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# IMPROVING DECISION MAKING IN DEFINING PRIORITIES FOR IMPLEMENTATION OF IRRIGATION PLANS USING AHP METHODOLOGY

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Subject review

The paper deals with the methodology of determining the priorities in implementing irrigation plans using multi-criteria analysis AHP (Analytic Hierarchy Process) methodology. The aims of this paper are: confirm the adequacy of using multi-criteria analysis approach and AHP method when determining priorities in fulfilling irrigation plans; present models for preparation of the input data for AHP method application; by analysing the use of AHP application on a specific case study, give suggestions for its application on priority determination in implementation of irrigation plans and for further research. The multi-criteria methodology is applied on the case study of the selection of the Primorsko-goranska County irrigation pilot location. The results of applying the AHP method are compared to the selection of the pilot location conducted in the adopted Irrigation plan of the Primorsko-goranska County and conclusions are given.

***Keywords**: AHP, decision making, irrigation plans, multi-criteria analysis, priority determination, selection*

**Unapređenje donošenja odluka u definiranju prioriteta realizacije planova navodnjavanja primjenom AHP metodologije**

Pregledni rad

U radu je prikazana metodologija definiranja prioriteta kod realizacije planova navodnjavanja primjenom metode višekriterijske analize AHP (Analytic Hierarchy Process). Ciljevi ovog rada su: potvrditi primjerenost korištenja višekriterijskog pristupa i AHP metode za definiranje prioriteta u realizaciji planova navodnjavanja, prikazati modele pripreme ulaznih podataka za primjenu AHP metodologije, analizom primjene AHP metode dati smjernice za njenu primjenu u definiranju prioriteta realizacije planova navodnjavanja, te za daljnja istraživanja. Primjena metodologije višekriterijske analize dana je na primjeru izbora lokacije pilot projekta navodnjavanja Primorsko-goranske županije. Rezultati primjene AHP metode uspoređeni su s rezultatima izbora pilot lokacije provedenog u Planu navodnjavanja Primorsko-goranske županije te su dani zaključci usporedbe.

***Ključne riječi**: AHP, donošenje odluka, izbor, definiranje prioriteta, planovi navodnjavanja, višekriterijska analiza*

## 1 Introduction

The complexity of decision making in water management planning process, is the result of multiple objectives that have to be satisfied, different criteria (economic, social and environmental) and different measures (quantitative and qualitative) that are used for objective fulfilment assessment, and also multiple stakeholders that are usually involved in the process [1, 2].

Also a large number of alternatives for solving water management problems make it often difficult to perform an objective analysis and selection of the optimal alternative with respect to a large number of, usually also different measure, criteria.

There are numerous procedures that give support to this kind of complex decision making problems, among which are multi-criteria decision analysis methods [3, 4, 5].

Multi-criteria decision analysis has been used for analyses of different types of water management problems [6, 7, 8, 9]. The multi-criteria decision analysis methods are used for ranking and selection of: water management strategies [10, 11] and projects [12], alternatives of irrigation [6, 13, 14, 15, 16] or water supply systems [17, 18], reservoir use alternatives [19], desalination procedures for drinking water production [20], waste water management alternatives [21] and waste water disposal locations [22], urban storm water drainage management alternatives [23], locations for hydropower plants and dams [24, 25], etc.

The water management problem of defining priorities in implementation of irrigation plans was one of the problems that was emphasised while irrigation plans for counties in Croatia were being prepared. A large number of alternatives and differently measured criteria made the process of selecting the pilot project on which to start the implementation of irrigation plans in counties very complex. This is the reason that authors decided to analyse the possibility of improving decision making in defining priorities for implementation of irrigation plans using multi-criteria methodology.

One of the recently used multi-criteria decision analyses method in water management is the multi-criteria decision analyses method AHP (Analytic Hierarchy Process) [6, 7, 16, 26]. AHP is widely used in irrigation planning and management: for evaluation of potential expansion for irrigated pasture [27], for selection of an appropriate irrigation method [28], for ranking suitable sites for irrigation with reclaimed water [29], for improvement of irrigation projects [30], for selecting irrigation water pricing alternatives [31], etc.

The adequacy of the AHP method for defining priorities in building civil engineers infrastructure facilities (in this case garage parking facility) has been confirmed by authors in [32] so the same method was selected to be applied on defining priorities in implementation of irrigation plans [33].

The stated will be presented in this paper on the case study of priority location selection for the irrigation pilot project in the Primorsko-goranska County.

As the starting point for applying the AHP method, the multi-criteria assessment of potential locations and the selection of the priority location by elimination, in the way which was applied in the Irrigation Plan of the Primorsko-goranska County, will be briefly presented. Then, the data for applying the AHP method are prepared. By applying the multi-criteria methodology and AHP

method the priorities are calculated and the selection of pilot project location is done.

Finally the comparison of results from the Irrigation Plan of the Primorsko-goranska County and from conducted prioritisation using AHP is done and conclusions are given.

The aims of this paper are: to confirm the adequacy of using multi-criteria analysis approach and AHP method when determining priorities in fulfilling irrigation plans; to present models for preparation of the input data for AHP method application by analysing its use on the case study and, finally, give suggestions for its application on priority determination in implementation of irrigation plans and for further research.

