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IMPORTANCE OF SUB-CRITERIA IN MCA FOR PRIORITIZATION OF INVESTMENTS FOR RECONSTRUCTION AND MODERNIZATION OF IRRIGATION INFRASTRUCTURE IN BULGARIA

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ABSTRACT

Multi-criteria analysis (MCA) is an appropriate tool for prioritization of investments for reconstruction and modernization (R&M) of irrigation infrastructure, considering different aspects of the investments. The funds for R&M included as a sub-measure of Rural Development Programme 2014 – 2020 were not sufficient for the needs of all 223 Irrigation Systems (ISs) in the country and the problem of most efficient allocation of the funds appear. MCA is suitable for solving complex problems, including both quantitative and qualitative features. This study is a review on the approach to selecting the criteria for MCA. Four main criteria for MCA are proposed in this study – Technical, Economic, Environmental and Social, each one of them comprising multiple sub-criteria. The study is focused on the criterion selection and the importance of including sub-criteria in MCA. A Simple Additive Weighting (SAW) MCA approach is used. Forty scenarios of different combinations of weighting factors for the main criteria and their sub-criteria are investigated. Estimates are performed for all 223 ISs in Bulgaria and the first fifty suitable schemes for R&M are determined. A Geographic Information System (GIS) overlay analysis was performed in parallel, and the results of the study are presented on a map.

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1. Introduction

The soils, climate and available water resources of Bulgaria are favorable of growing large variety of agricultural crops. The irrigation of these crops assures high and sustainable yields.

In a Report of the World Bank (WB Report) [1] is pointed that nearly one-third of the Bulgarian population directly depends on agriculture for its livelihood. The agriculture will significantly be affected by the climate change, since the annual average temperature in Bulgaria is expected to increase between 0,5 °C and 1,5 °C by 2029 and between 2,0 °C and 5,0 °C by the end of the century [1]. The temperature rise will impose irrigation of crops -- even those which now are grown under rainfed conditions.

By 1989 Bulgaria has a large irrigation infrastructure, capable of delivering water to over 1,2 million ha, and which greatly contributed to the agricultural sector boom. After 1990 this infrastructure significantly deteriorated due to variety of reasons. The process of reconstruction and modernization (R&M) of the irrigation infrastructure is necessary to meet the increased needs of irrigation due to the observed and expected climate change.

In the Report [1] for the purposes of programming and prioritization of investments in the rehabilitation, reconstruction, and modernization of the irrigation infrastructure in Bulgaria is recommended the use of multi-criteria analysis (MCA) to allow the ranking of projects. In the past, the traditional approaches for determining the most efficient systems for reconstruction and modernization were based on the lowest cost. Due to the growing environmental awareness in recent years, the analysis also includes environmental factors and the role of the irrigation systems (ISs) in environmental protection. The emphasis is no longer on the price, but on the potential water savings, as the climatic and environmental factors are involved. The main advantage of the MCA method is that it allows for each criterion to be added attributes to obtain an integrated result of a given decision.

For the study, the classification of the types of ISs as proposed in [2] is used:

- Type *G* – Gravity fed irrigation systems. Sub-divided in: *G_c* (Gravity fed ISs – Canal network) and *G_p* (Gravity fed ISs – Pressurized network).
- Type *P* – Pump fed IS, Sub-divided in: *P_c* (Pump fed ISs – Canal network) and *P_p* (Pump fed ISs – Pressurized network). An index shows the levels of pumping in the system.
- Type *S* – Sprinkler irrigation systems.
- Type *C* – Complex irrigation systems. Most of the Large and Medium ISs in Bulgaria belong to this class. It is a combination of the previous three.

The type of the irrigation system (IS) should not be considered as an unambiguous condition for prioritization of the investments. Some types ISs are flexible in the way of delivery of water, but not energy effective etc.

The constructed and equipped areas of the existing ISs have been analyzed in accordance with the existing categorization in the Standards for Design of Hydraulic Structures [3], and a new grouping has been proposed to ensure a more uniform distribution of the irrigation systems by area. The following data were used for the analysis [4]:

- Constructed area of ISs – 747 113,0 ha, distributed among 252 irrigation systems (ISs).
- Equipped area of ISs – 541 779,5 ha, distributed among 223 ISs.

The new categorization intervals proposed by [4] are as follows: Very large ISs with an area of over 25 000 ha, Large ISs – with an area of 7 500 and 25 000 ha, Medium ISs – with an

area of 2 500 to 7 500 ha, Small ISs – with an area of 1 000 to 2 500 ha, Very small ISs – with an area of less than 1 000 ha – figure 1.

