4.7	2183±44.3	723±41.3	1458±54.52	
V4	0	5755±61.4	184.0±3.0	19.13±0.38	96.1±18.4	22.44±4.6	0.09±0.001	1.16±0.01	63.14±10.6	210±14.7	158±14.6	51±7.02	129.2
	2	4330±34.9	162.0±5.0	14.3±0.56	214.72±12.4	151.18±9.1	0.617±0.07	1.21±0.02	16.32±5.6	319±21.8	221±21.4	106±8.0	
	4	1215±41.3	100.0±4.58	10.07±0.45	38.15±6.4	36.21±6.3	5.84±0.8	1.97±0.01	19.4±4.6	700±19.7	385±14.8	304±15.14	
	6	1281±21.8	77.33±3.51	7.57±0.57	7.21±2.3	15.84±4.5	23.14±2.4	4.18±0.4	18.3±3.1	1438±51.4	591±24.5	871±29.41	
	8	1312±33.9	61.67±5.03	6.73±0.50	8.14±2.7	16.21±3.7	24.63±6.1	6.51±1.3	15.6±3.4	1805±37.4	684±46.1	1115±26.41	
	10	1330±14.52	49.33±2.08	6.87±0.21	8.05±1.98	24.18±6.8	22.51±4.7	7.44±0.9	25.4±2.8	2095±61.4	775±40.8	1343±50.59	

Source: author's own work.

Conclusions

The conducted study demonstrated a very limited possibility of using the tested liquid phase in the proliferation process of *Chlorella vulgaris* microalgae owing to a high concentration of organic compounds, low transparency of the medium, and low concentrations of nitrogen and phosphorus. The highest technological effects in biomass growth were noted in the experimental variants in which the distillery stillage constituted 5% and 7% of culture medium volume. Concentration of biomass achieved in these variants reached 1416±45.30 $mg_{o.d.m.}/dm^3$ and 1458.3±54.52 $mg_{o.d.m.}/dm^3$, respectively. Increasing the content of the liquid waste fraction in the medium to 10% caused significant growth inhibition of biomass of algae from the species *Chlorella vulraris*. The use of such a culture medium for microalgae biomass production requires its pre-treatment to remove organic compounds, color and turbidity.

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The contribution of the authors

Marcin Dębowski – development of research methodology, supervision of experimental work, analyses and presentation of results – 25%
Marcin Zieliński – literature review, construction and operation of photobioreactors – 25%
Magda Dudek – experimental works and analyses of results – 25%
Paulina Rusanowska – operation of photobioreactors, draw conclusions and summary – 25%

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PSEUDOMONAS FLUORESCES OCCURRENCE IN SOIL AFTER FERTILIZATION WITH SEWAGE SLUDGE

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ABSTRACT: The aim of the study was to analyze the occurrence of *Pseudomonas fluorescens* in urban soil in the second year after fertilization with unprocessed sewage sludge from the wastewater treatment plant in Sokółka and processed sludge from wastewater treatment plant in Bialystok. The study was conducted on experimental plots located in the green belts along the main roads in Bialystok (Piastowska and Hetmańska streets). For the studied soil, two different types of sewage sludge were used: after-press dewatered sludge from the treatment plant in Sokółka and dry sludge in the form of pellets from the treatment plant in Bialystok. The experiment plots were fertilized with three doses of sewage sludge: 0-control, 14.5 and 29 Mg D.M./ha. In the second year after application of sewage sludge, microbiological tests of the rhizosphere area showed seasonal fluctuations in the number of *Pseudomonas fluorescens* bacteria. The highest number of *Pseudomonas fluorescens* bacteria was observed in April and in October, while the lowest number of bacteria occurred in July, which could have been conditioned by atmospheric factors. The analysis of the correlation indicates that in the urban soil mixed with sewage sludge the number of *Pseudomonas fluorescens* was significantly positively correlated with C:N ratio, organic carbonand content of phosphorus.

KEY WORDS: *Pseudomonas fluorescens*, urban soil, sewage sludge

Introduction

One of the forms of sewage sludge management is the environment use which is conditioned by its mineral and organic composition, similar to that of soil humus. Siuta (2003) reports that in sewage sludge organic fraction constitutes 35-40%. The organic matter and nutrients contained in the waste constitute a potential that should return to the natural cycle and should be used by plants. In addition, an important purpose of the use of sediments is to inhibit water or wind erosion of land by planting vegetation on the surface (Bień, Wystalska, 2011). Moreover, apart from the positive aspect of the use of sludge, there is also a negative aspect. As reported by Merrington and Smernik (2004), one of important threats related to sewage sludge use may occur when various xenobiotics are introduced into the soil along with sewage sludge. According to Singh and Agrawal (2008), the concentration of xenobiotic compounds in sewage sludge depends on such factors as sludge origin, sewage treatment and processing, the bioavailability of xenobiotics brought with sludge into the soil which are determined by soil properties such as pH, redox potential, content of organic matter as well as the size of applied sewage sludge dose (Wilk, Gawronek, 2009).

The biomass of microorganisms in soils constitutes approximately 85% of the total biomass of all organisms living in this environment. Approximately 90% of resulting carbon dioxide in soil is produced in microbes life, which indicates the high metabolic activity and the great importance of microorganisms for most processes occurring in the soil environment (Dahm et al., 2010). As a result of microbial processes of organic matter transformation, humus is formed, the quantity of which is one of the most important factors determining the soil ability to store water and nutrients. Microorganisms also contribute to the degradation and detoxification of various soil pollutants, reduce the development of pests and pathogens of plants and directly (symbiosis, mycorrhiza) or indirectly influence the growth of plants (Martyniuk, Księżak, 2011). Among many microorganisms found in soil, the numerous Pseudomonas bacteria present in the rhizosphere of plants, deserve scholarly attention.

Pseudomonas fluorescens belong to the most widespread groups of microorganisms in the environment which can occur in soil, on plants, in fresh water and in deep sea. These gram-negative sticks produce fluorescein – a dye that causes them to glow in UV light. The major source of their energy is hydrocarbons (Nagarajkumaret et al., 2004).

Bacteria of the genus Pseudomonas are representatives of the so-called rhizobacteria, which are characterized by forming associations with plant roots. These bacteria degrade many different sugars, amino acids, alcohols,

as well as highly molecular compounds, e.g. humic acids or pesticides (Nagarajkumaret et al., 2004). Some bacteria of the genus Pseudomonas produce diffusing, fluorescing compounds called siderophores which have a high affinity with iron compounds. These species are used for biological control of phytopathogens found in soil. These bacteria that produce siderophores trap iron and prevent pathogens from obtaining this compound from the environment (Mercado-Blanco et al., 2001).

The aim of the study was to analyze the occurrence of *Pseudomonas fluorescens* in urban soil in the second year after fertilization with two kind of sewage sludge obtainedfrom the treatment plant in Bialystok and the treatment plant in Sokółka.

Research methods

Experimental design

The study was conducted on experimental plots located in the green belts along the main roads in Bialystok (Piastowska and Hetmańska streets). Each of the test points of an area of 90 m^2 was divided into three blocksof an area of 30 m^2 each, which constituted further repetitions. For the studied soil, two different types of sewage sludge were used: after-press dewatered sludge from the treatment plant in Sokółka and dry sludge in the form of pellets from the treatment plant in Bialystok. The experiment plots were fertilized with three doses of sewage sludge: 0-control, 14.5 and 29 Mg D.M./ha.

Before the beginning of the experiment, the sewage sludge and soil collected from all combinations were analysed according to the Directive of Environmental Minister of February 6th, 2015 concerning municipal sewage sludge (tables 1 and 2).

Table 1. Chemical-physic properties of the soil before sludge application

Soil samples	pH	Heavy metals content in mg/kg of DM of sediment							[%]		
		Cd	Cu	Ni	Pb	Zn	Hg	Cr	Sand	Silt	Clay
Hetmańska street	8.1	0.5	16.7	6.3	7.5	50.8	0.06	12.1	75.9	22.0	2.1
Popiełuszki street	7.7	0.6	26.3	8.5	5.6	74.4	0.14	11.5	75.7	22.3	2.0

Source: author's own work.

Sewage sludge from the treatment plant in Sokółka and the treatment plant in Bialystok used in the experiment contained: dry matter 19.3% and 81.7%, organic matter 58.4 and 56.9% D.M., N – 3.99 and 4.6% D.M., P – 2.73

and 3.26% D.M., Ca 5.51 and 3.79% D.M., Mg 0.66 and 0.57% D.M. and its pH was 6.7 and 8.2, respectively.

Table 2. Selected chemical and biological properties of sewage sludge

Indicators	Heavy metals content in mg/kg of dry matter (D.M.)					
	Cd	Cu	Ni	Pb	Zn	Cr
after-press dewatered sludge	<0.5	194	22	23,5	1459	58
dry sludge in the form of pellets	<1.25	198	30.1	26.0	1045	76.6
limit value in the application of sludge to land reclamation for non-agricultural purposes	25	1200	400	1000	3500	1000
viable helminth ova of Ascaris sp., Trichris sp., Toxocara sp.	not detected					
bacteria of the genus Salmonella in 100 g of sludge	not detected					

Source: author's own work.

Physico-chemical parameters of soil samples

The particle size was determined using the Casagrande areometric method modified by Prószyński according to PN-R-04032 standardwhich is dedicated to the analysis of agricultural soils. In spring and autumn, the pH of the soil was evaluated in distilled water in the ratio 1:2.5 (m:v) using a HACH Lange pH-meter.

The organic matter content was determined by drying the soil samples at 105°C (removing hygroscopic water) and then burnt in a muffle furnace at 500ºC. The total organic carbon (TOC) was measured by Tiurin method described by Ostrowska et al. (1991). The total nitrogen content was analysed by Kjeldahl method using Gerhardt's Vapodest 50s after mineralization using Kjeldatherm (Gerhardt) block digestion.

Microorganisms analyses

The rhizosphere soil samples for microbiological analyses were collected at three times: in April, July and October in the second year after the application of sludge. The grass roots were taken with soil adhering to them from each test plot to specially marked containers inserted into the fridge and transported to the laboratory for a further analysis. Then, 5 g of roots with the soil was suspended in 45 ml of sterile saline solution (solution of 0.85% NaCl) shaken for 10 min and then subjected to dispersion. A serial ten-fold dilution (10-1–10-6) was prepared for each of the samples and each dilution was used to inoculate Petri dishes. The number of bacteria of the species *Pseudomonas fluorescens* cultured in a mineral medium containing Bacto-

-Pepton (20.0 g); KH_2PO_4 (1.5 g); $MgSO_4 \times 7H_2O$ (1.5 g) and agar (15.0 g) per liter of deionized water. The pH was adjusted to 7.2 with 1MNaOH and glycerol (10%; v/v; 1.37 M) was added as a sole source of carbon (Galimska-Stypa et al., 1999). The bacteria were incubated at 28°C for 72 h and then the fluorescence was detected in UV light on the transluminator (UV Transilluminator (MD-20/HD-20) from Wealtec), then selected colonies were checked using API 20E tests.

The mean number of colonies in triplicate was presented as a colony-forming unit (cfu) in grams of roots and soil dry matter (DM).

Statistical analysis

The effect of selected soil properties on the number of *Pseudomonas fluorescens* was assessed using Spearman's correlation analysis at the significance level of $p < 0.05$. The effect of sewage sludge fertilization and the date of sampling were determined using the ANOVA variance analysis. Material differences were statistically evaluated using the Tukey test at the significance level of $p \leq 0.05$. The Statistica 13 was used.

Results of the research

Due to the high content of organic matter as well as its macro- and micro components sewage sludge is increasingly used in fertilizing agricultural and forestry areas and in recultivation of urban soil (Kaniuczak et al., 2009; Wołejko et al., 2015). Augustynowicz et al. (2010) draw attention to the beneficial properties of using sewage sludge as a fertilizer stimulating the number of soil bacteria. Based on the results of the present study, one observed that applied doses of sewage sludge from the two sewage treatment plants had an influence on the number of *Pseudomonas fluorescens* bacteria in the rhizosphere area (figures 1 and 2). The sewage sludge from the treatment plant in Sokółka applied on plots at Popiełuszki street significantly influenced the number of analyzed bacteria. In the growing season, the highest average number of *Pseudomonas fluorescens* bacteria was observed in the plots where the dose of sewage sludge was applied in the amount of 29 Mg D.M./ha (12.0 $CFU*10^5\ g^{-1}$D.M.), and the lowest – on the control plots (7.6 $CFU*10^5\ g^{-1}$D.M.). In turn, on the plots at Hetmańska street, it was observed that average number of *Pseudomonas fluorescens* bacteria was the highest on the control plots – 11.26 $CFU*10^5\ g^{-1}$D.M., while for the plots fertilized with 29 Mg DM/ha, it was 5 $CFU*10^5\ g^{-1}$D.M.

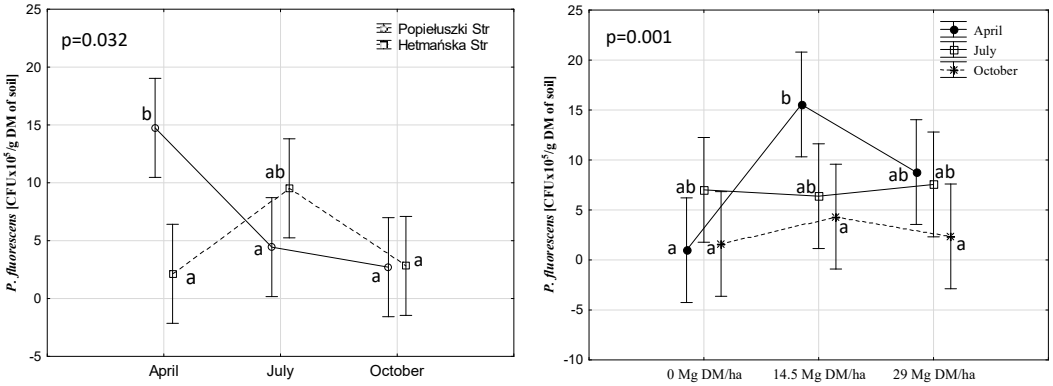

Figure 1. Occurrence of *Pseudomonas fluorescens* bacteria in the rhizosphere zone in the second year after application of sewage sludge from the treatment plant in Sokółka depending on the location and dose of sewage sludge. The same letters for average values mean no significant differences evaluated by Tukey test for p<0,05

Source: author's own work.

The present research study showed that in October there was the highest number of analyzed bacteria in the soil samples collected at Popiełuszki and Hetmańska streets, while in July the lowest was observed, which was probably caused by changes in environmental conditions (soil moisture and temperature) (figure 1). A similar relationship was also noticed in the research by Natywa et al. (2011) and Górska et al. (2007) who presented the dependence of the number of soil microorganisms on weather conditions in particular seasons. In the studied number of bacteria, periodic fluctuations may have been caused by the variability of atmospheric conditions, the length of precipitation, drought and changes in the microclimate.

On the plots where sewage sludge from the treatment plant in Bialystok was used, one observed the highest average number of *Pseudomonas fluorescens* at Popiełuszki street in April at the highest dose of sewage sludge of about 20.0 CFU*10^5 g^{-1}D.M., while the lowest was recorded on the control plots in September (3.5 CFU*10^5 g^{-1}D.M.) In turn, on the plots at Hetmańska street the highest number of *Pseudomonas fluorescens* bacteria was observed in July on the control plots (30.0 CFU*10^5 g^{-1}D.M.), while the lowest was recorded on the control plots in April (8.0 CFU*10^5 g^{-1}D.M.) (figure 2). The applied doses of sludge had a significant impact on the number of analyzed bacteria. On the plots fertilized with sewage sludge, the number of *Pseudomonas fluorescens* increased by approximately 15% compared with the control plots.As noted by Martin et al. (2004), after adding sewage sludge to the soil, it is very important to determine the (bio)chemical changes occurring in the vicinity of the roots, because they affect significantly the develop-

ment of soil microorganisms and decomposition of xenobiotics present in soil.

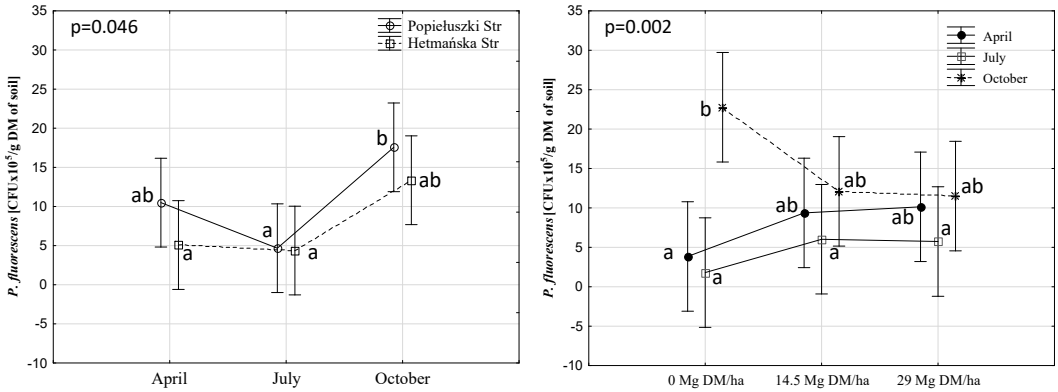

Figure 2. Occurrence of *Pseudomonas fluorescens* bacteria in the rhizosphere zone in the second year after application of sewage sludge from the Treatment Plant in Bialystok depending on the location and dose of sewage sludge. The same letters for average values mean no significant differences evaluated by Tukey test for p<0,05

Source: author's own work.

