Assessment of Important Factors for Water Resources Management in European Agriculture

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Abstract-**The present paper aims to estimate the areas equipped for irrigation and the desirability of agricultural water management in Europe. For this purpose, all necessary information was gathered from Food and Agriculture Organization of the United Nations (FAO) and cross referenced using the World Bank Group (WBG). Among all presented data in the FAO database, ten indices were selected (based on relevance and the availability of information on all the countries in Europe). The selected indices were analyzed for all 46 countries and the extent of areas equipped for irrigation of cultivated areas was estimated by two different formulas, using the other nine indices. The results demonstrate that value of relative error is less than 20%. In addition, an average index was calculated using two methods to assess each country's conditions for agricultural water management.**

Keywords- Europe; Irrigation; Socioeconomic Indices; Sustainable Development; Water Management

I. INTRODUCTION

To provide food for sustainable development, agricultural water management must be taken into account. Due to the limited nature of water resources, the role of macroeconomic policies in agricultural water management is vital and undeniable. Actual crop yield as a percentage of potential yield is approximatley 60% for Western and Central Europe, and approximately 30% for Eastern Europe and the Russian Federation [1]. In addition, the simulated net irrigation requirements for Europe range from 53 mm/yr in Denmark to 1120 mm/yr in Spain [2]. Therefore, studying agricultural water management is still necessary for Europe. Schaldach et al. [3] underlined the importance of considering both the change of the equipped area and agricultural management as well as hydrology aspects in analysis of regional water use. Knox et al. [4] claimed demonstrating efficient or 'best' use of water is not straightforward in England, but farmers and the water regulator proposed a rational approach that reflects the needs of the farming community whilst providing a policy framework for protecting the environment. Namara et al. [5] elucidated the role of agricultural water management to reduce poverty in the world by three pathways: improvement of production, enhancement of employment opportunities and stabilization of income and consumption using access to reliable water thus increasing high-value products identifying the relationship between water manatement and nutritional status, health, societal equity and environment. Valipour [6-8] analyzed the status of irrigated and rainfed agriculture in the world, and summarized advantages and disadvantages of irrigation systems. The author showed that 46% of cultivated areas in the world are not suitable for rainfed agriculture because of climate changes and other meteorological conditions. Franks et al. [9] studied developing capacity for agricultural water management in current practice and future directions. They suggested increased attention to the monitoring and evaluation of capacity development, and closer links to emerging work on water governance. Khan et al. [10] reviewed water management and crop production for food security. According to the authors, relationships between water and other development-related sectors such as population, energy, food, and environment, and the interactions among them require analysis, as they together will determine future food security and poverty reduction. In addition, the study of irrigated agriculture indicators has played an importnat role in agricultural water management during past years, and future [11-71]. Prior research was performed on a limited area, thus making it impossible to apply them to other regions or consider the roles of all important indices on agricultural water management. Thus, the goal of this study is to establish a relationship among important parameters in agricultural water management and to investigate conditions of irrigation and drainage systems and cultivated crops based on available European data from the previous fifty years. The current work provides an opportunity for key stakeholders to identify major and effective indices of agricultural water management for investment plans in Europe by an accurate analysis of ten considerable indices. Finally, we provide an estimation of the areas equipped for irrigation and the desirability of agricultural water management that have not been investigated by previous researchers.

II. METHODOLOGY

Although irrigation efficiency is a proper index to demonstrate the status of agricultural water management, it is not possible to increase it in magnitude to estimate the total equipped area, and thus encourage farmers to use irrigation systems instead of rainfed agriculture. Many variables are required to estimate the total area equipped for irrigation per cultivated area. However, this could not be previously considered due to lack of adequate data. In this study, using the AQUASTAT database [72], ten primary indices were selected to assess agricultural water management in Europe from 1962 to 2011; the magnitudes of them were then cross referenced using WBG database [73]. Then, magnitudes of relative error were determined, and preferred countries (based on agricultural water management) were proposed. The selected indices are: permanent crops per cultivated area (PC %), rural population to total population (RP %), total economically active population in agriculture to total

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economically active population (labour force in agriculture, LF %), human development index (HDI), national rainfall index (NRI, mm/year), the value added to gross domestic product by agriculture (GDP (agric) %), irrigation water requirement (IWR, mm/year), percent of total cultivated area drained (D %), difference between NRI and IWR (mm/year), and area equipped for irrigation (AI %). For the comparison of different indices, all of them have been normalized (In) based on the maximum values of each index in the study area. The estimation of AI and study of conditions of the countries for irrigation management were done using the Valipour method [34].

The current study aims to find a link among the main indices. For this purpose, several scenarios were tested and the role of each index was determined. Finally, a relationship function was calculated by two methods using data from 2011, as shown in the Appendix.

III. RESULTS AND DISCUSSIONS

Table 1 shows the value of the main indices of agricultural water management for all countries in 2011. According to Table 1, the value of permanent crops per cultivated area is close to zero for Northern Europe, Western Europe, Eastern Europe (with the exception of the Republic of Moldova at 14%), and Central Europe (with the exception of Slovenia at 14%). This index value is less than 30% for Mediterranean Europe (with the exception of Greece at 32% and Portugal at 39%). According to Table 1, the value of rural population per total population is less than 20% for Northern Europe (with the exception of Faroe Islands at 59% and Norway at 20%) and is less than 40% for Western Europe (with the exception of Liechtenstein at 86%), Mediterranean Europe (with the exception of Albania at 47% and the former Yugoslav Republic of Macedonia at 41%), and Eastern Europe (with the exception of the Republic of Moldova at 52%). This index value is higher than 30% for Central Europe (with the exception of Bulgaria at 28% and the Czech Republic at 26%). According to Table 1, the value of economically active population in agriculture is close to zero for Northern Europe, Mediterranean Europe (with the exception of Albania at 41% and Greece at 12%), and Western Europe, and is less than 20% for Central Europe and Eastern Europe. The value of HDI is more than 0.900 for Northern Europe (with the exception of Finland at 0.892) and is more than 0.800 for Western Europe and Mediterranean Europe (with the exception of Albania at 0.749 and the former Yugoslav Republic of Macedonia at 0.740), and is more than 0.700 for Central Europe and Eastern Europe (with the exception of the Republic of Moldova at 0.660). According to Table 1, the value of the NRI is more than 800 mm/yr for Western Europe. This index is less than 700 mm/yr for Eastern Europe (with the exception of Ukraine at 1813 mm/yr).