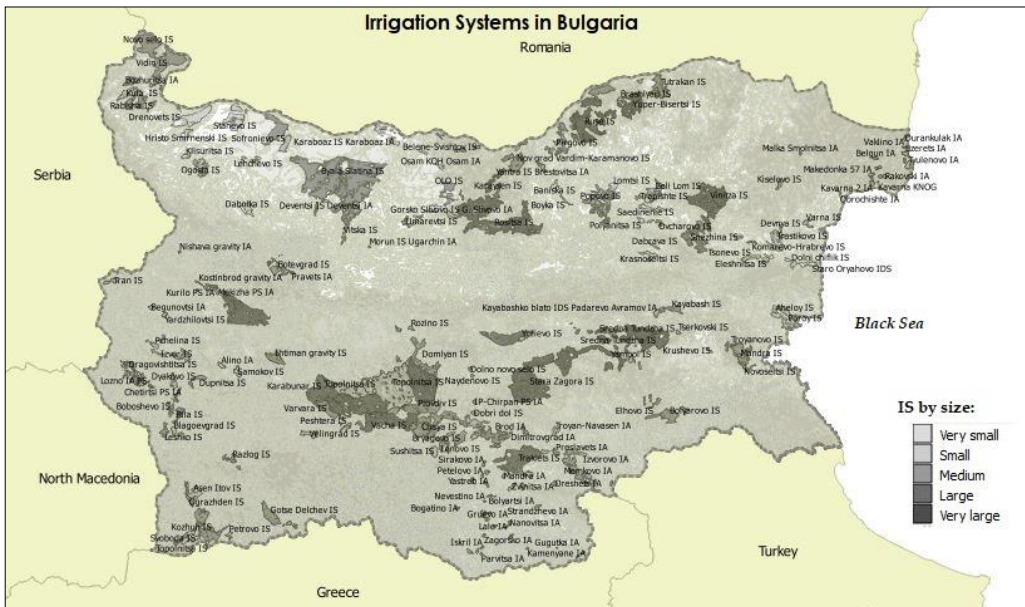


Figure 1. Map of Irrigation Systems in Bulgaria

2. Methodology

The prioritization of investments for ISs is a complex process, which consists of comparing data for individual systems and classifying them by a certain number of features. These features are commonly referred to as *Criteria*, and the values assigned to the irrigation systems under each criterion are *Alternatives* to analysis. To reach an unambiguous and objective solution, it is necessary to use an analysis method that eliminates the difficulties of comparing a large amount of data. The most widely used method is Multi-Criteria Analysis (MCA, MCDA – Multi-Criteria Decision Analysis). MCA is a form of integrated sustainability evaluation. It is an operational evaluation and decision support approach that is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multi-interests and different perspectives, and the accounting for complex and evolving biophysical and socio-economic systems [5].

The tasks of the MCA, which are part of the scientific discipline “Decision Making” [6], are decision-making tasks with multiple criteria when the number of alternatives is unlimited, but the set of alternatives is determined by a finite number of constraints. Their main characteristic is that they optimize more than one contradictory and incommensurable criterion (objective functions) on some non-empty allowable area of change of variables [7].

In water management, some of the most used MCA methods are the Weighted Sum Method, Preference Ranking for Organization Method for Enrichment Evaluation (PROMETHEE), and Elimination and Selection of Translated Reality (ELECTRE) [5, 8, 9]. In the analysis of the IS, the criteria can vary in number, each of which has a different weight and nature. Some of the criteria have a quantitative range – investments in euros per hectare, while

others have qualitative features (good, medium, bad). Some studies of the present years, as [8, 10 – 12] prove that the MCA analysis in different countries might use the same methods for MCA, but the analysis is made according to the data available for the specific region.

Most of the MCA methods require influenced specialists. The prioritization of the investments for reconstruction and modernization (R&M) of IS should be prepared by a team of experts, including economists, engineers, and lawyers. If the process becomes too complex (including many criteria), it might become error prone. Therefore, the use of elementary weighting methods for MCA is justified, as adding *Attributes* to the *Criteria* largely eliminates the subjective factor in decision-making. MCA approach, known as SAW (Simple Additive Weighting) [13] or Weighted Sum Method (WSM) [5] was used for the present study. It is a simplified version of the Multi-Attribute Value Theory (MAVT), [14]. In MAVT, the decision-making process begins with defining the problem from its original nature to defining it by quantitative and qualitative characteristics or numerical analysis [15]. SAW which is also known as weighted linear combination or scoring methods is a simple multi-attribute decision technique, based on the weighted average [16]. The decision-maker gives weights w_{in} with relative importance for each attribute x_{ij} , and the evaluation score S_i is calculated for each alternative by multiplying and summing the result as follows:

The cardinal score of given IS is a weighted sum of evaluation scores S_i of different criteria i :

$$S = \sum_{i=1}^n w_i S_i , \quad (1)$$

where w_i is the weight of the score S_i .

The score of a criterion S_i can be obtained analogically:

$$S_i = \sum_{j=1}^m w_j \cdot x_{ij} , \quad (2)$$

where w_j is the weight of the normalized value x_{ij} of the sub-criterion j of the criterion i .

2.1. Initial approach

In the initial calculations, it was decided that the criteria are general and 6 in number: Investment cost effectiveness, Potential incremental farm income, Benefit – Cost ratio (B/C ratio), Potential water savings, Water intake type, and Technical suitability.

Investment cost effectiveness is a ratio between the R&M investments and the size of the equipped area.

Potential incremental farm income is calculated as a difference between the possible income for farmers from irrigated crops and the income under rainfed conditions, expressed in Euros/ha.

Benefit – Cost ratio is a ratio between the Potential incremental farm Income and the operation and maintenance (O&M) costs for the rehabilitated and modernized infrastructure. Both items comprising the B/C ratio are expressed in Euros/year.

Potential water savings are estimated as a ratio between “saved” amount of water and the current water abstraction (IS consumption) for the IS. The “saved” water is a difference between the average current abstraction and the average expected abstraction after the R&M of IS. This criterion is unitless, so it is also referred to as Relative potential water savings.

Water intake type criterion takes into account the security of water source in terms of the capability of this source to assure water for irrigation purposes when it is needed. The ISs which use non-regulated water source (run-of-the-river ISs) have the lowest score, while “regulated runoff ISs” have the highest score.

Technical suitability criterion takes into account the types and the subtypes of the ISs, as they are classified in [2].

Two variants of criteria weights were investigated (Table 1).