According to the research conducted by Siuta (2003), sludge produced as a by-product of wastewater treatment should be used to increase the biological activity in the soil. The development of microorganisms in the soil is influenced by many factors such as: physical and chemical properties of the soil, organic matter, applied fertilization as well as climatic and environmental conditions (Jezierska-Tys, Frąc, 2008). Based on our results, it was found that the ratio of C:N for the control plots ranged from 3.7 to 14.5, but for the plots where one applied after-press sludge it was 3.9 to 9.2, while for the plots where dry sludge, it was from 6.2 to 11.8. Moreover, on all the test plots soil pH was alkaline and ranged from 7.3 to 8.3 for the plots fertilized with after-press sludge and from 6.9 to 8.1 for the plots where dry sludge was used.

The statistical analysis revealed a significant correlation between the number of *Pseudomonas fluorescens* in the soil and the C:N ratio, silt and organic carbon (r=0.43, r=0.49 and r=0.64, respectively) at $p \leq 0.05$. The normal development of soil bacteria will also depend on the availability of phosphorus in the soil. In this study, the content of phosphorus ranged from 15.0 to 72.0 mg P_2O_5/100 g D.M. for the plots where dry sludge was usedand for the plots where one applied after-press sludge it was 5.0 to 19.0 mg P_2O_5/100 g D.M. The content of this element in the soil influences the increase

of biochemical and microbiological activity of the soil, which results in the transformation and availability of other nutrients (Bünemann et al., 2013).

In this study, one observed a positive correlation between the number of *Pseudomonas fluorescens* in the soil and content of phosphorus (r=0.63), which suggests that increases of the number bacteria may cause the increases of the content of phosphorus in the soil thus it can be more accessible to plants. Jezierska-Tys and Frąc, (2008) indicate that *Pseudomonas fluorescens* belong to the group of microorganisms that dissolve phosphates. This process consists in the secretion of phosphorus-releasing organic acids in an inorganic form. Moreover, in our study, one observed a negative correlation between the number of *Pseudomonas fluorescens* with a pH, sand and clay (r=-0.62, r=-0.45 and r=-0.55, respectively) at $p \leq 0.05$.

Conclusions

1. In the second year after the application of sewage sludge, microbiological tests of the rhizosphere area showed seasonal fluctuations in the number of *Pseudomonas fluorescens* bacteria.
2. The highest number of *Pseudomonas fluorescens* bacteria was observed in April and in October, while the lowest number of bacteria occurred in July, which could have been conditioned by atmospheric factors.
3. On the plots where dry sludge pellets were used, one observed an increase in the number of *Pseudomonas fluorescens* bacteria by approximately 15% compared with the control plots.
4. The analysis of the correlation indicates that in the urban soil mixed with sewage sludge the number of *Pseudomonas fluorescens* was significantly positively correlated with C:N ratio, organic carbonand content of phosphorus.

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The contribution of the authors

Elżbieta Wołejko – formulation of research concept and objectives, literature review, statistical analysis – 55%
Urszula Wydro – participation in the samples preparation for microbiological analysis and literature review – 30%
Agata Jabłońska-Trypuć – improving the manuscript after the reviews – 5%

Andrzej Butarewicz – participation in the literature review – 5%
Tadeusz Łoboda – participation in the literature review – 5%

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Małgorzata **KRASOWSKA** • Zofia **TYSZKIEWICZ**

SOILS FROM BUFFER ZONES IN THE AGRICULTURAL CATCHMENT – SELECTED PHYSICAL, CHEMICAL, AND BIOLOGICAL PROPERTIES

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ABSTRACT:The research was undertaken to analyze selected physicochemical and biological properties of soils from the buffer zones of a small watercourse located in the agricultural catchment area of North-Eastern Poland. Research points were located in the buffer zone. Samples were taken from the surface soil level. In samples were measured the pH, organic carbon, total nitrogen, nitrates as well as the emission of carbon dioxide and nitrous oxide. The quantitative and qualitative composition of the microscopic fungi (micromycetes) communities that inhabit the analyzed soils was also determined. It was found that the soil in the buffer zone, which is formed by shrubs and which separates arable land from the river, is more abundant in selected solutes, has a higher carbon dioxide emission, also has a richer quantitative and qualitative structure of fungi. It was found that soils from buffer zones are the place of dynamic processes that affect biological and chemical properties.

KEY WORDS: buffer zone, soil, *micromycetes*

Introduction

Progressive agricultural intensification leads to changes in various ecosystems (Kamiński, Chrzanowski, 2007). It directly affects areas used for agriculture and areas adjacent to them. One such adverse impact is the impact on the eutrophication of surface waters located in agricultural areas, from which nutrients move with surface and ground runoff. This leads to a series of adverse environmental changes (Koc et al., 2003; Kwaśna, 2014; Krasowska, Banaszuk, 2015). Therefore, various measures are taken to reduce the migration of nitrogen and phosphorus compounds from agricultural sources (Pietrzak, 2012). Among other things, attention is paid to the need to create buffer zones (biogeochemical barriers) along surface watercourses, i.e. belts of trees and shrubs or permanent grassland. On the one hand, they are a natural part of the landscape, on the other hand, can effectively prevent the pollution of rivers and water reservoirs by biogenic compounds, which migrate from the crop fields (Borin, Bigon, 2002; Lam et al., 2011; Frątczak et al., 2012). The barrier slows the subsurface and surface outflow. It prolongs the contact time of water with the soil and plant roots, and thus allows microorganisms to decomposition of biogenic compounds, which leads to a reduction in the concentration of pollutants (Correll, 2005; Hefting et al., 2005; Liu et al., 2008).

Soil belongs to the most important and the most complicated environments in which microorganisms that take part in the decomposition of organic compounds from organic matter of plant and animal origin develop. Part of the decomposition products is used by plants for the production of biomass, some are incorporated into the biomass of microorganisms, some are in turn included inhardly decomposable soil organic matter (Barabasz, Vořišek, 2002; Bogacz et al., 2004; Niklińska, Stefanowicz, 2015). It was determined that 1 g of soil contains from several thousand to several billion cells of bacteria. The number of actinomycetes is similar. Among the soil fungi, saprophytic organisms dominate, which deal with the decomposition of organic compounds (Kwaśna, 2014). Thus, microscopic fungi (*micromycetes*) are an important ecological ingredient that determines the type of biological decomposition of organic matter and biomass production. Also, the structures of fungal communities depend on the ecological conditions of the environment. They are a component of biocenosis that reacts the most quickly to changes in the parameters of this environment. Therefore, they can be used as an indicator of environmental changes, including changes in soils (Błaszczyk, 2007; Mułenko, 2008; Frączak, 2010; Traczewska, 2011).

Undoubtedly, knowledge of individual elements of the natural environment that affect the functioning of buffer zones is important from the point of

view of assessing their role in agricultural catchments. For these reasons, soil research was undertaken in the buffer zones of a small watercourse in the agricultural landscape of North-Eastern Poland. These zones differed in vegetation and the research concerned the determination of selected physicochemical parameters of soils and the character of the *micromycetes* communities inhabiting them.

Research area

Research areas have been established in the agricultural catchment, in which there are both arable and grassland. The research was conducted near the small watercourse zone in North-Eastern Poland. The watercourse is a left-bank tributary of Horodnianka and is located about 1 km from Choroszcz.

The research surfaces were located at a distance of about 2 m from the watercourse, on both sides. These areas formed buffer zones, which differed in vegetation and land use above the riverbed. One of the research areas was under trees and shrubs, while the other was covered with turf. The crop structure was dominated by cereal crops and fodder maize. The meadows were mown once and then grazed.

The analyzed soils are mucky-black soils mounds that are made of clay sands (Systematyka Gleb Polski, 2011; Marcinek, Komisarek, 2015). The surface level from which the samples originated was characterized by a black color and crumbling structure. The crumbs were durable, well-formed, and they reached sizes ranging from 0.5 to 1.5 cm.

Methods

The soil samples came from a depth of 10-20 cm. In order to perform physicochemical analyzes, they were taken four times: on 2, 7, 13 and 22 November 2016, while microscopic fungal communities were assessed in a sample that was collected on November 7.

In the samples, the pH in H_2O was determined, which was measured potentiometrically. The organic carbon was measured by the catalytic oxidation method, total nitrogen was measured by the Kjeldahl method, and nitrate ions were determined spectrophotometrically. The emission of carbon dioxide (CO_2) and nitrous oxide (N_2O) was also determined. Measurements of CO_2 and N_2O emissions were made using the chamber method. The chamber was placed in a frame that was embedded in the soil. Gas samples were taken

from the chamber for 1 hour every 15 minutes with gas-tight syringes. The CO_2 and N_2O concentrations were determined in the laboratory using a gas chromatograph.

For the isolation of micromycetes fungi, the method of soil tiles Warcupa (1950) in the modification of Mańka was used (Johnson, Mańka, 1961; Mańka, 1964; Mańka, Salmanowicz, 1987). The similarity between fungal communities was determined using the Jaccard coefficient (Zak, Willig, 2004). In addition, air and topsoil temperatures (at a depth of approx. 5 cm) were measured on the day of sampling and the depth of groundwater retention was also measured.

Results and discussion

The average temperature of the air and the topsoil was about 4°C. The depth of ground water level at the beginning of the study (November 2) was 80 cm, while at the end of the study (November 22) it was 50 cm. The groundwater level was at the level of 75 cm on the day of sampling for mycological analyzes (November 7).

The analysis of the results of selected physicochemical properties of soils from the zone at the riverbed in arable land and grassland allows concluding that the mean values of determined parameters in both soils were similar to each other. The analyzed soils were slightly acidic (Gonet et al., 2015). The content of organic carbon (OC) and total nitrogen (TN) in both soils had comparable values. Although on 13 and 22 November in soil under the turf, the Cog content was higher the soil under shrubs and trees than in the soil under and trees. However, the content of nitrate nitrogen ($N\text{-}NO_3$) was higher in the soil from the buffer zone with bushes and trees (table 1).

Table 1. Emission of nitrous oxide (N_2O) and carbon dioxide (CO_2) from buffer zone soils

Measurement date	pH in H_2O		OC [%]		TN [%]		$N\text{-}NO_3$ [mg/100g soil]	
	I	II	I	II	I	II	I	II
02 November 2016	6.12	6.62	3.52	3.12	0.22	0.22	0.34	0.09
07 November 2016	6.06	6.59	3.40	3.06	0.23	0.23	0.36	0.07
13 November 2016	6.27	5.78	2.73	4.21	0.33	0.37	0.43	0.06
22 November 2016	6.26	6.06	3.14	4.33	0.26	0.27	0.41	0.54

Explanations:

I – buffer zone with shrubs and trees near the arable land

II – buffer zone with turf near grassland

Source: author's own work.

Based on measurements of emissions of selected greenhouse gases, it was found that the average value of emissions of nitrous oxide and carbon dioxide from the analyzed soils was bigger from the buffer zone under shrubs and trees (table 2). The analyzes showed that CO_2 and N_2O emissions increased with increasing carbon content in soils (tables 1 and 2), these gases are associated with soil biological activity, including the denitrification process (Turbiak, Miatkowski, 2010). These results correspond with the current knowledge that soil microorganisms develop more intensively in habitats rich in a dead organic matter (Paul, Clark, 2000; Błaszczyk, 2010). The inverse relation was demonstrated in the case of total nitrogen (TN) and nitrate nitrogen ($N\text{-}NO_3$). It was found that the CO_2 and N_2O emissions increased with the decrease in the content of nitrogen compounds in the soil (tables 1 and 2). These results confirm the observation that the decomposition of organic compounds (rich in nitrogen) is accompanied by active microbiological processes, the effect of which is CO_2 production. Also, denitrification works better in habitats that are rich in nutrients, including nitrogen (Paul, Clark, 2000; Błaszczyk, 2010; Frączek, 2010; Traczewska, 2011; Kucharski et al., 2015). One of the groups of microorganisms that can use various nitrogen compounds are *micromycetes* inhabiting soils (Kalbarczyk, 2012).

Table 2. Characteristics of selected physicochemical properties of the analyzed soils

Measurement date	N_2O [mg·m^{-2}·d^{-1}]		CO_2 [mg·m^{-2}·d^{-1}]	
	I	II	I	II
02 November 2016	0.92	0.28	2658.90	1846.40
07 November 2016	0.79	0.30	2028.05	1958.87
13 November 2016	0.38	0.07	467.26	920.34
22 November 2016	0.52	0.19	1080.44	1508.26

Explanations:
I – buffer zone with shrubs and trees near the arable land,
II – buffer zone with turf near grassland.
Source: author's own work.

The emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O) were also affected by air and soil temperatures. It has been found that at higher temperatures more of these gases are formed (figure 1). In other words the activity of soil microorganisms increased with increasing temperature. It was observed that more gases were formed in the soil of the buffer zone with shrubs and trees. This allows us to assume that the soil under the trees is characterized by a higher microbiological activity compared to the buffer zone soil under the turf.

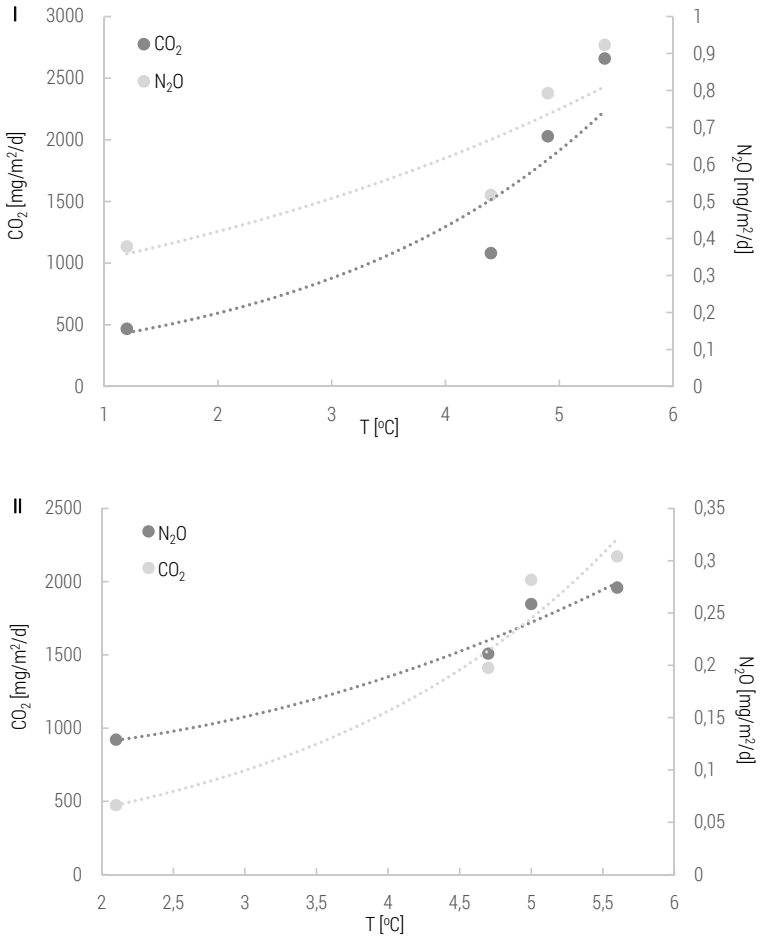

Figure 1. The relationship between the emission of nitrous oxide (N_2O) and carbon dioxide (CO_2) and the air temperature (I – buffer zone with shrubs and trees near the arable land, II – buffer zone with turf near grassland)

Source: author's own work.

Similar conclusions can be drawn by analyzing the composition of soil fungal communities. A total of 141 fungal isolates were obtained. They were represented by 37 different species. A more diverse quantitative and qualitative structure was possessed by the fungal community originating from the buffer zone with shrubs and trees in comparison to the buffer zone with turf. The authors received 82 isolates and 29 species from the soil under shrubs and trees. On the other hand 59 isolates and 25 *micromycetes* species were found in the soil under turf.

The similarity between fungal communities was at 41.7%. It follows that the communities differed despite their common features. There were found 7 species of fungi in soil from both research stands. The remaining species were found only in soil from one or the other research area. These results are not surprising because the biological decomposition of organic matter that causes fungi depends on climatic factors, soil properties, its fertility, pH, oxidoreductive potential, land use and agrotechnical treatments (Paul, Clark 2000; Błaszczyk 2010; Kucharski et al., 2015). Plant cover also affects the structure of *micromycetes* communities (Barabasz, Vořišek, 2002). The analyzed soil fungal communities came from buffer zones differing mainly with vegetation. The difference also concerned the way the land was used in the vicinity of the examined surfaces. On the one hand soil fungi shape the physical chemical and biological properties of soil by participating in the decomposition of organic matter and on the other hand, they depend on the properties listed (Kwaśna, 2014).

Selected fungal species that occurred most frequently in both analyzed soils are summarized in table 3. The most numerous species in both communities was *Pseudogymnoascus roseus* and its turnout was comparable. The frequency (number) of other species was on the level of 1 to 3 isolates. It should be emphasized that the most were species with low attendance (from 1 to 3 isolates). First of all, they determined the diversity of *micromycetes* quantitative and qualitative structures.

