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Assessment and forecast of water quality in the River Ingulets irrigation system

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Scarcity of water is one of the most important problems of irrigated farming. Safe use of contaminated water and waste-water needs continuous monitoring of the water quality and its influence on the irrigated lands and cultivated crops. The Ingulets irrigation system is one of the main systems, which supplies with water fields of Kherson and Mykolaiv regions of Ukraine. The water is contaminated by the effluent disposals and wastes of the metallurgic factories. The new water quality improvement technique was introduced in the Ingulets irrigation system in 2010. The study is dedicated to agricultural assessment of the Ingulets irrigation system water quality with the new amelioration technique by using the FAO and DSTU 2730-94 criteria. It was established, that water quality in the Ingulets irrigation system is still poor, though it becomes better each year since 2010 till nowadays. Total dissoluble salts content in the water is 1489-2280 mg/L, toxic ions content in eCl^- is 10.49-21.63 me/L, sodium adsorption ratio is 4.33-7.94 me/L, sodium percentage is 46.4-58.9%, magnesium to calcium ratio is 1.03-1.68, power of hydrogen is 7.31-8.72 in the period from 2007 to 2017. So, the Ingulets irrigation system water requires further amelioration to become safe and suitable for irrigation without any restrictions. Short-term forecast of the water quality by using the triple exponential smoothing with handling of the seasonal effects with multiplicative method of the Holt-Winters algorithm showed that significant improvement of the water quality by some criteria should be achieved till 2025: total dissoluble salts content in the water should be 1212 mg/L, toxic ions content in eCl^- should be 6.61 me/L, sodium adsorption ratio should be 4.31 me/L, sodium percentage should be 49.3%, magnesium to calcium ratio should be 1.05, power of hydrogen should be 8.05 in 2025.
Key words: water quality; triple exponential smoothing; the Holt-Winters algorithm; forecast; the River Ingulets; irrigation system

Introduction

The deficiency and low quality of water for irrigation requires appropriate solutions (Seckler et al., 1999; Pereira et al., 2002). One of them is use of ameliorated water from different contaminated sources. To supply fields of Kherson and Mykolaiv regions of Ukraine with water the Ingulets irrigation system is used. The water of the system is contaminated by the effluent disposals and wastes of the metallurgic factories, so it needs significant amelioration to be safe for plants and soils (Likhovid, 2015; Shakhman and Bystriantseva, 2017). The new way of water quality improvement, which is based on the mixture of the Ingulets water with fresh water from the Karachuniv reservoir, was introducted in 2010. The goal of the study was to determine water quality of the Ingulets irrigation system by the agronomical criteria due to the new amelioration technique functioning with accordance to the international FAO requirements and Ukrainian standards. Also we tried to make short-term forecast of the water quality by using the Holt-Winters multiplicative exponential smoothing algorithm (Beck, 1987; Shang et al., 2011).

Materials and methods

The study was conducted each year during the period from 2007 to 2017. Water samples from the Ingulets irrigation system main channel (latitude 47°0'55"N and longitude 32°47'20"E) were taken each month within the period from April to September. The collected water samples were analyzed in the laboratory of the Mykolaiv Regional Office of Water Management by the generally accepted procedures (APHA, 1995; DSTU 2730-94).

Sodium adsorption ratio (SAR) was calculated by using the formula 1 (Ayers and Westcott, 1985):

$$SAR=\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}, (1)$$

where SAR is the sodium adsorption ratio, me/L; Na, Ca, Mg – ions content, expressed in me/L.

Water toxicity in eCl was calculated by using the formula 2 (DSTU 2730-94, 1994):

$$eCl = Cl^{-} + 0,2SO_4^{2-} + 0,4HCO_3^{-} + 10CO_3^{2-}, (2)$$

where Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-} - ions content, expressed in me/L.

Sodium percentage (SP) was calculated by using the formula 3 (Todd, 1980):

$$SP=\left(\frac{Na}{Na+K+Ca+Mg}\right)\times 100\%, (3)$$

where SP is sodium percentage, expressed in per cents (%); Na, K, Mg, Ca – ions content, expressed in me/L.