Table 1. Variants of criteria weights

Criteria Description	Weighting	
	Variant 1	Variant 2
Investment Cost Effectiveness	1	3
Potential Incremental Farm Income	3	1
B/C Ratio	3	1
Relative Potential Water Savings	3	3
Water Intake Certainty	2	2
Technical Suitability	1	3
TOTAL	13	13

Variant 1 gives preference to the Potential Incremental Farm Income, B/C ratio and Relative Potential Water Savings. Variant 2 favors the Investment Cost Effectiveness, Technical Suitability and, again, Relative Potential Water Savings.

2.2. Initial results

The results of the initial MCA are shown in Table 2.

Table 2. Results by the initial MCA

GIS ID	Irrigation System	Equipped area, ha	Inv. Cost Eff.	Pot. Incr. Farm Income	B/C Ratio	RWS	WI	T. suit.	S	RANK
162	IS Ihtiman	3 901	0,54	0,95	1,00	1,00	1,00	0,50	0,91	1
172	IF Chirpan	60	0,78	0,81	1,00	1,00	1,00	0,00	0,86	2
6	IS Tserkovski	366	0,66	0,72	1,00	1,00	1,00	0,25	0,85	3
171	IS Dobri dol	1 085	0,72	0,76	1,00	1,00	1,00	0,00	0,85	4
119	IS Aleksandrovo	1 050	0,71	0,69	1,00	1,00	1,00	0,00	0,83	5
208	IF Bunarcha-Kap.Andreevo	255	0,79	0,64	1,00	1,00	1,00	0,00	0,82	6
115	KON Osam	1 208	0,82	0,62	1,00	1,00	1,00	0,00	0,82	7
204	IF Polyanovo	389	0,92	0,58	1,00	1,00	1,00	0,00	0,82	8
209	IS Biser	143	0,75	0,57	1,00	1,00	1,00	0,00	0,80	9
181	IS Beli Lom	3 508	0,69	0,86	1,00	0,72	1,00	0,00	0,80	10
159	IF PS Mekija	150	0,77	0,54	1,00	1,00	1,00	0,00	0,80	11
212	IF Momkovo	1 538	0,79	0,63	1,00	1,00	0,80	0,00	0,79	12
216	IF Dolno Lukovo	91	0,73	0,83	1,00	1,00	0,50	0,00	0,79	13
213	IF Kapkovo-Svilengrad	125	0,62	0,64	0,87	1,00	1,00	0,00	0,78	14
214	IF Byalo polyane	230	0,65	0,83	1,00	1,00	0,50	0,00	0,78	15

It is found that the most suitable ISs for R&M are very small, with an area of about 100 ha, which would lead to fragmentation of investment and at the same time benefits for a limited number of users.

It was also found that the analysis is very sensitive and even with minimal changes in the values of the weights of each criterion, radically different rankings of ISs are obtained. The most indicative examples are shown in Table 3.

Table 3. Comparison by the two variants results in the initial MCA

Variant 1			Variant 2		
Irrigation System	Equipped area, ha	Rank	Irrigation System	Equipped area, ha	Rank
IF Byalo polyane	230	15	IF Byalo polyane	230	57
IF Gugutka	165	33	IF Gugutka	165	85
IS Ovcharovo	723	52	IS Ovcharovo	723	8
IF Prileptsi	387	56	IF Prileptsi	387	97
IS Lehchevo	1 082	57	IS Lehchevo	1 082	102
IS Vinitsa	32 885	69	IS Vinitsa	32 885	9
IS Nov grad Vardim-Karamanovo	3 223	70	IS Nov grad Vardim-Karamanovo	3 223	112
IF PS Lozno	210	75	IF PS Lozno	210	126
IS Elhovo	2 212	76	IS Elhovo	2 212	33
IF Knijovnik	315	77	IF Knijovnik	315	30
IS Mechka	1 402	78	IS Mechka	1 402	32
IS Lomtsi	566	80	IS Lomtsi	566	27
IS Yantra-Borovo	817	84	IS Yantra-Borovo	817	127
IS Novo selo	1 667	90	IS Novo selo	1 667	140
IS Pchelina	1 817	91	IS Pchelina	1 817	150
IF Begunovtsi	300	93	IF Begunovtsi	300	166
IS Osam-Levski-Obnova	4 782	96	IS Osam-Levski-Obnova	4 782	24
IS Popovo	11 114	97	IS Popovo	11 114	19
IS Krushevo	696	100	IS Krushevo	696	41
IS Aleko-Pazardjik	11 175	101	IS Aleko-Pazardjik	11 175	60
IS Lom-zapad	5 614	102	IS Lom-zapad	5 614	148
IS Yulievo	638	104	IS Yulievo	638	59
IS Poroy	5 276	107	IS Poroy	5 276	67
IS Lenovo	2 323	109	IS Lenovo	2 323	44
IS Bryagovo	1 667	128	IS Bryagovo	1 667	88
IS Stara Zagora	33 768	135	IS Stara Zagora	33 768	95

These results indicated that the approach must be improved and search for a more sustainable solution to the problem and the readjustment of its constituent criteria in a way that would ensure a more objective result, to be made.

2.3. Improved methodology

Multiple criteria can be included according to the availability of the data for the specific investigation. It is decided the main Criteria to be four in number – Technical, Economic, Environmental and Social, each of which is divided into Sub-Criteria/Attributes (Table 4). To calculate the values of the main criteria, weighting method for multi-criteria analysis is applied. Then the final MCA is proceeded, which to rank the irrigation systems in Bulgaria. Forty

variants of different combinations of weights have been developed. The Criteria included in the present analysis are given in boldface in Table 4. The rest of the criteria are given for informational purposes for future analysis.