Table 3. The most abundant *micromycetes* species that inhabit the soil of both buffer zones

Species of fungi	frequency [no.]	
	I	II
Chrysosporium pannorum (Link) Hughes	7	3
Leptosphaeria coniothyrium (Fuckel) Sacc.	1	8
Penicillium brevicompactum Dierckx	5	2
Penicillium oxalium Curie and Thom	8	4
Penicillium verucosum var. ***cyklopium***(Westling) Samson. Stolk & Hadlok	5	-
Pseudogymnoascus roseus Raillo	16	15

Explanations:

I – buffer zone with shrubs and trees near the arable land.

II – buffer zone with turf near grassland.

Source: author's own work.

Conclusions

- Based on physicochemical analyzes. it was found that the average values of determined parameters in soils from both buffer zones were similar to each other.
- More carbon dioxide (CO_2) and nitrous oxide (N_2O) were produced at higher air and soil temperatures. It follows that the biological activity of the soil increased with increasing temperature. It was also found that the soil of the buffer zone under shrubs and trees near the arable ground was characterized by a higher microbiological activity compared to the buffer zone under turf near grassland.
- The fungal communities in the analyzed soils under the two buffer zones, which differed in vegetation and the way of using the neighboring area, differed in the quantitative and qualitative structure of the *micromycetes* communities. The community obtained from the buffer zone soil under shrubs and trees near the arable land had a richer composition and a richer qualitative structure compared to the community that inhabited the buffer zone under the turf.
- The nature of vegetation and land use have an impact on the microbiological activity of buffer zones of agricultural catchments. It seems that the buffer zone under shrubs and trees more effectively prevents contamination of surface water by biogenic compounds. which are moved from the area of agricultural land – due to the higher microbiological activity – in comparison with the buffer zone under the turf.

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The contribution of the authors

Małgorzata Krasowska – conception, literature review, methodology and interpretation of data – 50%
Zofia Tyszkiewicz – conception, literature review, methodology and interpretation of data – 50%

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GENERAL ENVIRONMENTAL AND SOCIAL PROBLEMS

PROBLEMATYKA OGÓLNOEKOLOGICZNA I SPOŁECZNA

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ECONOMIC AND TOURIST FUNCTIONS OF THE FORESTS IN LUBLIN PROVINCE

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ABSTRACT: The research objective was to present social and economic functions of forests in Lublin Province against the background of other Polish provinces, at the same time pointing at the most important functions performed by the forests of the studied region. The research was conducted with the use of the diagnostic survey method by employing the technique of questionnaire, statistical data analysis and the analysis of the documentation made available by the Directorate of National State Forests. The forests of Lublin Province yield the most forest berries in Poland (on average 2725,29 tons a year). The main motivation for visiting forests among rural residents and inhabitants of small towns is the collection of forest berries and mushrooms; 61.0% and 50.8% respectively, while for inhabitants of larger cities it is recreational tourism and rest opportunities (67.8%). The added value of the study is cohesive factsheet of the economic and social functions of forests in the Lublin Voivodship.

KEY WORDS: forest, Lublin province, forest functions

Introduction

Forests are one of the most valued resources in the world, as they have preserved the original form of nature, only slightly changed by man (Mandziuk, Janeczko, 2009, p. 64). The landscape of Poland is inseparably associated with forests. Forests deliver numerous benefits and have a positive impact on human life and communities (Dawidziuk, Klocek, 2005, p. 64-67). All those benefits called functions of the forest and their range and level depends on a given forest's characteristics, management and development plan and conducted forestry management (Cristan et al., 2016, p. 133-151). For every historic community forests may perform different functions, however among the most popular ones we can enumerate: protective, economic and social functions (Klocek, Płotkowski, 2007, p. 45).

Protective functions of forests consist in protecting pristine fragments of the natural environment, ones of particular value with regard to genetic, landscape and scientific qualities (Łonkiwiecz, 1996, p. 20). The economic function of forests consists in such management of forest resources which enables maximum timber production, harvesting forest berries and mushrooms in addition to other non-timber products, while simultaneously retaining the renewability of these resources (Barbier et al., 2017, p. 10-17). Forest administrators must remember about sustainable forestry management and skillful drafting the forest management and development plan, so that the economic and tourist usage of the woods would not adversely impact forest soil or water bodies (Buchowski et al., 2015, p. 90). The social function denotes exploiting the health benefits of forests in pursuit of tourism and recreation, as well as conducting ecological education in the natural environment (Cool, Patterson, 2000, p. 111-119). It ought to be borne in mind, however, that an increase of one function may negatively affect the other functions of forests and at the same time many functions are mutually complementary (Plotkowski, 2008, p. 254; Tuffery 2007, p. 33-41). Going for a walk in the woods we can pick berries and mushrooms, and also we can benefit from the healthy forest environment (Plotkowski, 2008, p. 255).

The following hypothesis was made during the research: the weight of the modern forest farm was shifted from the production function of the forest to tourist and recreational functions. The demand for social functions of the forest grows even more when the majority of the population lives in large cities.

The objective and methodology of research

At present, there is a misconception in the society that non-economic functions can only be performed by legally protected forests, which undervalues other forest complexes that also carry out these functions and are managed by self-financing and profitable businesses, for example by developing tourism and recreation. The research objective was to present social and economic functions of forests in Lublin Province against the background of other Polish provinces, at the same time pointing at the most important functions performed by the forests of the studied region. The research was conducted with the use of the diagnostic survey method by employing the technique of questionnaire, statistical data analysis and the analysis of the documentation made available by the Directorate of National State Forests.

The questionnaire survey was conducted among 1500 inhabitants of Lublin Province using a purposeful sample selection, 500 residents were selected from rural locations, towns up to 20 thousand residents and towns/cities with population above 20 thousand, who take trips to the forest at least once a year. The research objective was to determine the main purpose of visiting the woods. The research was conducted from April to June 2016.

For statistical analyses the program Statistica 10.1 PL was employed, with a discriminating function which is used for determining which variables discriminate emerging groups. Before commencing the analyses, a multidimensional normality was investigated by inspecting every variable for distribution normality. It was assumed that the matrices of the variance of variables are homogenous within groups. Slight deviations were not as important on account of considerable numbers of respondents in particular groups. Statistical significance was assigned to those differences between mean values whose probability of randomness was lower than $p<0,05$.

The study area characteristic

There are 584 034,25 hectares of forests in Lublin Province, where 59% are state forests and 41% are private ones. The forestation of Lublin Province is 23%. The largest forest complexes are: Janowskie Forests, Strzeleckie Forests, Roztocze Forests, Sobiborsko-Włodawskie Forests, Sandomierz Woods and Kozłowickie Forests. This terrain is geomorphologically diverse: lowland forests lie to the north of the province while uplands reaching even 300 metres above sea level lie in the south. Conifer forest habitats cover 46,8% of the area, broadleaf ones 44.3%, swampy ones 5.9% and upland ones 3.0% of the forested area. The dominant tree species in the forest of Lublin Province

is the pine (69.9%) with the remaining ones being: oak, alder, birch, beech, sycamore, fir, ash, aspen and poplar. The average forest age is 59 years (RPOPLP, 2003, p. 2).

Discussion and results of the research

Economic exploitation of the forests in Lublin Province

In opinion of Watson and Ward (2010) the economic functions of forests are exhibited as, among others, benefits from the production of timber and non-timber products (e.g. forest berries and mushrooms, game, mineral resources). Barszcz and Suder (2004) write that the traditional connection between forest and man still has huge importance. Picking mushrooms, forest berries and other forest fruits and products is one of the oldest customs.

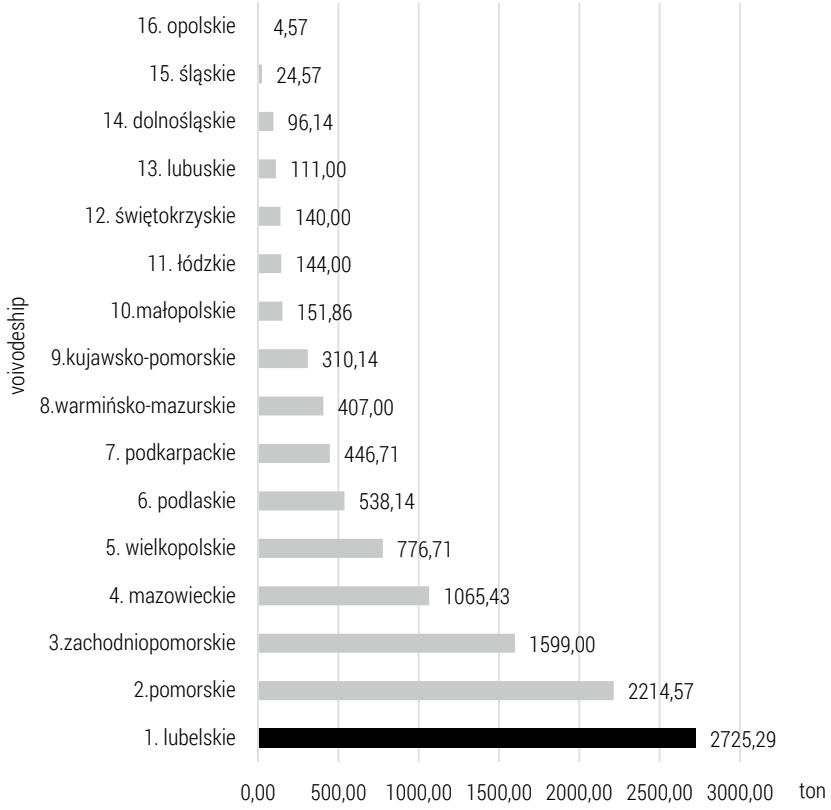

Figure 1. Supply of forest berries in Poland during 2009-2015; annual average in tons by province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

According to Regional Operational Program for Forest Policy published by National Forests (2003) forests perform a very important function, because thanks to this function new workplaces are created (in all of Poland in 2015, 375 thousand people were employed in forestry), participates in generating the gross national product (yields around 2% of GNP), the timber industry sales abroad amount to 45 billion PLN a year, accounting for 10% of the entire Polish export, provides raw materials to many industrial sectors; among others to paper, construction and furniture industries, etc.

Nationwide, Lublin region is ranked first in supplying forest berries (blueberries, raspberries, blackberries), as in the period from 2009 to 2015 gatherers supplied 2725,29 tons a year on average (figure 1).

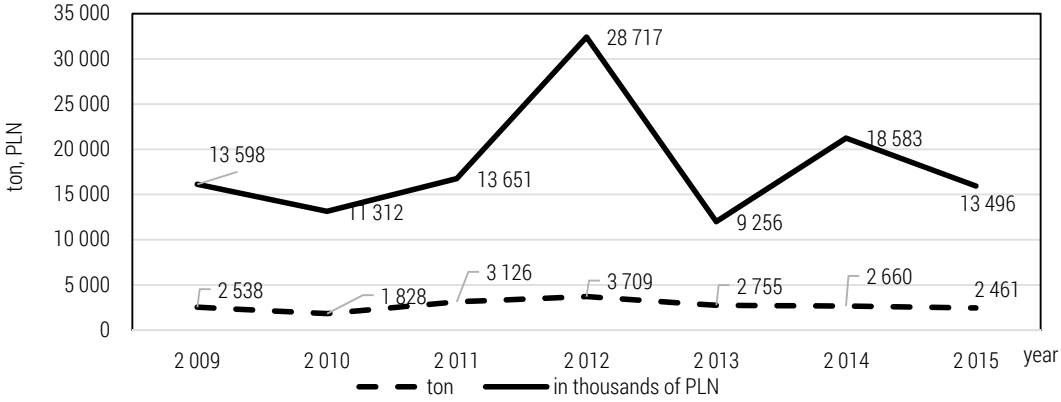

Figure 2. Purchase of forest berries in tons and its value in thousands of PLN during 2009-2015 in Lublin Province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

On the basis of the data shown in figure 2 one may note that the largest harvest of forest berries occurred in 2011 and 2012, when the purchase from gatherers was 3126 and 3709 tons of forest berries respectively. As regards purchase figures, the years 2012 and 2014 stand out with the value of purchased forest berries amounting to 28717 and 18583 thousand PLN respectively. The figures for fruit purchase also depend on the price. In the years mentioned before, the pricing of these fruits was the most favorable, since it was 7,74 PLN/kg in 2012 and 6,99 PLN/kg in 2014 (figure 3).

Purchase of mushrooms from gatherers is definitely of lesser importance in Lublin Province forests. The studied province was ranked twelfth in Poland regarding the quantity of purchased forest mushrooms. On average only 5,14 tons of mushrooms are purchased annually, while in Wielkopolskie Province as much as 1581,57 tons (figure 4).

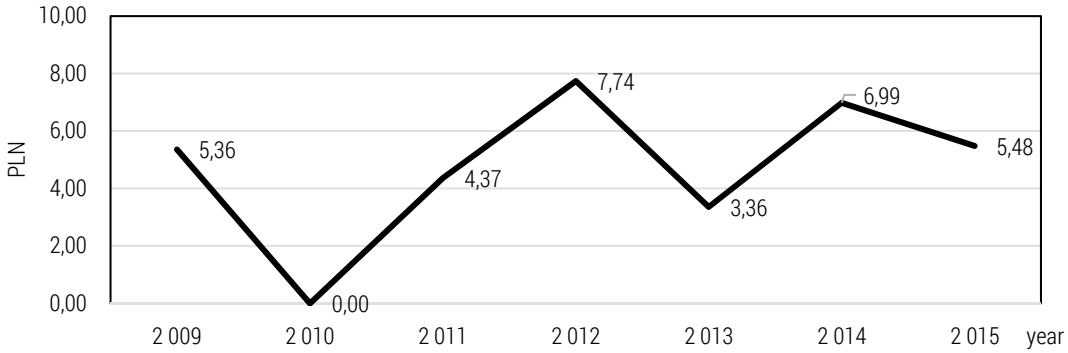

Figure 3. Average baseline purchase price of forest berries in PLN/kg during 2009-2015 in Lublin Province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

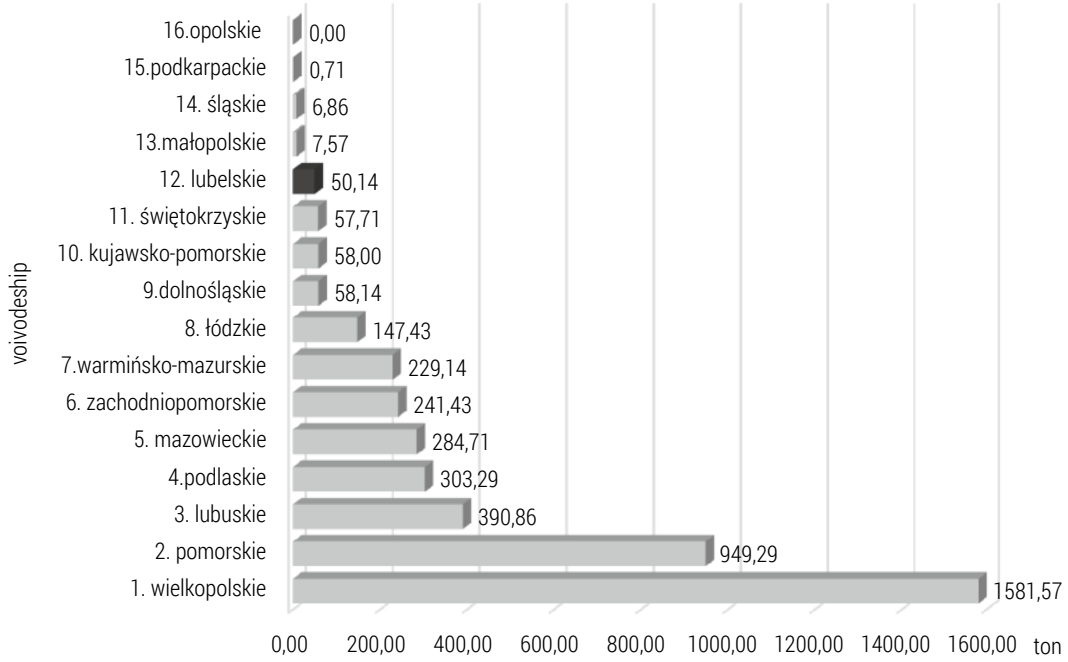

Figure 4. Average annual purchase of forest mushrooms from gatherers in Poland during 2009-2015, annual average in tons by province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

The most mushrooms were purchased in Lublin Province in 2013 (134 tons worth 1281 thousand PLN) and in 2014 (117 tons worth 927,9 thousand PLN) (figure 5). The highest purchase price of mushrooms was noted in 2015, when it was as high as 23,04 PLN/kg. it most probably stemmed from low supply of mushrooms (only 26 tons) caused by drought (figure 6).