Standard deviation of the water quality criteria was calculated by using the formula 4 (Furness and Bryant, 1996; Logan, 2011):

$$SD=\frac{\sqrt{\sum_{i=1}^{N}(x_i-\overline{x})^2}}{N-1}, (4)$$

where SD is the standard deviation; x_1, ..., x_n are the observed values of the water quality criteria; N is the number of observations.
The coefficient of variation of the water quality criteria was calculated by using the formula 5 (Everitt and Skrondal, 2002):

$$CV=\frac{SD}{\overline{x}}, (5)$$

where CV is the coefficient of variation; SD is the standard deviation; $\overline{x}$ is the mean value of the water quality criterion.
Water quality in the Ingulets irrigation system was forecasted by using the triple exponential smoothing with handling of the seasonal effects (Lewis, 1982; Billah et al., 2006; Gardner, 2006; Gelper et al., 2010; De Livera et al., 2011). Multiplicative method of the Holt-Winters algorithm was used (Hyndman et al., 2008). The essence of the applicated method is in solving the task of the time line forecasting. The time line is presented as: $y_i, \ldots, y_t, y_t \in R$. The task of the time line forecasting looks as follows (formula 6-9):

$$y_{t+d}=a_t(\tau_t)^d\Omega_t+(d \bmod s)-s \quad (6)$$

$$a_t=a_1\frac{y_i}{\Omega_{i-s}}+(1-a_1)a_{t-1}\tau_{t-1} \quad (7)$$

$$\tau_t=a_3\frac{a_i}{a_i-1}+(1-a_3)\tau_{t-1} \quad (8)$$

$$\Omega_t=a_2\frac{y_i}{a_i}+(1-a_2)\Omega_{t-s} \quad (9)$$

where s – seasonality, $\Omega_t, i\in 0,\ldots,s-1$ - season profile, I_t - trend parameter, a_t - forecast parameter without influence of the trend and seasonality.
Forecasting was performed with LibreOffice 5.4 software application.

Results and discussion

It was established that water quality in the Ingulets irrigation system is still poor, but it has been significantly improved since 2010 by the new amelioration technique that resulted in lower values of the main quality criteria (table 1). The water belongs to the second class “Limited suitable for irrigation” according to the DSTU 2730-94 requirements. FAO standards also define the Ingulets irrigation system water as water with restrictions for use in irrigation.

Table 1. Water quality in the Ingulets irrigation system: true and forecasted quality criteria values

Year	Ions content in me/L						TDS content in mg/L	pH, units	SAR, me/L	eCl^-, me/L	Mg^{2+}/Ca^{2+}, units	SP, %
	K^++Na^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-						
True values												
2007	21.97	6.80	8.50	3.10	12.00	19.75	2180	7.94	7.94	21.63	1.25	58.9
2008	15.85	7.60	9.00	3.10	12.13	17.30	2008	7.31	5.50	19.05	1.18	48.8
2009	16.67	7.70	11.55	2.10	14.13	24.16	2186	7.84	5.37	25.89	1.50	46.4
2010	23.00	6.80	10.00	2.60	15.30	18.20	2280	8.72	7.94	20.54	1.47	57.8
2011	14.95	5.62	7.74	3.48	12.27	9.75	1673	8.48	5.78	12.07	1.38	52.8
2012	13.46	7.13	7.35	4.00	10.58	9.81	1600	8.32	5.00	11.70	1.03	48.2
2013	10.71	5.74	6.50	3.63	9.91	9.41	1471	8.24	4.33	11.30	1.13	47.2
2014	14.29	5.20	7.03	3.94	10.26	10.03	1578	8.33	5.78	12.22	1.35	53.9
2015	12.51	5.10	8.55	3.33	10.14	9.02	1458	8.35	4.79	10.96	1.68	47.8
2016	11.83	5.10	7.10	3.65	9.80	8.42	1448	8.23	4.79	10.42	1.39	49.2
2017	13.08	5.85	7.25	3.50	10.73	8.51	1489	8.30	5.11	10.49	1.24	50.0
SD	3.95	0.99	1.50	0.57	1.81	5.61	332	0.37	1.21	5.55	0.18	4.28
$\overline{x}$	15.30	6.24	8.23	3.31	11.57	13.12	1761	8.19	5.67	15.11	1.33	51.00
CV, %	25.84	15.92	18.26	17.11	15.65	42.76	18.85	4.57	21.29	36.72	13.88	8.39
Forecasted values												
2018	11.96	5.76	6.54	3.95	10.62	7.85	1450	8.21	4.82	10.00	1.13	49.3
2019	11.11	5.18	6.70	3.56	10.74	7.34	1366	8.23	4.56	9.47	1.29	48.3
2020	11.42	5.63	6.02	4.03	10.97	6.77	1397	8.15	4.73	9.05	1.07	49.5
2021	10.60	5.05	6.15	3.63	11.08	6.26	1315	8.17	4.48	8.52	1.22	48.6
2022	10.88	5.49	5.51	4.11	11.31	5.70	1343	8.09	4.64	8.11	1.00	49.7
2023	10.09	4.93	5.60	3.70	11.42	5.18	1263	8.11	4.40	7.56	1.14	48.9
2024	10.35	5.35	4.99	4.18	11.66	4.63	1290	8.03	4.55	7.16	0.93	50.0
2025	9.58	4.80	5.06	3.77	11.77	4.11	1212	8.05	4.31	6.61	1.05	49.3

