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Performance indicators model assessment for water system quality and supply in Montenegro

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Abstract: The paper researches water quality, supply and management system assessment problems of the Montenegrin costal region. A significant problem is generated by seasonal tourism, the main branch of Montenegrin costal economy. The selected performance indicators model has been tested in the water supply system of the city Herceg Novi, as a representative experimental system for the Montenegrin costal area. The city Herceg Novi has 33.000 permanent residents and around 80.000 individual consumers during the summer touristic season. The research activities are based on the seasonal parameters defined by the monitored performance indicators of the water supply system. The study depicts the developed indicators performance model based on the obtained experimental monitoring data. Within the experimental analytical research performance an indicator matrix was established. The coastal area of Montenegro is experiencing over 50 % of water loss. Structure developed in the model applies the performance indicators and results in systematic losses reduction. The model takes into account the principle of seasonality, and the existence of two completely different periods of the year. This type of the experimental research with testing *in situ* was for the first time performed and implemented in the costal Adriatic region of Montenegro.

Keywords: water quality; aquatic system model; model assessment.

INTRODUCTION

The management of water supply systems in Europe and developed countries has been constantly improving through the last three decades. The development has been predominately focused on the rational use of natural water resources, and water losses using different methods and mechanisms, technical and

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administrative nature. The experimental activities apply a performance indicator matrix to the management of water supply systems, or systems in one region with similar basic parameters, starting from natural environmental conditions, through technical elements, to relations with other industries on which water production and consumption depend.

Tourism industry must be taken into account when planning water supply system in coastal regions. In water project management it is obligatory to keep in mind that the touristic activities are a very demanding and fluctuations in the required continuous water supply are the primary factors affecting beneficial economic development. The lack of regular water supply to consumers can have significant and large repercussions on the development of the tourism economy. The primary task in the tourist environment is the continuous supply of water all 365 days of the year, considering the peaks of high consumption, which occur at least twice a day.

The control assessment of the water supply companies in coastal regions implies the responsibilities for overcoming complex situation between the produced and the needed quantities of water. The solution for the complex interdisciplinary problem is of interest to many experts and institutions in the Mediterranean region, particularly where tourism is the dominant industry. Experiences from practice and studies in the Adriatic basin, as well as in the Mediterranean countries, such as the coastal parts of Spain, Italy, Portugal, regions similar to Montenegrin coast, were applied. In the "Water Management Strategy of Montenegro" new and modern approach to water resources management was applied, harmonizing laws with the legislation of the European Union and ratified international conventions and declarations.[1] The operational aspect of the "Water Management Strategy of Montenegro" has been set for 2035, with the main strategy to reduce losses in public water supply systems to less than 30 %. In the Coastal Region of Montenegro, water supply systems are characterized by a high percentage of unaccounted water losses (non-revenue water, NRW), above 50 %. The percentage of unaccounted water is in agreement with the administrative and technology management policy.

The matrix performance indicators have been established as the optimal algorithm and mechanism to control the operation of the water supply system. Performance indicators (*PI*) provide a set of measures to monitor and improve water supply services to consumers (developed theory of the *PI* use in water systems).[2–4] In the last twenty years, the significant progress has been made in the application of *PI* research. *PI* knowledge has been significantly expanded as the water supply system has been implemented in Mediterranean countries.[5] The system has proven that it can be adapted and used in very different contexts and for a variety of purposes.[6–9]

In the technological, economic and ecomanagement field of water supply systems, *PI* model classifies types in the sphere of losses, defines methodology for detection and reduction in the system. In coastal regions the highlight and emphasize is on seasonal fluctuations in available water resources and water consumption.