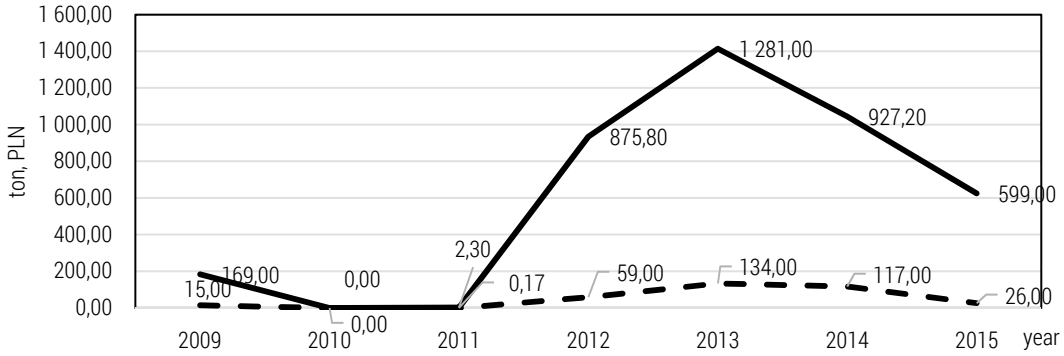

Figure 5. Purchase of forest mushrooms in tons and its value in thousands of PLN in Lublin Province during 2009-2015

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

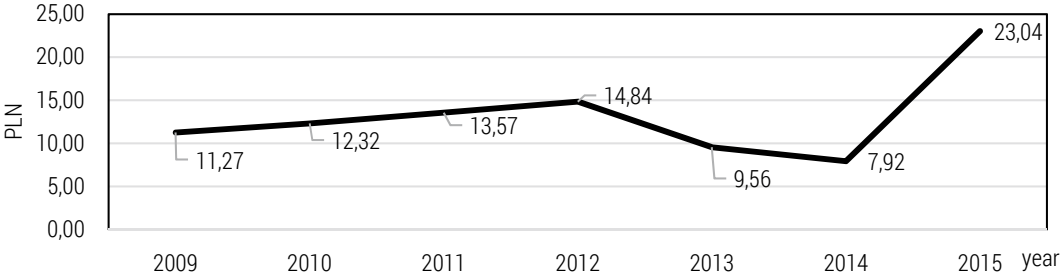

Figure 6. Average purchase price of forest mushrooms in PLN/kg during 2009-2015 in Lublin Province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

Similarly as in the case of mushrooms purchase, the supply of game placed Lublin Province in the 12th position in Poland. During 2009-2015 an annual average level of 1957,37 tons was achieved. Nationwide the largest quantities of game were purchased in Zachodniopomorskie Province (13708,03 tons), and the smallest quantity in Świętokrzyskie Province (304,51 tons), which is depicted in figure 7.

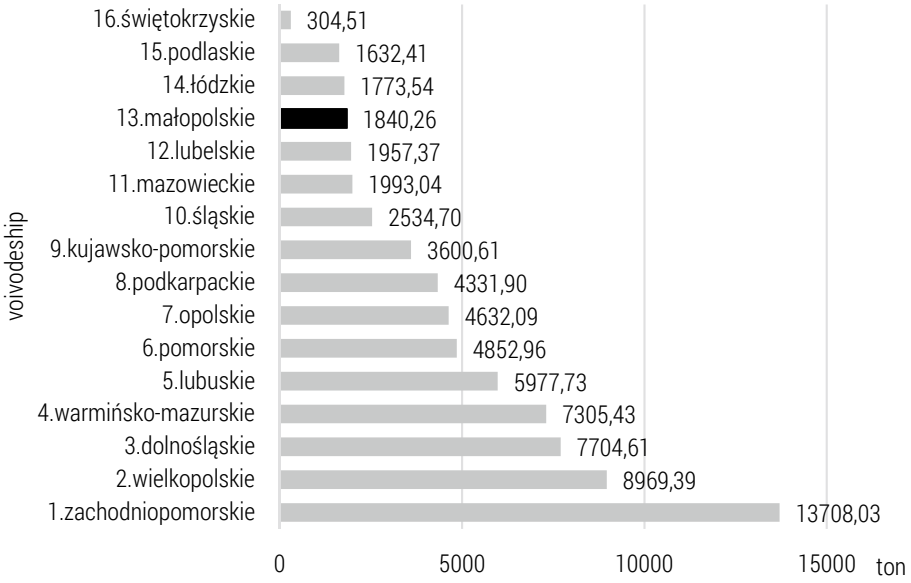

Figure 7. Average annual purchase of wild game in Poland during 2009-2015, annual average in tons by province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

When analyzing the purchase of wild game in Lublin Province during 2009-2015 it was found that the largest quantity of game was supplied in 2011 (3288,6 tons), while in 2012 there was a decrease by as much as 991,4. In 2014 the purchase amounted to 1427,6 tons, in the following year it rose by 530,3 tons, and in 2015 it maintained the level of 2163,3 tons (figure 8).

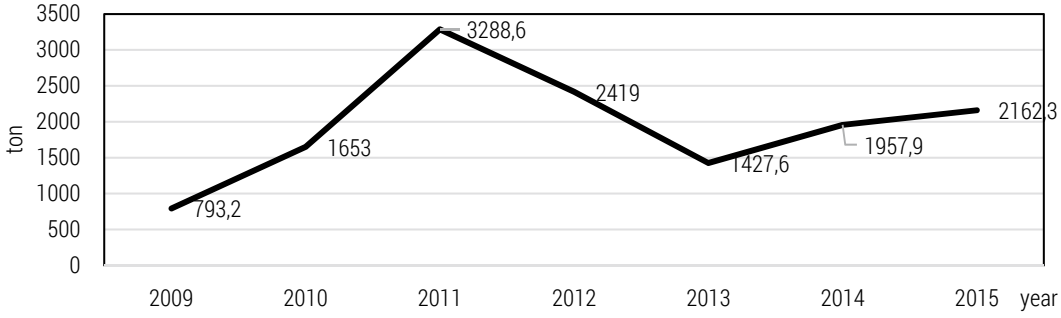

Figure 8. Purchase of wild game in tons in Lublin Province during 2009-2015

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

A similar situation was recorded in the case of timber purchase. In Lublin Province this purchase amounted to an annual average of 1486,96 m^3 of timber, allowing the studied province to hold the 12th position in Poland, ahead of Opolskie, Świetokrzyskie, Łódzkie and Małopolskie Provinces (figure 9).

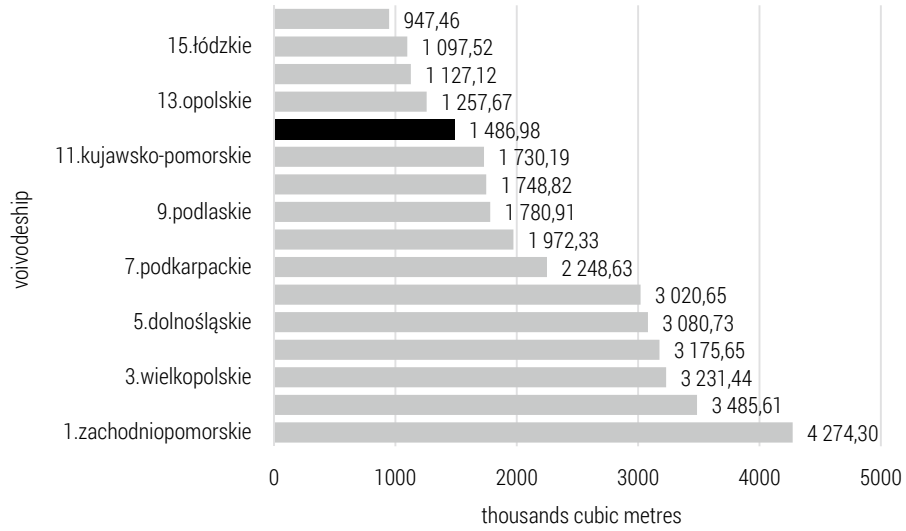

Figure 9. Average annual purchase of timber in thousands cubic metres during 2009-2015 in Poland by province

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

It is noteworthy that in this respect the purchase value increased year over year. In 2009, 1225,87 m^3 of timber was purchased and in 2015 as much as 1710,55 m^3, thus over a six-year period there occurred a nearly 40% increase, which was depicted in figure 10.

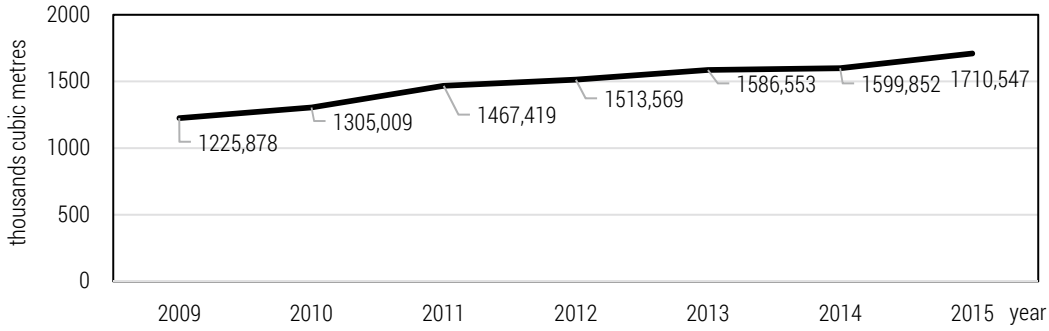

Figure 10. Purchase of timber in thousands of cubic meters in Lublin Province during 2009-2015

Source: author's own work based on data from GUS (Central Statistical Office), Economic functions of the forests, Warsaw, 2016.

In the process of harvesting timber in state forests, the principle of sustainable forestry is applied, which consists in the requirement whereby wood and paper processing should take place in regions of high forestation indicator and a large number of companies dealing with wood processing. In Lublin Province such regions include Districts of Biłgoraj, Tomaszów, Zamość, Janów, Bialsko, Radzyń, Ryki, Lubartów, Puławy, Opole, Parczew and Włodawa. In such regions new areas should be reforested for production purposes. In accordance with the forest development plans such terrains should cover an area of at least 5 hectares with width of no less than 200 meters (Buchowski et al., 2015, p. 91).

Similar values were ascertained also in other European countries (Merlom Croitoru, 2005, p. 406). For example studies by Sisak and Dudik (2016) revealed that average annual value of the intensive forestry timber production sold from Czech forests is 19,000 mil CZK (262 EUR/ha of forest) and the material value of collected mushrooms and berries is more than 3500 mil CZK (48 EUR/ha of forest).

Management and development of Lublin Province forests for tourism

Tourism and recreation in forests is one of the major forms of non-commercial functions of forests and ought to be continuously developed and refined (Tuffery, 2017, p. 33-41). Mandziuk and Janeczko' survey (2009, p. 65) shows that in recent years there has been observed a growing interest of the society in tourism and recreation in forests, which stems from, among others, an increase in the ecological awareness of the population. According to the data by POT, forest tourism in 2014 was pursued by circa 63% of the Polish citizens (Zientarska, 2016 p. 3). Nevertheless, in many European countries, forests has not only a economics but also the social, entertaining, recreational importance (Glück, 2000, p. 178-185).

The management and development of forests for tourism purposes consists in equipping them with accommodation and recreational facilities and amenities (Destan, 2011, p. 212-223). The development intensity is largely dependent on the location of forests and the functions associated with them, as well as on the financial capabilities of forestry inspectorates (Reeson et al., 2015, p. 267-272).

Table 1. Management and development of Polish forests for tourism per province

Description	Car parks in forests	Forest campsites	Sites for campfires	Lodging for hunters	Accommodation in forested areas	Educational trails and tourist trails	Education and museum facilities	Training and recreation centres
dolnośląskie	36	3	16	7	9	51	10	3
kujawsko-pomorskie	142	17	6	5	5	43	10	2
lubelskie	**53**	**4**	**18**	**10**	**12**	**66**	**10**	**3**
lubuskie	153	43	17	7	1	76	15	2
łódzkie	10	0	1	7	2	29	9	2
małopolskie	18	18	10	2	4	16	13	4
mazowieckie	80	3	16	3	5	55	19	2
opolskie	114	21	8	0	4	37	9	0
podkarpackie	25	9	6	4	5	103	25	2
podlaskie	33	21	25	5	16	74	26	4
pomorskie	186	20	14	7	8	82	11	5
śląskie	32	4	4	2	1	45	12	2
świętokrzyskie	35	2	6	1	4	31	9	0
warmińsko-mazurskie	100	49	10	6	11	78	23	1
wielkopolskie	197	22	25	8	12	75	29	4
zachodniopomorskie	247	78	13	4	7	73	20	6
Amount	**1461**	**314**	**195**	**78**	**106**	**934**	**250**	**42**

Source: author's own work based on the data from the Directorate of State National Forests in Warsaw.

Table 1 presents tourism-oriented development of forests in Lublin Province against the background of other provinces. What follows here is that in the forests of Lublin region there are still too few equipped forest campsites (with only 4 functioning), hunters' lodgings (only 10) or forest centers for training and recreation (only 3). Hunters' lodgings are located within the grounds of Centers for Game Husbandry belonging to State National Forests and are used both by foreign hunters and, increasingly, by domestic tourists, hence care should be taken to increase their number. Also for the purposes of tourism and recreation, forest centers for training and recreation, of which there are only 3 (Biłgoraj, Hanów and Zwierzyniec), should be used to a greater extent. Presently, none of these facilities is not used in its full capacity despite the very good technical condition of these facilities and possibility full catering.

Main purposes of visiting forests among the residents of Lublin Province

On the basis of the data shown in figure 11, one can notice that for 61% of rural residents of Lublin Province the main purpose of staying in the forest is the collection of mushrooms and berries, while only for 19.6% of them it is recreational tourism. A similar situation is recorded in the case of respondents from small towns of up to 20 thousand population. Nearly 51% of respondents indicated that the main purpose behind forest visits is berries and mushrooms gathering, and for only 33.2% it is tourism and recreation.

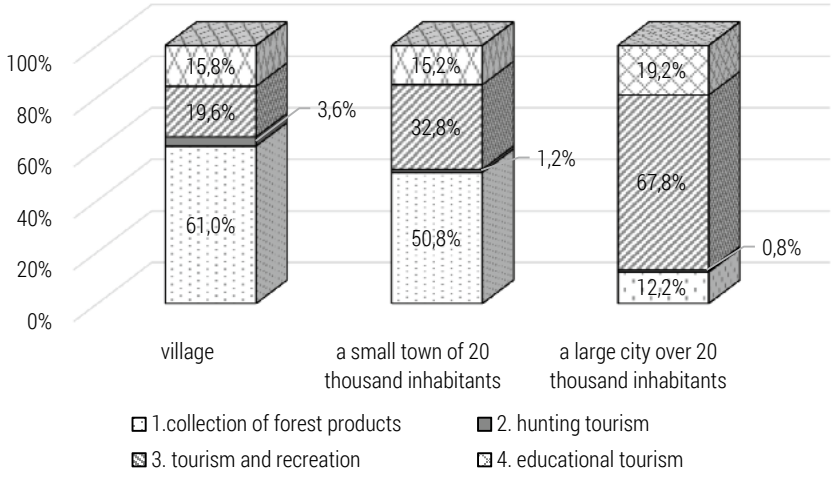

Figure 11. The main purpose of visiting the forest per the place of residence of respondents

Source: author's own work based on questionnaire survey.

The conducted research shows that residents of large cities treat forest mainly as a location for rest and recreation (62.8% of indications), as well as the place for gaining new knowledge (19.2% of indications). Hunting tourism is mainly pursued by rural residents (3.6%).

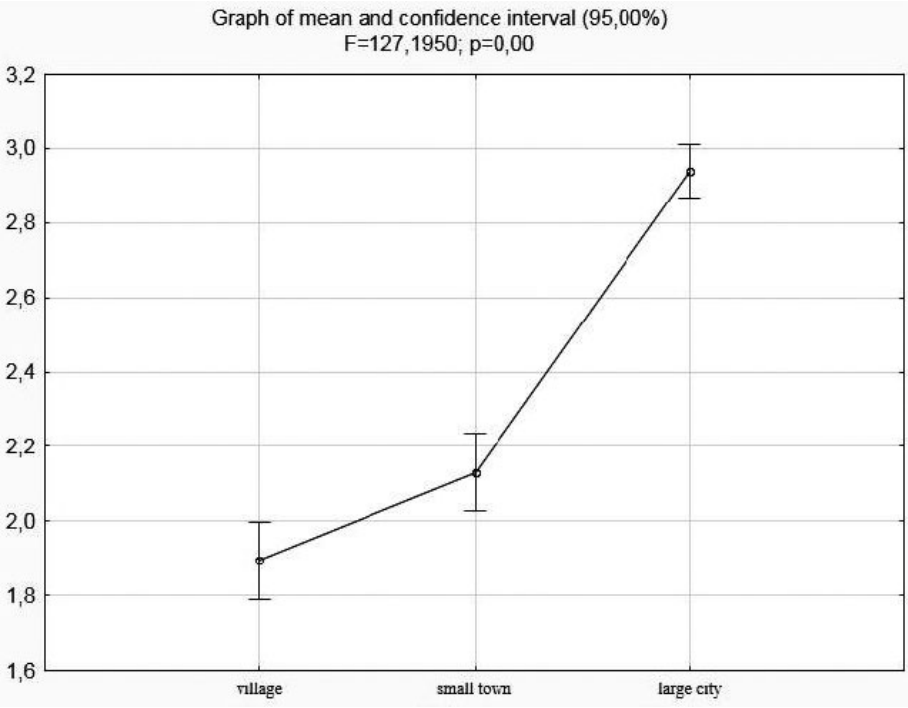

Figure 12. Interaction graph – the main purpose of visiting the forest per the place of residence

Source: author's own work based on questionnaire survey.

By resorting to the analysis of variance, the significance of differences between the place of residence and the main purpose of visiting forests was investigated. What follows from the variance analysis is that at p=0,00, i.e. p>0,005, the zero hypothesis postulating the lack of the significance of differences should be rejected in favour of an alternative hypothesis which states significant differences between the place of residence of respondents and the main purpose of their visits in forests. Test results confirm the interaction graph (figure 12).