Table 4. Criterion for MCA for prioritization of investments for R&M of Irrigation Systems (*Adaptation for ISs from a publication on MCA in energetics [5]*)

Result	Method Criterion	Criterion	Method Sub-criteria	Sub-criteria	
Ranking of the Irrigation Schemes ←	Multi-criteria analysis (MCA)	Technical ←	MCA	Equipped/Constructed Area ratio	
				Irrigation system size	
				Water intake type	
				IS efficiency	
		Economic ←	B/C Ratio		Automation opportunity
					Reliability
					Safety
					Others
		Environmental ←	MCA		Specific investment cost for R&M
					Depreciation, operation and maintenance cost
					Electricity expenses
					Net present value
		Social			Payback period
					Potential additional farm income
					Benefit/Cost ratio
					Others
				Water savings potential	
				Water body status	
				Land use	
				Others* [16]	
				Priority within the NRDP 2014-20	
				Social acceptability	
				Job creation	
				Social benefits	
				Others	

To compare and illustrate the results, a Geographic Information System (GIS) overlay analysis was performed in parallel. The GIS database update allows analyses for single irrigation system (IS), for all the irrigation systems in Bulgaria or for the affected by the investments area of particular IS.

Rationale for inclusion of each Criterion and sub-criteria in the MCA is given below.

2.4. Technical criterion

2.4.1. Irrigated/Equipped Area ratio

This qualitative criterion considers the extent to which the system is up-to-date and the methods of water distribution, means of automation, equipment, etc. are still usable and applicable. It was accepted that irrigation systems with a suitable area of zero by the year 2000 should not participate at all in the prioritization process. A suitable area of zero practically means that the system must be rebuilt. In the presence of a limited investment, R&M of systems with a suitable area of zero is considered inexpedient. The criterion is calculated by the ratio between the equipped to the constructed areas. This Sub-criterion is automatically giving the lowest priority to systems with areas of 0 ha. It has values from 0 to 1, where 1 is the best and it means that the infrastructure is well preserved.

2.4.2. IS size

The criterion “Irrigation system size” is one of the most important criteria in MCA for R&M of ISs. After the initial MCA of ISs was made, it was established that very small irrigation systems are ranked best for funding. However, this would lead to a “fragmentation” of investments, and the social aspect of the number of users who would benefit from R&M in a specific region is also disrupted. It was decided the “IS size” criterion to have values from 0 to 1, with the highest score being the systems with an area over 25 000 ha (all ISs with a larger area receive 15 points), and the rest to receive a proportional to their area assessment, according to the new classification by area [4]. The points by categories are given as follows:

- ISs with an area greater than 25 000 ha receive 15 points.
- ISs with an area from 7 500 to 25 000 ha receive 13 points.
- ISs with an area from 2 500 to 7 500 ha receive 8 points.
- ISs with an area from 1 000 to 2 500 ha receive 3 points.
- ISs with an area less than 1 000 ha receive 1 point.

The values are normalized from 0 to 1.

2.4.3. Water intake type

Priority is given to systems with a “regulated runoff” type of supply. To the needs of MCA, the lowest score is given to “run-of-the-river” and “groundwater intake” – 5 points, to “regulated runoff” the highest score – 10 points, to “multiple sourced” – 8 points, and an additional value is entered for the Danube River, as it should not be included in the water sources with a low level of security – 8 points. Normalization from 0 to 1 is applied, where 1 is best.

2.4.4. Present efficiency coefficient

From a technical point of view, the current efficiency of the existing system is an important indicator of its suitability and efficiency. Average values by types of systems have been adopted after an analysis of the current values of the efficiency of ISs in Bulgaria. The sub-criterion takes values from 0 to 1, with 1 corresponding to the lowest current efficiency. It is accepted with priority to restore systems that need R&M more urgently, as high current efficiency would mean that the system is currently operating in a relatively satisfactory way and R&M costs may be delayed. The values for each system are obtained after normalization between the lowest and highest current efficiency of the ISs in Bulgaria.

2.4.5. Automation opportunity

Objects of the automation of water distribution in ISs are the water intakes, the canals, the water distribution structures, the water measurement, the regulation, and the operation of the system. For the study, the most used and appropriate technical structures for automation of existing water delivery network (WDN) are studied and implemented in the investment cost calculations for each IS system type. According to the [4], the level of automation of WDN is also determined according to the hierarchical structure operation of the IS, as follows: i) Partial automation – automation of the individual operations of the technological process, which are not interconnected in a local control automation system; This type of automation is most often applied to systems of type *Gc* and *Gp*. At specific sections in the system, technical equipment of automation and “upstream control” are provided, such as a long-crested weir.; ii) Local

automation; iii) Full automation; For the different types of ISs a rating is given from 1 to 5, where 1 – bad, 2 – satisfactory, 3 – good, 4 – very good, 5 – excellent. Type *S* (Sprinkler) systems are rated with the highest points (5), as the water flow in the WDN is always automatically coordinated with the actual requested consumption.

2.4.6. Reliability

Reliability of irrigation systems may be defined to the capacity of a device or system to perform as designed; the resistance to failure of a device or system; the ability of a device or system to perform a required function under stated conditions for a specified period; or the ability of something to “fail well” (fail without catastrophic consequences) [4]. This criterion may take in mind also the danger of theft, which is still a problem in Bulgaria. Another problem that can occur regarding the reliability of the system is the interruption of the power supply. In such a situation, the systems that need electricity (Type *P*, Type *S*) will stop working, not only during the power outage, but also until the system is reconfigured, deaerated, etc. The criterion is scored from 1 to 5, where 1 – bad, 2 – satisfactory, 3 – good, 4 – very good, 5 – excellent. A different number of points are given for each type of system/subsystem. Systems with multiple stages of water lifting (Type *P2p*, *P3p*, *P2c*, etc.) rate with the lowest number of points, as practice shows that these systems are most vulnerable to theft/scrap sale in Bulgaria and most of this type of constructed ISs have equipped areas of zero. Even if some of the pumping stations are stored, the systems do not work as they were designed. The maximum of 5 points is given to Type *Gc* gravity systems.