Remarkable experiences from the Italian practice for urban areas in the case of insufficient water or in the case of climatic arid areas (town Ferragina) are valuable, with focus on the terms which included the loss analysis and applicable calculation.[5,9] To analyse the losses in the system, it is significant to recognize the water balance with all structural components of the system.[8,10] The components of the water balance, on the other hand, must be determined in volumetric form before beginning any loss reduction activities. The conserving water in local conditions usually means reducing the volume of water for one or more purposes. The concept of "water conservation" improves quality and capitalizes social, touristic, technological, public, economic and environmental benefits.[6,8]

The research aims to determine the model for adaptability and improvement of water quality and supply systems in the coastal region, where high technical water losses are evident. The *PI* model has been tested in the coastal area of Montenegro with six selected corresponding municipalities. The regional water supply system of the Montenegrin coast reimburses insufficient quantities in local water resources when required.

The experimental research is oriented on the water quality and supply system management with increasing efficiency, reduction of the unaccounted water percentage, and rational use of water resources.

EXPERIMENTAL

The assessment of water supply, supplementary conditions and problems was conducted for the coastal region of Montenegro in six municipalities: Herceg Novi, Kotor, Tivat, Budva, Bar and Ulcinj including about 140000 permanent residents. In 2019, a total of 14.45 million overnight stays were registered for the entire territory of Montenegro, in various types of accommodation services, of which 85 % stayed in the coastal region. The number of tourists and the number of overnight stays, is growing from year to year.

In the research activities, data for comparative analysis, assessment and modelling was obtained from local water supply companies of the coastal region of Montenegro. All the data is collected through the monthly reports and edited by "Vodacom", a joint management enterprise for six water supply companies in the coast. The state Energy Regulatory Agency is in charge of monitoring the water supply companies in Montenegro, and the data is provided by yearly reports.[11-15] Apart from statistical data, which are published by both institutions in a monthly or annual summary report, there are no available information and research papers dealing with analysis of parameters, performance indicators, considering causes and consequences, as well as the of specific chemical and environmental characteristics in management system assessment.

PI *model design*

The *PI* model was prepared for the water supply system based on the assessment of positive and negative factors in the operational phase of existing structures in the coastal region, with two highly differentiated periods of the year. The research included the SWAT analyses.[16] The model creates approximate representation of the system and process management, with a goal to improve the performance of the active water supply system. Modelling comprises the creation of the basic *PI*s matrix with more than 50 *PI*s. The decisive *PI*s for the water supply systems management are covered in Table I.

TABLE I. Performance indicators for application in the water system management

PI No.	Description of the indicator
*PI*1	Coverage of water supply service by number of connections (%)
*PI*3	Water production per consumer (m^3/consumer/month)
*PI*4	Water production per connection (m^3/connection/month)
*PI*5	Water consumption per user (m^3/consumer/month)
*PI*6	Water consumption - households (l/s/d)
*PI*7	Water consumption-households (m^3/consumer - households/month)
*PI*8	Water consumption - economy (m^3/consumer/month)
*PI*9	Percentage of reported water consumption for households in relation to the total measured amount of water consumed (%)
*PI*10	Percentage of water consumption for the economy in relation to the total measured amount of water consumed (%)
*PI*13	Percentage of non-revenue water in the total amount of water produced (%)
*PI*14	Volume of non-revenue water expressed per user per day (m^3/p/m)
*PI*15	Non-revenue water per km of network per day (m^3/km/day)
*PI*16	Unit electricity consumption per m^3 of invoiced water (kWh/m^3)
*PI*19	Number of failures per 1000 consumers
*PI*20	Number of failures per km of water supply network (breakdowns/km)
*PI*21	Average duration of failures (number of hours spent/total number of failures)

The water supply system model is defined by the expert system and experience from practice and application of the abstraction mechanism. The abstraction provides elements, variables, parameters and characteristics crucial for achieving the objective, while all other are neglected. The experience contributes in expanding the theoretical platform with known parameters by applying performance indicators. After theoretical consideration, the model should provide directions and guidelines for improving the practical operational state of the water supply system. The model expresses the complex and physical reality in mathematical system quantifying calculations in order to recognize risks and uncertainties. The application of the model minimize uncertainties and risks by replicating real circumstances and adjusting theoretical and practical parameters. Water supply systems are highly dynamic, variable in both spatial and temporal parameters and constantly adjusting the extent and the scope. The only constant in the system is volume of the tank, with the fluctuating water level, which adds another variable in system. Network extensions on the basis of newly built pipelines are part of the extrapolation of the network, as well as new water supply facilities. The changes in the pipeline network are in smaller strokes, considering the time intervals of the change. The quantities of water entering and leaving the system, number of failures, water gauges, interventions and other activities are considered as variables in the model. Selected variables arrange a basic parameters matrix as a structural component of the water supply system mathematical model. Seasonal disproportion is an imperative characteristic of the coastal region, the starting point in performance indicators model.