## 2 AHP method

There are numerous multiple-criteria decision making methods: dominant, maxmin, minmax, conjunctive method, disjunctive method, lexicographic method, elimination by aspects, permutation method, linear assignment method, simple additive weighting (SAW), hierarchical additive weighting, MAUT (Multi-Attribute Utility Theory), ELECTRE (ELimination and (Et) Choice Translating REality), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), LINMAP (Linear Programming Techniques for Multidimensional Analysis of Preference), PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations), AHP (Analytic Hierarchy Process) and other [6, 34, 35].

AHP is a priority method applicable to problems that can be represented by a hierarchical structure [36,37,38]. The top of the hierarchy is the goal, one level lower are criteria and there is the possibility of having more levels for sub-criteria. The lowest level is represented by alternatives that are alternative solutions for the defined problem.

AHP method is based on estimating relative priorities (weights) of criteria and alternatives on which pair-wise comparison matrix for criteria and pair-wise comparison matrices for alternatives (one matrix for each criterion) are generated. These matrices are formed by pair-wise comparison of alternatives regarding their importance with respect to each criterion and pair-wise comparison of criteria respect to the goal using a pair-wise comparison scale shown in Tab. 1.

**Table 1** The AHP pair-wise comparison scale [36]

| Intensity of weight, importance, preference | Definition |
|---|---|
| 1 | Equal importance (no preference) |
| 3 | Moderate importance (moderate preference) |
| 5 | Strong importance (strong preference) |
| 7 | Very strong importance (very strong preference) |
| 9 | Extreme importance (extreme preference) |
| 2, 4, 6, 8 | Intermediate values |

The columns in matrices are normalized in order to calculate the priority vector for criteria and the priority vectors for alternatives regarding each criterion. As a result, the overall priority matrix of alternatives is formed in the way that columns are priority vectors of alternatives for each criterion. Multiplying this matrix with the priority vector of criteria the overall priority vector of alternatives is calculated. The overall priority vector defines the priority (weight) of each alternative in respect to the goal so the ranking of alternatives can be made.

The advantage of this multi-criteria method is that it can be used when just the pair-wise comparison of alternatives according to each criterion and the pair-wise comparison of criteria towards the goal are known. Therefore this method enables the ranking of alternatives which are not exactly valued under each criterion separately, that is, if the importance of every single criterion is not exactly defined. It can be also used if there is a possibility to evaluate every alternative to each criterion and define criteria weights in relation to the goal.

In the case of pair-wise comparison of alternatives or criteria the consistency of pair-wise comparison matrices of alternatives, criteria and also of overall priority matrix is analysed by calculating the inconsistency index. The inconsistency index should be lower than 0,1 to assure that the judgments made are consistent. If the inconsistency index is higher than the re-evaluation of pair-wise comparison of alternatives and criteria is required.

For ranking alternatives using the multi-criteria method AHP the next steps have to be performed:

- Define the problem (the goal, the criteria, the alternatives),
- Define the hierarchy,
- Perform pair-wise comparison of alternatives in respect to each criterion/or evaluate each alternative in regard to each criterion,
- Perform pair-wise comparison of criteria in respect to the goal / or define the weight of each criterion,
- Apply the AHP method to estimate the overall priority vector of alternatives in respect to the goal,
- Form the rank-list of alternatives,
- Perform the sensitivity analysis,
- Make the final decision.

In this paper, the stated methodology will be examined on defining the priority for irrigation plans implementation by using the software EXPERT CHOICE 11.5 which has been developed based on the theoretical and mathematical principles of the AHP method [38].

## 3 Selection of irrigation pilot-project location conducted in the Irrigation plan of Primorsko-goranska County

Primorsko-goranska County in Croatia is relatively poor in agricultural resources [16, 33]. The area is characterized by division of small estates into several plots. The quality of the soil is also unfavourable as well as the attendance of plots and agricultural production. The population and the economy are less related to agriculture than in other parts of the country. However, the significance of agriculture in the County is extraordinary and unavoidable due to its influence on different segments of the region and the society. On several locations the agriculture can be the most significant income and employment source for the population, and can have the role of retaining the population in the country and prevent negative demographic migrations as well as further lithoralization of the area.

Potentially favourable irrigation areas were determined in the Irrigation plan of the Primorsko-goranska County by analyzing the potential agricultural areas at disposal (excluding ones that are in protected areas like areas for sanitary protection of water sources or national nature parks, etc.) and the possibility of irrigation introduction. Forty areas dispersely spread in the Primorsko-goranska County, which make potential locations for irrigating relatively small agricultural plots (between 9 and 3525 ha in size), were singled out (Fig. 1).

The conducted analysis of soil suitability for agriculture, the availability of water resources required for irrigation and the possibility of water supply, the farmland attendance grade, the existing planning and project documentation and the interest of the local population for irrigation introduction were the basic criteria for determining the complete adequacy for irrigation of a specific area in the Primorsko-goranska County. Meeting the criteria of natural resources (soil and water) as well as the possibility of blending into the present spatial planning documentation, was established by an expert assessment based on the created technical documentation.