The results of the water quality analysis have shown that the main problems in the Ingulets irrigation system are high total dissoluble salts (TDS), toxic ions (eCl^-) and sodium content: 1489-2280 mg/L, 10.49-21.63 me/L and 11.83-21.97 me/L respectively. Irrigation with such water leads to deterioration of the physical, chemical and biological properties of soils, decrease in crops growth, productivity and yield quality (Wilcox, 1955; Kelly, 1963; Ayers and Westcott, 1985; Ould Ahmed et al., 2007; Feizi et al., 2010; Lozovitsii, 2012; Kim et al., 2016; Banjaw et al., 2017; Lykhovyd and Lavrenko, 2017). The statistical data processing has also shown that the most variable quality criteria in the Ingulets irrigation system water are chloride and sodium ions content (CV was 42.76% and 25.84% respectively), and the most stable one was power of hydrogen (pH) with CV at 8.39%.
The results of the triple exponential smoothing conducted by using the Holt-Winters multiplicative algorithm have shown probability of significant improvement of the Ingulets irrigation system water quality till 2025. If current water amelioration system function properly, significant decrease of TDS and toxic ions content will be achieved: to 1212 mg/L and 6.61 me/L respectively (Figs 1-4).

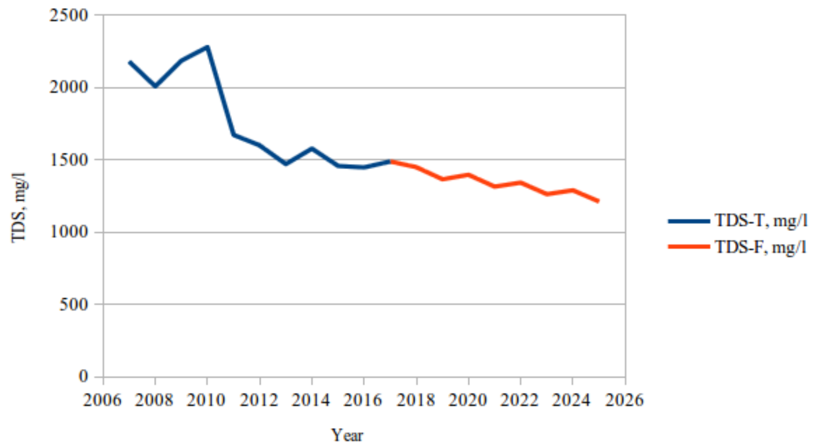

Figure 1. TDS content. TDS-T – true values; TDS-F – forecasted values.