The water supply system is modeled in the mathematical correlation VS = {E, V, F} where VS is water supply system, E is a set of the most important elements of the system, V is set of connections and F is a function of the target system. E is defined as a set of primarily important elements consists of variables and constants in the water supply system: the length of water supply network, number of consumers, number of water gauges, number of tourists, quantity of produced water, quantity of consumed water, number of network failures. V is determined by set of connections of key performance indicators (*PI*1, *PI*3, *PI*4,…, *PI*21). F indicates the function of the system to reduce losses, *i.e.*, the percentage of unaccounted for water, and to provide sufficient and necessary amount of water (in the tourist season).

Essential premise of the model is the observation of the water supply system and functioning through two periods of the year (winter and summer).

Very complex and dynamic structure of the mathematical management model depicted in Fig. 1 with two distinguished annual periods, suggests the introduction of two operational subsystems for winter and summer. Both subsystems introduce fundamental characteristics: the amount of water produced and consumed, and the number of network failures and technical water losses. System is defined by variables: the amount of produced and consumed water in system, and the number of failures as a multiplier (n), which has a value of $n > 1$. Summer variables are compared to the variables of the winter functional system. Total water losses in the system are technically lower in summer than in winter, defining the multiplier as summer/winter, $n < 1$. In general, the characteristic of the entire Montenegrin coast is that the amount or volume of water produced in local resources in winter is much higher than in summer, and inversely proportional to water needs. The multiplier of produced water, for the amount available for entering the system, is: *V*winter/*V*summer > 1.

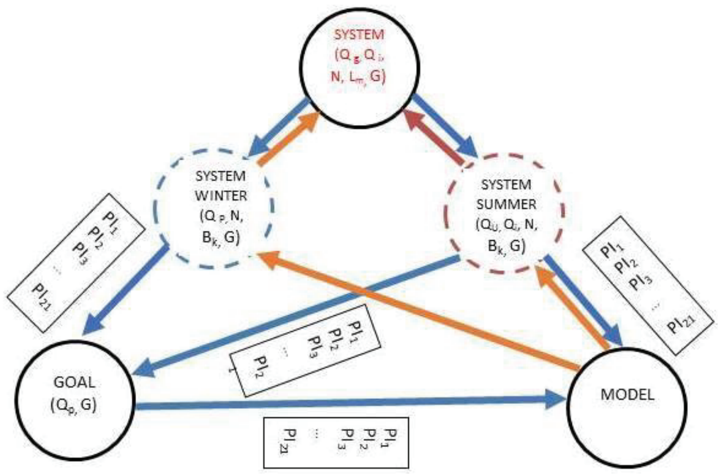

Fig. 1. Schematic mathematical model of a water supply system.

The system performance indicators, as indicators of status and change, indicate the functionality of the system, and their comparison in time frames identifies monthly and seasonal changes. The mathematical model was reduced on the matrix of seventeen key indicators: *PI*1, *PI*3, *PI*4, *PI*5, *PI*6, *PI*7, *PI*8, *PI*9, *PI*10, *PI*13, *PI*14, *PI*15, *PI*16, *PI*19, *PI*20 and *PI*21. Indicators are a relation that organizes pulsing signal, pointing out what needs to be corrected in order to improve the functionality and efficiency of the system.