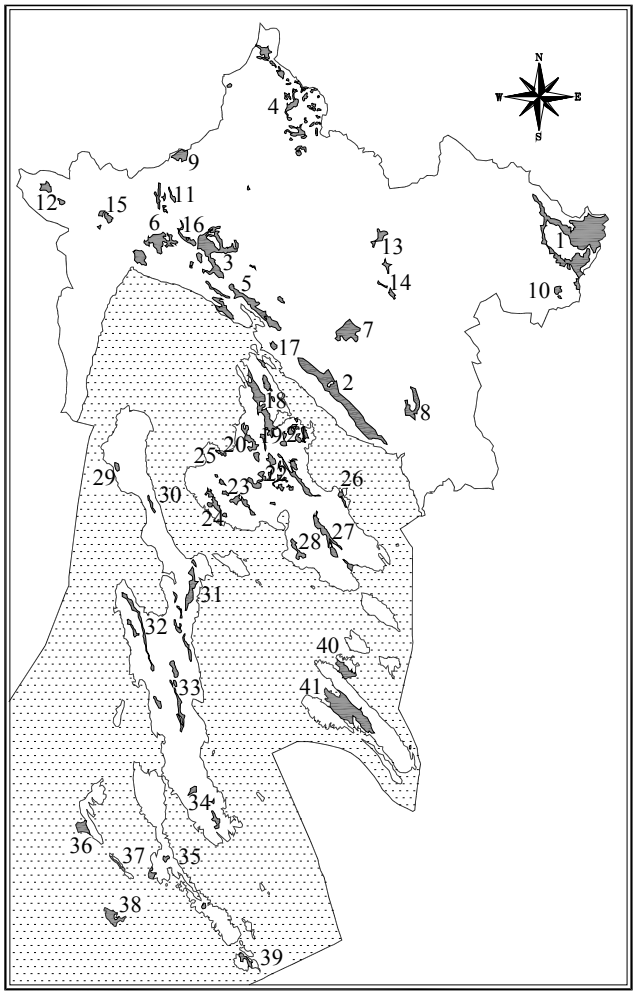


**Figure 1** Map of potential irrigation areas locations in the Primorsko-goranska County (marked in grey and numbered) [33]

The interest of local inhabitants for irrigation was established by interviewing the authorized persons in cities and municipalities of the County and included in analyses as a separated criterion.

The analysis of potential 40 locations was therefore conducted according to the following criteria (Tab. 2):

C1 - Class of soil suitability for agricultural use: the suitability was marked by: P1 – particularly valuable cultivable land (best), P2 – valuable cultivable land (worse), P3 – other cultivable land (worst),

C2 - Agricultural land area (expressed in ha), the larger the farmland, the more favourable the location with respect to the criterion,

C3 - Current way of using the land, since there are different ways the potential agriculture land is used today: the current use for agriculture (A) is favourable, use for agriculture and livestock farming (LF) or pasture (P) is less favourable and if the land is not used for agriculture the location is assest as the worst with respect to the criterion,

C4 - Avaliability of water resources and water management structures which could provide sufficient water amounts for irrigation (watercourses, ground water, existing wells, reservoirs, etc.),

C5 - Interest of local inhabitants for irrigation (no expressed interest, expressed interest, very expressed interest).

Based on the results of analyses conducted on all locations and under all the selected criteria nine locations were sorted out where irrigation should be introduced in the County (the locations under number 2, 7, 12, 14, 19, 22, 27, 36 and 40). On those locations smaller areas of land were singled out where the pilot project of irrigation could be implemented, the approximative costs for ensuring the required irrigation water quantities were defined and the existing and available planning and project documentation was analyzed (Tab. 3) together with defining the following criteria:

C2-P (instead of C2) - Agriculture land area for the pilot project (in ha),

C6 - Cost of ensuring the required irrigation water resources (in Croatian kunas per ha),

C7 - Existing documentation (studies, plans, projects) on potential water resources use on the analysed location.

**Table 3** The group of 9 potential locations for pilot project selection [33]

| No. | LOCATION | Area for the pilot project (ha) | Cost (mio kn/ha) | Existing documentation (projects, plans) |
|---|---|---|---|---|
| | | C2-P | C6 | C7 |
| 2 | VINODOL | 54 | 0,12 | large number |
| 7 | FUŽINE | 480 | 0,01 | some |
| 12 | MUNE- ŽEJANE - BRUSAN | 13 | 0,33 | hardly any available |
| 14 | MRKOPALJ | 63 | 0,10 | hardly any available |
| 19 | ČIŽIĆI | 62 | 0,12 | large number |
| 22 | KRAS- GARICA-VRBNIK | 200 | 0,10 | large number |
| 27 | DRAGA BAŠČANSKA | 418 | 0,04 | some |
| 36 | UNIJE | 229 | 0,01 | hardly any available |
| 40 | LOPAR – KAMPOR | 295 | 0,05 | some |

The pilot project selection within the Irrigation plan of the Primorsko-goranska County was quite a difficult task because a large number of potential locations (40) was considered and assessed under five criteria (C1 ÷ C5). The selection was conducted by gradually eliminating the less favourable solutions until the number of favourable locations was brought down to nine locations. Those nine locations are well distributed over the area of the Primorsko-goranska County. The nine selected locations were further analysed (under also C2-P, C6 and C7 criteria) and again, by eliminating the less favourable solutions, the final location of the pilot project was singled out, this being the location 2 – the Vinodol valley (Pavlomir).