2.4.7. Safety

The safety of the facilities of the ISs can be considered both from a technical and a social aspect. The irrigation infrastructure includes a number of significant facilities and structures such as dams, reservoirs, large irrigation canals, high-pressure pipelines. A dam break is not only seen as damage to the infrastructure, but also as a potential danger to the entire population in the surrounding areas. The investment costs include funds for safety and repair of the dams. Irrigation canals can become a public hazard if the security equipment is damaged and very often the people living near the ISs themselves create dangerous conditions by stealing it. With the data available by 2020, *safety* as a criterion can be included in the technical assessment with subjective quality value, as there is no information on all irrigation facilities to determine their level of safety. The criterion is evaluated on a scale from 1 to 5, where 1 – bad, 2 – satisfactory, 3 – good, 4 – very good, 5 – excellent. A different number of points is given for each type of system/subsystem. In the present analysis, it is accepted that this feature of the technical criterion has a weight of zero, as much additional information on irrigation systems is needed for it to be objective.

2.5. Economic criterion

The economic aspect is fundamental in the evaluation of all irrigation systems and has a decisive role in the process of ranking the systems. Economic information can be divided into two categories: concerning the irrigation system and concerning the area occupied by a given IS.

The economic parameters, which refer to the respective area, are necessary for determining the relative economic benefits of R&M. These include interest rate (real and nominal), inflation costs for the value of electricity, the core inflation rate, equipment rental fees, water price, land cost (for new systems) and irrigation returns for each crop [18].

The system-dependent parameters or those concerning the irrigation system are determined separately for each system. These include: the cost of the elements of the system (e.g.: pipelines, canals, significant dams, pumping stations, water intakes, etc.), the service life of individual equipment, labor costs, electricity costs and maintenance costs. Depending on the number of systems considered, subject to analysis and ranking, different economic features can be used to participate in the preliminary economic analysis. At further stages, after the design of the individual systems, a detailed economic analysis should be prepared for each system. The economic components of the MCA are listed below, and for the preliminary ranking process, it is not necessary to include all the sub-criteria, as detailed information on each individual system may be missing at the preliminary stages.

2.5.1. Specific investment cost for reconstruction and modernization

The specific investment costs for R&M of ISs, are defined as the total investment costs are divided into the constructed areas by systems and subsystems. The highest score is given to the type of irrigation systems with the lowest value of investment per hectare. The investment costs for irrigation systems vary from 259 euros/hectare to 30 000 euros/hectare, as most of the projects are between 500 – 3 500 euros/hectare (218 ISs). When evaluating the results, the highest result is given to the specific investment costs of 6 437 euros/hectare, which corresponds to the 90 % quintile of all calculated costs. All irrigation systems with a higher value of investment than the specified one, receive a coefficient of 0, corresponding to a low degree of efficiency, and the most efficient – 1.

2.5.2. Depreciation, operation and maintenance cost

The cost estimates for operation, maintenance refer to primary and secondary systems levels only. They are exclusive of O&M costs incurred at the level of internal networks. Consequently, they are only indicative of regional differences in operation and maintenance. They are intended to guide the prioritization and programming of investments. Cost estimates are given as a percentage of itemized system rehabilitation and modernization investment cost. The percentages used are according to WB Report [19].

2.5.3. Electricity expenses

It is accepted these costs to be included in the total cost of depreciation, operating and maintenance costs and their significance for the analysis has already been reported in two of the criteria. They do not participate as a stand-alone criterion, as some types of systems do not have significant electricity costs. They could be included in the MCA as part of the environmental criteria also.

2.5.4. Net present value

This criterion is widely used in investment projects. It compares the current investment with future cash flows. Expected revenues and the rate of return are included in the calculations. In the initial stage of the R&M process, it is very difficult to correctly calculate future revenues, so NPV does not participate in the current MCA. Capital Recovery Factor (CRF) also can be used instead.

2.5.5. Payback period

The payback period is the time required to recoup the initial investment or the time for which the system “pays off”. The R&M of ISs is aimed at increasing crop yields and mitigating

the effects of climate change, with water saving being a top priority. At this stage, it is too early to talk about a return of investments, as farmers describe irrigation services as too expensive, and to switch again from non-irrigated to irrigated agriculture, they must first have access to quality irrigation services. This criterion does not participate in the current MCA.

2.5.6. Potential additional farm income (incremental net revenue)

The assessment of this sub-criteria is made with agriculture statistics data, with priority given to irrigation systems with the greatest potential for increasing the income of agricultural holdings. The gross additional income from irrigated and non-irrigated agriculture is calculated by municipalities, and then by irrigation systems, in proportion to the irrigated area of each municipality falling within the system. The average additional net income from irrigated agriculture is 2 070 euros/hectare, and the maximum is 4 190 euros per hectare.

The criterion assumes values from 0 to 1, where 0 is the lowest and 1 is the highest.