Each subsystem aspires to a defined objective, and the status is analytically expressed by PIs. The function of the model is to modify the subsystems, based on the facts, ignoring problems from the real system, which often neglect crucial information. The flow of system dynamics is defined based on the real structure, from the intent to the model, and then modifying the elements again, for the next iterative cycle, which reduces losses in the system. The objective is transformed into a time function of reducing technical losses to an acceptable level of up to 30 % during the summer, since everything in the tourist region is subordinated to the summer and the supply of touristic facilities.

Technical losses in the winter are a completely different in comparison with the summer. Winter season characteristics are too much water, not enough consumers, pressures increased to high levels. In winter period, the operation of the maintenance teams on the network is important for repairing failures and damage to pipelines, installation of valves to reduce pressures, and discharging out of the system all unnecessary quantities before entering the distribution system. It is vital to reduce the technical losses in the winter as well, as the ratio of produced and consumed water.

RESULTS AND DISCUSION

The key indicators for analysing the state of the water supply system, defined in Table I are: *PI*1, *PI*3, *PI*4, up to *PI*20 and *PI*21. *PI*s are related to water production and consumption, grid failures, non-revenue water and electricity consumption. WSM benchmarking, as a set of performance indicators, provides relevant data for the system. Table II defines the key *PI* for the period between 2015–2019 with seasonal identification, for winter, W, and summer, S, period. Water consumption is growing yearly (*PI*5, *PI*6, *PI*7, *PI*8) indicating the tourism industry and household consumption twice higher in the summer than in the winter.

The significant seasonal deviations are evident in the Table II showing that seasonal observation is justified. Indicators differ from each other in almost all elements of the water supply network functioning, in the entire water supply system. Very differentiated indicator values are obtained: *PI*13, *PI*14 and *PI*15 for unaccounted water and network losses by season (winter 81.81 and summer 71.79).

The percentages of the unaccounted water from 2015 to 2019, imply a declining trend, as 2019 is with more favourable coefficients for the winter 80.76, and for the summer 69.06 period.

The ratio of unaccounted water summer:winter is calculated as 0.86 and is adopted as the index of seasonal balance in unaccounted water. The correlation is used in calculations when designing pipelines, and when adopting the relevant diameters in the sizing of pipelines, starting from the fact that in the summer, when consumption is higher, more water is in circulation and less pressure.

TABLE II. Key performance indicators, observed by season for 2015–2019 for the water supply system of Herceg Novi

PI	2015		2016		2017		2018		2019	
	W	S	W	S	W	S	W	S	W	S
*PI*1	95.63	95.76	96.04	96.04	96.16	96.16	96.21	96.27	96.39	96.39
*PI*3	51.66	54.35	44.37	56.32	46.73	57.02	42.08	52.17	42.36	53.06
*PI*4	84.00	88.54	72.00	91.37	72.28	94.37	66.12	81.77	67.51	84.56
*PI*5	16.69	15.27	7.58	15.30	7.51	15.66	10.38	21.05	7.83	16.25
*PI*6	143.02	280.47	138.16	278.30	137.51	292.83	145.23	297.18	139.65	284.65
*PI*7	6.56	12.81	6.32	12.58	6.29	13.31	11.09	17.15	6.26	12.87
*PI*8	25.70	48.94	24.72	52.71	22.66	41.89	42.93	80.66	29.97	63.82
*PI*9	77.89	78.22	78.03	76.77	79.24	78.63	78.67	76.71	74.41	73.61
*PI*10	22.11	21.78	21.97	23.23	20.76	21.37	21.33	23.29	25.59	26.39
*PI*13	84.45	71.10	82.67	73.26	83.80	73.06	82.05	69.77	81.50	69.06
*PI*14	43.79	39.08	36.80	41.02	38.83	42.22	60.82	42.26	34.52	36.78
*PI*15	103.65	92.08	88.38	98.16	93.72	101.76	81.74	85.40	82.90	88.25
*PI*16	0.86	0.80	0.79	0.68	0.84	0.72	0.67	0.41	0.45	0.54
*PI*19	4.75	9.48	5.14	7.29	5.26	8.70	5.19	8.59	5.14	7.78
*PI*20	0.33	0.66	0.36	0.51	0.37	0.62	0.39	0.61	0.38	0.56
*PI*21	4.54	3.68	5.12	3.82	4.58	3.87	5.25	6.07	4.68	4.26