**Table 2** Locations for possible irrigation in the Primorsko-goranska County with defined criteria analysis [16, 33]

| No. | NAME OF LOCATION (Belonging to…) | Suitability class | Area (ha) | Current use of land | Existing watercourses or water management structures | Interest of inhabitants |
|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 |
| 1 | SEVERIN (Town Vrbovsko) | P3 | 3525 | P | - | not expressed |
| 2 | VINODOL (Municipality Vinodolska) | P3 | 1126 | A | watercourse that dries up – mini reservoir | very expressed |
| | | P1 | 1059 | | | |
| 3 | JELENJE (Municipality Jelenje) | P3 | 1255 | A, P | - | not expressed |
| | | P1 | 153 | | | |
| 4 | ČABAR (Town Čabar) | P-3 | 1167 | A, P | watercourse that dries up – mini reservoir | not expressed |
| 5 | BAKAR (Town Bakar) | P3 | 1133 | A | - | expressed |
| 6 | SROKI (Municipality Viškovo) | P3 | 616 | A | - | not expressed |
| 7 | FUŽINE (Municipality Fužine) | P3 | 581 | A, P | multipurpose reservoir and lake | expressed |
| 8 | BATER (Town Novi Vinodolski) | P3 | 271 | P | - | not expressed |
| 9 | GOMANCE (Municipality Klana) | P3 | 260 | P | - | not expressed |
| 10 | GOMIRJE (Town Vrbovsko) | P3 | 99 | P, LF | watercourse that dries up | not expressed |
| 11 | KLANA (Municipality Klana) | P3 | 214 | A | watercourse that dries up | expressed |
| 12 | MUNE- ŽEJANE - BRUSAN (Municipality Matulji) | P3 | 200 | A | watercourse that dries up – mini reservoir | very expressed |
| 13 | DELNICE (Town Grad Delnice) | P3 | 167 | A | - | not expressed |
| 14 | MRKOPALJ (Municipality Mrkopalj) | P3 | 156 | A | - | expressed |
| 15 | VELI BRGUD (Municipality Matulji) | P3 | 154 | A | watercourse that dries up | not expressed |
| 16 | KUKULJANI (Municipality Jelenje) | P3 | 140 | A | watercourse that dries up | not expressed |
| 17 | MALI DOL (Town Kraljevica) | P3 | 63 | A | - | not expressed |
| 18 | OMIŠALJ (Municipality Omišalj) | P3 | 657 | A | - | not expressed |
| 19 | ČIŽIĆI (Municipalities Omišalj and Dobrinj) | P3 | 539 | A | lake Njivice | not expressed |
| 20 | MIHOLJICE (Municipalities Malinska Dubašnica and Dobrinj) | P3 | 326 | A | - | expressed |
| 21 | SVETI VID DOBRINJSKI (Municipality Dobrinj) | P3 | 338 | A, LF | - | not expressed |
| 22 | KRAS- GARICA-VRBNIK (Municipalities Dobrinj and Vrbnik and town Town Krk) | P3 | 758 | A | - | very expressed |
| | | P1 | 145 | | | |
| 23 | NENADIĆI-VRH (Town Krk) | P3 | 304 | A, LF | multipurpose reservoir Ponikve | expressed |
| 24 | ŠKRBČIĆI (Town Krk) | P3 | 230 | A, LF | - | expressed |
| 25 | PORAT (Municipality Malinska Dubašnica) | P3 | 49 | A, LF | - | expressed |
| 26 | SRŠĆICA (Municipality Baška) | P3 | 68 | LF | - | not expressed |
| 27 | DRAGA BAŠČANSKA (Municipality Baška) | P3 | 592 | A | - | very expressed |
| 28 | DOKOLOVO ( Municipality Punat) | P3 | 163 | A, LF | - | expressed |
| 29 | DRAGOZETIĆI (Town Cres) | P3 | 57 | LF | - | not expressed |
| 30 | PREDOŠĆICA (Town Cres) | P3 | 62 | LF | - | not expressed |
| 31 | DRAGARSKA-ORLEC (Town Cres) | P3 | 644 | LF | - | not expressed |
| 32 | PERNAT-BERTULČIĆI (Town Cres) | P3 | 358 | A, LF | lake Vrana | expressed |
| 33 | VRANA-BELEJ (Town Cres) | P3 | 486 | LF | lake Vrana | not expressed |
| 34 | OSOR-PUNTA KRIŽA (Town Mali Lošinj) | P3 | 245 | A, LF | - | expressed |
| 35 | LOŠINJ (Town Mali Lošinj) | P3 | 83 | A, LF | - | expressed |
| | | P2 | 82 | | | |
| 36 | UNIJE (Town Mali Lošinj) | P2 | 229 | A, LF | - | expressed |
| 37 | VELE SRAKANE (Town Mali Lošinj) | P3 | 36 | A, LF | - | not expressed |
| 38 | SUSAK (Town Mali Lošinj) | P2 | 134 | A | - | expressed |
| | | P3 | 217 | | | |
| 39 | ILOVIK (Town Mali Lošinj) | P3 | 127 | A, LF | - | not expressed |
| 40* | LOPAR - KAMPOR (Town Rab) *(in Figure 4 numbered as 40 and 41) | P3 | 1385 | A | - | expressed |
| | | P2 | 9 | | | |
| | | P1 | 620 | | | |

## 4 Ranking potential locations for irrigation using AHP methodology

### 4.1 Assessment of locations and selected criteria

Defining objectives, criteria and alternatives (e.g. locations) and the detailed analysis of locations under all defined criteria are presented in detail in the Irrigation plan of the Primorsko-goranska County [33] so only the final data from the Plan shown in Tab. 2 and Tab. 3 are used in this paper.

