Group decision-making in land evaluation for irrigation: a case study from Serbia
Bosko Blagojevic, Zorica Srdjevic, Atila Bezdan and Bojan Srdjevic

ABSTRACT

Presented in this paper is a methodology for a spatially based multi-criteria evaluation of land suitability for irrigation (IR). A group of experts use the analytic hierarchy process (AHP) and the consensus convergence model (CCM) to define weights of factors relevant in validating areas of land as suitable for IR and to develop IR suitability maps in the geographic information system (GIS) environment. Then, using those maps, a group of policy-makers apply voting methods to identify districts with priorities for installing new IR systems. The presented methodology has several benefits. Group decision can aggregate the wisdom of the different domain experts involved in the process while effectively coping with the risk inherent in any decision problem. In CCM, cooperation among experts is rewarded and non-cooperation yields the risk of being excluded from the process or having very little impact on the group decision. The presented methodology is more precise than previously published methodologies, which is more helpful for policy-makers. Finally, sometimes experts’ opinions are not comprehensive enough to formulate an objective decision, as they are based on scientific facts whereas real-life decision-making is often based on economic or political factors. Owing to that, policy-makers are included in the presented methodology.

Key words | AHP, consensus, GIS, land suitability for irrigation, voting methods

INTRODUCTION

The autonomous Province of Vojvodina (Figure 1), situated in Northern Serbia, covers an area of 21,506 km² and is administratively divided into seven districts: Srem, West Backa, South Backa, North Backa, South Banat, Central Banat, and North Banat. The population in 2011 was ca. 1.9 million, according to the information given in the 2011 census. The autonomous Province of Vojvodina is the main agricultural region, 75% of which is arable land; however, out of the total province area (21,506 km²) only 3% is irrigated.

One of the strategic national development goals is to increase the amount of irrigated land especially in lowlands and alluviums of major rivers throughout the country. The government of Vojvodina Province plans to invest more than 11 million euros in irrigation (IR) systems and other water infrastructure (IN) over the next two years alone. In the near future, the development of IR systems will require much more governmental and international investments as well as appropriate loan lines. Due to the lack of funds to achieve this while preserving the balanced developments of all seven administrative units (districts) of the Province, it is necessary to establish a methodology which will provide a satisfactory basis for predicting the results of investments. To define priorities and staging phases in reconstructing existing and installing new IR systems, policy-makers, along with others, need to have reliable field data, legal documents, and trustful land suitability maps for irrigation (LSMI) with defined priority zones.

The main objective when starting any land evaluation effort is to clearly define factors to be used for land evaluation and what their respective weights should be. According to Purnell (1979), an evaluation is of the land,
not just the soil (SO), and all aspects of the environment need to be considered. The FAO (1985) proposed Guidelines for land evaluation for irrigated agriculture where 32 potential factors for land evaluation were presented (Table 1). 'The reader should use these Guidelines selectively, as not all the factors listed will be relevant in a given evaluation, but at a level that is consistent with achieving practicable recommendations' (FAO 1985). Other authors (Maletic & Hutchings 1967; Purnell 1979; Sys et al. 1991; Procedures 2004; Miljkovic 2005; Albaji et al. 2008; Ali 2010; Chen et al. 2010; Srdjevic et al. 2010; Belic et al. 2011; Anane et al. 2012; Tadic 2012; Rabia et al. 2013) proposed different factors for land evaluation for IR, but their description is not necessary for our work (because they are all related to specific locations). A commonality between all the above-mentioned papers is the agreement that factor suitability classes are defined as S1, S2, S3, N1, and N2, indicating, in terms of a single factor or a single interaction of a group of factors, whether the land is highly suited, moderately suited, marginally suited, marginally not suited, or permanently not suited, respectively.