As shown in Table 1, the GDP index is less than 10% for Western and Central Europe (with the exception of Albania at 19% and the former Yugoslav Republic of Macedonia at 11%). Note that this index has not been correctly reported for the Republic of Moldova (97%) and Serbia (34%) by FAO [72]; the author has modified it using WBG [73]. According to Table 1, the value of irrigation water requirement is less than 100 mm/yr for Northern Europe, less than 200 mm/yr for Western Europe (with the exception of Luxembourg at 408 mm/yr), less than 300 mm/yr for Central Europe (with the exception of Poland 330 mm/yr) and Eastern Europe, and it is less than 400 mm/yr for Mediterranean Europe (with the exception of Greece at 656 mm/yr and Spain at 679 mm/yr). According to Table 1, drainage is more than 40% for Northern Europe (with the exception of the Faroe Islands, without drainage). This index is close to zero for Mediterranean Europe (with the exception of Albania at 21% and Greece at 13%) and Eastern Europe (with the exception of Ukraine at 10%), and it is less than 40% for Central Europe (with the exception of Hungary at 51%). In Table 1, value of difference between NRI and the irrigation water requirement is positive for Europe (with the exception of Greece at -58 mm/yr and Spain at -143 mm/yr). Table 1 also shows the area equipped for irrigation per cultivated area in 2011 (see also [74]). According to the Table 1, the value of equipped areas is poor for Northern Europe (with the exception of Denmark at 19% and Norway at 13%), Eastern Europe, and Central Europe (with the exception of Slovakia at 12%), and it is less than 20% for Western Europe (with the exception of the Netherlands at 42%). Fig. 1 summarizes the obtained results from Table 1. All upward and downward movement of the indices in Fig. 1 have been determined based on the mentioned cases above. For instance, value of drainage is more than 40% for Northern Europe, it is close to zero for Mediterranean Europe and Eastern Europe, and it is less than 40% for Central Europe (Table 1). Therefore, the author has considered an upward arrow for Northern Europe and three downward arrows for the other regions (Fig. 1).

If we accept the negative role of NRI (5th index), the difference between NRI and the irrigation water requirement (9th index), and the positive role of other main indices on the equipped area (10th index) based on the Appendix (with the assumption that reduction of 5th index and 9th index increases 10th index and increase of the other main indices, increases the 10th index), the, Fig. 1 will be interpretable. In Figs. 1(b), (c), and (d), the value of HDI is suitable (represented by green arrows), but the value of the equipped area is not suitable (represented by red arrows), therefore the role of the other indices could be effective on the 10th index in Western Europe, Central Europe, and Mediterranean Europe. In Fig. 1(a), the values of HDI and the percent of total cultivated area drained are suitable, but the value of equipped area is not suitable, thus the role of the other parameters can be effective on the 10th index in Northern Europe. In Fig. 1(e), the values of HDI and NRI are suitable but the value of the equipped area is not suitable, thus the role of the other indices can be effective on the 10th index in Eastern Europe. As was observed from Table 1, differences of the effective main indices on agricultural water management have a wide range in Europe. Therefore, if we want to establish a relationship among the indices, each country must be considered separately.

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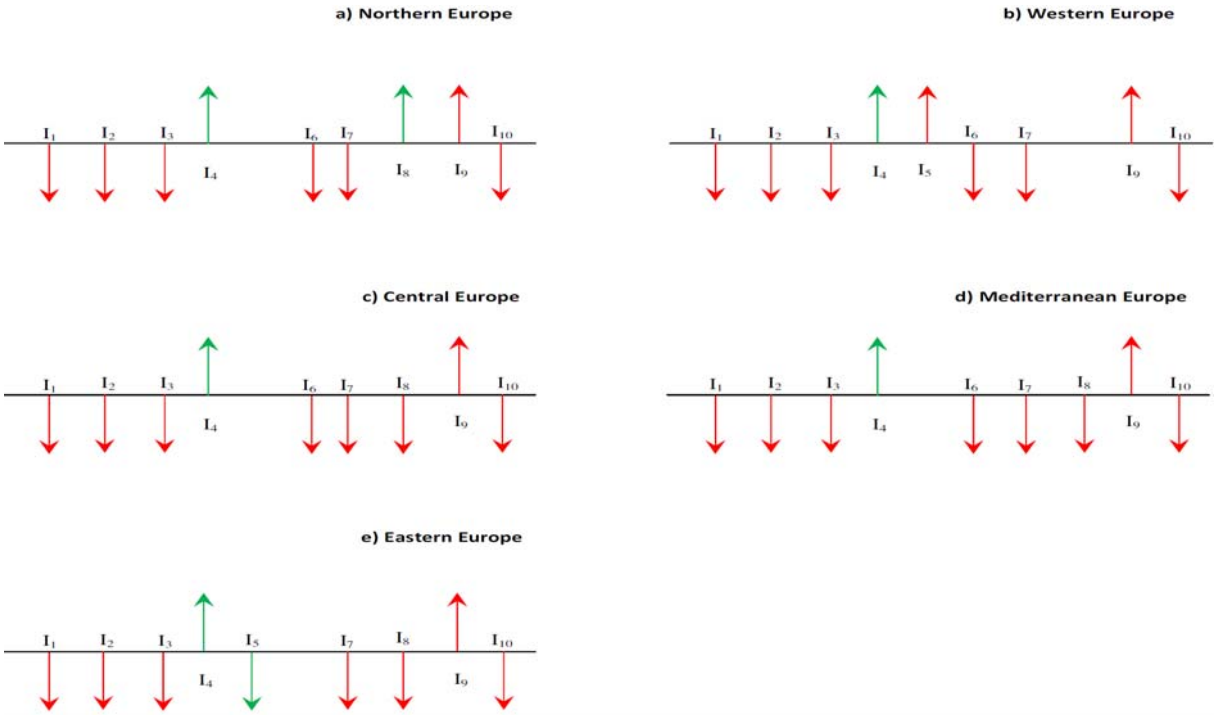

Fig. 1 A binary (qualitative) diagram to specify status of the main indices in different regions of Europe. I1, permanent crops per cultivated area (PC %); I2, rural population to total population (RP %); I3, labour force in agriculture (LF %); I4, human development index (HDI); I5, national rainfall index (NRI, mm year−1); I6, value added to gross domestic product by agriculture (GDP (agric) %); I7, irrigation water requirement (IWR, mm year−1); I8, percent of total cultivated area drained (D %); I9, difference between NRI and IWR; I10, the land use index (equipped area for irrigation per cultivated area, AI %)