Barszcz's survey (2006, p. 2) shows also that a great socio-economic role of forests in small as well as great communities but its importance is different and depends on place of residence. Forests for inhabitants of villages and small towns are the place of working. They harvest a greater amount mush-

rooms and fruit in comparison with the residents of large towns. City-dwellers do not treat forests as a source of income but rather as an element of recreation.

Conclusions for practice:

- The forests of Lublin Province yield the most forest berries in Poland (on average 2725,29 tons a year). Of lesser importance is the harvest and sale of mushrooms (50,14 tons) or sourcing game (1957,37 tons). These forests meet the local demand for timber, whose purchase reaches the level of 1486,98 cubic metres a year.
- The tourist function of the forests in Lublin Province is not fully exploited. In the studied area there are as many as 66 educational trails and tourist trails. There are, however, too few accommodation facilities, campsites or training centres. Moreover, the existing tourism infrastructure is not too plentiful and the accommodation facilities, found in the forests, require better promotion as they are not fully booked, especially outside the tourist season.
- The main motivation for visiting forests among rural residents and inhabitants of small towns is the collection of forest berries and mushrooms; 61.0% and 50.8% respectively, while for inhabitants of larger cities it is recreational tourism and rest opportunities (67.8%). The data also indicate that the population of villages and small towns seek additional income in forests but they lack knowledge with regard to opportunities of gaining profits from the recreational function of the forest.
- Further research should address the reasons for low occupancy of hunting lodges and recreation centers in Lublin forests.

Conclusions for science

- From an economic point of view, it is very important to indicate both the total benefits and the social costs of implementing the economic and social functions of the forest. Knowledge of these categories is essential for practical solutions that are today the subject of the forest management reforms in many countries.
- One should look at the role and function of forests from the perspective of the social value of the forest concept. This is reflected in the complex perception of forest values.

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Roman KISIEL • Joanna ZIELIŃSKA-SZCZEPKOWSKA • Dominika TARADEJNA

NATURAL AND CULTURAL RESOURCES OF GREEN KURPIE AS DRIVERS OF TOURISM DEVELOPMENT

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ABSTRACT: The purpose of this paper is to present the natural and cultural resources of the region of Green Kurpie (identified with the Green Wilderness of Kurpie) as drivers of tourism development. The region under analysis, located across two voivodeships: Mazowieckie and Podlaskie, has special natural resources: woods and nature reserves which preserve the natural beauty of the Kurpie Forest, as well as its own culture manifested in original buildings, ornamentation, folk handicrafts, clothing and local dialect. It is a theoretical and empirical article. The author applied the following research methods: deductive studies of literature on the subject and questionnaire studies with the use of a standardised questionnaire survey carried out among 400 respondents from 12 voivodeships in Poland (N=400). In the eyes of the respondents, vast forests, natural reserves, a wealth of rivers and meadows, as well as a distinctive culture: local dialect, unique architecture, crafts and folk costumes are conducive to the development of nature and culture tourism in the region. Although most respondents believe that the region is attractive for tourists, they also see the necessity to take additional measures to active policy on wider tourism promotion.

KEY WORDS: natural areas, cultural resources, tourism attractiveness

Introduction

Tourism development in a given region depends mostly on natural resources, but sometimes on cultural heritage as well. Green Kurpie, stretching across the Mazowieckie and Podlaskie voivodeships, is a region which stands out in many respects when compared to other regions. The presence of large forests, interesting terrain, numerous rivers, meadows, and dunes are resources which render the region unique in terms of climate, allowing the development of nature tourism.

This article contains a presentation of the natural and cultural resources of Green Kurpie. Prior to categorising the resources, deductive studies of the literature on the subject were performed to attempt to systematise the meaning of "tourism resources", "tourism values", and "tourism attractiveness". In addition, the article presents the results of a survey carried out among 400 tourists visiting 12 Tourist Information Centres in Poland. The studies were designed to answer the following question: do the nature and culture of Green Kurpie actually define that region and foster tourism in the analysed area?

An overview of literature

In Polish literature on the subject, the notions of "resources", "values", and "attractions" in terms of tourism are sometimes interchangeable and sometimes deemed separate concepts. According to Kowalczyk (2013), the aforementioned notions should be treated separately. Tourism resources may be understood as objectively existing environmental and cultural attributes (both tangible and intangible) that can attract potential tourists. Though resources are an objective category, values are more subjective and should be treated as resources valued by every tourist individually. Thus, not all resources may be values (Kozak, 2009). Thanks to their diversity and often their uniqueness, tourism values stimulate mental experiences in the tourist's mind, trigger aesthetic impressions, generate interest, are an important part of education, and can create an environment for rest and recuperation.

Whether a given piece of space is attractive in terms of tourism depends on the objective presence of certain conditions in it, on the one hand, and on its subjective reception and assessment by tourists, on the other hand. Thus, just like Kowalczyk (2013), the authors of this article consider tourism attractiveness as attributes of an area resulting from a group of natural and cultural (anthropogenic) features which attract tourists and get them interested in an area.

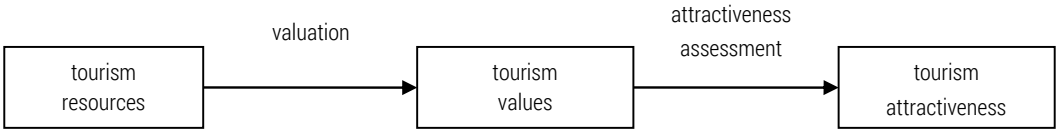

Figure 1. Interrelations between the notions of "tourism resources", "tourism values", and "tourism attractiveness"

Source: author's own work based on (Kowalczyk, 2013).

Determinants of tourism development in an area include environmental and cultural factors alongside economic, marketing and market, organisational and legal, as well as infrastructural factors. Tourism development is dependent on such natural values as, among other things, woodiness, flora, the number of water reservoirs, quality of the environment, landscape diversity (as proved by Kowalczyk 2001; Machnik, Kurczewski 2014; Mickiewicz 2006 and others) and cultural values and their condition (i.a. monuments of architecture and construction, traditional folk culture) (see Stasiak, 2007; Mikos von Rohrscheid, 2008; Jędrysiak, 2008). Values attract tourists and are the fundamental element of tourism supply (Gołembski, 1999).

Natural and cultural values lead to the development of "culture tourism" and "nature tourism" in a given area. There are numerous definitions of both of those forms of tourism in the literature. According to Mika (2008), nature tourism entails any journeys whose main purpose is to discover, observe or admire nature, especially those of its parts that have been least affected by human activity. On the other hand, Zaręba (2008) believes that nature tourism includes any forms of tourism whose purpose is to discover wild nature, "tamed" nature or even nature organised by people. Cultural tourism entails travelling in order to discover cultural heritage which, in a broader sense, is also understood as everyday life, science and technology and geographical environment (landscapes, their interpretation, etc.), as well as literature on various regions and cuisine perceived as an art of living (Buczkowska, 2008). Such interpretation of culture tourism allows for including aspects of nature in culture. In the approach preferred by culture tourism scholars, the term of "nature and culture tourism" also appears. Mikos v. Rohrscheidt (2008) suggest that nature and culture tourism is a form of tourism where the main purpose of travelling is discovering natural values and travellers wish to discover protected natural heritage or natural heritage arising from human activity or to increase their knowledge about the surrounding world.

As suggested by Kowalczyk, the authors of this article assume that natural and cultural environment resources are attributes of the environment and the cultural landscape, both tangible and intangible and they begin their analysis with this assumption. The surveys carried out among the respond-

ents in Poland sought to value the previously categorised resources (and to give them the status of values) and then to assess the natural and cultural tourism development potential in the Green Kurpie region.

Research methods

The goal of this paper is to present the natural and cultural resources of Green Kurpie and their importance for nature and culture tourism development. It is a theoretical and empirical article. The theoretical part is based on the literature on the subject, journal articles and statistical studies and it was to serve the presentation of natural and cultural resources of the analyzed area. In turn, qualitative research in the form of a questionnaire survey was used to assess the importance of these resources in the development of nature and cultural tourism. Empirical research was carried out in July and August 2016 among randomly selected tourists visiting the Tourist Information Centres located in 16 voivodeships in Poland. To that end, an original questionnaire survey consisting of 18 open and closed questions was designed and used. The questions were divided into three sections. The authors tried to obtain information on, i.a. tourists' opinions about the nature and culture of Kurpie, reasons for coming to Green Kurpie, the status of Green Kurpie when compared to other Polish regions attractive in terms of tourism and respondents' recommendations regarding tourism development trends in a given region.

In total, 316 women and 84 men took part in the survey (N=400) from 12 voivodeships in Poland. The division of the respondents by age is illustrated in figure 2. A majority of the respondents were 19-25 years old. Slightly fewer respondents were between 26-35 and 36-45 years old. The fewest respondents were over 45 years old (8%) and below 18 years old (5%).

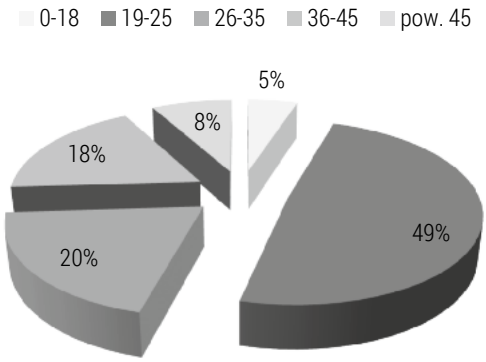

Figure 2. Age of the respondents

Source: author's own work based on the conducted research.

A majority of the respondents were residents of the Warmińsko-Mazurskie voivodeship (96 people), the Podlaskie voivodeship (68 people) and the Mazowieckie voivodeship (60 people). Fewer of them were from the Zachodniopomorskie voivodeship (36 people), the Kujawsko-Pomorskie voivodeship (32 people) and the Łódzkie voivodeship (7 people). The Pomorskie and Śląskie voivodeships were represented by 16 people each. The Świętokrzyskie and Wielkopolskie voivodeships were represented in the study by 12 people each. The fewest respondents were from the Dolnośląskie and Lubelskie voivodeships. The diversity of the places of residence of the respondents made it possible to collect diverse opinions about the natural and cultural values of Green Kurpie and their importance for tourism development.

Results of the research

Natural resources of Green Kurpie

The Kurpie Forest may be divided into two areas – the Green Wilderness and the White Wilderness. It is very difficult to draw the administrative boundaries of Green Kurpie. Chętnik defined those boundaries as follows: The Green Wilderness covers the following towns and cities: Kolno, Myszyniec, Chorzele, Przasnysz, Ostrołęka and Nowogród; parts of the following poviats (a poviat is an administrative area of Poland, lower than a voivodeship, but larger than a municipality): Łomża, Kolno, Ostrołęka, and Przasnysz (Suchowiecki, 2010). Currently, one may claim that the Green Wilderness covers the Mazowieckie and Podlaskie voivodeships. It is assumed that it stretches across the following municipalities and communes: Baranowo, Czarnia, Zbójna, Kadzidło, Turośl, Lelis, Myszyniec, Nowogród, and Łyse. Table 1 presents data on the area of individual municipalities and communes in Green Kurpie, the forest area, and the forest percentage share (table 1).

The area of the Kurpie Forest is 1705 km^2, where forests constitute 34.22% of the total area. As far as the size is concerned, the largest municipalities and communes include: Kadzidło, Łyse, and Myszyniec. When it comes to the size of forests in absolute terms, the communes of Kadzidło, Łyse and Zbójna have the largest forests. Taking into account the percentage of forests in the total area, most forests – 46.5% – are in the commune of Zbójna, quite fewer – 39.8% – in the commune of Kadzidło, and 39.5% in the commune of Czarnia.

Table 1. Share of forests in the total area of Green Kurpie

Municipality/ Commune	Area of the municipality/commune [km^2]	Forest area [ha]	Forest share [%]
Nowogród	101	2,365.01	23.40
Turośl	199	5,411.17	27.20
Łyse	246	8,748.00	35.40
Lelis	196	7,391.48	37.60
Kadzidło	258	10,307.87	39.80
Czarnia	93	3,658.10	39.50
Baranowo	198	6,125.84	31.00
Myszyniec	228	5,683.01	24.90
Zbójna	186	8,652.07	46.50
Total/share	1,705	58,342.55	34.22

Source: author's own work based on the data of the Statistical Office in Warsaw and Białystok in 2016.

A considerable share of forests affects, among other things, the number of nature reserves which are abundant in the region of Kurpie. Table 2 illustrates data on the nature reserves in individual municipalities and communes.

Table 2. Nature reserves located in individual municipalities and communes of Green Kurpie

Municipality/ Commune	Nature reserve	Established	Area [ha]	Type of nature reserve	Accessibility for tourists
Czarnia	Czarnia	19/10/1964	141.87	Forest	Can be accessed from the "Barci kurpiowskich" hiking trail
	Surowe	26/10/1964	4.57	Forest	Non-accessible
Kadzidło	Podgórze	10/03/1987	37.76	Forest	Can be accessed from the "Wach" bicycle path running near the nature reserve
	Torfowisko Karaska	03/08/2000	402.69	Peat-bog	Non-accessible
Lelis	Olsy Płoszyckie	23/09/1997	140.86	Forest	Accessible
Łyse	Mingos	17/12/1971	13.46	Forest	Accessible near the external borders
	Tabory	01/09/1974	17.21	Forest	Accessible near the external borders
	Torfowisko Serafin	29/12/1998	184.92	Peat	Accessible

Municipality/ Commune	Nature reserve	Established	Area [ha]	Type of nature reserve	Accessibility for tourists
Turośl	Ciemny Kąt	01/07/1984	125.95	Forest	Accessible near the external borders
Zbójna	Czarny Kąt	15/04/1989	32.97	Forest	Accessible near the external borders
	Kaniston	01/08/1984	136.59	Forest	Accessible near the external borders
	Łokieć	15/04/1989	139.50	Forest	Accessible near the external borders

Source: author's own work based on the data of the General Directorate for Environmental Protection, of the Forest Districts of Myszyniec, Nowogród, and Ostrołęka.

The six communes of the Kurpie Forest comprise 12 nature reserves with a total area of 1378.35 ha. For the most part, they are forest reserves; only the "Torfowisko Karaska" nature reserve in the commune of Kadzidło and the "Torfowisko Serafin" nature reserve in the commune of Lelis are peat-bog reserves. Accessibility of most of the peat bogs for tourists gives them an opportunity to discover stands of trees typical of Green Kurpie and to actively spend time in nature.

Culture of Green Kurpie

The culture of Kurpie is distinct in both tangible and intangible aspects. One of the first characteristic features of the region that can be seen after crossing the borders of Kurpie are Kurpian houses. Originally, Kurpian houses were divided into an entrance room and a living room. As a consequence of transformations, new rooms appeared – there was an entrance room, an alcove, a living room and a small storeroom. Houses were built along the street, with their front towards the road. Wooden beams of the front of a Kurpian house were decorated – most frequently with animal heads at the top (so-called "śparogi" in Kurpian). Windows had shutters which were usually blue with flowers painted on them. Walls were decorated with Kurpian paintings and paper-cut art created by women (*Kurpiowszczyzna*..., 2007).

Another determinant of the culture of Kurpie are folk costumes. Women's costumes included headwear (characteristic hat called "czółko" in Polish for unmarried girls and shawls for married women), a linen shirt, a corset or a vest and a broad ankle skirt. On top of that, women wore an apron made of white cloth with crochet lace or colourful embroidery. Their traditional, bast shoes were called "kurpie", from which the name of the region is derived.

Women's clothing was complete with amber jewellery. Men dressed primarily in brown, covering their heads with a hat or a peaked cap. They donned caftans or long coats of cloth ("sukmana") worn over a shirt and a pair of linen trousers. Traditional footwear included slippers, clogs and top-boots for the wealthy. Finishing touches on men's costumes were added with a pipe, a snuffbox or a cane. Presently, despite certain changes that have occurred over time, the Kurpian costume is still an important and cherished element of the culture of Kurpie.

Since Kurpian land was not good for farming, people originally engaged in fishing, forest bee-keeping and amber processing. Amber emerged in Kurpie in the process of relocating deposits originating from the Tertiary by Pleistocene glaciers. Kurpian people usually found amber when they were fishing. Most of this resource was found in the Rozoga, Szkwa, and Piasecznia Rivers.

Apart from amber processing, forest bee-keeping was also a very important part of the culture of Kurpie. An event commemorating the passion of Kurpie for forest bee-keeping is the Kurpie Honey Harvest ("Miodobranie Kurpiowskie" in Polish) that is celebrated every year on the last Sunday of August and it is attended not only by numerous bee-keepers, but also by tourists.

The inhabitants of Green Kurpie were also sculptors; they usually made religious sculptures. Wooden figures of Saint John of Nepomuk and the Pensive Christ may be found in houses, wayside shrines and forests (Niedziałkowska, 1981).

The region of Kurpie has also its own local dialect. Kurpie has developed its own local dialect spoken even today, but mainly by the elder population, though the characteristic Kurpian accent can also be heard among the younger generation of Kurpians. The local dialect of Kurpie belongs to the group of Masovian local dialects (the Masovian dialect). Even though the region of Kurpie is said to be homogeneous in terms of language and culture, it is diverse thanks to northern Masurian and southern Masovian settlers.

A majority of the respondents confirmed that the culture of Kurpie is distinct (78%). The respondents had no doubt as to the diversity of the culture of Kurpie. Behaviour, customs, and folklore art are values that, in their opinion, make the region stand out. It makes cultural tourism possible there. The Kurpian people may employ well-preserved Kurpian values in, among other things, service provision activities and, thus, earn a profit.

