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PROPOSAL FOR WATER SUPPLY SYSTEMS EVALUATION DUE TO DIVERSIFICATION OF WATER INTAKES AND WATER TANKS

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ABSTRCT: The aim of the study was to compare the various water supply systems – from rural to agglomerations, in terms of continuity of water supply to the inhabitants in a crisis situation. The work included the diversification of water intakes with their number and the maximum daily production capacity and the diversification of water in the water tanks, knowing their number and volume. RB1 and RB2 diversification indexes have been proposed. Assessment criteria were included with comment. The research component is a two-parameter assessment of diversification for selected water supply systems using the indicators proposed by the authors.The use of proprietary indicators to assess the diversification of water supply using preference functions gives the ability to perform calculations easily and accurately.

KEY WORDS: water supply, diversification, water intakes, water tanks, allocation

JEL: Q530, Q570

Introduction

The appurtenance of collective water supply systems (CWSS) to critical infrastructure implies that one of the basic conditions for cities is to provide water for consumption in adequate quality. It is obligatory to cover the current and prospective water demand in a technically and economically justified manner with respect tonatural water resources. Among the technical factors, the reliability of CWSS is the most important. Safety is defined as the system's ability to protect internal values against external threats (Kucharski, Rak 2009; Pietrucha-Urbanik, 2013; Szpak, Tchórzewska-Cieślak, 2015; Tchórzewska-Cieślak, Boryczko, Piegdoń, 2015; Tchórzewska-Cieślak, Rak, 2010). Analyses and assessments of both reliability and safety related to the CWSS functioning indicate the significant role of water supply diversification (Boryczko, 2016; Pietrucha-Urbanik, Studziński, 2017; Rak 2014a; Rak, 2014b; Rak, 2015; Rak, Boryczko, 2017; Rak, Włoch, 2015; Weitzmann, 1992).

The basic diversification indicators used by the authors to assess the diversification of water supply in earlier works are Shannon-Weaver (1962), Pielou (1979, 1984), Simpson (1949, 1951) and Hurlbert (1971).

The main objective of the work is to show the methodology of water supply diversification analysis and assessment taking into account the production capacity of water intakes and volume of water tanks. The use of proprietary diversification indicators has been proposed. The work also includes calculations for selected cities of Poland.

Methodology of water supply diversification analysis and assessment

The starting point in the structure of the diversification index is the selection of the preference function. It determines the volume of supplies most desirable for CWSS. The preference function is defined on the range <0,1>, it has positive values and additionally in 0 and 1 it takes the value 0.

So there are endless possibilities to choose preference functions. The work considers the diversification index based on the functions:

$$x^3 - 2x^2 + x \text{ for } x \in \langle 0,1 \rangle \tag{1}$$

The function promotes 0.5 shares.

Authors (Rak, Boryczko) diversification index built on function (1) is:

$$d_{RB1}(V) = \sum_{i=1}^{n} \left(u_i - 2u_i^2 + u_i^3 \right) \tag{2}$$

where:
n – number of water tanks,
u_i – the share of the i-th water tank in the total volume of network water tanks.

The contribution of the i-th tank is given by the formula:

$$\sum_{i=1}^{n} u_i = 1 \tag{3}$$

where $u_i \in \left(0,1\right\rangle$.

The water intakes diversification index is set in the same way:

$$d_{RB1}(Q) = \sum_{j=1}^{m} \left(u_j - 2u_j^2 + u_j^3\right) \tag{4}$$

where:
m – number of water intakes,
u_j – share of the j-th water intake in the total water production of CWSS.

The contribution of the i-th tank is given by the formula:

$$\sum_{j=1}^{m} u_j = 1 \tag{5}$$

where $u_j \in \left(0,1\right\rangle$.

The work also considers the diversification index based on the following function:

$$y = x - x^2 \text{ for } x \in \left\langle 0,1 \right\rangle \tag{6}$$

The function promotes 0.5 shares.

The water tanks diversification indicator built on this function is as follows:

$$d_{RB2}\left(V\right) = \sum_{i=1}^{n} \left(u_i - u_i^2\right) \tag{7}$$

The water intakes diversification index can be determined from the formula:

$$d_{RB2}(Q) = \sum_{j=1}^{m} \left(u_j - u_j^2\right) \tag{8}$$

A two-parameter assessment of the water supply diversification was carried out according to additive models for RB1 and RB2, respectively:

$$d_{RB1} = \alpha \cdot d_{RB1}(V) + d_{RB1}(Q) \tag{9}$$

$$d_{RB2} = \alpha \cdot d_{RB2}(V) + d_{RB2}(Q) \tag{10}$$

where:
α – allocation factor – the ratio of the total amount of water accumulated in water tanks to the total capacity of all water intakes.