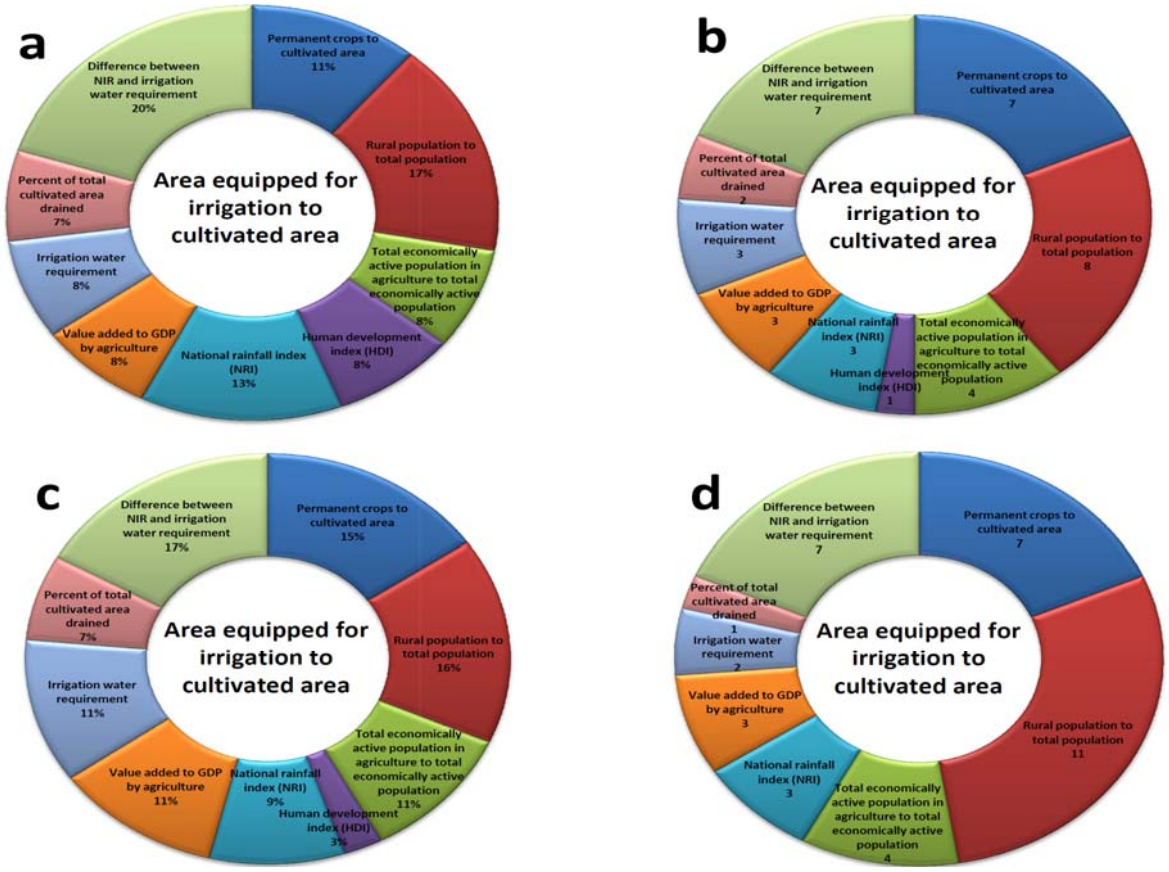

Fig. 2 Effect of the main indices on equipped area (10th index) in Europe (38 countries according to available data); (a) and (c) average of coefficients for each index in Table 1 and Table 2, respectively; (b) and (d) the number of cases that each index has been introduced as the main factor to estimate the 10th index (maximum coefficient in each formula) based on the Valipours method

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TABLE 1 MAIN INDICES OF AGRICULTURAL WATER MANAGEMENT FOR THE EUROPEAN COUNTRIES IN 2011

Country	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}
Albania	11	47	41	0.749	1136	19	171	21	965	27
Andorra	0	13	5	0.846						
Austria	5	32	3	0.895	1126	2	51	14	1075	8
Belarus	2	25	9	0.793	616	10				2
Belgium	3	3	1	0.897	1070	1	95	8	975	3
Bosnia and Herzegovina	9	51	2	0.735	1019	9				0.3
Bulgaria	5	28	3	0.782	543	6	208	2	335	3
Croatia	8	42	4	0.805	824	5		13		0.4
Cyprus	28	30	5	0.848	344	2	201		143	32
Czech Republic	2	26	6	0.873	707	2	59	12	648	1
Denmark	0.2	13	2	0.901	694	1	82	58	612	19
Estonia	1	30	9	0.846	621	4	9		612	0.1
Faroe Islands	0	59	0					0		0
Finland	0.2	15	3	0.892	518	3	41	45	477	3
France	5	14	2	0.893	818	2	89	13	729	14
Germany	2	26	2	0.920	836	1	74	41	762	4
Greece	32	38	12	0.860	598	3	656	13	-58	48
Holy See										
Hungary	4	32	7	0.831	588	4	262	51	326	3
Iceland	0	6	6	0.906	923	7				
Ireland	0.1	38	6	0.916	1202	1	182	17	1020	0.1
Italy	27	31	3	0.881	830	2	203	1	627	41
Latvia	1	32	9	0.814	605	4				0.1
Liechtenstein	0	86	0	0.883				0		0
Lithuania	1	33	8	0.818	585	4	104		481	0.1
Luxembourg	2	15	1	0.875		0.3	408	0		0
Malta	13	5	1	0.847		2	375	0		34
Monaco		0	0					0		0
Montenegro	9	39	12	0.791		9	21			1
Netherlands	3	17	2	0.921	893	2	123	100	770	42
Norway	0.5	20	3	0.955	1414	2	59		1355	13
Poland	3	39	17	0.821	601	4	330	37	271	1
Portugal	39	39	9	0.816	921	2	345	0.4	576	31
Republic of Moldova	14	52	14	0.660	541	15		2		11
Romania	5	42	9	0.786	647	7	130	3	517	7
Russian Federation	1	27	8	0.788	489	4	212	6	277	4
San Marino	0	6	0					0		0
Serbia	8	44	12	0.769		9	23			3
Slovakia	1	45	7	0.840	763	4	72		691	12
Slovenia	14	51	1	0.892	949	2		37		4
Spain	27	22	4	0.885	536	3	679	2	-143	20
Sweden	0.3	15	2	0.916	700	2	26	42	674	6
Switzerland	5	26	3	0.913	1450	1	13	28	1437	13
Macedonia	8	41	7	0.740	622	11	61		561	27
Ukraine	3	31	10	0.740	1813	10		10		7
United Kingdom	1	20	1	0.875	1082	1	72	76	1010	4

I_1, permanent crops per cultivated area (PC %); I_2, rural population to total population (RP %); I_3, labour force in agriculture (L, %); I_4, human development index (HDI); I_5, national rainfall index (NRI, mm year^{-1}); I_6, value added to gross domestic product by agriculture (GDP (agric) %); I_7, irrigation water requirement (IWR, mm year^{-1}); I_8, percent of total cultivated area drained (D %); I_9, difference between NRI and IWR; I_{10}, the land use index (equipped area for irrigation per cultivated area, AI,%).

