Article

Increasing Efficiency in the Field Water Re-injection during Mature Hydrocarbon Reservoirs Water-Flooding, Case Study from the Sava Depression, Northern Croatia

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Abstract: Here is analysed the process of water re-injection in the two hydrocarbon reservoirs/fields in the Upper Miocene sandstone reservoirs, located in the western part of the Sava Depression (Croatia). Namely, those are the "A" field with "L" reservoir and the "B" field with "K" reservoir. Both currently produce hydrocarbons using a secondary recovery method, i.e. water injection (in fact reinjection of the field waters). Three regional reservoir variables had been analysed, namely porosity, permeability and injected water volumes. The number of data was small in all three cases. For porosity: reservoir "L" included 25 data, reservoir "K" 19 data; for permeability: reservoir "L" 10 data, reservoir "K" 18 data; for injected volumes of water: reservoir "L" 10 data; reservoir "K" 3 data. It defined selection of mapping algorithms mostly designed for small datasets (less than 20 points), i.e. Inverse Distance Weighting, Nearest and Natural Neighbourhood. Additionally, the Ordinary Kriging was used, but only with jack-knifed variograms, producing many "artificial points". Results are extensively tested, using cross-validation and shape recognitions, and the Inverse Distance Weighting method is described as the most appropriate approach for mapping permeability and injected volumes in both reservoirs ("K" and "L"). The Kriging could be slightly outlined as the best approach for porosity. Obtained maps made possible application of the modified geological probability calculation as tools for prediction of successfulness of future injection (probability of 0.56). Consequently, results made possible to plan future injection more efficiently, with smaller injected volumes and same of higher hydrocarbon recovery. That could prevent useless injection, decrease number of injection wells, and save energy and funds invested in such processes.

Keywords: water injection, efficiency, sandstones, Neogene, Croatia

1. Introduction

The numerous geological variables are analysed numerically and spatially. The results are applied for creation of different geological models with different scales. Here are analysed injected water volumes into the Neogene hydrocarbon reservoir located in the Sava Depression (Northern Croatia) as primary and accompanied porosities and permeability as secondary variables. Selected field and reservoir are named as "field A/reservoir L", in Lower Pontian sandstones of the Kloštar Ivanić Formation. In both reservoirs is currently active water-flooding regime for increasing recovery

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and period of production. All used datasets are described as the small ones, i.e. sets with less than 20 measured points projected at reservoir 2D section. Consequently, this was challenging task that depends on (a) distribution of injection and measurement wells, (b) number of fault zones, (c) number of wells with production and log data.

2. Applied interpolation methods

All selected statistical interpolation methods were from the group of methods created primary for the small datasets, namely inverse distance weighting, nearest neighbourhood and natural neighbourhood. All of them have simpler algorithm and are not characterised with separate function for calculation of spatial model (like variogram in the kriging).

2.1. Inverse distance weighting (IDW)

This is widely used interpolation method, both for small and large datasets. The unknown value is calculate based on all known points and inversely proportional to their distances (Equation 1, e.g. [1,2,3]) is defined as:

$$z_{IU} = \frac{\frac{z_1}{d_1^p} + \frac{z_2}{d_2^p} + \dots + \frac{z_n}{d_n^p}}{\frac{1}{d_1^p} + \frac{1}{d_2^p} + \dots + \frac{1}{d_n^p}}$$
(1)

Where are:

ZIU - estimated value,

d1...dn - distance between estimated value and known value 1...n,

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p - power (distance) exponent,
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 $z_1...z_n$ - known values at locations 1...n.

The mapping results are greatly influenced by power exponent, which could stressed influence of more distance points and smooth the map (for p<=2) or force very local estimation (p>2) and even, for large "p", result in zonal estimation, i.e. in map like Voronoi polygons. This method has been proved for mapping problems in the CPBS for all datasets where clustering was not largely imposed, and for datasets smaller than 15 points too (e.g., [4,5]).

2.2. Nearest neighbourhood (NN)

This is the simplest statistical interpolation method when unknown point is estimated only from the closest known value. The results are valued polygons, like Voronoi diagram. The distance between points is Euclidian (Equation 2):

$$d(x,T) = \sqrt{\left(X_1 - T_1\right)^2 + \dots + \left(X_n - T_n\right)^2}$$
(2)

Where are:

d - distance,
n - n-th pair of points,
x and T - unknown and measured points.