The *PI* Table II displays that the amount of water lost is significantly lower in summer than in winter. In the experimentally tested coastal region of Montenegro it is evident that the development of water supply systems happens mostly spontaneously and deteriorated over time, pipes are very damaged or remained trapped by subsequently built facilities. Interpolations and extrapolations of the water supply network were not accompanied by the adequate hydraulic checks of the pipeline network parameters, which is reflected in high network pressures (between 6 and 12 bar) and frequent cracks and occurrences of various damages in the network.

Indicator *PI*3 and *PI*5 are the basic seasonality indicators for the water supply system. The ratio of available (produced) and required (consumed) water in the system indicates the unused amount of water. Indicator *PI*13 (percentage of non-revenue water in the total amount of water produced) is an indicator of the lost amount of water, which did not reach the consumer, *i.e.*, which is not registered on water gauges. In 2015 and 2016, there were regular restrictions on water supply, during the summer months, June–August, while this was not the case in 2018–2020, although the amount of water available in the system was the same. However, the difference was made by the increased degree of intervention in the repair of network failures, increased mobility, throughout the year, continuously, which was not the practice previously. *PI*15 has a downward trend, with a difference from 2015–2019 of 103.65 – 82.90 = 20.75 $m^3 km^{-1}$ per day in summer. The significant reduction is also noteworthy in winter 13.51 $m^3 km^{-1}$ per day.

The scheme presented in Fig. 1 provides a simplified methodology for the application of indicators, with the greater the number of indicators included in the analysis, the closer the results are to the real situation, and thus the easier it is to achieve the goal of improvement.

The indicators *PI*19, *PI*20 and *PI*21 deal with the number of network failures per 1000 consumers, the number of failures per km of water supply network and the average duration of fault repair. Construction works performed over the pipelines are the most common reason for damage.

Indicators are not just criterion of the current state of the water supply system, but imperative for the necessary changes in the system through management.

In the Coastal region of Montenegro, parameter of water losses in the system are much less important in the off-season. The available amount of water in all local water system exceeds the needs of consumers. Non-revenue water is important because of the electricity consumption in pressure subsystems, while the fact of losing the amount of water is not important. The separation of indicators by seasons demands rational needs of water production, electricity consumption, the necessary design of water supply network with accompanying facilities: pumping and hydrophore stations and reservoirs, different profiles, for summer and winter period. The *PI*s indicate need for circular, extensive design, with two pipelines (for winter and summer supply) as rational and beneficial solution.

CONCLUSION

The coastal area of the Montenegro is a challenging tourist region with distinct peaks in water consumption in the summer season compared to the rest of the year. *PI* model matrix is assembled on the experimental data for water supply systems (summer and winter) and includes parameters of water production and consumption, number of grid failures, unaccounted for water losses. The WMS benchmarking defines necessity to introduce seasonal analyses, the ratio of touristic and off season, when water resources are at minimum and maximum. Since the tourist season is not year-round, but lasts intensively in the period May–September, when water resources are at a minimum and consumption is at a maximum. The period is representative for analysing the system and observing the matrix of performance indicators. The treatment of water loss issues is different from the aspect of seasonality.

Current Montenegrin coastal region practice in water supply, neglect the issues and significance of seasonality concept, while the *PI* model through the research indicates importance for use.

The indicators performance model assessment for water system management in the coastal region of Montenegro was for the first time effectively performed with the depiction of unique and effective management plan.