2.5.7. Benefit/Cost ratio

The criterion includes data from potential income, similar to the methodology in the WB Report [1]. Priority is given to irrigation systems that have the highest degree of additional income to cost ratio (Benefit/Cost Ratio, B/C Ratio). Income is assumed to be generated gradually by farmers, and the corresponding operating and maintenance costs are estimated based on the following elements:

- Annual depreciation costs of complex and significant dams, other dams, water intakes and reservoirs, canals, pipelines and pumping stations in euros/year;
- Annual costs for the operation of complex and significant dams, other dams, water intakes and reservoirs, canals, pipelines and pumping stations in euros/year;
- Annual costs for maintenance of complex and significant dams, other dams, water intakes and reservoirs and maintenance of canals, pipelines and pumping stations in euros/year;
- Annual electricity costs (type *P* and *S* systems), calculated for irrigation rates for average years and data on the pumps in the specific system, in euros/year.

Annual costs are calculated as a percentage of the detailed (by items) investment costs for the R&M of irrigation systems. The B/C ratio varies considerably from 0,3 to 133. To avoid overestimation, the maximum one-point score is given for a value of 19, which corresponds to a security value of 90 %. The B/C ratio, with a score higher than 19, is scored with a value of 1, respectively. The B/C ratio is a generally accepted indicator of the economic efficiency of the system and is used in the present analysis to assess the “Economic Criterion”.

2.6. Environmental criterion

2.6.1. Water savings potential (Relative water savings)

Potential water savings is a key criterion, with the highest degree of significance. Priority is given to irrigation systems that offer the greatest potential for water savings. It represents the difference between existing water consumption and future water consumption. It is accepted to be calculated on the basis of the future efficiency of IS. More information can be found in WB Report, Annex 6 [19].

2.6.2. Ecological status of water bodies

The indicator used is the current ecological status of the surface water body from which irrigation water is abstracted. Map material with the condition of the surface water and

groundwater bodies is used. Highest coefficient of 1,0 is given to systems and subsystems which are supplied by water body in “very good” condition.

2.6.3. Land use

This criterion would have weight in the construction of new irrigated areas. In practice, it is included in almost all analysis concerning infrastructure projects. It is known as “Land Use” and is used for Land Use/Land Cover (LULC) analysis. In the current MCA, it is assumed that R&M affects only constructed areas, therefore this criterion is excluded from the analysis. A possible problem would arise from the change of land use, but it would be local and would not affect the analysis of all the ISs.

2.6.4. Requirements for water reuse

According to the new Directive of EU – REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 May 2020 [17] on minimum requirements for water reuse, The Union’s ability to respond to the increasing pressures on water resources could be improved by wider reuse of treated wastewater, limiting extraction from surface water bodies and groundwater bodies, reducing the impact of the discharge of treated wastewater into water bodies, and promoting water savings through multiple uses for urban wastewater, while ensuring a high level of environmental protection. This requirement should be included as a criterion in future analyses. This study is made before the resolution of the Directive and this criterion is not included in the present MCA.

2.7. Social criterion

2.7.1. Priority within the NRDP 2014-20

Priority is given to projects, which are in those municipalities, which enjoy preferential support under Sub-measure M4.1. “Investments in agriculture holdings” of the RDP 2014-20. Nowadays, this criterion is out of date, so it is not included in the MCA.

2.7.2. Social acceptability

Social perception considers the attitude of people to R&M of ISs. A social study must be conducted regarding the possible implementation of the R&M process. Social perception is a qualitative criterion. This criterion is controversial because even if farmers state that they do not want to pay for the irrigation service, due to expected climate change, there is a possibility that non-irrigated agriculture (for certain crops) to become impossible. In addition, the policy of reducing water usage is absolutely mandatory for the conditions of raising the air temperature. The criterion is not used in the current MCA but can be included if needed.

2.7.3. Job creation

The R&M process creates jobs during the entire period of construction and operation of the systems, e.g., project designers, builders and operators of facilities, employees in government agencies, and employees for measuring water levels. Jobs are changing as the level of automation of the system and government policy in the sector are also changing. At this stage, this sub-criterion cannot be assessed quantitatively or qualitatively.

2.7.4. Social benefits

In the past, social benefits were important criteria for determining people's living standards, especially in regions with low economic development. This criterion can be included

by reading the jobs created and additional income for irrigation farmers, which is very difficult to quantify, as the probability of improved life quality must be calculated by the factor “access to irrigation service”. Its influence on the MCA can be ignored.

Social criterion is excluded as for the present research no sufficient data is available.

2.8. Planning the research experiment

The main criteria are considered in five variants *A, B, C, D* and *E*, each variant is giving an advantage to each individual criterion (Table 5). There is also a variant in which all criteria have the same weight – Scenario *D*. For the technical criterion, four variants are considered – *1, 2, 3* and *4*, as variant 1 assumes equal weights for all attributes. Option 2 is analogous, but the “Reliability” attribute assumes twice the weight as it is considered subjective. In Option 3, preference is given to the size of the IS and its current efficiency, as of all the sub-criteria, they have a value that is not influenced by the assessor's judgment. The last Option 4 is analogous to the 3rd, but the difference in the severity of the individual features is lower. The values are selected by the evaluator from multiple combinations of weighting factors to achieve objectivity of the calculations. The ecological criteria are developed in two variants – *i* and *j*.