The method is meaningful to apply only for very small datasets, like 5 or less points. The output is not map, but schematic polygon view.

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2.3. Natural neighbourhood (NaN)

It's modification of the NN and results are also shown as Voronoi diagrams (polygons). The unknown point is estimated from the several nearest points (e.g., [6,7,8]) using Equation 3:

$$X(x, y) = \sum_{i=1}^{n} (\mathbf{w}_{i} A(\mathbf{X}_{i}, \mathbf{Y}_{i}))$$
(3)

Where are:

X(x,y)- estimated value in point (x,y),A(Xi,Yi)- known value in point (Xi,Yi),wi- proportion of polygon "i" in total area.

2.4. Cross-validation

The cross-validation is numerical procedure that could be applied also as error-based comparison tool for several maps with the same input but interpolated sequentially with two or more methods. The procedure is repeated as many times as there is measured (hard) values, dropping one known point out and calculating the estimation in the same location from the rest of hard data (Equation 4). The result is often named as Mean Square Error (abbr. MSE, e.g., [4,9,10]). This value is often criteria for the most appropriate map selection in the CPBS (e.g., [11,12]).

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (SV - P)_{i}^{2}$$
(4)

Where are:

MSE - Mean Square Error value,
n - number of known values,
SV - measured value of point "i",
P - estimated value of point "i",
i - i-th point.

2.5. Geological probability for presence of the subsurface fluid-rock system

Geological probability calculation is deterministic method developed for estimation of hydrocarbon system existence. That is quantitative procedure based on geological categories probabilities for selected play and prospect. Such probability tables are constructed from expert knowledge and are unique for any geological province. Like the CPBS (e.g., [13,14,15]). The basic independent categories are trap, reservoir, migration, source rock and hydrocarbon preservation. The final value, is named as Probability Of Success (POS), resulted from Equation 5:

$$POS = p(t) \cdot p(r) \cdot p(m) \cdot p(s) \cdot p(p)$$

Where are:

POS - geological probability of success (%),

p(t) - trap probability (%),

p(r) - reservoir probability (%),

p(m) - migration probability (%),

- p(s) source rock probability (%),
- p(p) preservation probability (%).

(5)

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In this paper the probability classes valid for the Croatian part of the Pannonian Basin System (CPBS) are used as follows: 1 – proven event, 0.75 – very probable, 0.5. – probable event, 0.25. – possible, 0.05 – unknown or non-existent event (e.g., [14]). Each class has accompanied one or more geological event for each category. The method could be easily modified for estimation of specific properties of such subsurface systems, what was also applied in this paper.

3. Geographical location of analysed reservoirs

The analysed sandstone reservoirs are part of oil field, here named as "A", about 90 km SE from Zagreb (Figure 1), Croatian capital, in the Sisak-Moslavina County. The field terrain is crossed by highway A3 and Paneuropean railway. The prospect "A" covers 14 km².



Figure 1. Geographical location of the "A" Field in the Northern Croatia.

4. The basic geology of researched area

Analysed field is in the Sava Depression as part of the Croatian part of the Pannonian Basin System (CPBS). The maximum thickness of Neogene reached in the western part of depression (8000 km²) more than 5000 m [16]. The mapped sandstones belong to the Kloštar-Ivanić Formation (Lower Pontian, 7.1-6.5 Ma), deposited in the slightly brackish environment of the late Pannonian Lake. The huge quantities of sand and silt detritus had been transported by turbidites, and in the meantime the calcitic rich mud was deposited in the calm, lacustrine environment. Consequently, today sediments of the Upper Miocene in the CPBS are regular alteration of turbiditic sandstones and lacustrine marls (e.g., [16,17]). So, all discovered hydrocarbon sandstone reservoirs in the Northern Croatia are of such origin. Reservoirs are in the middle of structure medium-grained sandstones that laterally are gradually transformed into clayey siltstones (i.e. psammitic detritus into pelitic). Typical litho- and chronostratigraphical section of analysed reservoir is given at Figure 2. That includes Lower Pontian and younger sediments due to wells are not drilled deeper rocks.

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Figure 2. Typical geological section of analysed field.