И З В О Д

ПРОЦЕНА МОДЕЛА ИНДИКАТОРА ПЕРФОРМАНСИ КВАЛИТЕТА И ВОДОСНАБДЕВАЊА У ЦРНОЈ ГОРИ

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Истраживање приказује проблеме квалитета и управљања у систему водоснабдевања црногорског приморја. Значајан проблем је сезонски туризам, главна грана црногорске приморске привреде. Примењени модел индикатора перформанси тестиран је у систему водоснабдевања града Херцег Новог, као репрезентативног експерименталног примера за црногорско приморје. Град Херцег Нови има 33.000 сталних становника и око 80.000 индивидуалних потрошача током летње туристичке сезоне. Истраживачке активности су засноване на сезонским параметрима дефинисаним праћеним индикаторима перформанси система водоснабдевања. Рад приказује модел индикатора перформанси развијен на реалној матрици, а тестиран на примеру водовода у Херцег Новом. У оквиру експерименталног аналитичког истраживања креирана је матрица индикатора перформанси. Услед сезонских варијација, бележи се преко 50 % губитака воде у приморју Црне Горе. Структура развијена у моделу примењује индикаторе перформанси и резултира систематским смањењем губитака. Модел се базира на принципу сезонских варијација, два потпуно различита периода у години. Експериментално истраживање са тестирањем *in situ* први пут је спроведено у приморском јадранском региону Црне Горе.

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REFERENCES

1. M. of A. and R. D. Government of Montenegro, *Water Management Strategy of Montenegro*, Ministry of Agriculture and Rural Development, Podgorica, 2017 (in Montenegrin)
2. H. Alegre, M. do Céu Almeida, *Strategic Asset Management of Water Supply and Wastewater Infrastructures,* IWA Publishing, London, 2009, (https://doi.org/10.2166/9781780401720)
3. H. Alegre, J. M. Baptista, E. Cabrera, F. Cubillo, P. Duarte, W. Hirner, W. Merkel, R. Parena, *Performance indicators for water supply services*, IWA Publishing, London, 2006
4. R. Parena, Performance Indicators for Water Supply Services, IWA Publishing, London, 2000
5. M. Scoullos, E. Ferragina, C. Narbona, *Environ. Sustain. Dev. Mediterr.* (2010) 53 (http://www.iemed.org/observatori-es/arees-danalisi/arxius-adjunts/10-papers-for-barcelona-2010/8-environmental-and-sustainable-development-in-the-mediterranean/ferragina_8.pdf)
6. M. Oberascher, M. Möderl, R. Sitzenfrei, *Water* **12** (2020) 3446 (https://doi.org/10.3390/w12123446)

7. A. O. Lambert, T. G. Brown, M. Takizawa, D. Weimer, *J. Water Supply Res. Technol.* **48** (1999) 227 (https://doi.org/10.2166/aqua.1999.0025)
8. H. E. Mutikanga, S. K. Sharma, K. Vairavamoorthy, *J. Water Resour. Plan. Manag.* **139** (2013) 166 (https://doi.org/10.1061/(ASCE)WR.1943-5452.0000245)
9. H. Mutikanga, S. Sharma, K. Vairavamoorthy, E. Cabrera, *J. Water Supply Res. Technol.* **59** (2010) 471 (https://dx.doi.org/10.2166/aqua.2010.066)
10. C. Bozkurt, M. Firat, A. Ates, S. Yilmaz, O. Ozdemir, *Sigma J. Eng. Nat. Sci. – Sigma Mühendislik ve Fen Bilim. Derg.* **40** (2022) 310 (https://doi.org/10.14744/sigma.2022.00035)
11. Vodacom, *Annual report on business indicators of water supply and sewerage companies, report for 2017*, 2018
12. Vodacom, *Annual report on business indicators of water supply and sewerage companies, report for 2018*, 2019
13. Vodacom, *Monthly Report on Performance Indicators of Water Supply and Sewerage Companies for February 2018*, 2018
14. Vodacom, *Annual report on business indicators of water supply and sewerage companies, report for 2019*, 2020
15. Vodacom, *Monthly Report on Business Indicators of Water Supply and Sewerage Companies for August 2018*, 2018
16. N. Elezovic, D. Komatina Ilic, I. Dervisevic, S. Ketin, P. Dasic, *Fresenius Environ. Bull.* **27** (2018) 2505.