TABLE 2 ESTIMATED FUNCTIONS USING THE FIRST METHOD [34] FOR VALUE OF AREA EQUIPPED FOR IRRIGATION IN EUROPE

Country	Suggested formula to estimate value of area equipped for irrigation to cultivated area (%)
Albania	$I_0 = -0.067I_1 + 0.248I_2 + 0.080I_3 + 0.104I_4 - 0.216I_5 + 0.081I_6 + 0.056I_7 + 0.060I_8 - 0.088I_9 + 30.398$
Austria	$I_0 = -0.012I_1 + 0.387I_2 + 0.007I_3 + 0.053I_4 - 0.464I_5 + 0.008I_6 + 0.007I_7 + 0.023I_8 - 0.039I_9 + 50.349$
Belarus	$I_0 = -0.007I_1 + 0.065I_2 + 0.844I_3 + 0.025I_4 - 0.028I_5 + 0.031I_6 + 2.766$
Belgium	$I_0 = -0.016I_1 + 0.006I_2 + 0.006I_3 + 0.070I_4 - 0.146I_5 + 0.008I_6 + 0.053I_7 + 0.029I_8 - 0.666I_9 + 81.204$
Bosnia and Herzegovina	$I_0 = -0.153I_1 + 0.142I_2 + 0.278I_3 + 0.140I_4 - 0.144I_5 + 0.143I_6 + 14.401$
Bulgaria	$I_0 = -0.008I_1 + 0.410I_2 + 0.005I_3 + 0.020I_4 - 0.023I_5 + 0.207I_6 + 0.304I_7 + 0.001I_8 - 0.023I_9 + 4.553$
Croatia	$I_0 = -0.142I_1 + 0.128I_2 + 0.189I_3 + 0.124I_4 - 0.127I_5 + 0.137I_6 + 0.154I_8 + 12.680$
Cyprus	$I_0 = -0.178I_1 + 0.214I_2 + 0.025I_3 + 0.135I_4 - 0.150I_5 + 0.022I_6 + 0.128I_7 - 0.148I_9 + 29.775$
Czech Republic	$I_0 = -0.026I_1 + 0.041I_2 + 0.127I_3 + 0.029I_4 - 0.031I_5 + 0.523I_6 + 0.070I_7 + 0.122I_8 - 0.033I_9 + 6.359$
Denmark	$I_0 = -0.0004I_1 + 0.023I_2 + 0.007I_3 + 0.098I_4 - 0.207I_5 + 0.008I_6 + 0.017I_7 + 0.143I_8 - 0.497I_9 + 70.363$
Estonia	$I_0 = -0.146I_1 + 0.105I_2 + 0.106I_3 + 0.104I_4 - 0.104I_5 + 0.107I_6 + 0.224I_7 - 0.104I_9 + 20.804$
Finland	$I_0 = -0.002I_1 + 0.122I_2 + 0.036I_3 + 0.143I_4 - 0.167I_5 + 0.101I_6 + 0.024I_7 + 0.212I_8 - 0.193I_9 + 35.997$
France	$I_0 = -0.003I_1 + 0.004I_2 + 0.001I_3 + 0.012I_4 - 0.036I_5 + 0.002I_6 + 0.003I_7 + 0.004I_8 - 0.936I_9 + 97.246$
Germany	$I_0 = -0.0001I_1 + 0.003I_2 + 0.0001I_3 + 0.002I_4 - 0.005I_5 + 0.0001I_6 + 0.0004I_7 + 0.007I_8 - 0.983I_9 + 98.825$
Greece	$I_0 = -0.090I_1 + 0.484I_2 + 0.053I_3 + 0.078I_4 - 0.128I_5 + 0.003I_6 + 0.072I_7 + 0.018I_8 - 0.074I_9 + 20.201$
Hungary	$I_0 = -0.027I_1 + 0.253I_2 + 0.074I_3 + 0.076I_4 - 0.089I_5 + 0.090I_6 + 0.211I_7 + 0.094I_8 - 0.086I_9 + 17.491$
Ireland	$I_0 = -0.040I_1 + 0.116I_2 + 0.121I_3 + 0.115I_4 - 0.117I_5 + 0.138I_6 + 0.118I_7 + 0.119I_8 - 0.118I_9 + 23.446$
Italy	$I_0 = -0.110I_1 + 0.161I_2 + 0.008I_3 + 0.075I_4 - 0.232I_5 + 0.011I_6 + 0.075I_7 + 0.001I_8 - 0.327I_9 + 55.878$
Latvia	$I_0 = -0.263I_1 + 0.147I_2 + 0.149I_3 + 0.146I_4 - 0.146I_5 + 0.146I_6 + 0.149I_7 + 14.603$
Lithuania	$I_0 = -0.148I_1 + 0.121I_2 + 0.123I_3 + 0.120I_4 - 0.120I_5 + 0.123I_6 + 0.124I_7 - 0.120I_9 + 23.993$
Malta	$I_0 = -0.303I_1 + 0.017I_2 + 0.003I_3 + 0.194I_4 + 0.031I_6 + 0.451I_7$
Montenegro	$I_0 = -0.287I_1 + 0.166I_2 + 0.211I_3 + 0.140I_4 + 0.158I_6 + 0.038I_7$
Netherlands	$I_0 = -0.008I_1 + 0.026I_2 + 0.005I_3 + 0.071I_4 - 0.431I_5 + 0.011I_6 + 0.023I_7 + 0.059I_8 - 0.365I_9 + 79.682$
Norway	$I_0 = -0.006I_1 + 0.234I_2 + 0.046I_3 + 0.381I_4 - 0.204I_5 + 0.050I_6 + 0.051I_7 - 0.028I_9 + 23.214$
Poland	$I_0 = -0.765I_1 + 0.028I_2 + 0.029I_3 + 0.026I_4 - 0.026I_5 + 0.043I_6 + 0.028I_7 + 0.028I_8 - 0.026I_9 + 5.238$
Portugal	$I_0 = -0.013I_1 + 0.788I_2 + 0.007I_3 + 0.015I_4 - 0.076I_5 + 0.003I_6 + 0.058I_7 + 0.0001I_8 - 0.039I_9 + 11.544$
Republic of Moldova	$I_0 = -0.976I_1 + 0.002I_2 + 0.018I_3 + 0.001I_4 - 0.001I_5 + 0.001I_6 + 0.00005I_8 + 0.142$
Romania	$I_0 = -0.024I_1 + 0.139I_2 + 0.075I_3 + 0.073I_4 - 0.091I_5 + 0.434I_6 + 0.057I_7 + 0.005I_8 - 0.102I_9 + 19.289$
Russian Federation	$I_0 = -0.005I_1 + 0.309I_2 + 0.049I_3 + 0.072I_4 - 0.080I_5 + 0.075I_6 + 0.319I_7 + 0.011I_8 - 0.079I_9 + 15.922$
Serbia	$I_0 = -0.293I_1 + 0.113I_2 + 0.384I_3 + 0.082I_4 + 0.119I_6 + 0.009I_7$
Slovakia	$I_0 = -0.005I_1 + 0.234I_2 + 0.036I_3 + 0.096I_4 - 0.175I_5 + 0.053I_6 + 0.018I_7 - 0.383I_9 + 55.828$
Slovenia	$I_0 = -0.369I_1 + 0.107I_2 + 0.002I_3 + 0.062I_4 - 0.198I_5 + 0.019I_6 + 0.244I_8 + 19.759$
Spain	$I_0 = -0.187I_1 + 0.145I_2 + 0.027I_3 + 0.140I_4 - 0.185I_5 + 0.045I_6 + 0.133I_7 + 0.005I_8 - 0.133I_9 + 31.788$
Sweden	$I_0 = -0.003I_1 + 0.132I_2 + 0.020I_3 + 0.135I_4 - 0.182I_5 + 0.045I_6 + 0.013I_7 + 0.222I_8 - 0.247I_9 + 42.975$
Switzerland	$I_0 = -0.047I_1 + 0.243I_2 + 0.021I_3 + 0.173I_4 - 0.085I_5 + 0.016I_6 + 0.005I_7 + 0.411I_8 + 8.492$
Macedonia	$I_0 = -0.016I_1 + 0.640I_2 + 0.013I_3 + 0.051I_4 - 0.068I_5 + 0.089I_6 + 0.005I_7 - 0.118I_9 + 18.618$
Ukraine	$I_0 = -0.014I_1 + 0.559I_2 + 0.159I_3 + 0.092I_4 + 0.145I_6 + 0.031I_8$
United Kingdom	$I_0 = -0.003I_1 + 0.082I_2 + 0.005I_3 + 0.079I_4 - 0.604I_5 + 0.005I_6 + 0.019I_7 + 0.078I_8 - 0.125I_9 + 72.918$

