



## INTEGRATED ASSESSMENT OF IRRIGATION WATER QUALITY BASED ON HARRINGTON'S DESIRABILITY FUNCTION

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### ABSTRACT

It was proposed the integrated approach to the irrigation water assessment as its quality index IWQI. This criteria united the quantitative assessment of different risks such as soil sodicity, plant toxicity, biofilm formation in drippers of irrigation systems etc. It is proposed to combine agronomic, ecological and technological requirements to the irrigation water using a generalized Harrington's desirability function (HDF). Within the framework of this concept, it was developed the scales of particular HDF for physico-chemical indicators, SAR values, and the Stebler's irrigation coefficient. IWQI was determined for the assessment of water quality for irrigation purpose on the examples of 3 dug wells located on the Agronomic Experimental station of National University of Life and Environmental Sciences of Ukraine (Pshenichne village, Kiev region). It is shown that water quality varies considerably (from 56 till 85%).

**Keywords:** Irrigation, Water Quality Index (IWQI), Harrington's Desirability Function, Physical-Chemical Parameters

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### INTRODUCTION

Global climate change requires reviewing the approaches to irrigated agriculture using. In particular, irrigation is assessed as a mitigation factor potentially reduced the impacts of climate change on agriculture by about 40% [1]. Therefore, the environmental and land reclamation assessment of natural waters should be comprehensive, taking into account the soil-climatic conditions of the irrigation zone, the physiological features of agricultural crops and the requirements of the functioning of the technical means of the irrigation system.

The concept of the generalized water quality assessment in the form of so-called Water Quality Index (WQI) has been proposed by R. Horton in 1965 [2]. During last decades this idea was significantly improved and expanded [3-6]. WQI modifications has been accepted as regional or state standards of complex water assessment in the Great Britain, USA, Canada, India, Poland. The comprehensive review of the WQI concepts, its application included classification, analysis of methodological collisions, applied computer software, and WQI using for monitoring and

simulation of water resource quality dynamics for the sustainable development was made by Abassi and Abassi [7]. Simsek and Gunduz [8] proposed GIS-integrated irrigation water assessment in the form multi-parametric irrigation water index IWQ. Authors used the linear combination of the parameters determined the different kinds of irrigation risks for soils and plants and subdivided the water quality into three groups. Sutadian et al. [3] pointed on the methodological problems of WQI using as a water assessment technique: (i) there is no unified step-by-step strategy of WQI development; (ii) most WQIs are designed for a specific region or separated biocenosis (objects with an individual set of hydro-chemical, hydrological characteristics); (iii) random choice of parameters, their weighting factors, procedure of sub-indices generating, etc.

Agronomic, soil, environmental requirements to irrigation water quality and, as a result, the demand to irrigation projects are a subject of intensive discussions [9, 10]. Thus, agronomic criteria focus on indicators that should ensure the quantitative and qualitative composition of the

crop and not cause soil degradation (salinity, sodicity, infiltration, gas disruption, oxidation-reduction potential). To do this, it is necessary to monitor water temperature, the pH, the electrical conductivity, the total mineralization, mineral matrix composition ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{HCO}_3^-$  +  $\text{CO}_3^{2-}$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ), the nutrient elements contents ( $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{PO}_4^{3-}$ ,  $\text{C}_{\text{org}}$ ,  $\text{P}_{\text{org}}$ ), trace elements and toxicants (B, Cu, Zn, Mo, F, Co).

## MATERIALS AND METHODS

### Water Sources

Mainly, the rural areas in Ukraine are supplied of local water sources for human and animal consumption, and irrigation [11]. Three boreholes situated on the territory adjoining to the Agronomic Experimental station of National University of Life and Environmental Sciences of Ukraine (Pshenichnoe village, Kiev region) were determined for experimental assessment of its water quality for irrigation purposes:

Object # 1 – 50°05'45.8''N, 30°12'22.4''E (50.096043, 30.206210);

Object # 2 – 50°05'43.2''N, 30°12'25.9''E (50.095322, 30.207190);

Object # 3 – 50°05'30.2''N, 30°12'29.8''E (50.091724, 30.208282).