The aplication of AHP was done first on the set of forty (40) alternatives and then on the set of nine (9) alternatives previously selected in the Irrigation plan.

For the set of 40 alternatives a quantified assessment (explained by the authors in detail in [16]) of each alternative to each criterion was done based on data from Tab. 2 and the final results are shown in Tab. 4. The quantified assessment of each alternative to each criterion was done because it was very complex to make pair-wise comparision for such a large number of alternatives.

For the set of 9 alternatives a pair-wise comparision of alternatives regarding each criterion is done for this paper based on data from Tab. 2 and Tab. 3.

The goal for both sets of alternatives is to determine the priority in implementation of the Primorsko-goranska county irrigation plan, that is, select the location on which the first (pilot-project) irrigation system will be built.

**Table 4** Assessment of 40 locations with respect to selected criteria [16]

| CRITERIA | | C1 | | C2 | | C3 | C4 | C5 |
|---|---|---|---|---|---|---|---|---|
| No. | LOCATION | Location assessment | | | | | | |
| 1 | SEVERIN | 3 | | 3525 | | 1 | 0 | 0 |
| 2 | VINODOL | 3<br>1 | 2 | 1126<br>1059 | 2185 | 3 | 2 | 2 |
| 3 | JELENJE | 3<br>1 | 2,78 | 1255<br>153 | 1408 | 2 | 0 | 0 |
| 4 | ČABAR | 3 | | 1167 | | 2 | 2 | 0 |
| 5 | BAKAR | 3 | | 1133 | | 3 | 0 | 1 |
| 6 | SROKI | 3 | | 616 | | 3 | 0 | 0 |
| 7 | FUŽINE | 3 | | 581 | | 2 | 3 | 1 |
| 8 | BATER | 3 | | 271 | | 1 | 0 | 0 |
| 9 | GOMANCE | 3 | | 260 | | 1 | 0 | 0 |
| 10 | GOMIRJE | 3 | | 99 | | 1 | 1 | 0 |
| 11 | KLANA | 3 | | 214 | | 3 | 1 | 1 |
| 12 | MUNE- ŽEJANE - BRUSAN | 3 | | 200 | | 3 | 2 | 2 |
| 13 | DELNICE | 3 | | 167 | | 3 | 0 | 0 |
| 14 | MRKOPALJ | 3 | | 156 | | 3 | 0 | 1 |
| 15 | VELI BRGUD | 3 | | 154 | | 3 | 1 | 0 |
| 16 | KUKULJANI | 3 | | 140 | | 3 | 1 | 0 |
| 17 | MALI DOL | 3 | | 63 | | 3 | 0 | 0 |
| 18 | OMIŠALJ | 3 | | 657 | | 3 | 0 | 0 |
| 19 | ČIŽIĆI | 3 | | 539 | | 3 | 3 | 0 |
| 20 | MIHOLJICE | 3 | | 326 | | 3 | 0 | 1 |
| 21 | SVETI VID DOBRINJSKI | 3 | | 338 | | 2 | 0 | 0 |
| 22 | KRAS- GARICA-VRBNIK | 3<br>1 | 2,67 | 758<br>145 | 903 | 3 | 0 | 2 |
| 23 | NENADIĆI-VRH | 3 | | 304 | | 2 | 3 | 1 |
| 24 | ŠKRBČIĆI | 3 | | 230 | | 2 | 0 | 1 |
| 25 | PORAT | 3 | | 49 | | 2 | 0 | 1 |
| 26 | SRŠČICA | 3 | | 68 | | 1 | 0 | 0 |
| 27 | DRAGA BAŠČANSKA | 3 | | 592 | | 3 | 0 | 2 |
| 28 | DOKOLOVO | 3 | | 163 | | 2 | 0 | 1 |
| 29 | DRAGOZETIĆI | 3 | | 57 | | 1 | 0 | 0 |
| 30 | PREDOŠĆICA | 3 | | 62 | | 1 | 0 | 0 |
| 31 | DRAGARSKA-ORLEC | 3 | | 644 | | 1 | 0 | 0 |
| 32 | PERNAT-BERTULČIĆI | 3 | | 358 | | 2 | 3 | 1 |
| 33 | VRANA-BELEJ | 3 | | 486 | | 1 | 3 | 0 |
| 34 | OSOR-PUNTA KRIŽA | 3 | | 245 | | 2 | 0 | 1 |
| 35 | LOŠINJ | 3<br>2 | 2,5 | 83<br>82 | 165 | 2 | 0 | 1 |
| 36 | UNIJE | 2 | | 229 | | 2 | 0 | 1 |
| 37 | VELE SRAKANE | 3 | | 36 | | 2 | 0 | 0 |
| 38 | SUSAK | 2<br>3 | 2,62 | 134<br>217 | 351 | 3 | 0 | 1 |
| 39 | ILOVIK | 3 | | 127 | | 2 | 0 | 0 |
| 40 | LOPAR - KAMPOR | 3<br>2<br>1 | 2,38 | 1385<br>9<br>620 | 2014 | 3 | 0 | 1 |

The goal for both sets of alternatives is to determine the priority in implementation of the Primorsko-goranska county irrigation plan, that is, select the location on which the first (pilot-project) irrigation system will be built.