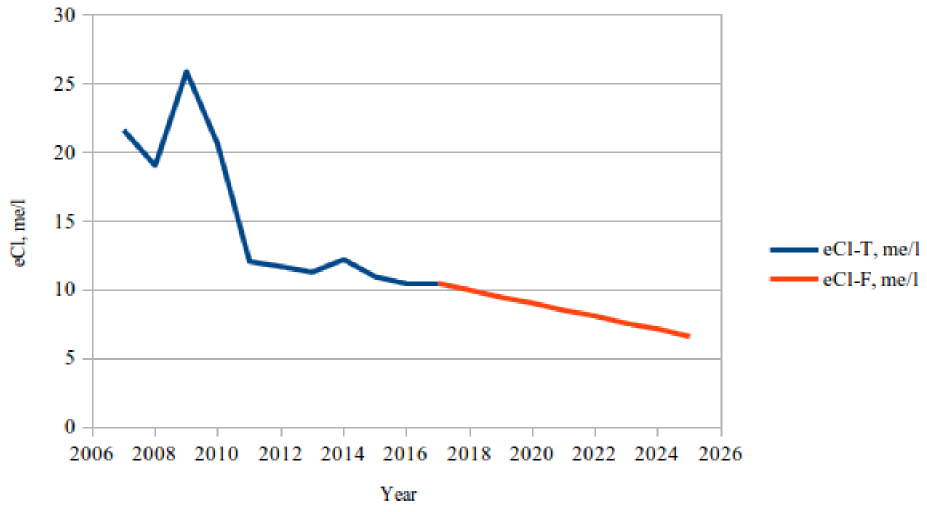

Figure 2. eCl^- content. eCl-T – true values; eCl-F – forecasted values

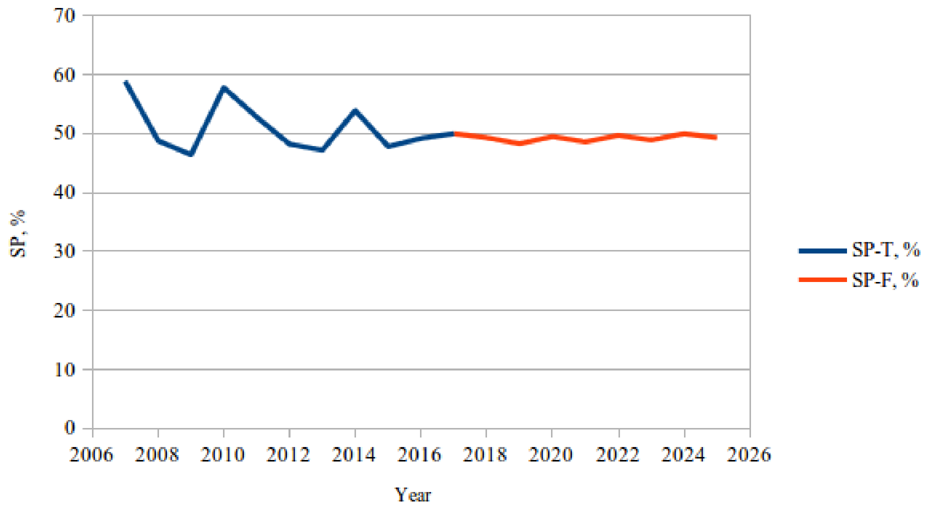

Figure 3. SP values. SP-T – true values; SP-F – forecasted values.

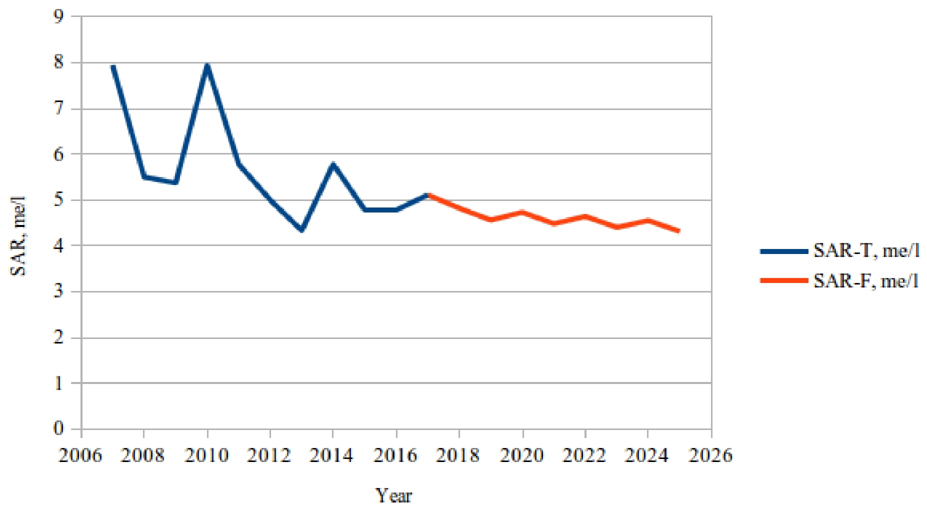

Figure 4. SAR values. SAR-T – true values; SAR-F – forecasted values

The forecast has also shown that the SP and SAR values will probably leave on a higher, then optimal for use of the water for irrigation without any restrictions, level: 48.3-50.0% and 4.31-4.82 me/L respectively.
The designed forecast model should be useful for management and control of the Ingulets irrigation water quality. Application of the Holt-Winters multiplicative algorithm to forecasting water quality in the Ingulets irrigation system keeps on the modern trend of the mathematical modeling use in environmental management (Reckhow, 1999; Palani et al., 2008; Singh et al., 2009; Liu et al., 2013).

Conclusions

Current quality of the Ingulets irrigation system water requires provision of the adequate reclamation techniques to prevent deterioration of the irrigated soils and reduce toxic influence on the cultivated plants.
Current amelioration technique is quite good. The forecast has shown the prospects of significant improvement of the Ingulets irrigation water quality in the nearest future if the technique function properly.

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