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TABLE 3 ESTIMATED FUNCTIONS USING THE SECOND METHOD [34] FOR VALUE OF AREA EQUIPPED FOR IRRIGATION IN EUROPE

Country	*Suggested formula to estimate value of area equipped for irrigation to cultivated area (%)*
Albania	$\hat{I}_0 = -0.102I_1 + 0.188I_2 + 0.033I_3 + 0.055I_4 - 0.240I_5 + 0.071I_6 + 0.093I_7 + 0.096I_8 - 0.121I_9 + 36.167$
Austria	$\hat{I}_0 = -0.035I_1 + 0.347I_2 + 0.031I_3 + 0.019I_4 - 0.410I_5 + 0.026I_6 + 0.031I_7 + 0.044I_8 - 0.058I_9 + 46.816$
Belarus	$\hat{I}_0 = -0.028I_1 + 0.049I_2 + 0.868I_3 + 0.007I_4 - 0.009I_5 + 0.040I_6 + 0.899$
Belgium	$\hat{I}_0 = -0.058I_1 + 0.049I_2 + 0.049I_3 + 0.018I_4 - 0.085I_5 + 0.045I_6 + 0.090I_7 + 0.069I_8 - 0.539I_9 + 62.368$
Bosnia and Herzegovina	$\hat{I}_0 = -0.074I_1 + 0.027I_2 + 0.594I_3 + 0.021I_4 - 0.037I_5 + 0.247I_6 + 3.742$
Bulgaria	$\hat{I}_0 = -0.025I_1 + 0.492I_2 + 0.021I_3 + 0.010I_4 - 0.013I_5 + 0.019I_6 + 0.391I_7 + 0.017I_8 - 0.013I_9 + 2.570$
Croatia	$\hat{I}_0 = -0.057I_1 + 0.023I_2 + 0.166I_3 + 0.013I_4 - 0.020I_5 + 0.639I_6 + 0.083I_8 + 2.015$
Cyprus	$\hat{I}_0 = -0.113I_1 + 0.286I_2 + 0.094I_3 + 0.070I_4 - 0.085I_5 + 0.071I_6 + 0.198I_7 - 0.083I_9 + 16.773$
Czech Republic	$\hat{I}_0 = -0.125I_1 + 0.038I_2 + 0.249I_3 + 0.009I_4 - 0.015I_5 + 0.076I_6 + 0.233I_7 + 0.237I_8 - 0.019I_9 + 3.346$
Denmark	$\hat{I}_0 = -0.047I_1 + 0.069I_2 + 0.054I_3 + 0.047I_4 - 0.151I_5 + 0.048I_6 + 0.063I_7 + 0.090I_8 - 0.430I_9 + 58.067$
Estonia	$\hat{I}_0 = -0.219I_1 + 0.011I_2 + 0.018I_3 + 0.004I_4 - 0.006I_5 + 0.126I_6 + 0.609I_7 - 0.007I_9 + 1.288$
Finland	$\hat{I}_0 = -0.097I_1 + 0.217I_2 + 0.131I_3 + 0.046I_4 - 0.071I_5 + 0.106I_6 + 0.119I_7 + 0.116I_8 - 0.096I_9 + 16.688$
France	$\hat{I}_0 = -0.009I_1 + 0.010I_2 + 0.007I_3 + 0.006I_4 - 0.029I_5 + 0.007I_6 + 0.009I_7 + 0.010I_8 - 0.915I_9 + 94.343$
Germany	$\hat{I}_0 = -0.001I_1 + 0.004I_2 + 0.001I_3 + 0.001I_4 - 0.004I_5 + 0.001I_6 + 0.001I_7 + 0.006I_8 - 0.981I_9 + 98.529$
Greece	$\hat{I}_0 = -0.054I_1 + 0.531I_2 + 0.091I_3 + 0.042I_4 - 0.093I_5 + 0.057I_6 + 0.037I_7 + 0.056I_8 - 0.038I_9 + 13.158$
Hungary	$\hat{I}_0 = -0.100I_1 + 0.265I_2 + 0.162I_3 + 0.033I_4 - 0.050I_5 + 0.075I_6 + 0.210I_7 + 0.057I_8 - 0.047I_9 + 9.740$
Ireland	$\hat{I}_0 = -0.099I_1 + 0.002I_2 + 0.005I_3 + 0.001I_4 - 0.002I_5 + 0.883I_6 + 0.003I_7 + 0.003I_8 - 0.003I_9 + 0.480$
Italy	$\hat{I}_0 = -0.070I_1 + 0.194I_2 + 0.045I_3 + 0.036I_4 - 0.188I_5 + 0.039I_6 + 0.110I_7 + 0.038I_8 - 0.281I_9 + 46.859$
Latvia	$\hat{I}_0 = -0.756I_1 + 0.017I_2 + 0.030I_3 + 0.008I_4 - 0.010I_5 + 0.179I_6 + 0.972$
Lithuania	$\hat{I}_0 = -0.394I_1 + 0.030I_2 + 0.062I_3 + 0.013I_4 - 0.017I_5 + 0.388I_6 + 0.077I_7 - 0.019I_9 + 3.559$
Malta	$\hat{I}_0 = -0.317I_1 + 0.091I_2 + 0.081I_3 + 0.074I_4 + 0.082I_6 + 0.276I_7 + 0.078I_8$
Montenegro	$\hat{I}_0 = -0.171I_1 + 0.048I_2 + 0.094I_3 + 0.022I_4 + 0.506I_6 + 0.158I_7$
Netherlands	$\hat{I}_0 = -0.041I_1 + 0.057I_2 + 0.038I_3 + 0.031I_4 - 0.359I_5 + 0.035I_6 + 0.055I_7 + 0.020I_8 - 0.365I_9 + 72.390$
Norway	$\hat{I}_0 = -0.098I_1 + 0.200I_2 + 0.115I_3 + 0.077I_4 - 0.187I_5 + 0.098I_6 + 0.118I_7 - 0.107I_9 + 29.412$
Poland	$\hat{I}_0 = -0.918I_1 + 0.007I_2 + 0.008I_3 + 0.003I_4 - 0.004I_5 + 0.045I_6 + 0.006I_7 + 0.007I_8 - 0.004I_9 + 0.780$
Portugal	$\hat{I}_0 = -0.006I_1 + 0.800I_2 + 0.014I_3 + 0.008I_4 - 0.071I_5 + 0.008I_6 + 0.053I_7 + 0.007I_8 - 0.033I_9 + 10.361$
Republic of Moldova	$\hat{I}_0 = -0.977I_1 + 0.001I_2 + 0.019I_3 + 0.001I_4 - 0.001I_5 + 0.0004I_6 + 0.001I_8 + 0.073$
Romania	$\hat{I}_0 = -0.108I_1 + 0.155I_2 + 0.190I_3 + 0.048I_4 - 0.076I_5 + 0.088I_6 + 0.161I_7 + 0.078I_8 - 0.095I_9 + 17.179$
Russian Federation	$\hat{I}_0 = -0.044I_1 + 0.332I_2 + 0.086I_3 + 0.029I_4 - 0.087I_5 + 0.045I_6 + 0.342I_7 + 0.050I_8 - 0.036I_9 + 7.274$
Serbia	$\hat{I}_0 = -0.357I_1 + 0.059I_2 + 0.336I_3 + 0.027I_4 + 0.156I_6 + 0.066I_7$
Slovakia	$\hat{I}_0 = -0.059I_1 + 0.191I_2 + 0.092I_3 + 0.047I_4 - 0.130I_5 + 0.060I_6 + 0.073I_7 - 0.348I_9 + 47.793$
Slovenia	$\hat{I}_0 = -0.427I_1 + 0.075I_2 + 0.040I_3 + 0.027I_4 - 0.170I_5 + 0.041I_6 + 0.219I_8 + 17.022$
Spain	$\hat{I}_0 = -0.122I_1 + 0.254I_2 + 0.121I_3 + 0.069I_4 - 0.120I_5 + 0.096I_6 + 0.061I_7 + 0.096I_8 - 0.061I_9 + 18.091$
Sweden	$\hat{I}_0 = -0.091I_1 + 0.213I_2 + 0.107I_3 + 0.040I_4 - 0.085I_5 + 0.094I_6 + 0.101I_7 + 0.122I_8 - 0.147I_9 + 23.160$
Switzerland	$\hat{I}_0 = -0.086I_1 + 0.204I_2 + 0.071I_3 + 0.047I_4 - 0.109I_5 + 0.059I_6 + 0.061I_7 + 0.305I_8 - 0.058I_9 + 16.691$
Macedonia	$\hat{I}_0 = -0.041I_1 + 0.674I_2 + 0.037I_3 + 0.033I_4 - 0.052I_5 + 0.030I_6 + 0.028I_7 - 0.105I_9 + 15.721$
Ukraine	$\hat{I}_0 = -0.065I_1 + 0.488I_2 + 0.204I_3 + 0.037I_4 - 0.051I_5 + 0.074I_6 + 0.081I_8 + 5.125$
United Kingdom	$\hat{I}_0 = -0.044I_1 + 0.114I_2 + 0.046I_3 + 0.028I_4 - 0.491I_5 + 0.042I_6 + 0.058I_7 + 0.027I_8 - 0.151I_9 + 64.170$