A majority of the respondents (67%) selected the local dialect of Kurpie as being the most distinctive element of the region. Although today it is spoken mostly by the elder population and the younger generation usually uses few Kurpie-specific words, the Kurpian accent is noticeable for non-inhabitants of the region of Kurpie.

Half of the respondents (52%) also found traditions and customs as determinants of cultural distinctiveness of Kurpie. During major religious holidays and local festivities Kurpians wear traditional Kurpian costumes. The fewest respondents said that Kurpian buildings make the culture of Kurpie more distinct. Probably, that is because there are fewer and fewer typical Kurpian houses in the region. They are being replaced with new houses, not necessarily in the traditional Kurpian style. Old houses can be still seen in an open-air museum in Nowogród or in the "Zagroda Kurpiowska" museum in Kadzidło.

Development of nature and cultural tourism in the region of Green Kurpie

Within the scope of tourism infrastructure, a prerequisite for tourism development of any region is accommodation, which includes hotels, guesthouses, camping sites, agritourism locations and other lodgings (Kisiel et al., 2014). The overview of current accommodation facilities available in the Green Kurpie region was based on data from the Central Registration and Information on Economic Activity (CEIDG) and the National Court Register (KRS) with reference to the Polish Classification of Activities (PDK) (figure 3).

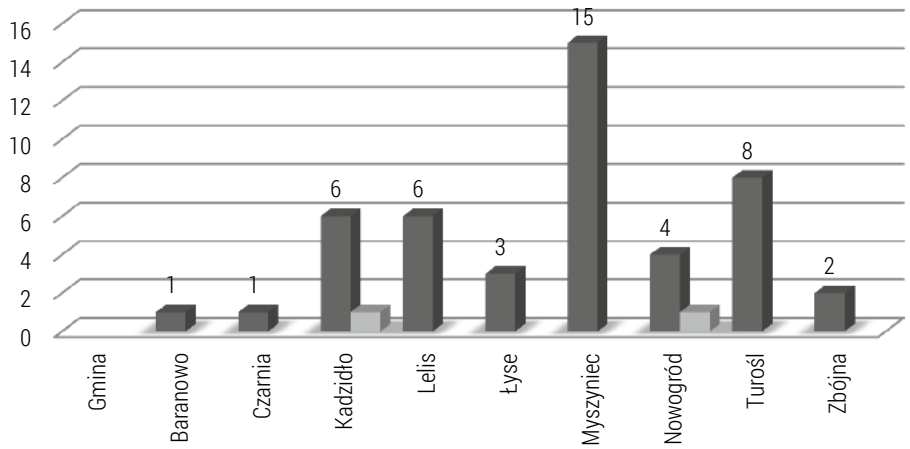

Figure 3. Accommodation facilities in Green Kurpie

Source: author's own work based on data from Central Registration and Information on Economic Activity (CEIDG), https://prod.ceidg.gov.pl/ceidg.cms.engine/ [14-08-2017]; National Court Register (KRS), https://ems.ms.gov.pl/krs/wyszukiwaniepodmiotu?t:lb=t [15-08-2017]; http://www.krs-online.com.pl/ [15-08-2017].

Companies registered in the municipalities of the Kurpie Forest include 48 economic entities engaged in economic activity classed in section I, unit 55 of the Polish Classification of Activities (PKD). The largest concentration of those entities was observed in the municipalities of Myszyniec and Nowogród and in the commune of Turośl. The overwhelming majority were single owner businesses, those entities provide tourists with accommodation either as their main economic activity or as an additional line of business secondary to their main occupation, usually in the agricultural sector.

Since Green Kurpie is located on agricultural land, it has seen an especially marked expansion of agritourism. Benefitting from the natural qualities of the region, owners of different facilities organise cycling and kayaking trips, horseback rides or sleigh rides. Tourists can also venture into the lush forests to pick blueberries or go mushroom hunting. Owners serve regional delicacies such as milk products or honey from their own apiary. In an effort to fully cater to the needs of prospective clients, they invest in recreational infrastructure such as tennis courts, sports grounds, playgrounds and other facilities dedicated to sport and active leisure.

Tourism in Kurpie also draws on the rich history of the region. Its traces include multiple monuments and tombs that commemorate the events of the January Uprising, the Swedish Deluge and other wars. History enthusiasts can broaden their knowledge by visiting Kurpie history museums in Ostrołęka and Wach. Some agritourism farms offer meetings with folk artists and lessons in Kurpie crafts: sculpture, making tissue paper flowers or cut-outs. As emphasised by the owners, these workshops are a valued attraction for people interested in learning new skills while on holidays.

There are no official statistics on the number of tourists in the region of Green Kurpie. However, some estimates can be provided on the number of participants in the biggest events that are the most famous among visitors (table 3).

Table 3. Number of participants at the largest cultural events in the region of Green Kurpie in 2016

Event	Estimated number of participants
Kurpie Honey Harvest (Myszyniec municipality)	40,000
Kurpie Wedding (Kadzidło commune)	10,000–15,000
Palm Sunday (Łyse commune)	10,000

Source: author's own work based on the data from the Regional Centre of Kurpie Culture (RCKK) in Myszyniec, Kurpie Culture Centre (CKK) in Kadzidło and the Municipal Centre of the Culture of Sport and Recreation (GOKSR) in Łyse.

The most popular event of 2016 was the two-day Kurpie Honey Harvest. According to the data collected by the Regional Centre of Kurpie Culture (RCKK), it was attended by a total of approx. 40,000 people. Many visitors came from outside of the Kurpie Forest. Kurpie Wedding and Palm Sunday were attended by approx. 20,000-25,000 people in total. Both events originated as local celebrations but with the passage of time they have evolved into huge folk festivals and magnets for tourists interested in the culture of Kurpie.

In the survey conducted, most respondents (56%) indicated that they visited the region of Green Kurpie. Within this group, 54% visited the region multiple times, 29% – twice, and 17% – once. The results reveal that Green Kurpie is perceived as a region worth more than one visit. The motives inspiring its visitors are presented in figure 4.

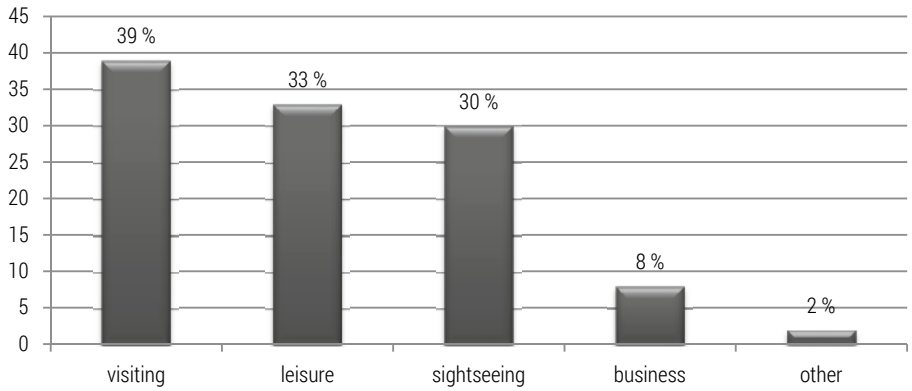

Figure 4. Reasons for coming to Green Kurpie according to the respondents (%)*

*multiple answers possible
Source: author's own work.

The respondents came to Green Kurpie to pay a visit (39%), for leisure (33%) and for sightseeing (30%). During their stay, they expected hospitality, 'conditions conducive to relaxation', and 'a respite from everyday responsibilities in a natural environment'. In addition, the respondents appreciated opportunities to explore the culture of the region. A small group (8%) came for business purposes. Those people valued the availability of attractive deals on accommodation and the opportunity to taste Kurpie cuisine.

The survey reveals that tourists are drawn to Green Kurpie mainly because of attractive natural conditions and rich cultural resources of the region. However, a prospective tourist expects local decision makers to create conditions where in those assets can be enjoyed to the fullest. In addition, visitors appreciate clear and widely accessible information on leisure activi-

ties available in the region. Therefore, in order to unlock the potential of Green Kurpie, local authorities ought to highlight its assets and minimise the inconveniences which, in the eyes of the respondents, include insufficient promotion of the region in mass media. In their mind, promotional activities should involve not only advertising cultural events but also reviving the old traditions of Kurpie. One respondent suggested arranging dance parties which used to be very popular in the region. Despite its beautiful nature, the region is believed to lack man-made tourist attractions which would allow visitors to fully enjoy their stay. Furthermore, limited transport accessibility and insufficient number of parking lots make it difficult for tourists to reach their destinations in Kurpie and often leads them to giving up the idea of visiting. The respondents also noted a scarcity of agritourism farms. Their opinions are affected by two factors: firstly, an insufficient promotion of specific facilities and secondly, a gap between the rapidly growing demand and the slowly changing supply. Another weakness of the region is the insufficient number of tourist signs which complicates finding the most interesting tourist attractions.

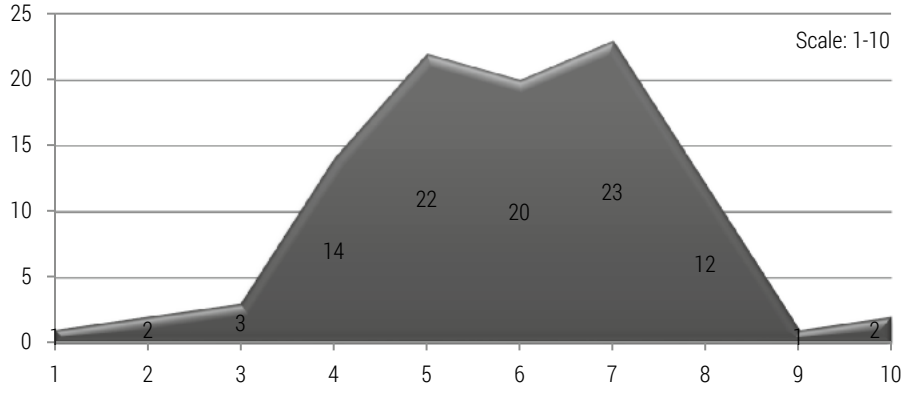

Figure 5. The position of Kurpie among other regions by the potential for tourism development in the assessment of survey respondents [%]

Source: author's own work.

Both the strengths and weaknesses of Kurpie impact its position on the map of tourism regions in Poland. On a scale from 1 to 10, 22% of the respondents rated the position of the region as average (rate 5) in comparison with others. Almost one-fourth of the respondents favourably evaluated Kurpie's potential for tourism development (rate 7) and a handful viewed the position of the region unfavourably (figure 5). In conclusion, there are varying opinions on the placement of Kurpie in the ranking of regions by their potential for tourism development. Such a discrepancy may result from many reasons,

including different preferences and expectations of tourists. The qualities which some people would appreciate (e.g. calm, serenity) could seem problematic for other, more active visitors looking for an adventure. Thus, it is necessary to continually adapt the services to individual expectations so that all visitors can find something for themselves.

Undeniably, nature and culture are the main factors defining Kurpie. However, one cannot overlook activities aimed at making the region more competitive and recognisable. In the opinion of 76% of the respondents, Kurpie shows potential for becoming a region widely known for its culture and nature tourism. In the age of the Internet, promotion of a region is far easier than before. Therefore, areas that have tourism potential and can fulfil it in a custom-made advertisement campaign are certain to become popular tourist destinations. 14% of the respondents had no opinion on the future development of tourism and recreational attractiveness of the region. One-tenth believed that despite its incontestable natural and cultural values, the Kurpie region does not stand a chance of becoming a tourism region widely recognisable either in Poland or abroad.

Conclusions

The abundance of natural and cultural resources distinguishes Green Kurpie from other Polish regions. Nature constitutes a particularly valuable asset. In the eyes of the respondents, vast forests, natural reserves, a wealth of rivers and meadows deserve to attention above all. In turn, the greatest distinguishing feature of Kurpia's distinctive cultural in the eyes of tourists are local dialect and traditions and customs. These resources are conducive to the development of nature and culture tourism in the region.

Although most respondents believe that the region is attractive for tourists, they also see the necessity to take additional measures to improve its transport accessibility, place clear tourist signs and ensure broader promotion of the region and its accommodation facilities. It is also worth emphasizing that because the possibility of using the valuable natural areas by the public is most often carried out in conjunction with the cultivation of favourite forms of tourism, scientific research on environmental management (Manfredo et al, 2003; Bruskotter, Fulton, 2008) suggest or even recommend monitoring exploiting the environment in terms of its use for tourism purposes. Such activities are intended to help central and local authorities to anticipate people's intentions in the use of natural resources and to create an appropriate policy in the field of environmental protection, and at the same time opportunities to associate people with the natural environment (Bengston et al., 2004).

Finally, it is worth mentioning that the municipalities of Green Kurpie have a good chance of enhancing their offer with the use of EU funds available for 2014-2020, particularly under the Regional Operational Programmes for the Mazowieckie and Podlaskie voivodeships. Will the region leap at this opportunity? We shall try to answer this question in upcoming years.

The contribution of the authors

Roman Kisiel – conception – 40%; literature revive – 20%; acquisition of data – 20%; analysis and interpretation of data – 30%
Joanna Zielińska-Szczepkowska – conception – 20%; literature revive – 40%; acquisition of data – 40%; analysis and interpretation of data – 30%
Dominika Taradejna – conception – 40%; literature revive – 40%; acquisition of data – 40%; analysis and interpretation of data – 40%

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VARIETY OF RAW MATERIALS IN THE FORMATION OF TRADITIONAL CULINARY PRODUCTS AS A TOURIST ATTRACTION

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ABSTRACT: The article presents the influence of natural conditions not modified by man on the authenticity of traditional culinary products. Tourists can travel along tourist routes and visit agritourism farms. The analysis presents the presence in the rural tourist area of products and raw materials certified as traditional. Increasing interest in local and traditional products is most often considered in the context of a region as a phenomenon of globalization or as a tendency to change consumer preferences stemming from the desire to preserve and show the wealth of culinary heritage.

KEY WORDS: traditional culinary products, agritourism

Introduction

The natural conditions of an unmodified human environment have a significant impact on the authenticity of traditional culinary products. The relationship between natural values and their origin is an element that affects the characteristics of a traditional product of a given region. Regional products should be characterized by a high quality of unified environmental protection. The combination of manufacturing features, consumption of regional products and respecting the principles of sustainable development was a factor in the protection of this food and the emergence of slow food (Jakubiak, Lupa, 2013, p. 163).

Sustainable development

Sustainable development, environmental protection and the willingness to preserve and continue the tradition of producing products may be the result of growing demand for products based on principles and technologies that meet ecological criteria and constitute an element of promotion of a given region. Among the most important causes are the negative effects of environmental pollution and the process of globalization, the increase of ecological awareness of the society and the desire to return society to what is traditional and specific to the region. There are many high-processed products in the food market, so the growing recognition in the food market is generated by products known as regional and traditional (Minta, Tansa-Hus, Nowak 2013, p. 2887-2898).

The definition of sustainable development was formally adopted in 1987 in the World Commission on Environment and Development. It is "a process aimed at satisfying the development aspirations of the present generation in a way that enables the same pursuit of the next generations" (www.unesco.org; Plebańczyk, 2013, p. 24, 32).

The trend of returning to nature means that more and more tourists are choosing to rest in green, unpolluted areas. The creation of region and local products very often takes place according to old recipes, often without preservatives. Another positive aspect is often the ecological character of traditional or regional products (Minta, Tańska-Hus, Nowak 2013, p. 2887-2898).

The traditional way of growing or breeding raw materials, especially without additives, is not only a feature of a given region, but often decides and is responsible for the taste qualities of a given product. This method of cultivation is undoubtedly a great asset of these products, sought in Polish

and foreign markets (Gąsiorowski, 2005, p. 279). Such production is conducive to the development of organic farming, develops a system of farming with sustainable production of plants and animals. Organic production is a way of obtaining a product that uses as natural as possible methods of production without compromising the natural balance (Rzytki, 2015, p. 32).

Definition of traditional food

According to the European Commission's definition, the term "traditional" refers to foods that are marketed in the Community market at least for a period that indicates transmission from generation to generation, which is defined as at least 25 years (Żakowska-Biemas, 2012, p. 5-18; Rozporządzenie Rady WE Nr 509/2006). Food is characterized by specific characteristics that distinguish it from other products in terms of "traditional ingredients" from which it was made, "traditional composition" and "traditional methods of production and/or processing" (Żakowska-Biemas, 2012, p. 5-18). Traditional raw materials or semi-finished products are raw materials (species and/or variants) or semi-finished products that are either individually or as a component of a specific geographic area, in accordance with specifications and national regulations. The traditional composition should be characteristic of the product group. Traditional methods of production and/or processing are methods that were passed down from generation to generation. According to the degradation, "local product" is a product, an agricultural product or a product that is closely related to the area in which it is produced (FOOD-CT-2005-513944, 2008). The purchase of such a product by a tourist may constitute the first stage of linking the region. Purchase of the product will mean contact with cultivated traditions, customs, unique culture, but also with the natural environment (Chojka, 2012, p. 105-120). Regional products will be products strictly dependent on the conditions prevailing in a specific area. These articles are related to the area, traditions, culture. Their specialty is that they are made in a place and based on traditional recipes.

These products have their own traditional name and composition, as well as distinguishing them from other products, products, regional cuisine (Ziółkowski, Jalinik, 2009, p. 40).