Lithologically, the Kloštar Ivanić Formation sandstones are well sorted. In older part those are hard sandstones, changed in the youngest part into weakly consolidated, fine-grained sediment.

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Marls are compact, medium hard, in the younger part with larger portion of clay. Average thickness of marls is 30-150 m, and of sandstones 20-150 m.

Example of Upper Miocene sandstones (surface outcrop, Medvednica Mt., Northern Croatia) is given on Figure 3. Those are thin layered to laminated grey-brown fine sandstones, passing into cleavaged grey siltites and marls.



Figure 3. Typical sandstone samples from outcrop.

Laminated fine sandstones (quartz arenites), predominantly consisting (Figure 4) of single quartz grains (white), poorly rounded and partly sorted, and subordinately of mica flakes (elongated) and carbonate grains (pink to red coloured). Carbonate grains are mainly planktonic foraminifera (Globigerinae), followed by some bioclasts. Grains are cemented together with sparry calcite cement. Primary porosity is mainly of intergranular and intragranular (intraskeletal) type, and it is partly reduced by secondary diagenetic pyrite within globigerinid ventricles (black).



Figure 4. Micro photograph of the sandstone sample.

5. Mapping of reservoir "L" (field "A")

Three variables had been considered in the reservoir analysis. Those are porosity, permeability and injected water volumes. All of them are crucial in the process of optimising water injection. The mean values for reservoir are porosity 18.4 % (oil saturation) and 19.7 % (gas), permeability 17,5x10⁻³ μ m2. The production started in 1962 and currently is supported by water injection. Here is outlined part of the reservoir "L" with currently active 10 injection wells. For all are available data about injected volumes and permeabilities (Figure 5).



Figure 5. Permeability (left) and injected volumes (right) maps interpolated using IDW, NN and NaN in reservoir "L" – present-day values [12]

The cross-validation for Figure 5 is given in Table 1.

Variable	No. of	Cross-validation			
	data	IDW	NN	NaN	
Volume	10	$1.21 \cdot 10^{10}$	$2.64 \cdot 10^{10}$	$2.36 \cdot 10^{10}$	
Permeability	10	1.41	2.22	3.48	

Table 1. Cross-validation for the reservoir "L".

The injected volumes are dynamical variable, depends on number of injection wells as well as injected quantities. Here are summarised cumulative volumes recorded in 2005 and 2015 retrospectively based on 10 wells active between 1985-2015. Such datasets are mapped with IDW (Figure 6) as the most appropriate algorithm (Table 5.1) for this variable.



Figure 6. Cumulative volumes of injected waters in 2005 and 2015 interpolated with IDW.

The cumulative IDW map (Figure 5.2) clearly outlined the main directions of water flooding. It could be recognised that volumes in the eastern part are lower than in the western part. It is direct reflection of lithological properties of sandstone, that changes from east (higher permeability, lower silty content) toward west. Also, the injected volumes distribution is also influenced by fault zones that play role as barrier between east and west part. Interestingly, inside the fault zone is highly permeable matrix zone (Figure 5.1), but tectonic contacts are impermeable. Consequently, water flooding was less successful in the western part, but even there the clear response between injected in L-154, 160, 161 wells and recovered volumes in L-27, 87, 131 wells could be followed at Figure 7.



Figure 7. Comparison between injected water volumes and recovered oil in reservoir "L".

6. Modified geological probability applied for estimation of water injection successfulness

The western part of the depression in well explored area, with numerous wells and seismic. The discovered fields are equipped with infrastructural facilities. Using the basic geological probability

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calculation, POS value for wider area of the field "A" is 0.42. The value is higher than 0.2 what legitimise further exploration (e.g., [18]). This locality is in the secondary production phase where reservoir pressure is maintained by water injection. Moreover, the basic POS calculation valid for the CPBS (e.g., [13,14,18]) can be easily modified for estimation of injection efficiency on future production. In such case, some basic categories could be neglected (source rocks, migration) as important only for exploration phase, not developing one. However, other can be emphasised during development, like reservoir pressure and field water. Moreover, water injection (e.g., [19,20,21,22]) is cost effective process even for fluid with water portion larger than 90 %.

In this case, modified POS is applied. Modified and basic values will differ but never be highly different, because are based on the same two crucial categories (trap, reservoir). The modification has been done in category "hydrocarbon preservation" (Table 2).