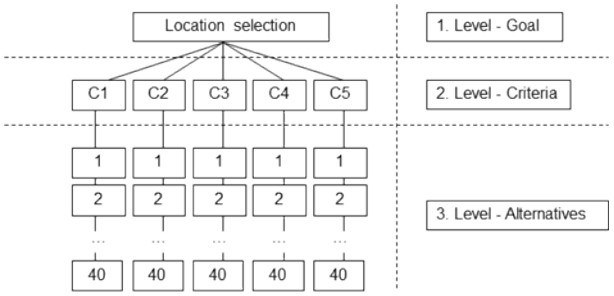


**Figure 2** The hierarchy and assessment of alternatives for the set of 40 locations

The next level of the hierarchy is rapresented by criteria C1 to C5 in the case of defining the priority list between 40 locations, and C1 to C7 in the case of defining the priority list between 9 locations from the narrowed set of locations selected in the Plan.

At the lowest level of the hierarchy there are the alternatives. Fig. 2 shows the hierarchy for the set of 40 locations and Fig. 3 for the set of nine locations.

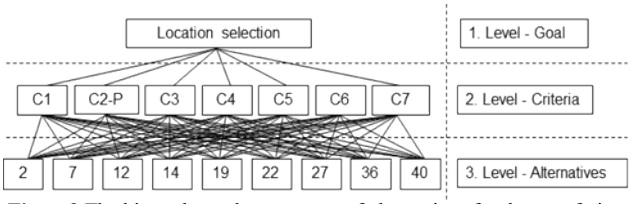


**Figure3** The hierarchy and assessment of alternatives for the set of nine locations

The pair-wise assessment of 9 alternatives with respect to each selected criterion is shown in Tab. 5.

The preference value written without brackets defines the alternative in that line to be better than the alternative in that column with respect to the selected criterion. If the

alternative preference is written in brackets, then the alternative in that line is worse than the alternative in the column.

**Table 5** Pair-wise comparison of alternatives from the set of 9 locations in relation to each criterion

| C1 (I=0,03) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
|---|---|---|---|---|---|---|---|---|---|
| 2 | | 9 | 9 | 9 | 9 | 4 | 9 | 1 | 6 |
| 7 | | | 1 | 1 | 1 | (4) | 1 | (9) | (6) |
| 12 | | | | 1 | 1 | (4) | 1 | (9) | (6) |
| 14 | | | | | 1 | (4) | 1 | (9) | (6) |
| 19 | | | | | | (4) | 1 | (9) | (6) |
| 22 | | | | | | | 7 | (4) | (2) |
| 27 | | | | | | | | (9) | (7) |
| 36 | | | | | | | | | 6 |
| 40 | | | | | | | | | |
| C2-P (I=0,09) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
| 2 | | (8) | 3 | 1 | 1 | (6) | (8) | (6) | (7) |
| 7 | | | 9 | 6 | 6 | 5 | 2 | 5 | 6 |
| 12 | | | | (3) | (3) | (7) | (9) | (7) | (8) |
| 14 | | | | | 1 | (6) | (8) | (6) | (7) |
| 19 | | | | | | (6) | (8) | (6) | (7) |
| 22 | | | | | | | (5) | (2) | (3) |
| 27 | | | | | | | | 6 | 5 |
| 36 | | | | | | | | | (2) |
| 40 | | | | | | | | | |
| C3 (I=0) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
| 2 | | 1 | 5 | 1 | 1 | 1 | 1 | 5 | 1 |
| 7 | | | (5) | (5) | (5) | (5) | (5) | 1 | (5) |
| 12 | | | | 1 | 1 | 1 | 1 | 5 | 1 |
| 14 | | | | | 1 | 1 | 1 | 5 | 1 |
| 19 | | | | | | 1 | 1 | 5 | 1 |
| 22 | | | | | | | 1 | 5 | 1 |
| 27 | | | | | | | | 5 | 1 |
| 36 | | | | | | | | | (5) |
| 40 | | | | | | | | | |
| C4 (I=0,02) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
| 2 | | (5) | 1 | 5 | (5) | 5 | 5 | 5 | 5 |
| 7 | | | 5 | 9 | 1 | 9 | 9 | 9 | 9 |
| 12 | | | | 5 | (5) | 5 | 5 | 5 | 5 |
| 14 | | | | | (9) | 1 | 1 | 1 | 1 |
| 19 | | | | | | 9 | 9 | 9 | 9 |
| 22 | | | | | | | 1 | 1 | 1 |
| 27 | | | | | | | | 1 | 1 |
| 36 | | | | | | | | | 1 |
| 40 | | | | | | | | | |
| C5 (I=0,02) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
| 2 | | 5 | 1 | 5 | 9 | 1 | 1 | 5 | 5 |
| 7 | | | (5) | 1 | 5 | (5) | (5) | 1 | 1 |
| 12 | | | | 5 | 9 | 1 | 1 | 5 | 5 |
| 14 | | | | | 5 | (5) | (5) | 1 | 1 |
| 19 | | | | | | (9) | (9) | (5) | (5) |
| 22 | | | | | | | 1 | 5 | 5 |
| 27 | | | | | | | | 5 | 5 |
| 36 | | | | | | | | | 1 |
| 40 | | | | | | | | | |
| C6 (I=0,04) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
| 2 | | (6) | 1 | (2) | 1 | (2) | (3) | (5) | (3) |
| 7 | | | 9 | 4 | 5 | 4 | 2 | 1 | 2 |
| 12 | | | | (5) | (4) | (5) | (8) | (9) | (8) |
| 14 | | | | | 2 | 1 | (3) | (5) | (3) |
| 19 | | | | | | (2) | (3) | (5) | (3) |
| 22 | | | | | | | (3) | (5) | (3) |
| 27 | | | | | | | | (3) | 2 |
| 36 | | | | | | | | | (2) |
| 40 | | | | | | | | | |
| C7 (I=0,03) | 2 | 7 | 12 | 14 | 19 | 22 | 24 | 36 | 40 |
| 2 | | 5 | 9 | 9 | 1 | 1 | 5 | 9 | 5 |
| 7 | | | 5 | 5 | (5) | (5) | 1 | 5 | 1 |
| 12 | | | | 1 | (9) | (9) | (5) | 1 | (5) |
| 14 | | | | | (9) | (9) | (5) | 1 | (5) |
| 19 | | | | | | 1 | 5 | 9 | 5 |
| 22 | | | | | | | 5 | 9 | 5 |
| 27 | | | | | | | | 5 | 1 |
| 36 | | | | | | | | | 5 |
| 40 | | | | | | | | | |