An important element of tourism is also tourism education, concerning the provision of information on raw materials from crops, plant and animal breeding. The aims of education are mainly focused on:

- cultivation ecological awareness,
- acquaintance with natural, historical and cultural values,
- creating new behavioral patterns for children and adolescents,

- shaping eco-friendly tourist attitudes,
- creating eco-friendly tourist products (Wartecka-Ważyńska, 2010, p. 268).

The role of the Slow Food movement in preserving traditional food

The Slow Food movement as initiated by Carlo Petrini as a spontaneous reaction to the rise of the first fast food restaurant in Italy in 1985. The basic principles of the movement are goodness, purity and justice. This movement refers to the consumption of high quality products when produced under environmental conditions (Chabzda, 2014, p. 14-17).

The Slow Food organization is the founder of the Biodiversity Observatory in agriculture, which informs and presents problems, indicates solutions and draws attention to the positive results and experiences of other actions that can be replicated and adapted to local conditions. Intensive food production is the main cause of the loss of biodiversity, while the multifunctional, versatile and small-scale farming model is able to ensure the quality and repeatability of natural resources and preserve biodiversity and guarantee the integrity of ecosystems (www.slowfood.com).

This food and the phenomenon that accompanies it are conducive to:

- developing a culture of life and enriching it with new experiences,
- maintain, cultivate the traditions of the region, the country, maintain the culinary traditions, develop local, regional agriculture, and thus improve the economic situation of farmers, breeders and local food producers,
- development of local identity, building of "small homeland",
- development of culinary tourism,
- improvement of the natural environment,
- education and public health, by promoting good and valuable nutrition and raising awareness within these values.

Slow Food promotes a lifestyle that is based on the values of local communities and the consumption of locally produced products. This group includes both producers and consumers of food (Jakubiak, Lupa, 2013, p. 163).

The most important factors of slow tourism are:

- quality and safety of products and tourist services, including its attractiveness,
- production, service provision and sale of products respecting the principles of sustainable development,
- the availability of products, through convenient distribution, sales, the ability to observe production,

- accessibility of culinary tourism services, and thus targeting the needs of the consumer (tourist consumer),
- authenticity, that is, credibility of origin, traditional, local way of production and product delivery.

The role of agritourism in preserving culinary traditions

The feature of rural tourism is the ability to show not only the village but also elements of traditional local culture. This is achieved by:

- cooking of regional cuisine, preparation of dishes and products based on natural ingredients with characteristics often different from nationwide,
- cooking and culinary arts related to local traditions,
- encouraging farm work,
- education in the sphere of breeding and cultivation of species with an old regional tradition, unique in the national scale,
- education in the area of healthy eating, traditional and organic food production,
- education in the field of herbalism and the use in the kitchen of savory varieties of plants,
- advertising among guests participating in local holidays (Musiał, Kania, Leśniak, 2005, p. 197).

In the case of particular voivodships of Poland, natural qualities are taken into account for the development of agri-tourism. The share of protected areas and the possibility of using the area for organic farming affect the attractiveness of agri-tourism (Mucha-Szajek, 2006, p. 125). Most agro-tourism farms in Poland produce food according to the conventional agri-foodstuffs applicable throughout the agricultural and food sector. The second group of agrotourism farms are ecotourism farms that produce food by organic methods (Dominik, 2011, p. 131-135).

Traditional culinary products are designed for both leisure and leisure travelers as well as for those who are interested in nature and are open to local culture and traditions (Witkowski, 2010, p. 285).

The main factors related to the production of fresh produce in Poland include:

- a specific microflora, which makes cucumbers, cabbage, mushrooms, produces curdled milk and white cheese and sour cream,
- ecological way of agricultural production,
- soil not contaminated with chemicals,
- natural way of feeding and raising animals (meat during picking takes a specific taste),
- lakes and rivers (Woźniczko, Jędrysiak, Orłowski, 2015, p. 160-161).

Dietary habits are often referred to as the way in which individuals or groups select and consume food in accordance with social and cultural constraints. They are an important part of the culture of the societies and their cultivation is important for preserving the cultural heritage of the nations (Warmińska, 2006, p. 437-438).

Traditional products on a regional basis

The research carried out by Nestorowicz et al. (2016) shows that respondents are aware that the purchase of regional products contributes to supporting the local economy (26%). An important element was also the information about the local origin of the product from the supplier and the certificate of organic food (45%). A significant part of the survey was that regional products are made from natural ingredients (67%) and are environmentally friendly (65%). Of the surveyed 56% declared willingness to buy domestic products.

The most frequent reasons for purchasing regional products according to the respondents were their taste (20%) and tourist reasons (66%) (Grębowiec, 2017, p. 65-80).

Traditional methods of producing regional products are related to the area of origin. The European Union has introduced a system of protection for these products, which are characterized by regional or culinary heritage. The system of protection and promotion of regional products is an important element of tourism and gastronomic development (Gulbicka, 2016, p. 22-23).

The legal basis for the functioning of the system of protected designations of origin, protected geographical indications and guaranteed traditional specialties in the European Union is Regulation (EU) No 1151/2012 of the European Parliament and of the Council of November 21, 2012 on the quality systems of agricultural products and foodstuffs (Rozporządzenie Parlamentu Europejskiego i Rady (UE) nr 1151/2012 z dnia 21 listopada 2012 r. w sprawie systemów jakości produktów…).

In Poland, the Ministry of Agriculture and Rural Development is responsible for maintaining the product registration system with a specific geographical origin and specific traditional quality (According to the Act on Registration and Protection of Names and Marks of Agricultural Products and Foodstuffs and on Traditional Products).

Very often the emergence of a traditional culinary product is associated with a characteristic region of the region such as Małopolska Miodowa, or a tourist attraction (Woźniczko, Orłowski, 2010, p. 250-251).

Culinary routes are a kind of designated routes where tourists can meet traditional culinary products. One of them is the Fruit Route, which runs through seven communes of the Malopolska province – Zawoja, Raciechowice, Laskowa, Trzciana, Łącko, Stary Sącz. There are over 150 products and row materials marked with a special logo. You can sample local produce and learn how to grow apples, plums, blueberries, cherries, and other fruits. In addition, in Łącko there is a folk festival "Jubilee of Apple Blossom", where the regional music of the band can taste local specialties, such as the famous slivovitz or pear. Another example of a culinary tourist route can be located along the Dunajec "Fasolowa Dolina". Polish tourists also visit the vineyards on the land of Lubuskie, the oscickie trail Podhale and the famous Suwalszczyzna croaking, where in many agritourism farms can learn to prepare these regional delicacies.

The name of traditional or regional food products is often abused, so the characteristics of the products registered as protected geographical indications (Gulbicka, 2016) are presented.

According to Woźniczko and Piekut (2015), the highest number of products registered in the list of traditional products, depending on the region is located in the Podkarpackie voivodship (dairy products) and Pomerania (fisheries, drinks).

For the purposes of the article, an analysis of the presence in rural tourism space of products and raw materials classified as traditional, whose values and status depend on the natural environment unaffected by anthropogenic modifications. Examples have been selected that have been qualified for traditional culinary products and are on the List of Traditional Products of the Ministry of Agriculture and Rural Development. The example of these products shows the relationship between natural values and the origin and characteristics of traditional culinary products in tourism.

The below presented examples clearly notice the impact of the natural context of the creation of traditional culinary products and their authenticity, which can be an element of increasing the tourist attractiveness.

1. Lamb Podhalans. For the production of lamb in Podhale, lambs of the "Polish sheep of the mountain" and "lambs" are used, kept at the mothers kept in the traditional way and unchanged for centuries. The production of lamb is mainly in the Cieszyn, Żywiec and Małopolskie districts. Meat is characterized by brittleness and during cooking the fat remains inside the muscle resulting in high juicy (www.minrol.pl).
2. Carp zatorski. Zator carp production is conducted in three neighboring communes located in the western part of the Małopolskie voivodship. The municipality of Zator, Gmina Przeciszów is located in the district of Oswiecim and the municipality Spytkowice, located in the district of

Wadowice. Since 2003 they have jointly implemented the project "Carpathian Valley" (www.minrol.pl).

3. Bean of the Dunajec Valley. Contemporary sources state that the best conditions for growing dried beans are as follows: 1) southern Lublin region with Rzeszów, Przemyśl and Jarosław; 2) the Poznań-Pomerania-Lodz region, covering the south-western part of the Poznań-southern Pomeranian Province, and the Radom region, and 3) the Cracow region – primarily the Tarnów area, where the bean plantation is usually rich in calcium and phosphorus. sodium. Beans contain easily digestible starch and soluble fiber that helps to remove bad cholesterol deposits (www.minrol.pl).
4. Apples Leckie. The expressive taste and smell of apples are due to the microclimate of the Łącka Basin. Most of the fruits obtained in the Łącka region are characterized by exceptional succulence and aroma. The shape of the fruit depends on the particular variety. The blush is clearly stronger than apples from another region. Due to the specific microclimate and terrain, the fruit rust is relatively small (www.minrol.pl).
5. Narvian cheese. The cheese is characterized by a touch of fresh milk, mild, delicate, aromatic, with a slight saltiness. The addition of herbs causes the cheese to get the right taste and aroma (garlic, marjoram, cumin, blackcurrant and other herbs). Nutritious cheeses have a creamy aroma with a possible blend of herbs. The milk used to produce these cheeses must come from the vicinity of the Narew National Park, preferably from Poland Red Cows (www.minrol.pl).
6. Crispy coffee. Boiled coffee is a healthy, nutritious and strengthening drink, giving a feeling of satiety, strengthening the stomach, liver and spleen, eliminating stomach disorders (www.minrol.pl).
7. Juniper sausage from Masurian meat factory. Sausage made from pork meat with a high content of carbohydrates. Cured meats by the method of flooding or dry, in wooden barrels and stoneware pools. Wood from deciduous trees – alder, oak, ash (www.minrol.pl).
8. Stewed cabbage Kraśnicka. The production of sauerkraut is concentrated in the area of Rzeczyca Ziemiańska. Raw materials produced on their own farms are used. Cabbage is grown on the basis of organic fertilizers. No artificial preservatives are used in the production of this cabbage (www.minrol.pl).
9. Cowshed. Krzeszów is located in the south-eastern part of Poland (in the county of Nińsko). The cows were known to have been bred without sugar, and their persistence kept for a dozen or so years. The tradition of making sauces has passed from generation to generation and has survived to this day. For several years the fry is accompanied by a celebration called "Spidlaki" (www.minrol.pl).

10. Rye oil. The name comes from the seedlings plant from which the oil is pressed. The rusty color of the seed, reminiscent of the color of rice, has become the basis for the name of the oil. The abundance of fatty acids, mainly omega-3, is 54%, an additional advantage is its high durability (www.minrol.pl).

Conclusions

Food production that combines best practices for the environment, high biodiversity is of interest to tourists for whom it is important to know and experience authenticity, cultural and natural education, and a healthy lifestyle. It is important, therefore, to use traditional methods of production that meet their requirements during production.

Regional and traditional products are increasingly popular in Poland and in the world. The sense of responsibility for your own health leads to the search for products that are organic, natural, without artificial additives, rich in new flavor and unique aroma, which is often characterized by a regional product.

Traditional culinary products become an element of the tourism offer of a given area or region, which increases the attractiveness of a given place. In addition, regional products, due to the nature of origin and production, are conducive to economic development and can provide real benefits for local communities.

The contribution of the authors

Piotr Dominik – 33%
Anna Fabisiak – 33%
Józef Grochowicz – 33%

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ECONOMIC AND ENVIRONMENTAL ASPECTS OF THE CULTIVATION OF ENERGY PLANTS IN THE PODLASIE PROVINCE

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ABSTRACT: Dynamic economic growth of EU countries, including Poland, forces to reduce the use conventional energy sources and to replace them with renewable energy sources (RES). Biogas produced in agricultural bio-gas plants becomes one of the most important source of that energy. The most advanced technologies of biogas and electricity from biogas production are found in Germany. In Poland, biogas energy accounts for 2.5% of RES. Basic substrates for agricultural biogas plants are: maize, slurry, manure and other agricultural waste. The emerging biogas plants require stable and reliable cultivation of energy crops, mainly maize silage. In the Podlasie province, 9 agricultural biogas plants with a total capacity of 67.6 MWe were installed in 2014-2016. In order to provide the raw material base for a biogas plant, the area of maize cultivation is estimated at around 3,500 ha. Intensive cultivation of maize (high mineral fertilization, pesticides) in the long term may reduce the utility and biological values of light soils. When locating a biogas plant in the Podlasie province, one should take into account the great landscape values of rural areas and significant areas of protected landscape.

KEY WORDS: biogas, substrates for biogas plant, maize, profitability of plantation, environmental effects, landscape value

Introduction

In the dynamic economic development of the modern world, there is a gradual reduction of energy generation from conventional sources. This is in line with the Kyoto Protocol of 1997, which shows that counteracting the global warming is possible by introducing the new technologies for the production of energy from renewable sources (RES). The EU policy on renewable energy is also closely related to the global strategy for combating the climate change and reducing CO_2 emissions (Piotrowski et al., 2014). The share of energy from renewable sources in the final gross energy consumption in Poland is 7.2%, and in 2020 an increase of this share is assumed to 15%. In the EU countries, the largest share of energy production from renewable sources occurs in Sweden 39.8%, Latvia 34.9%, Finland 28.0%, Austria 23.3%, and Portugal 20.5%. The lowest amount of energy from renewable sources is produced in Luxembourg 0.9%, Great Britain 1.3%, Belgium 2.3%, Netherlands 2.4%, Cyprus 2.9%, and Ireland 3.1% (GUS, 2017).

The basic source of RES are currently solid biofuels that in EU countries constitute 44.6% (table 1). In addition to solid fuels, wind farms and agricultural biogas plants also have a significant share in the production of renewable energy. Biogas obtained in the process of anaerobic biomass fermentation is an important source of renewable energy supported by the European Union and Poland (Directive 2001/77/EC of the European Parliament). In the longer term, however, the share of biomass in renewable energy will be decreasing in favor of solar and wind energy (Banaszuk et al., 2015).

According to the Ministry of Economy, by 2020 it is planned to launch at least one agricultural biogas plant in each commune, the power of which will be in the range of 0.7 to 2 MW. The total power of such biogas plants in Poland in 2020 is estimated at about 2000-3000 MW (*Kierunki rozwoju biogazowni rolniczych*, 2010).

The subject of the study is the assessment of current state of biogas plants and the use of plant raw materials for the production of biogas (mainly maize) in Podlasie province, as well as indication of economic benefits and environmental effects of introducing the large-scale energy crops.

Renewable energy sources in the EU and in Poland

The basic source in the RES structure are currently solid biofuels that in EU countries constitute 44.6%, and in Poland – 73.2% (table 1). Biogas produced from crops and other organic waste accounts for only 7.6% of renewable energy in EU countries. The most energy from biogas is produced in

Germany (20.2%). In Poland, biogas accounts for only 2.5% of energy generated from renewable sources. Opinions about the rapid development of biogas plant networks are different. Not always the energy production in agricultural biogas plants is profitable and competitive in relation to solar and wind energy. Limitations and environmental conditions as well as consequences in the environment have an impact on the slow development of biogas installations (Faber, 2008).

Table 1. Structure of renewable energy sources [%] in some EU countries in 2012-2016

Energy source	Years	EU	Austria	Czech Republic	Finland	France	Netherlands	Lithuania	Germany	Poland	Slovakia	Italy
Solid bio-fuels	2012	48,7	48,3	70,6	79,7	46,0	31,6	82,8	34,1	82,1	55,9	34,4
	2016	44,6	48,1	69,0	76,0	45,2	28,3	82,2	31,0	73,2	55,9	31,2
Solar energy	2012	4,9	2,2	5,3	-	2,1	1,1	0,0	8,9	0,2	2,9	8,4
	2016	6,4	2,9	5,0	-	3,4	2,6	0,4	10,3	0,5	3,1	9,2
Water energy	2012	40,3	40,3	4,9	14,5	24,9	0,2	3,0	5,8	2,1	24,6	17,1
	2016	34,2	34,2	3,6	13,9	21,9	0,2	2,0	4,2	1,7	20,9	16,6
Wind energy	2012	9,7	2,3	1,0	0,4	6,3	10,9	3,9	13,6	4,8	-	5,5
	2016	12,7	4,5	1,2	1,9	8,5	13,5	4,8	17,5	10,4	-	5,4
Biogas	2012	6,7	2,2	10,1	0,6	1,9	7,4	1,0	20,0	2,0	4,3	5,6
	2016	7,6	3,2	14,3	1,0	2,5	6,8	1,6	20,2	2,5	9,3	7,9
Liquid biofuels	2012	6,3	2,8	5,9	2,8	11,7	26,6	9,0	9,3	8,0	10,5	1,8
	2016	6,7	4,8	5,0	4,6	11,8	29,9	7,8	8,5	10,4	9,4	2,9
Geothermal energy	2012	3,1	0,4	-	-	0,9	0,3	0,3	0,3	0,2	0,4	23,5
	2016	3,2	0,4	-	-	1,0	1,2	0,1	0,5	0,2	0,4	23,2
Municipal waste	2012	4,6	1,5	2,2	1,9	6,2	21,8	-	8,1	0,4	1,3	3,8
	2016	4,6	2,0	1,9	2,6	5,7	17,5	1,1	7,7	0,4	0,9	3,6

Source: author's own work based on (GUS, 2016).