Hydrocarbon preservation							
Field water	probability	Injection of field water	probability				
Aquifer is still	1.00	Recovered quantities has been increased in >95 % wells	1.00				
Aquifer is active	0.75	Recovered quantities has been increased in 75-95 % wells	0.75				
Reservoir is infiltrated with field water from surrounding rocks	0.50	Recovered quantities has been increased in 50-75 % wells	0.50				
Reservoir is infiltrated with surface water	0.25	Recovered quantities has been increased in 25-50 % wells	0.25				
Data are not available	0.05	Recovered quantities has not been observed or on less than 25 % wells	0.05				

Table 2. POS modification in the	e category "hydrocarbo	'n preservation"	(greyed events are d	leleted,
У	yellowed applied as mo	odification).		

In modification the injection is divided in subcategories regarding percentage of production wells where increased hydrocarbon recovering in observed. Such 5 subcategories, based on production wells with positive response, are: (a) >95 %, (b) 75 – 95 %, (c) 50 - 75 %, (d) 25- 50 %, (e) less than 25 % wells. In the analysed field the response is observed for more than 95 % wells. So, it could be summarised the modified POS calculation by categories as follows: trap 0.75, reservoir 1.0, hydrocarbon preservation 0.75. Consequently, modified POS is 0.56 and it is larger than value of regional basic POS. The result means that there is 56.25 % chance to expect that injected volumes result in increased production (oil and water) in recovering wells.

7. Risk neutral value for future water injection

The efficiency and benefits for quality water injection system eventually needs to be financially evaluated. Such tasks could be made using risk neutral value (RNV). The first examples of RMV calculation in the CPBS were done in the Bjelovar Subdepression [14]. The result, including POS, offered economic and geological input for planning sustainability development of hydrocarbon production in that area. The similar procedure has been repeated here but using modified POS with aim to evaluate the most efficient way of future water injection. The cost of water separation [22] are 0.68 - 1.37 USD/m³. The cost of water injection for single system [21] are $8.68\pm 2,00$ HRK/m³. The costs also included equipment maintaining. In case of occurrence of sand during the production of hydrocarbons for Klostar Ivanic Formation, according to [23,24], continuous production of

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hydrocarbons is ensured, and thus in the model the given production time. The observed period in 10 years and asked response in recovered fluid has been set at 0.5, 1 and 2 %. Discount rate was 10 %. The annual budget available for injection process in western part of depression (regional costs) are 35 x 10⁶ USD. The average oil price is 390 /m³ (Feb 2019). Applied POS is 0.56, using risk-averse function of 1/5 of annual capital investments (7). All data are summarised in Table 3.

Description	Reservoir "L"		
Production period (years)		10	10
Discount rate (%)		10	10
Net Present Value (10 ⁶ \$)		4.98	10.11
Geological Probability (POS)	0.56	0.56	0.56
Expected monetary Value (10 ⁶ \$)	0,66	2.18	4.42
CAPEX for recovery maintaing (10 ⁶ \$)	35	35	35
Risk averse function	7	7	7
Utility units (10 ⁶ \$)	1.34	3.56	5.34
The first approximation of utility function	0.03	0.03	0.03
Hydrocarbon production costs (10 ⁶ \$)	0.58	0.78	1.17
Risk adjusted value (\$)	0.26	2.03	4.46
Expected utility units (\$)	0.64	1.11	1.05
Risk neutral equivalents (RN\$)	0.68	1.21	1.15

Table 3. Calculation of risk-neutral value (of cash flow) for three scenarios in reservoir "L" (from left – 0.5, 1, 2 % higher recovery).

The net present value (NPV) was increased following the higher fluid volume, i.e. the larger recovery. The NPV was the highest when response yielded recovery 2 % larger, i.e. 10.11×10^6 USD. The expected monetary value (EMV) is 4.42×10^6 USD and utility units (U) 5.34×10^6 USD. However, regarding the regional exploration level, expected annual budget and increased recovery, the additional 1 % is scenario set as realistic. In such case, the equivalent value of 1.21×10^6 USD is recommended for invest in future water injection.