The most significant criteria are C1 and C5, followed by less important C3, C4 and in the restricted alternatives group also C6. The criteria C2 and C2-P are the least important. The importance of criterion C7 is varied, first it has the least importance ($^{1}$) and after it has the same importance as criteria C1 and C5 ($^{2}$).

The ranking of all potential locations (40) using AHP was conducted by applying the following group of criteria A: C1, C2, C3, C4 and C5.

The ranking of locations from the restricted group (9) using AHP was conducted by applying the following combinations (groups) of criteria:

B: C1, C2-P, C3, C4, C5;

C: C1, C2-P, C3, C4, C5, C6;

D: C1, C2-P, C3, C4, C5, C6, C7 (with varied importance);

E: C1, C3, C4, C5, C6, C7 (with varied importance).

Based on criteria importance a pair-wise comparision regarding the goal was done. As an example the pair-wise comparison of criteria with respect to the goal for the group of criteria B is shown in Tab. 6.

**Table 6** Pair-wise comparison of criteria with respect to the goal for the group B

| (I=0,01) | C1 | C2-P | C3 | C4 | C5 |
|---|---|---|---|---|---|
| C1 | | 5 | 3 | 3 | 1 |
| C2-P | | | (3) | (3) | (5) |
| C3 | | | | 1 | (3) |
| C4 | | | | | (3) |
| C5 | | | | | |

### 4.2 Results

The results of ranking locations by applying the AHP method, on the set of 40 locations and the narrowed set of 9 locations on data explained in 4.1, are presented in Tab. 7 and Tab. 8.

**Table 7** Results of ranking all locations by applying the AHP method on data from Tab. 4 and the group of criteria A [16]

| Rank | Location | Rank | Location | Rank | Location | Rank | Location |
|---|---|---|---|---|---|---|---|
| 1 | **2** | 11 | **19** | 21 | 25 | 31 | 1 |
| 2 | **12** | 12 | **36** | 22 | 28 | 32 | 37 |
| 3 | **22** | 13 | 5 | 23 | 34 | 33 | 39 |
| 4 | **27** | 14 | **14** | 24 | 6 | 34 | 10 |
| 5 | **40** | 15 | 20 | 25 | 18 | 35 | 31 |
| 6 | **7** | 16 | 35 | 26 | 33 | 36 | 8 |
| 7 | 23 | 17 | 4 | 27 | 13 | 37 | 9 |
| 8 | 32 | 18 | 15 | 28 | 17 | 38 | 26 |
| 9 | 11 | 19 | 16 | 29 | 3 | 39 | 29 |
| 10 | 38 | 20 | 24 | 30 | 21 | 40 | 30 |

By ranking the 40 potential locations it can be concluded that the locations selected in the Plan, locations 2, 12, 22, 27, 40 and 7 are ranked within the first 6 places.

The locations 19, 36 and 14 are ranked as the 11$^{th}$, 12$^{th}$ and 14$^{th}$. It can be concluded that all the 9 locations from the restricted group of the Irrigation plan of the Primorsko-goranska County are ranked within the first 14 places.

The ranking of locations from the restricted group of nine locations selects the location 2 as the most favourable one, the location 22 as the second most favourable and location 14 as the last favourable one. The results for the 3$^{rd}$ rank are uniform selecting the location 27 for all groups of criteria except for the group

of criteria C. The locations on ranks from 4th to 8th differ depending on the involved criteria and their importance.