TABLE 4 CALCULATED ERRORS FOR SUGGESTED FUNCTIONS (TABLES 1 AND 2)

Country	*Relative error in the first formula (%)*			*Relative error in the second formula (%)*		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Albania	3.1	16.6	27.2	3.7	15.5	26.7
Austria	7.3	14.9	23.5	6.6	14.9	22.6
Belarus	6.6	17.1	29.7	5.3	16.8	27.0
Belgium	7.5	15.0	25.6	5.2	11.2	24.5
Bosnia and Herzegovina	8.4	16.6	27.1	3.9	10.3	17.3
Bulgaria	2.6	14.2	26.4	2.9	12.9	25.8
Croatia	7.1	13.7	25.6	3.1	10.2	16.6
Cyprus	0.7	14.8	21.7	1.9	13.1	17.3
Czech Republic	1.0	16.7	28.7	1.1	14.7	26.8
Denmark	6.5	15.3	23.3	2.7	15.8	26.2
Estonia	12.6	26.2	47.4	6.2	24.6	46.6
Finland	2.7	19.3	38.3	3.8	20.7	33.9
France	8.5	16.9	26.2	8.2	14.8	15.8
Germany	3.6	10.3	20.3	3.0	11.2	15.7
Greece	2.2	16.1	21.6	2.2	14.4	20.5
Hungary	4.4	15.0	21.6	6.5	14.4	18.0
Ireland	2.9	13.5	21.2	4.4	11.7	19.5
Italy	6.2	12.1	18.7	4.2	13.7	17.5
Latvia	2.3	15.8	24.5	1.1	15.0	19.4
Lithuania	5.2	13.1	18.6	4.7	12.1	17.4
Malta	0.9	7.3	17.3	2.0	8.2	14.9
Montenegro	4.0	7.3	14.5	4.8	7.4	14.9
Netherlands	5.5	16.1	25.0	2.7	16.7	20.6
Norway	5.5	16.1	25.0	2.7	16.7	20.6
Poland	1.6	12.1	17.7	1.0	13.6	18.4
Portugal	2.7	13.2	20.5	3.7	14.0	18.2
Republic of Moldova	12.0	26.6	37.8	14.0	24.2	29.8
Romania	10.7	26.6	44.3	12.3	25.7	31.6
Russian Federation	3.9	16.6	20.0	3.7	10.8	16.2
Serbia	8.2	14.0	25.4	3.1	7.0	13.1
Slovakia	4.4	13.4	15.8	3.1	13.0	18.6
Slovenia	8.4	15.9	28.9	4.5	16.7	26.4
Spain	2.5	10.4	21.9	2.9	9.3	16.1
Sweden	2.0	11.9	17.9	2.0	13.9	17.4
Switzerland	6.9	12.4	24.3	0.8	6.6	13.5
Macedonia	3.9	11.8	19.2	3.9	11.2	17.6
Ukraine	3.8	12.1	25.6	1.9	8.4	14.0
United Kingdom	5.3	9.7	18.3	4.6	9.3	17.1