Table 5. Variants of criteria and sub-criteria weights [20]

Main Criteria	Weights in points					Relative weight within a group				
	Variants					Variants				
	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Technical	6	4	3	3	1	0,6	0,4	0,3	0,333	0,25
Economic	3	4	6	3	1	0,3	0,4	0,6	0,333	0,25
Environmental	1	2	1	3	2	0,1	0,2	0,1	0,333	0,5
Technical Sub-criteria	Variants				Variants					
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>		
E/C Area Ratio	1	2	2	2	0,167	0,182	0,100	0,125		
IS size	1	2	5	4	0,167	0,182	0,250	0,250		
WI Type	1	2	4	3	0,167	0,182	0,200	0,188		
Present IS Efficiency	1	2	5	4	0,167	0,182	0,250	0,250		
Automation opportunity	1	2	3	2	0,167	0,182	0,150	0,125		
Reliability	1	1	1	1	0,167	0,091	0,050	0,063		
Safety	0	0	0	0	0	0	0	0		
Economic Sub-criteria	Variants				Variants					
	<i>0</i>				<i>0</i>					
B/C ratio	1				1					
Ecological Sub-criteria	Variants		Variants							
	<i>i</i>	<i>j</i>	<i>i</i>	<i>j</i>						
RPWS	1	3	0,5	0,75						
Water body status (WBS)	1	1	0,5	0,25						

3. Results and discussion

3.1. Scenario-based MCA and results analysis

The values of sub-criteria and main criteria are estimated for each of 237 ISs in Bulgaria. It was found that several IS appear in the forefront in all 40 scenarios (e.g. Ihtiman IS).

A list of ranked systems is arranged in descending order, with the systems that are most often in the first place.

Average ranking result R in relative terms of the ISs which fell in top 30 of each scenario is used. The result R is calculated by the formula:

$$R_i = 1 - \frac{\sum_{j=1}^m Y_{ij}}{m.n}, \quad (3)$$

where Y_{ij} is the place in ranking of IS i , in scenario j ; m is the total number of scenarios ($m = 40$); n are the top places in each ranking ($n = 30$).

This list is compared with all forty scenarios and three of them are selected, in which the rankings of the systems coincide the most. These are the $B40i$, $B30j$ and $D40j$ scenarios. After analysis of $D40j$ and $B30j$, it was found that although they are similar, some systems (e.g.: “Rositsa IS”), which fell 21 times in the top 30 in the other scenarios. Scenarios $B40i$ and $B30j$ give advantage to Technical criterion and to its sub-criteria IS size, IS Efficiency and WI Type. Scenario $D40j$ does not tolerate neither of the main criteria, but again the mentioned three technical sub-criteria are weighted more, as well as the RPWS in the Environmental criterion [20].

The results from Scenario $B40i$ are shown in Table 6.

Table 6. Sample on MCA results of Scenario $B40i$ [20]:

	Irrigation Scheme	IS Type	Technical Criteria						Econ. criteria	Environmental criteria		Final Score
			E/C Area	IS size	WI Type	Present efficiency	Autom. opp.	Reliability	Norm. B/C Ratio	RPWS normal.	WBS	S
1	Ihtiman IS	<i>Gp</i>	1,00	0,50	1,00	0,61	0,50	0,75	1,00	1,00	0,60	0,84
2	Dobromirski IF	<i>Pp</i>	1,00	0,14	1,00	0,81	0,75	0,25	1,00	1,00	0,41	0,80
3	Karaysen IS	<i>C-P2c-S</i>	0,16	0,50	1,00	0,99	0,45	0,07	0,86	1,00	1,00	0,80
4	Petelovo IF	<i>Pp</i>	0,95	0,00	1,00	0,81	1,00	0,25	1,00	1,00	0,41	0,80
5	Bolyarovo IS	<i>C-Pc-P2c</i>	1,00	0,50	1,00	0,56	0,25	0,41	1,00	0,78	0,54	0,79
6	Peshtera IS	<i>C-Gc-Pc</i>	0,53	0,50	0,50	0,64	0,25	0,93	1,00	1,00	0,71	0,78
7	Yastreb IF	<i>Pp</i>	0,71	0,00	1,00	0,81	0,75	0,25	1,00	1,00	0,41	0,78
8	Gorskoslivovo IS	<i>Gc</i>	0,45	0,14	1,00	0,79	0,25	1,00	1,00	1,00	0,47	0,77
9	Vitska IS	<i>C-Gc-Pg-Pp</i>	0,72	1,00	1,00	0,79	0,25	0,58	0,77	1,00	0,47	0,77
10	Polyanovo IF	<i>Plp</i>	1,00	0,14	0,50	0,81	0,75	0,25	1,00	1,00	0,41	0,77

The funds allocated for R&M of ISs under Rural Development Programme 2014 – 2020 amount to 54 699 274 €. As evident by data in Table 7, these funds can be used for R&M of only 10 ISs out of 237 if R&M of the entire ISs are assumed.

The area affected by the investments is insignificant – only 48 959,8 ha will benefit from it, which is about 10 % of the currently equipped area of Bulgarian ISs.

It should be noted that there is only one significant IS – “Vitska IS”, which is considered as Very Large, according to [2]. Two of the ISs are of category Very small, and other three are classified as Small ISs.