Sampling was done in September, 2017. Monitoring design was made due to the EPA

recommendations [12].

### Chemical Analysis

The water quality parameters were measured in the Measuring laboratory of surface, underground waters and wastes of Analytical and Bio-inorganic Chemistry & Water Quality Department, which is the structural subdivision of Ukrainian Laboratory of Quality and Safety of AIS Products of National University of Life and Environmental Sciences of Ukraine (certificate of approval No TUB Lab-01).

## RESULTS AND DISCUSSION

It is proposed to combine agronomic, ecological and technological requirements to the irrigation water using a generalized Harrington's desirability function (HDF) [13]. On our opinion, this conception is very similar to the WQIs, but more flexible and may be adapted to any kind of water consumption/nature of water sources (surface, underground).

Within the framework of this concept, it was developed the scales of particular HDF  $d_i$  for physico-chemical indicators, SAR values, and the Stebler's irrigation coefficient (Table 1).

In accordance with recognized procedures [9, 14] it was calculated SAR coefficient (Table 2) and Stebler's irrigation coefficient (Table 3).

**Table 1.** Scale for particular  $d_i$  assessment

i	Parameters	Units	Values of particular $d_i$				
			1,00...0,80 Very good	0,80...0,63 Good	0,63...0,37 Satisfactorily	0,37...0,20 Badly	0,20...0,00 Very badly
1	Salinity	mg/L	320-480	481-1000 150-319	1001-3500 100-149	3501-5000 80-99	5001-10000 0-79
2	Temperature	Celsius degree, °C	21-16	12-15 22-24	9-11 25-28	7-9 29-31	0-8 32-45
3	pH	pH units	6,9-7,0	6,5-6,8 7,1-7,5	6,1-6,4 7,6-8,5	5,5-6,0 8,6-9,0	3,5-5,4 9,1-11,0
4	Iron total	mg/L	0-0,05	0,06-0,20	0,21-1,00	1,01-5,00	5,01-90,000
5	Turbidity	NTU	0-5	6-10	11-50	52-200	201-5000
6	SAR	-	2,0-3,0	1,5-1,9 3,1-6,0	1,2-1,4 6,1-12,0	0,9-1,1 12,1-20,0	0,1-0,8 20,0-40,0
7	Stebler's irrigation coefficient $K_c$	-	25,0-18,0	17,9-6,0	5,9-4,0	3,9-1,2	1,1-0,2
8	Boron	mg/L	0-0,4	0,4-1,0	1,1-2,0	2,1-5,0	5,0-30,0
9	Nitrogen nitrates, $\text{N-NO}_3$	mg/L	0-4	5-15	16-20	21-30	30-1000

**Table 2.** SAR calculation

# object	Total hardness (Ca+Mg), mmol/L	Ionic composition, mmol/L					Salinity y, mg/L	PK <sub>2</sub> -PK <sub>0</sub>	P(Ca+Mg)	P <sub>Alk</sub>	pH <sub>c</sub>	SAR
		Na <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	Ca <sup>2+</sup> +Mg <sup>2+</sup> +Na <sup>+</sup>						
1	29,30	1,56	9,35	1,52	19,99	30,86	2039	2,41	1,90	2,70	6,01	1,38
2	12,37	2,03	3,22	0,18	11,00	14,40	917	2,31	2,20	1,95	6,46	2,40
3	10,81	2,64	0,96	0,13	12,36	13,45	618	2,30	2,30	1,90	6,20	3,63