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TABLE 5 TOTAL CONDITIONS OF THE COUNTRIES FOR AGRICULTURAL WATER MANAGEMENT

Country	I_{n1}	I_{n2}	I_{n3}	I_{n4}	I_{n5}	I_{n6}	$100-I_{n7}$	I_{n8}	I_{n9}	I_{n10}	I_{avg1}	I_{avg2}	Status
Albania	27	55	100	78	63	100	75	21	70	56	65	67	Suitable
Andorra	0	15	12	89	NA	NA	NA	NA	NA	NA	29	NA	Difficult
Austria	12	37	8	94	62	8	92	14	77	17	42	41	Fairly
Belarus	6	29	21	83	34	53	NA	NA	NA	4	33	16	Difficult
Belgium	7	3	3	94	59	4	86	8	71	6	34	26	Difficult
Bosnia and Herzegovina	24	59	5	77	56	47	NA	NA	NA	1	38	4	Difficult
Bulgaria	12	33	9	82	30	30	69	2	30	7	30	20	Difficult
Croatia	22	49	10	84	45	28	NA	13	NA	1	31	6	Difficult
Cyprus	72	34	12	89	19	11	70	NA	18	66	44	61	Suitable
Czech Republic	6	31	15	91	39	12	91	12	50	2	35	16	Difficult
Denmark	0.4	15	6	94	38	6	88	58	48	39	39	57	Suitable
Estonia	2	35	21	89	34	19	99	NA	48	0.1	39	39	Fairly
Faroe Islands	0	69	0	NA	NA	NA	NA	0	NA	NA0	14	NA	Difficult
Finland	1	17	8	93	29	16	94	45	39	6	35	23	Difficult
France	13	16	5	94	45	9	87	13	55	28	37	59	Suitable
Germany	4	30	4	96	46	5	89	41	57	9	38	38	Fairly
Greece	81	45	28	90	33	17	3	13	5	100	42	62	Suitable
Holy See	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hungary	10	37	18	87	32	19	61	51	30	6	35	26	Difficult
Iceland	0	8	15	95	51	39	NA	NA	NA	NA	35	NA	Difficult
Ireland	0.2	44	15	96	66	5	73	17	74	0.2	39	4	Difficult
Italy	69	37	8	92	46	10	70	1	49	85	47	83	Suitable
Latvia	2	38	22	85	33	22	NA	NA	NA	0.1	29	1	Difficult
Liechtenstein	0	100	0	92	NA	NA	NA	NA0	NA	NA0	32	NA	Fairly
Lithuania	4	38	19	86	32	19	85	NA	40	0.1	36	6	Difficult
Luxembourg	6	17	3	92	NA	2	40	0	NA	0	20	NA	Difficult
Malta	32	6	1	89	NA	10	45	0	NA	72	32	78	Suitable
Monaco	NA	0	0	NA	NA	NA	NA	0	NA	0	0	NA	Difficult
Montenegro	22	45	29	83	NA	51	97	NA	NA	3	47	17	Difficult
Netherlands	9	19	6	96	49	11	82	100	58	87	52	91	Suitable
Norway	1	24	8	100	78	9	91	NA	95	28	48	53	Suitable
Poland	9	45	41	86	33	19	51	37	26	2	35	15	Difficult
Portugal	100	45	22	85	51	13	49	0.4	45	65	48	70	Suitable
Republic of Moldova	36	61	35	69	30	80	NA	2	NA	23	42	37	Fairly
Romania	12	49	21	82	36	37	81	3	42	14	38	29	Difficult
Russian Federation	4	31	19	83	27	23	69	6	27	7	29	17	Difficult
San Marino	0	7	0	NA	NA	NA	NA	0	NA	0	1	NA	Difficult
Serbia	21	51	30	81	NA	48	97	NA	NA	5	48	27	Difficult
Slovakia	4	52	17	88	42	21	89	NA	53	26	43	50	Suitable
Slovenia	35	59	2	93	52	13	NA	37	NA	8	37	34	Fairly
Spain	70	26	10	93	30	15	0	2	0	42	29	42	Fairly
Sweden	1	18	5	96	39	10	96	42	52	13	37	26	Difficult
Switzerland	14	31	8	96	80	6	98	28	100	27	49	50	Suitable
Macedonia	20	47	17	77	34	60	91	NA	45	57	50	54	Suitable
Ukraine	7	36	24	77	100	51	NA	10	NA	14	40	33	Fairly
United Kingdom	2	24	4	92	60	4	89	76	73	8	43	36	Fairly

I_{n1}, normalized permanent crops per cultivated area (PC %); I_{n2}, normalized rural population to total population (RP %); I_{n3}, normalized labour force in agriculture (LF %); I_{n4}, normalized human development index (HDI); I_{n5}, normalized national rainfall index (NRI, mm year^{-1}); I_{n6}, normalized value added to gross domestic product by agriculture (GDP (agric) %); I_{n7}, normalized irrigation water requirement (IWR, mm year^{-1}); I_{n8}, normalized percent of total cultivated area drained (D %); I_{n9}, normalized difference between NRI and IWR; I_{n10}, normalized the land use index (equipped area for irrigation per cultivated area, AI %). NA and NA0 indicate unavailable data.

Tables 2 and 3 show the functions estimated for the value of the equipped area in Europe. A comparison between Table 2 and Table 3 demonstrates that obtained coefficients for the main indices are very similar in some cases, and very different in other cases, due to differences in Valipour's methods. Fig. 2 assesses the effect of the main indices on equipped area (10th index) in Europe. Fig. 2 shows the difference between NRI and irrigation water requirement, rural population per total population, and permanent crops per cultivated area have significant effects on the estimation of area equipped for irrigation per cultivated area (10th index), for accurate scheduling to increase irrigation efficiency and to encourage farmers to use irrigation systems instead of rainfed agriculture. On the contrary, HDI has the least impact on the equipped area, as supported by Fig. 1. Table 1 shows that the difference between NRI and irrigation water requirement is positive, demonstrating a tendency toward rainfed agriculture for Europe. Meanwhile, Table 1 (and Fig. 1) shows that values of rural population per total population and permanent crops per cultivated area are low; hence, these factors lead to a decreasing tendency of governments and/or farmers to use irrigation systems. Note that Greece and Spain, with negative values for the difference between NRI and irrigation water requirement (Table 1) have considerable irrigation. On the other hand, the value of HDI is high for Europe; therefore this index has the least significant role in low values of equipped areas for Europe (Fig. 2).