6. Discussion and conclusions

The analysed reservoir "L" in the field "A" represents typical Upper Miocene (Lower Pontian) sandstone reservoir in the Sava Depression. The portion of sandy detritus reached 72 % with porosity varies between 14.5 – 23.9 %. The appropriate interpolation is key method for better understanding of reservoir variables distribution as well as water injection results. As number of data was low (<20), included variables (porosity, permeability, injected volumes) had been interpolated using three interpolation methods were evaluated (IDW, NN, NaN). The cross-validation and visual

interpretation (bull-eying, batter-fling) resulted in selection of the IDW as the most appropriate interpolation. It was especially emphasised for injected volumes as only dynamic variable where cumulative values per decades are observed. The influence of permeability distribution highly determined the spreading of injection volumes.

Using the modified POS calculation, it was possible to estimate future costs optimised by risk and production variables. Some categories are dropped (source rocks, migration) and other replaced (field water activity with response on injection). Modified POS of 56.25 % was used for economic evaluation with neutral monetary value. Three cases are selected, for periods of 10, 20 and 30 years of future production, with increase of recovery 1, 2 and 3 %. The highest value on money equivalent has been calculated for 20 year's period with maximal investment 2.32 x 10⁶ USD (with 50 x 10⁶ USD regional annual budget) worth to spent for discovering of particular satellite reservoirs, and/or 1.17 x 10⁶ USD (with 35 x 10⁶ annual regional budget) to invest in maintain water injection in existing reservoir "L". Consequently, it could be concluded:

- 1. The mapping of reservoir variables, and the most important of the injected volumes, is the most-sensitive task in the analysis of such injection system.
- 2. The most appropriate interpolation for such variables in IDW, due to low number of input (20 or less).
- 3. It is welcome to analyse injected volumes during several time intervals, like this are used decades, and compare results with permeability's and fault zone's distribution.
- 4. The results are crucial for optimise such tasks in future and obtain higher recovery with lower operational costs.