**Table 8** Results of ranking the locations from the restricted group by applying the AHP method on data from Tab. 5 and groups of criteria B, C, D and E

| Rank | Ranking depending on the group of criteria selected | | | | | |
|---|---|---|---|---|---|---|
| | B | C | $D^1$ | $D^2$ | $E^1$ | $E^2$ |
| 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| 2 | 22 | 27 | 22 | 22 | 22 | 22 |
| 3 | 27 | 22 | 27 | 27 | 27 | 27 |
| 4 | 12 | 36 | 36 | 19 | 36 | 19 |
| 5 | 36 | 12 | 12 | 36 | 12 | 36 |
| 6 | 40 | 40 | 40 | 12 | 40 | 12 |
| 7 | 19 | 7 | 7 | 40 | 7 | 40 |
| 8 | 7 | 19 | 19 | 7 | 19 | 7 |
| 9 | 14 | 14 | 14 | 14 | 14 | 14 |

The use of performance sensitivity graph (shown in Fig. 5 for the restricted group of 9 locations and the group of criteria E) gives to the decision maker the possibility to analyse better the relations between alternatives and also in relation to criteria that led to a certain priority ranking.

Hence, the coordination of the selection conducted within the adopted Irrigation plan of the Primorsko-goranska County and the selection resulting from applying the AHP method can be confirmed.

## 5 Conclusion

The application of the AHP method for determining priorities in implementation of irrigation plans (in this paper tested on the case study of the Primorsko-goranska County irrigation plan) has shown different advantages.

The AHP method can be used, if only pair-wise comparisons of alternatives and/or criteria are available but also if there is a possibility to make the assessment for each alternative in regard to each criterion and each criterion to the goal.

It has been concluded in the paper that multi-criteria ranking method AHP can be applied both on a larger and a smaller number of alternatives.

For a larger number of alternatives it is simpler to make assessment for each alternative in regard to each criterion. For smaller sets of alternatives a pair-wise comparison of alternatives in regard to each criterion is more appropriate.

In comparison to the elimination procedure used in the Irrigation plan of the Primorsko-goranska County, where the selection of irrigation locations and determination of the priority location to be used as a pilot project was done without use of any multi-criteria decision analysis tool, the selected AHP method enables the ranking of alternatives taking into account all, or just selected, criteria at the same time.

By varying groups of different criteria and criteria importance and also using the performance sensitivity graph, the sensitivity of selection can be analysed.

The transparency of the decision process starting by alternatives assessment (exact or pair-wise) with respect to each criterion and definition of criteria importance assures the objectivity in decision making and improves the auditability of the decision.

The correspondence of results from the Irrigation plan of the Primorsko-goranska County and from the conducted analyses in this paper by AHP application confirms the adequacy of applying the selected AHP method for determining priorities in implementation of irrigation plans.

It must be stressed that the quality of the decision making process, regardless of the use of multi-criteria methods like AHP, depends primarily on the quality of the input data (definition of the problem - objectives, criteria and measures, definition of criteria importance, definition of alternatives, etc.). If the quality of input data is good the multi-criteria decision analysis method can be of significant help in the process of decision making assuring objectivity, transparency and auditability.

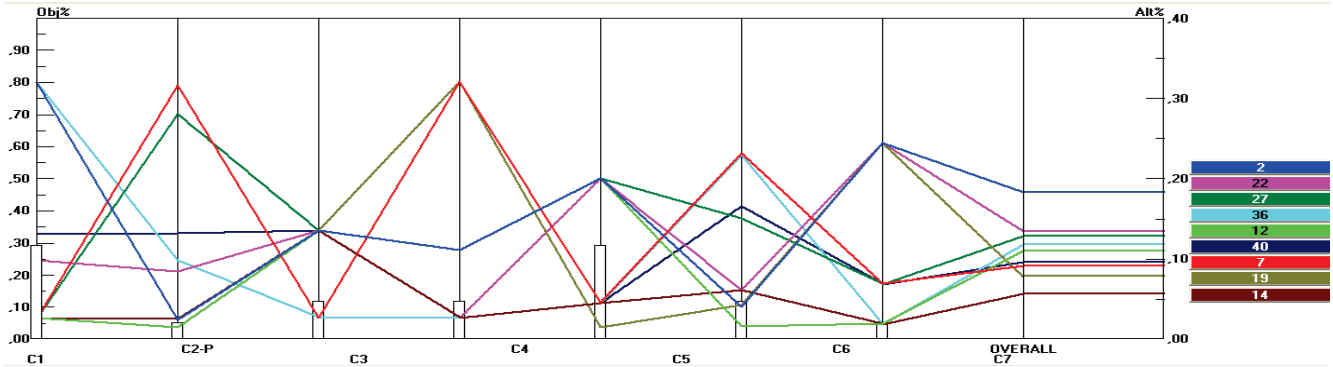


**Figure 4** Performance Sensitivity graph for ranking locations by applying the AHP method on restricted group of locations and the group criteria E (C7 - very important)

Further research should be directed into developing support tools that cover the whole process of priority determination in implementation of irrigation plans (starting from definition of the problem, goal, criteria and alternatives and especially in the input data preparation) in which multi-criteria decision analysis method AHP can be implemented. Also further research should be done in regarding the involvement and evaluation (qualitative) of uncertainities in the AHP method.

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