Considerable reduction in the agricultural waste deposition on landfills, reduction in methane and nitrogen compounds emissions from stored biomass fermentation, is a positive effect of biogas production. Post-fermentation mass from a biogas production plant may be also a source of a valuable fertilizer for agricultural purposes.

Material and methodology

For preparing the material contained in this paper, data and information from the National Center for Agricultural Support (Rejestr wytwórców

biogazu, www.kowr.pl), Podlasie Agricultural Advisory Center, and the Central Statistical Office, were used. It is problematic to determine data on the area of energy crops, because ARiMR does not keep such records due to the elimination of subsidies for energy crops. Biogas plant owners do not always have full and reliable information about contracted maize crops for biogas plant purposes. In the present study, estimates were made regarding the area of maize cultivation for the needs of biogas plants, assuming that 0.4 ha of maize cultivation is needed per 1 kW of energy (Ginalski, 2014).

Methane fermentation and characteristics of biomass used in biogas installations

Methane fermentation in agricultural biogas plants takes place under anaerobic conditions with the participation of acid-forming bacteria, acetate bacteria and methanogenic bacteria. In the fermentation chamber in the agricultural biogas plant, decomposition of organic matter occurs with the production of biogas, the main component of which is methane CH_4, and CO_2, hydrogen sulfide H_2S, ammonia NH_3 are released in smaller amounts. During anaerobic fermentation, depending on the substrate, approximately 30-60% of the organic matter decomposes most frequently. After the fermentation process, the material (post-fermentation mass) containing minerals remains. The post-fermentation mass is used as agricultural fertilizer. In the natural environment, where organic matter decomposes (boggy and swamp areas), and also in municipal waste landfills, uncontrolled methane emission also occurs (Curkowski, Mroczkowski, 2011).

In agricultural biogas plants, the following substrates are used for the production of biogas: maize silage, perennial plants grown for energy purposes, sugar beets, grasses, natural fertilizers (slurry, manure, bird manure), as well as by-products of the agri-food industry. For the production of biogas, the most effective substrate is biomass with a content of over 30% of organic matter.

According to the Agricultural Market Agency, almost half of the substrate used for biogas production comes from slurry. Most biogas plants using slurry as a substrate occur in the western part of Poland. Depending on local conditions and the specificity of agricultural production, a mixture of several substrates (so-called co-substrates) can be used for biogas plants. The use of co-substrates allows to increase the production of biogas in relation to mono-substrates. Besides, by appropriate selection of the proportion of substrates used, among others, dry matter content and the ratio of basic macronutrients in the mixture obtained can be regulated. The optimal C:N:P:S ratio

should be around 600:15:5:1. It guarantees a proper supply of nutrients to bacteria carrying out the methane fermentation process.

Maize silage and other substrates for biogas plant

In agricultural biogas plants, mostly and in the largest amounts, maize silage and slurry are used as the substrate. In practice it is possible to obtain 15 t·ha^{-1} grain or 25 t DM ha^{-1} (Fugol, Szlachta, 2010). Maize silage is a good substrate for biogas plants due to:

- high yields of green forage (40-45 t·ha^{-1}),
- good properties of green forage for silage,
- high biogas production (450-700 m^3·t DM),
- stabile biogas production in technological process.

Maize (*Zea mays*L.) from grass family (*Poacea*) is a species with multitude of utility features: it adapts to different soil conditions during growing and depending on a cultivar, it has quite high yielding capacity. In technological processes in biogas production plant, it is a good substrate with large biogas production efficiency (table 2). Agrotechnics of maize fir the biogas production purposes is similar to that for fodder, yet high mineral fertilization is applied for the former (up to about 400 kg NPK·ha^{-1}). Applying a high mineral nutrition on light soils with simultaneous tillage, in a longer time perspective can contribute to soil degradation.

Table 2. Technological parameters of maize used as a substrate in a biogas plant

	Seed maturity phase			
	milky	beginning of wax	wax	full
Dry matter [%]	21,9	27,8	32,6	40,1
Organic substance [% DM]	95,7	94,8	94,7	96,3
Green forage yield [t/ha]	45	50	55	45
Biogas efficiency [m^3/ha]	5445	8550	10890	10305

Source: (Podkówka, 2006).

Maize for biogas should be harvested from the field at a content of 30-35% of dry matter (table 3), i.e. at the stage of wax and full grain maturity. In these maturity stages, there are optimal levels of sugars, protein, fat, and raw fiber, and these components are most effectively used for biogas (Michalski, 2002; Podkówka, 2006).

Depending on local conditions and the specificity of plant production in a given region, green forage made of grass (from permanent pastures) and grass from field crops may be used as a substrate for the biogas plant. The best biogas yield is obtained at a content of 30-40% dry matter (so-called preliminarily dried grass). The optimal date for harvesting the green forage intended for silage falls on the stage of the formation of panicles by tall grasses. In this phase of vegetation, the grass contains 17-22% of dry matter. Good results are obtained by ensiling the biomass from grasses dried to a dry matter content of 30-40%. With higher dry matter content in the hay, there are difficulties with its ensiling. If the grass cultivation for the biogas plant is planned, the best results (due to biomass size) are achieve dusing the following species: common ryegrass (*Arrhenatherum elatius* J.et.C.Presl), meadow fox (*Alopecurus pratensis* L.), timothy grass (*Phleum pratense* L.), multiflorous ryegrass (*Lolium multiflorum* Lam.), reed fescue (*Festuca arundinacea* Schreb.), grasshopper (*Dacytlis glomerata* L.), and for light sandy soils, sand reed (*Calamagrostis epigejos* L.Roth. The use of cereal crops (wheat, rye, triticale) as substrates for biogas plant can be debatable due to nutritional and fodder use of these plants.

Selection of plant species for biogas results mainly from the maximization of biomass production volume and obtaining a large income. Often, in the absence of agrotechnical knowledge and with incomplete identification of habitat (soil and water) conditions, large-scale monoculture maize cultivation is introduced. Such crops change the agricultural landscape, reduce the biodiversity of flora and fauna species. The use of valuable, in terms of floristics, permanent grassland as a base for biogas plant can cause significant changes in these valued ecosystems.

Agricultural biogas plants in Poland and in the Podlasie province

As many as 296 biogas plants are registered in Poland (table 3). They use substrates from sewage treatment plants (99 biogas plants), landfills (98 biogas plants) and biomass from agricultural sources (95 biogas plants). Most biogas plants were established in the Mazowieckie and Śląskie provinces, and the smallest in Świętokrzyskie and Opolskie. The most dynamic development of biogas plants has been noted in the last three years and this mainly concerns the creation of agricultural biogas plants. Currently existing 95 agricultural biogas plants have the technical capacity to produce 391 439 352 m^3 of biogas and production of 101,204 MWe (Rejestr wytwórców biogazu, www.kowr.pl). In western provinces, biogas plant substrates are animal waste (slurry and liquid manure), while in eastern provinces, biogas

plants are based on biomass from arable crops, mainly maize silage. According to Michalski (2002), maize silage is characterized by the highest efficiency of biogas production in comparison to other crops.

Table 3. Biogas plants in Poland

Province	The number of individual types of biogas plant installations				Total for provinces
	Biogas from wastewater treatment plants (BGO)	Agricultural biogas plants (BGR) (condition on 16/10/2017)	Biogas from landfills (BGS)	Biogas plants with mixed technology (BGM)	
mazowieckie	10	5	19	-	34
śląskie	16	3	14	1	34
wielkopolskie	7	10	10	-	27
dolnośląskie	9	8	9	1	27
pomorskie	4	9	6	-	19
zachodniopomorskie	4	13	9	1	27
małopolskie	10	2	5	-	17
kujawsko-pomorskie	4	6	7	-	17
warmińsko-mazurskie	6	10	3	-	19
łódzkie	3	4	5	-	12
lubelskie	4	7	2	-	13
podlaskie	5	9	1	-	15
podkarpackie	10	3	3	-	16
lubuskie	2	4	2	-	8
opolskie	3	1	2	-	6
świętokrzyskie	2	1	1	-	4
Total by type	99	95	98	3	295

Source: author's own work based on (National Center for Agricultural Support, www.kowr.pl [17-11-2017]; Woźniak, 2016).

In the Podlasie province, there are currently 9 agricultural biogas plants registered, located in different parts of the province (table 4). The first biogas plant was launched in the Ryboły in 2014. Existing biogas plants with optimal raw material conditions can produce 29.6 million m^3 of biogas, and as a result of its co-generation, about 7.5 MWe can be obtained. The substrates in

the biogas plant in Podlasie are: maize silage, grass, waste from animal production (slurry, bird manure, manure).

Table 4. Agricultural biogas plants in the Podlasie province [condition on 16-10-2017]

Localization	Name of the biogas plant owner	Date of launch	Annual biogas production capacity [$m^3 \cdot year^{-1}$]	Annual power obtained from a co-generator [MWe]	Estimated area of maize cultivation for biogas plant purposes [ha]
Ryboły, commune Zabłudów	Adler Biogaz	2014	4380000	1,000	450
Szepietowo, commune Wysokie Mazowieckie	CHP Energia	2015	4555000	1,200	540
Sokółka, commune Sokółka	Eko-Farmenergia	2015	3338700	0,999	446
Czerwonka, commune Szypliszki	Gospodarstwo Rolne M. Dyczewski	2015	420000	0,100	45
Michałowo, commune Michałowo	Zielona Energia Michałowo	2015	2300000	0,600	270
StaryKornin, commune Dubicze Cerkiewne	Polska Grupa Biogazowa Energetyka	2015	4009120	0,999	446
Dzierżki, commune Poświętne	Polska Grupa Biogazowa Energetyka	2016	4009120	0,999	446
Krasowo Częstki, commune Nowe Piekuty	Green Energy	2016	2221154	0,700	315
Krzywa ,commune Bielsk Podlaski	Polska Grupa Biogazowa Energetyka	2016	4380000	0,999	446
Total			29 613 094	7,596	3404

Source: author's own work based on www.kowr.gov.pl [17-11-2017].

The basic substrate in biogas plants in Podlasie, however, is the maize silage. Currently, there is no precise data on maize cultivation areas contracted by individual biogas plant owners. Also in the ARiMR, there is no data on the area of cultivation of maize for biogas plant purposes. In the present study, a conversion factor of 0.4 ha of maize per 1 kW of energy was adopted for the calculation of maize cultivation area (Woźniak, 2016; Ginalski, 2014). The minimal area of silage maize cultivation for a 1 MW biogas plant should

amount to 400-450 ha. For the needs of Podlasie biogas plants, maize should be grown on 3 404 ha (table 4). According to the Statistical Office in Białystok (Urząd Statystyczny Białystok, 2016), the area of maize cultivation in the main yield in the province in 2016 amounted to 128 300 ha. Maize for biogas plants purposes is 2.6% in the area of its total cultivation.

Economic aspects of the creation of biogas plants in agricultural areas

An important motive for making a decision on the location of a biogas plant is the need to diversify sources of agricultural income. In the market economy and the Common Agricultural Policy of the EU, there is a need to adapt the direction of agricultural production to the market, environmental and climate requirements. Launching the biogas plants, growing energy crops, selling electricity under favorable conditions can be a source of stable and stable income for agricultural producers and local self-governments. Agricultural biogas plants also have a pro-environmental aspect, because they enable management of by-products from agriculture and agri-food processing. The remaining post-fermentation mass can be used as an organic fertilizer, reducing the cost of mineral fertilization (Kowalczyk-Jusko, Szymanska, 2015). The production of maize silage for agricultural biogas plants can be profitable. Research by Szlachta and Tupieka (2013) show that in the production of silage at the level of 41.5 $t \cdot ha^{-1}$ and the sales price of 132 PLN per 1 ton, a profit of PLN 3890 from 1 ha can be achieved. The costs of profit also include an amount of approximately PLN 880, which is a direct subsidy to each hectare.

Under conditions of the Podlaskie province, the emergence of biogas plants in areas of extensive agriculture creates opportunities to stop the outflow of population and labor from such rural areas. Growing crops and maize on arable lands with poor bonitation classes allows to reduce fallow lands. At the same time, there is a fear about the proper agrotechnics.

The liquidation of small farms for social and economic reasons, means that a large part of agricultural land ceases to be agriculturally developed. Such situations take place in many communes of the Hajnówka, Bielsk Podlaski, Bialystok and Sokółka. Taking over small farms by new dynamic owners, creating a larger farm area and diversifying traditional farming directions are important in maintaining proper arable land. One of the sources of constant and stable income in newly established large farms focused on crop production may be the cultivation of maize for biogas plants. With this

change, young producers should pay attention to and adapt to existing climatic and water and soil conditions (Kiryluk, 2016).

Environmental aspects of energy crops in the Podlaskie province

Trends to quickly expand the area of energy crops for agricultural biogas plants may limit the size of other field production. In the case of the Podlaskie province, such a threat should not be expected, because intensive field production was abandoned in large areas, and many arable land of worse bonitation classes is temporarily excluded from production. The limitation in the creation of new biogas plants in the Podlasie province may be unfavorable environmental conditions, large areas of protected areas, occurring in about 40% of the province area. Due to a short lifetime of agricultural biogas plants, there is no reliable information indicating the negative effects of growing energy crops on the environment (Faber, 2008; Jarosz et al., 2013). This assumption does not exclude the thesis that changes in the environment will not occur after a long period of energy crops cultivation. At the stage of biogas plant location, attention should be paid to the existing soil and water conditions of arable land, constituting the target energy base. In special situations and in biogas plants with a capacity above 0.5 MW, it is advisable to prepare an environmental impact (Zarębski, 2013).

In the majority of the area of agricultural land of the Podlasie province, there are not very favorable conditions for the intensive production of cereals, maize and other crop species. The synthetic indicator of the quality of agricultural production space (including soil quality, agroclimate, land relief, water conditions) for the Podlaskie province amounts to 55 points, which is 11.6 points lower than the average for whole Poland (table 6).

Table 5. The synthetic index of agricultural production area in the Podlasie province

Area	Bonitation indicator				Synthetic indicator of the quality of agricultural production space
	The quality and agricultural suitability of soils	agroclimate	land relief	water conditions	
Podlasie province	41,0	7,5	3,7	2,8	55,0
P o l a n d	49,5	9,9	3,9	3,3	66,6

Source: (Biesiacki et al., 2004).

Analyzing the production capacities of the Podlaskie province, it should be noted that soils on the area of 439.3 thousand ha (58.5% of total arable lands), are included in good, weak and very weak rye complexes. It should be borne in mind that introducing the intensive soil and plant cultivation methods in such soil conditions may be inappropriate for economic and environmental reasons. The use of fertilization approximately 400 kg NPK·ha^{-1} on light soils for maize cultivation, will limit the organic matter resources. In such conditions, it will be rational and necessary to use the post-fermentation mass from a biogas plant. Factors limiting the increase in the area of energy crops is also about 30% share of TUZ in the structure of agricultural land. Plowing the meadows and pastures and introducing maize cultivation is inadvisable due to agro-technical reasons and it is inconsistent with the EU's WPR policy of greening.

Energy crops and maize growing due to the high production of plant biomass require a significant amount of water. According to Kowalik and Scalenghe (2015), maize characterized by a transpiration coefficient of 358 kg H2O·kg DM with a minimum yield of 5.5 tons of grain, requires 1,969 m^3 of water in the growing season, i.e. 196 mm of rainfall. If the yield is increased, water consumption will also increase. Light soils in the Podlasie province are characterized by low rainwater retention capacity and low groundwater, therefore irrigation may be necessary for intensive maize cultivation. The use of ploughless cultivations *(stripp-till*) and herbicides in the cultivation of maize for biogas plant causes the reduction of soil utility value and, in particular, reduces its biological activity. Large-scale and multi-annual monocultures of energy crops can reduce the species diversity of plant communities on arable land (Banaszuk et al., 2015; Kiryluk, 2016; Tryjanowski et al., 2011). Elimination of mid-forest afforestation and introduction of maize cultivation on the surface of several dozen or several hectares causes diminution in landscape values of rural areas. The treatment of agricultural areas mainly as places of intensive biomass production in the longer term will result in the emergence of new pests, development of wild boar population and the problem of ASF. In the Podlasie province, rural areas occupy about 60% of its area, and are characterized by a large diversity of habitats, diversified buildings and they are the place of residence and everyday life for about 50% of the province population. Excessive development of modern technologies of agricultural production, elimination of traditional system of fields, gaps, ecotone zones, can significantly diminish the landscape and cultural values of the villages in Podlasie.

Summary and Conclusions

1. Biogas produced mainly in agricultural biogas plants in EU countries constitutes 7.6% of renewable energy sources (RES). In Poland, this proportion is only 2.5%, and in Germany 20.2%.
2. In Podlasie province, according to estimates, it is necessary to cultivate maize for the needs of 9 agricultural biogas plants on the area of approximately 3,500 ha. Currently, the total area of maize cultivation according to GUS data is about 130,000.
3. Agricultural biogas plants in Podlasie province should not be located near natural values areas, as the main raw material base for these biogas plants is intensive cultivation of maize silage.
4. Due to the cultivation of maize in monoculture and the use of high mineral fertilization (about 400 kg NPK·ha^{-1}), there is a gradual reduction in soil biological activity and reduced organic matter content.
5. The elimination of traditional field system, elimination of gaps and unpaved mid-field roads, reduces the landscape values of rural areas in Podlasie.
6. Concentration of large areas of maize cultivation close to compact forest complexes (Puszcza Białowieska) promotes development of wild boar population and the spread of ASF disease, because wild boars find good feed and living conditions in these crops.

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