**Table 3.** Stebler's irrigation coefficient calculation

# object	Ionic composition, mmol/L			Relation between rNa, rCl, and rSO <sub>4</sub>	Formula of Stebler's irrigation coefficient K <sub>C</sub>	K <sub>C</sub>
	Na <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>			
1	1,56	9,35	1,52	$rNa < rCl$	$288/5rCl$	14,1
2	2,03	3,22	0,18	$rNa < rCl$	$288/5rCl$	6,2
3	2,64	0,96	0,13	$rNa > (rCl+rSO_4)$	$288/(10rNa - 5rCl - 9rSO_4)$	17,9

The procedure of mathematical transformation of measured natural parameters into  $d_i$  [13], is made as for the parameters of so-called "one-side" limitation:

$$d_i = \exp(-\exp(-x_i)), 0 \leq d_i \leq 1,$$

where  $x_i$  is coded value of  $i$ -parameter ( $i=4, 5, 7, 8, 9$ , Table 1). These parameters are limiting as "less is better", or having "maximum permissible concentration" (MPC).

If executing parameter is limited as optimum field (having "two-side" limitation), it is transformed as:

$$d_i = \exp[-(x_i)^n], \text{ where } n - \text{any positive figure } (0 < n < \infty) (i=1, 2, 3, 6, \text{ Table 1}).$$

This scale permits to transform any physical parameter in dimensionless entity expressed in psychophysical terms – "very good", "good", "satisfactorily", "badly", and "very badly".

So, the physical values of measured parameter are translated as the functions to a common scale [0, 1] (Table 4), combine them using the geometric mean (generalized HDF  $d_z$ ):  $d_z = \sqrt[n]{\sum_{i=1}^n d_i}$ .

So, results of integrated assessment of water quality for irrigation purposes demonstrate the significant variability – from 56,61 % - "satisfactorily" (object #1) till 85,17 % - "very good" (object #3). It means that the underground waters have different degree of suitability. Analyzing particular  $d_i$ , it is clear that the critical parameter dramatically decreasing water quality of object #1 is the nitrates pollution.

**Table 4.** Transformation of measured parameters into particular  $d_i$  and generalized HDF  $d_z$ 

# water source	Measured values of water quality parameters									Generalized HDF $d_z$
	Salinity, mg/L	Temperature, °C	pH, units	Iron total, mg/L	Turbidity, NTU	SAR	Stebler's irrigation coefficient K <sub>C</sub>	Boron, mg/L	Nitrogen nitrates, N-NO <sub>3</sub> , mg/L	
1	2039	21	7,25	0,049	1	1,38	14,1	< 0,05	35,3	
2	917	20	7,30	0,075	1	2,40	6,2	< 0,05	3,8	
3	618	18	6,95	0,060	1	3,63	17,9	< 0,05	4,8	
	Values of particular $d_i$									
1	0,3902	1,0000	0,7920	0,8010	0,9845	0,3805	0,7437	0,9998	0,1530	0,5661
2	0,6480	0,9998	0,7837	0,7528	0,9845	0,9162	0,6506	0,9998	0,8137	0,8085
3	0,7425	1,0000	0,9892	0,8000	0,9845	0,7480	0,8000	0,9998	0,8000	0,8517

## CONCLUSION

Analysis of the assessment principles of water quality for irrigation was done. It was shown that there is no standardized method because existing approaches evaluate the risks of different nature – for plants, soils, or the water supply network. It was proposed to unite agronomic, environmental, and technician requirements to water quality in the form of the united Harrington's desirability function. In the framework of this conception it was developed the scales of the partial desirabilities for physical-chemical parameters, values of sodium-absorption ratio SAR, Stebler's irrigation coefficient. On the example of the three dug wells which are situated near Agronomic Research station (Pshenychne Village, Kyiv Oblast) use of the developed method was demonstrated. It has been established that water quality varied significantly within the study area. The quantitative assessment ranged from 56 till 85 % in terms on requirements of irrigation. The same methodology should be developed for water, which is used for foliar dressing, which often takes place simultaneously with irrigation.

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