Table 7. Analysis of Investments for the first ten ISs [20]

No	IS name	Constr. Area, ha	Total Investments, €	IS Type	Score MCA	Score GIS	Top 30	R
1	Ihtiman IS	3 901,3	7 553 522	Gp	0,84	0,84	40	0,96
2	Dobromirski IF	1 538,3	1 347 101	Pp	0,80	0,80	40	0,89
3	Karaysen IS	3 119,0	4 253 557	C-P2c-S	0,80	0,80	35	0,61
4	Petelovo IF	350,8	159 194	Pp	0,80	0,80	40	0,89
5	Bolyarovo IS	4 975,4	5 479 360	C-Pc-P2c	0,79	0,79	40	0,68
6	Peshtera IS	3 596,8	4 376 725	C-Gc-Pc	0,78	0,78	40	0,75
7	Yastreb IF	545,9	190 774	Pp	0,78	0,80	40	0,77
8	Gorsko slivovo IS.	1 180,8	544 567	Gc	0,77	0,76	40	0,76
9	Vitska IS	29 200,4	34 679 990	C-Gc-Pg-Pp	0,77	0,80	32	0,54
10	Polyanovo IF	1 097,0	534 348	Pp	0,77	0,79	40	0,69
Total Investments:		48 959,8	59 119 138	€				

3.2. GIS overlay analyses result

GIS overlay analysis was performed in parallel, implementing data by [2] and [21]. For this purpose, the same weights are used. The attributes first are added as vector files. The vector files are converted to raster files for each layer/attribute/sub-criterion. Performing MCDA consists of generating a new raster file using the tool “Raster Calculator” with the weights for each scenario from A to E. Overlay of all scenarios, is the final result of the MCA – figure 2. Irrigation systems are ranked as Bad, Satisfactory, Good, Very good, and Excellent.

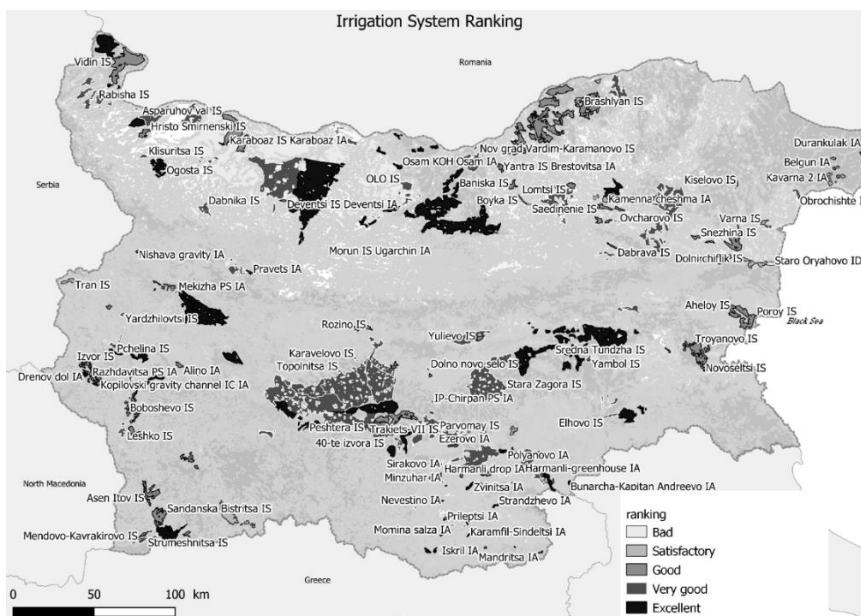


Figure 2. Map of ranked Irrigation Systems in Bulgaria

4. Conclusions

The prioritization of the investments for R&M of ISs is a substantial process at every stage of development of the different countries.

– The presented MCA approach might be used both in government and private sector assessments. It allows different analyses and calculations, especially implemented in GIS environment. The use of the simple weighted MCA method allows decision-makers with less experience to prepare the assessments.

– The inclusion of three criteria in the MCA – technical, economic and environmental, with sub-criteria, makes it possible to objectively assess all indicators of the irrigation systems in Bulgaria.

– MCA with only major criterion is sensible to the judgement of the decision-maker and are not recommended.

– Although different weights are given in the forty scenarios, “Ihtiman IS” always ranks first, which shows that the MCA method completely excludes the factor of subjectivity in evaluation.

– The GIS overlay analysis shows similar results to SAW MCA method.

– Small ISs (constructed area less than 2 500 ha) are ranked with high scores, despite the low weight, given to IS Size sub-criteria.

– This MCA approach allows for future analyses based on sub-systems.

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ЗНАЧИМОСТ НА ПОДКРИТЕРИИТЕ ПРИ МУЛТИКРИТЕРИАЛЕН АНАЛИЗ ЗА ПРИОРИТИЗИРАНЕ НА ИНВЕСТИЦИИТЕ ЗА РЕКОНСТРУКЦИЯ И МОДЕРНИЗАЦИЯ НА НАПОИТЕЛНАТА ИНФРАСТРУКТУРА В БЪЛГАРИЯ

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Ключови думи: ГИС, напоителна инфраструктура, напоителни системи, мултикритериален анализ, модернизация, реконструкция

РЕЗЮМЕ

Многокритериалният анализ (МКА) е подходящ инструмент за приоритизиране на инвестициите за реконструкция и модернизация (РиМ) на напоителната инфраструктура, като се вземат предвид различните аспекти на инвестициите. Средствата за РиМ, включени като подмярка на Програмата за развитие на селските райони 2014 – 2020 г., не бяха достатъчни за нуждите на всички 223 напоителни системи (НС) в страната и се появи проблемът за ефективно разпределение на средствата. МКА е подходящ за решаване на комплексни проблеми, включващи както количествени, така и качествени характеристики. Това изследване е обзор на подхода за избор на критериите за МКА. Предложени са четири основни критерия за МКА – технически, икономически, екологичен и социален, като всеки един от тях включва множество подкритерии. Изследването е фокусирано върху избора на критерии и важността на включването на подкритерии в МКА. Използва се прост тегловен метод за МКА, известен като SAW. Изследвани са четиридесет сценария с различни комбинации от тежестни коефициенти за основните критерии и техните подкритерии. Оценени са всички 223 НС в България и са анализирани първите 50 класирани НС. Паралелно е извършен анализ чрез географски информационни системи (ГИС) и резултатите от изследването са представени на карта.

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