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References

- [1] Balić, D.; Velić, J.; Malvić, T. Selection of the most appropriate interpolation method for sandstone reservoirs in the Kloštar oil and gas field. *Geologia Croatica* **2008**, *61*, 27-35.
- [2] Medved, I., Pribičević, B., Medak, D. & Kuzmanić, I. Usporedba metoda interpolacije batimetrijskih mjerenja za praćenje promjena volumena jezera (Comparison of Interpolation Methods of Bathymetry Data Used for Monitoring of Lake Volume Change – in Croatian). *Geodetski list* 2010, 2, 71–86.
- [3] Ly, S.; Charles, C.; Degré, A. Geostatistical interpolation of daily rainfall at catchment scale: the use of several variogram models in the Ourthe and Ambleve catchments, Belgium. *Hydrology and Earth System Sciences* 2011, 15, 2259-2274.
- [4] Husanović, E.; Malvić, T. Review of deterministic geostatistical mapping methods in Croatian hydrocarbon reservoirs and advantages of such approach. *Nafta* **2014**, *65*, 57-63.
- [5] Ivšinović, J. Deep mapping of hydrocarbon reservoirs in the case of a small number of data on the example of the Lower Pontian reservoirs of the western part of Sava Depression. Proceedings of the 2nd Croatian congress on geomathematics and geological terminology, 2018, Zagreb, Croatia, 6 October 2018b, Malvić, T. (ed.); Velić, J. (ed.); Rajić, R. (ed.), University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering; pp. 59-65.
- [6] Traversoni, L. Natural neighbour finite elements. Transactions on Ecology and the Environment 1994, 8, 291-297.
- [7] Boissonnat, J-D.; Cazals, F. Natural neighbor coordinates of points on a surface. *Computational Geometry* **2001**, *19*, 155–173.
- [8] Tsidaev, A. Parallel Algorithm for Natural Neighbor Interpolation. Abstract's proceedings of the 2nd Ural Workshop on Parallel, Distributed, and Cloud Computing for Young Scientists, Russia, 2016; Sozykin, A.; Akimova, E., Ustalov, D. Eds.; Pubisher: Ural-PDC, Yekaterinburg, Russia, 2016; 78-83, 83 p.
- [9] Rodriguez, J. D.; Perez, A.; Lozano, J. A. Sensitivity Analysis of k-Fold Cross Validation in Prediction Error Estimation. *IEEE transactions on pattern analysis and machine intelligence* **2010**, *3*, 32, 569-575.
- [10] Arlot, S.; Lerasle, M. Choice of V for V -Fold Cross-Validation in Least-Squares Density Estimation. *Journal of Machine Learning Research* 2016, 17, 1-50.
- [11] Malvić, T.; Ivšinović, J.; Velić, J.; Rajić, R. Kriging with a Small Number of Data Points Supported by Jack-Knifing, a Case Study in the Sava Depression (Northern Croatia). *Geosciences* 2019a, 36, 9, 1-24.
- [12] Malvić T.; Ivšinović J.; Velić J.; Rajić, R. Interpolation of Small Datasets in the Sandstone Hydrocarbon Reservoirs, Case Study of the Sava Depression, Croatia. *Geosciences* 2019b, 9, 5, 201.
- [13] Malvić, T. Oil-Geological Relations and Probability of Discovering New Hydrocarbon Reserves in the Bjelovar Sag. Doctoral dissertation, University of Zagreb, 2003.
- [14] Malvić, T.; Rusan, I. Investment risk assessment of potential hydrocarbon discoveries in a mature basin. Case study from the Bjelovar Sub-Basin, Croatia. *Oil, gas - European Magazine (Hamburg)* **2009**, *35*, 67-72.
- [15] Malvić, T. Stochastical approach in deterministic calculation of geological risk theory and example (Stohastički pristup u determinističkom izračunu geološkog rizika- teorija i primjer – in English and Croatian). Nafta 2009, 60, 658-662.
- [16] Velić, J. Geologija ležišta nafte i plina (Geology of oil and gas in Croatian). Faculty of Mining-Geology-Petroleum Engineering Zagreb, Croatia, 2007; 342 p.
- [17] Malvić T. Review of Miocene shallow marine and lacustrine depositional environments in Northern Croatia. Geological quarterly 2012, 56, 493-504.
- [18] Režić, M.; Varenina, A. A new freeware program for the Probability of Success calculation of new gas discoveries within the Croatian part of the Po depression. *Rudarsko-geološko-naftni zbornik (The Mining-Geology-Petroleum Engineering Bulletin)* 2017, 32, 49-55.
- [19] Ivšinović, J.; Dekanić, I. The basics of model for marginal testing of costs for disposal of extracted formation water. Rudarsko-geološko-naftni zbornik (*The Mining-Geology-Petroleum Engineering Bulletin*) 2015, 30, 2, 85-99.
- [20] Ivšinović, J. Statistička obrada troškova odvajanja pridobivene slojne vode iz pješčenjačkih ležišta Savske depresije (Statistical analysis of the costs of separating the produced formation water from a sandstone reservoir of Sava Depression). Proceedings of the 1nd Croatian congress on geomathematics and geological terminology, 2016, Zagreb, Croatia, 29 October 2016, Malvić, T. (ed.); Velić, J. (ed.); University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering; pp. 69-74 (in Croatian).

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- [21] Ivšinović, J. The analysis of water injection systems in sandstone hydrocarbon reservoirs, case study from the western part of the Sava Depression. *Rudarsko-geološko-naftni zbornik (The Mining-Geology-Petroleum Engineering Bulletin)* **2017**, *32*, 17-24.
- [22] Ivšinović, J. The cost analysis of the separation of produced formation water from the hydrocarbon reservoir using the example of the upper Miocene sandstone deposits of the Sava Depression. *Rudarsko-geološko-naftni* zbornik (The Mining-Geology-Petroleum Engineering Bulletin) 2018, 33, 35-43.
- [23] Ivšinović, J. The relationship between sandstone depositional environment and water injection system, a case study from the Upper Miocene hydrocarbon reservoir in northern Croatia. Proceedings of the 2nd Croatian congress on geomathematics and geological terminology, 2018c, Zagreb, Croatia, 6 October 2018, Malvić, T. (ed.); Velić, J. (ed.); Rajić, R. (ed.), University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering; pp. 65-75.
- [24] Ivšinović, J.; Pleteš, V.; Marinić, M. Production of hydrocarbons from weakly consolidated sandstone reservoirs in the Croatian part of the Pannonian basin system. *Mining of Mineral Deposits* 2018, 12, 2, 116-121.