Table 4 shows the calculated errors for suggested functions, shown in Tables 2 and 3. Table 5 presents total conditions of the countries for agricultural water management. According to Table 5, conditions of agricultural water management is suitable in Albania, Cyprus, Denmark, France, Greece, Italy, Malta, the Netherlands, Norway, Portugal, Slovakia, Switzerland and the former Yugoslav Republic of Macedonia; conditions are fairly suitable in Austria, Estonia, Germany, Iceland, Liechtenstein, Republic of Moldova, Slovenia, Spain, Ukraine, and the United Kingdom. However, conditions of agricultural water management are difficult for the other countries in Europe. As shown in Table 5, conditions in each country is different due to nature of the Appendix; the desirability of conditions for agricultural water management is suitable in Mediterranean Europe (with the exception of Spain at 42%) and is more than 30% for Western Europe (with the exception of Belgium at 26% and Ireland at 4%). The desirability of conditions for agricultural water management is less than 30% for Central Europe (with the exception of Slovakia at 50% and Slovenia at 34%). The Netherlands is the best country for agricultural water management because its desirability of condition (91%) is higher than all the other countries in Europe. In other words, agricultural water management in Netherlands is more comfortable than in the other countries [75-90]. Although determined functions to estimate equipped area (10th index) were tested for all years that data was available, a more comprehensive study is required to assess the trend of agricultural water management in the past fifty years.

IV. CONCLUSIONS

The present study examined the role of agricultural water management in Europe within the past fifty years. Eighteen indices (as the main and sub-main indices) were selected to assess agricultural water management based on their importance; other indices were not studied due to the lack of adequate data. The variations in the main indices for 2011 showed that they

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had similar values in some regions and had very different values in other regions due to the nature of the indices and conditions of the countries. Next, the value of the area equipped for irrigation per cultivated area (10th index) was estimated using the other main indices. Using the obtained functions, not only the mentioned index in any year (with a relative error less than 20%) was estimated, but also the importance of each index for every region was assessed. In addition, the change of the 10th index due to the increase or decrease of each index in future years was predicted. The prioritization of the main indices showed that the difference between NRI and irrigation water requirement, rural population per total population, and permanent crops per cultivated area had significant effects on the estimation of area equipped for irrigation per cultivated area (10th index). Classification of the countries based on the main indices showed that the Netherlands had the highest desirability of conditions for agricultural water management compared to all other European countries.

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Appendix

$$I_{10}=\frac{1}{\sum_{i}^{1,2,3,4,6,7,8}\frac{1}{\left|1-\left(\frac{I_{10}}{f_c I_{ni}}\right)_{2011}\right|}+\sum_{i}^{5,9}\frac{1}{\left|1-\left(\frac{I_{10}}{f_c(100-I_{ni})}\right)_{2011}\right|}}\left[\sum_{i}^{1,2,3,4,6,7,8}\frac{I_{ni}}{\left|1-\left(\frac{I_{10}}{f_c I_{ni}}\right)_{2011}\right|}+\sum_{i}^{5,9}\left(\frac{100-I_{ni}}{\left|1-\left(\frac{I_{10}}{f_c(100-I_{ni})}\right)_{2011}\right|}\right)\right]$$

$$I_{10}=\frac{1}{\sum_{i}^{1,2,3,4,6,7,8}\frac{1}{\left|f_c I_{ni}-I_{10}\right|_{2011}}+\sum_{i}^{5,9}\frac{1}{\left|f_c(100-I_{ni})-I_{10}\right|_{2011}}}\left[\sum_{i}^{1,2,3,4,6,7,8}\frac{I_{ni}}{\left|f_c I_{ni}-I_{10}\right|_{2011}}+\sum_{i}^{5,9}\left(\frac{100-I_{ni}}{\left|f_c(100-I_{ni})-I_{10}\right|_{2011}}\right)\right]$$

$$I_{ni}=\textit{Normalized index}=100\times\frac{I_i}{(I_i)_{\max}}$$

$$(I_i)_{\max}=\textit{Maximum value of index among all countries in Europe}\ (46\ \textit{countries})$$

where f_c is correction factor and can be updated at the end of each water year. It will be 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, or 0.1, if I_{n10} is 90-100, 80-90, 70-80, 60-70, 50-60, 40-50, 30-40, 20-30, 10-20, or 0-10, respectively. To determine the error of the obtained functions, these formulas were applied for other years, and magnitudes of error were calculated as:

$$\textit{Mean error}=\frac{1}{\textit{Number of tested years}}\sum_{i=1}^{\textit{Number of tested years}}\left(100\times\frac{\left|(I_{10})^{i}_{\textit{actual}}-(I_{10})_{\textit{estimated}}\right|}{(I_{10})^{i}_{\textit{actual}}}\right)$$

$$\textit{Maximum error}=\underset{i=1}{\overset{\textit{Number of tested years}}{\textit{Max}}}\left\{100\times\frac{\left|(I_{10})^{i}_{\textit{actual}}-(I_{10})_{\textit{estimated}}\right|}{(I_{10})^{i}_{\textit{actual}}}\right\}$$

$$\textit{Minimum error}=\underset{i=1}{\overset{\textit{Number of tested years}}{\textit{Min}}}\left\{100\times\frac{\left|(I_{10})^{i}_{\textit{actual}}-(I_{10})_{\textit{estimated}}\right|}{(I_{10})^{i}_{\textit{actual}}}\right\}$$

Status of all countries was identified using the following two methods:

$$\textit{Desirability}=I_{avg1}=\frac{1}{\textit{Number of available indexes}}\left[I_{n1}+I_{n2}+I_{n3}+I_{n4}+I_{n5}+I_{n6}+(100-I_{n7})+I_{n8}+I_{n9}+I_{n10}\right]$$

$$\textit{Desirability}=I_{avg2}=\frac{1}{1+\sum_{i=1}^{1,2,3,4,5,6,8,9}\frac{1}{\left|f_c I_{ni}-I_{10}\right|}+\frac{1}{\left|f_c(100-I_{n7})-I_{10}\right|}}\left[\sum_{i=1}^{1,2,3,4,5,6,8,9}\frac{I_{ni}}{\left|f_c I_{ni}-I_{10}\right|}+\frac{100-I_{n7}}{\left|f_c(100-I_{n7})-I_{10}\right|}+I_{n10}\right]$$

Suitable status: $\textit{Desirability}\geq 50\%$

Fairly status: $30\%\leq\textit{Desirability}<50\%$

Difficult status: $\textit{Desirability}<30\%$

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