The α indicator is calculated as:

$$\alpha = \frac{\sum_{i=1}^{n} V_i}{\sum_{j=1}^{m} Q_i} \qquad (11)$$

Tables 1 to 3 present the values of the dRB1 and dRB2 index calculated with formulas (2), (4), (7), (8).

Table 1. The numerical values of d_{RB1}(V,Q) and d_{RB2}(V,Q) for m, n=2

m=2	u_1 = 0,5 u_2 = 0,5	u_1 = 0,6 u_2 = 0,4	u_1 = 0,7 u_2 = 0,3	u_1 = 0,8 u_2 = 0,2	u_1 = 0,9 u_2 = 0,1	u_1 = 0,95 u_2 = 0,05	u_1 = 0,99 u_2 = 0,01
d_{RB1}	0,25	0,24	0,21	0,16	0,09	0,0475	0,0099
d_{RB2}	0,5	0,48	0,42	0,32	0,18	0,095	0,0198

Source: author's own work.

Table 2. The numerical values of d_{RB1}(V,Q) and d_{RB2}(V,Q) for m, n=3,

m=3	u_1 = 0,33 u_2 = 0,33 u_3 = 0,33	u_1 = 0,4 u_2 = 0,3 u_3 = 0,3	u_1 = 0,5 u_2 = 0,3 u_3 = 0,2	u_1 = 0,6 u_2 = 0,3 u_3 = 0,1	u_1 = 0,6 u_2 = 0,2 u_3 = 0,2	u_1 = 0,7 u_2 = 0,2 u_3 = 0,1	u_1 =0,8 u_2 = 0,1 u_3 = 0,1
d_{RB1}	0,444	0,438	0,4	0,324	0,352	0,272	0,194
d_{RB2}	0,663	0,66	0,62	0,54	0,56	0,46	0,34

Source: author's own work.

Table 3. The numerical values of d_{RB1}(V,Q) and d_{RB2}(V,Q) for m, n=4,

m=4	u_1 = 0,25 u_2 = 0,25 u_3 = 0,25 u_4 = 0,25	u_1 = 0,3 u_2 = 0,3 u_3 = 0,2 u_4 = 0,2	u_1 = 0,4 u_2 = 0,3 u_3 = 0,15 u_4 = 0,15	u_1 = 0,5 u_2 = 0,3 u_3 = 0,1 u_4 = 0,1	u_1 = 0,6 u_2 = 0,2 u_3 = 0,1 u_4 = 0,1	u_1 = 0,7 u_2 = 0,1 u_3 = 0,1 u_4 = 0,1
d_{RB1}	0,5625	0,55	0,508	0,434	0,386	0,306
d_{RB2}	0,75	0,74	0,705	0,64	0,58	0,48

Source: author's own work.

The Analysis of d_{RB1} (V, Q) and d_{RB2} (V, Q) contained in tables 1÷3 indicates that:

- their maximum values are different for subsequent m or n,
- with the increase of m or n indexes values are growing,
- in cases of similar shares, the value of diversification indexes remains close to the maximum value for a given number m or n.

Proposal of categorization and standards determination of d_{RB1} diversification index taking into account the water intakes production and the volume of water tanks:

- lack of diversification $d_{RB1} = 0$
- small diversification $0 < d_{RB1} \leq 0,200$
- average diversification $0,200 < d_{RB1} \leq 0,400$
- sufficient diversification $0,400 < d_{RB1} \leq 0,600$
- very satisfactory diversification $d_{RB1} > 0,600$

Proposal of categorization and standards determination of d_{RB2} diversification according to (9):

- lack of diversification $d_{RB2} = 0$
- small diversification $0 < d_{RB2} \leq 0,300$
- average diversification $0,300 < d_{RB2} \leq 0,600$
- sufficient diversification $0,600 < d_{RB2} \leq 0,800$
- very satisfactory diversification $d_{RB2} > 0,800$

Calculations and discussion of results

The calculations for CWSS Rzeszów are presented below.

Two water intakes:

$Q_1 = 36120\ m^3/d$

$Q_2 = 47880\ m^3/d$

$Q = 84000\ m^3/d$

Twelve water tanks:

$V_1 = 600\ m^3$

$V_2 = V_3 = 1800\ m^3$

$V_4 = V_5 = V_6 = V_7 = 3000\ m^3$

$V_8 = 17700\ m^3$

$V_9 = V_{10} = V_{11} = V_{12} = 750\ m^3$

$V = 36900\ m^3$

$$\alpha = \frac{36900}{84000} = 0,44$$

$d_{RB1}(V) = 0,583$

$d_{RB2}(V) = 0,738$

$d_{RB1}(Q) = 0,245$

$d_{RB2}(Q) = 0,490$

$d_{RB1} = 0,44 \cdot 0,583 + 0,245 = 0,5$ – sufficient diversification

$d_{RB2} = 0,44 \cdot 0,738 + 0,490 = 0,81$ – very sufficient diversification

Table 4. Calculations of the two-parameter diversification index dRB1 including the allocation factor α

City	α	d_{RB1} (V)	d_{RB1} (Q)	d_{RB1}	diversification
Gorzów Wlkp.	0,23	0,296	0,403	0,47	sufficient
Jasło	0,39	0,192	0,019	0,09	small
Krosno	0,05	0,25	0,258	0,27	average
Poznań	0,39	0,222	0,227	0,31	average
Racibórz	0,31	0,444	0,188	0,33	average
Rzeszów	0,44	0,583	0,245	0,5	sufficient
Sanok	0,33	0,322	0,248	0,35	average
Szczecin	0,23	0,692	0,083	0,24	average
Tarnobrzeg	0,23	0,571	0,146	0,28	średnia
Tarnów	0,56	0,656	0,237	0,6	very sufficient

Source: author's own work.

Based on the analysis, it can be stated:

- inCWSS Tarnów very satisfactory diversification were found, due to the high α allocation factor,
- in SZZW Rzeszów a sufficient category of diversification was found, which results both from the high value of the allocation factor α (the second highest after CWSS Tarnów), and from the high (third of the analyzed CWSS) values of the d_{RB1} (V) index,
- low diversification was found in CWSS Jasła due to the low value of d_{RB1} (Q), which results from a large difference in the water produce of two basic water intakes.

The results of the d_{RB2} index calculation for all analyzed CWSS are presented in table 5.

Table 5. Calculations of the two-parameter diversification index dRB1 including the allocation factor α

City	α	dRB1 (V)	dRB1 (Q)	dRB1	diversification
Gorzów Wlkp.	0,23	0,494	0,55	0,66	sufficient
Jasło	0,39	0,384	0,04	0,19	small
Krosno	0,05	0,5	0,458	0,48	average
Poznań	0,39	0,444	0,454	0,63	sufficient
Racibórz	0,31	0,666	0,376	0,58	average

City	α	dRB1 (V)	dRB1 (Q)	dRB1	diversification
Rzeszów	0,44	0,738	0,49	0,81	very sufficient
Sanok	0,33	0,51	0,496	0,66	sufficient
Szczecin	0,23	0,828	0,166	0,36	average
Tarnobrzeg	0,23	0,752	0,292	0,46	average
Tarnów	0,56	0,799	0,41	0,86	very sufficient

Source: author's own work.

Based on the analysis, it can be stated:

- in the CWSS Tarnów and Rzeszów, categories of very satisfactory diversification were found, due to the high α allocation factor (the two highest among those analyzed) and the high value of both the $d_{RB2}(V)$ and $d_{RB2}(Q)$ indexes,
- in the CWSS Poznań, a sufficient diversification category was found, which results both from the high value of the α allocation factor (the third highest after the CWSS Tarnów and Rzeszów), as well as from the high values of $d_{RB2}(V)$ and $d_{RB2}(Q)$,
- despite the high value of the α allocation factor (the third highest), low diversification was found in CWSS Jasło – also due to the low value of $d_{RB2}(Q)$, which results from a large difference in the water produce of two basic water intakes.

Conclusions

The use of proprietary indicators to assess the diversification of water supply using preference functions gives the ability to perform calculations easily and accurately.

The proposed alpha allocation factor takes into account total amount of water accumulated in water tanks to the total capacity of all water intakes.

The high value of the alpha indicator should be interpreted as better diversification of water supply in a crisis situation.

The contribution of the authors

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

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