Based on previous works and the available data, the group of agricultural and IR experts identified 16 factors (criteria) that play an important role in land evaluation for IR in Vojvodina, which are as follows: land slope (SL), soil drainage (DR), soil suitability for IR, geomorphology (GM), total available water in the root zone (AW), water deficit (WD), drought vulnerability (DV), soil fertility and production potential (FP), land use (LU), proximity to markets (PM), development of livestock (DL), distance from water bodies (DW), density of drainage network (DN), land consolidation (LC), surface water quality (SW), and sub-surface water quality (UW). The selected factors are not sufficient on their own to make a proper decision on where to build new IR systems, because policy-makers need spatial information on where the most suitable land is located. This can be easily analyzed by using a combination of the geographic information system (GIS) and multi-criteria decision methods (MCDM) (Anane et al. 2012). The purpose of GIS is to represent all factors as maps or raster layers with a set of geographically defined spatial units (e.g., cells) (Chen et al. 2010), while MCDM will be used for defining factors’ weights. Then, a (LSMI) will ultimately be developed by multiplying the cell values in each of the factors’ layers by the corresponding weights of the factors and then summarizing weighted cell values (using raster calculator in GIS software).

There are several MCDM that can be used in combination with GIS, but we decided to use the analytic...
hierarchy process (AHP) (Saaty 1980) as it is a widely used MCDM in the field of agriculture and water resources management (Pažek et al. 2006; Hajkowicz & Collins 2007; Karmakar et al. 2007; Srdjevic 2007; Srdjevic & Medeiros 2008; Srdjevic et al. 2012; García et al. 2014; Jaiswal et al. 2014) and is one of the most popular methods for obtaining the weights of factors in GIS-based spatial analysis (see, e.g., Carver 1991; Malczewski 1999, 2004; Marinoni 2004; Marinoni et al. 2009; Nekhaya et al. 2009; Chen et al. 2010; Srdjevic et al. 2010; Machiwal et al. 2011; Anane et al. 2012; Zelenovic-Vasiljevic et al. 2012; Akinci et al. 2013; Chowdary et al. 2013; Wang et al. 2014). Over 300 papers published between 2000 and 2009 reporting MCDM applications in the environmental (EN) field were identified through a series of queries in the Web of Science database. The percentage distribution of MCDM per application area is shown in Table 2. In terms of the total number of papers published, AHP dominates, being mentioned in 80% of spatial/GIS papers (Huang et al. 2011).

Most land evaluation problems are very complex and AHP is based on the subjective opinions of experts, the main weakness of the method. To counter this weakness, it is necessary that AHP decision-making processes take place in group settings. In such cases, it is appropriate to adopt formal methods for consensus building to ensure transparent and repeatable decisions (factor weights),

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Factors for land evaluation for irrigated agriculture (FAO 1985)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management requirements and limitations</td>
<td>14. Location; 15. Water application management requirements; 16. Pre-harvest farm management; 17. Harvest and post-harvest requirements; 18. Requirements for mechanization</td>
</tr>
<tr>
<td>Conservation and EN requirements</td>
<td>27. Long-term salinity, sodicity hazards; 28. Ground or surface water hazards; 29. Long-term erosion hazards; 30. EN hazards</td>
</tr>
<tr>
<td>Socio-economic requirements</td>
<td>31. Farmers’ attitudes to IR; 32. Others that are class-determining</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Percentage distribution of MCDM per application area (Huang et al. 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
<td>MAUT</td>
</tr>
<tr>
<td>Waste management</td>
<td>50%</td>
</tr>
<tr>
<td>Water management</td>
<td>19%</td>
</tr>
<tr>
<td>Air quality/emissions</td>
<td>0%</td>
</tr>
<tr>
<td>Energy</td>
<td>42%</td>
</tr>
<tr>
<td>Natural resources</td>
<td>50%</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>48%</td>
</tr>
<tr>
<td>Strategy</td>
<td>39%</td>
</tr>
<tr>
<td>Sustainable engineer.</td>
<td>64%</td>
</tr>
<tr>
<td>Remediation/restorat.</td>
<td>27%</td>
</tr>
<tr>
<td>Spatial/GIS</td>
<td>80%</td>
</tr>
<tr>
<td>EN impact</td>
<td>62%</td>
</tr>
</tbody>
</table>
which was not the case in previous combinations of GIS and AHP methods when used in land evaluation. In this paper, we use and demonstrate the utility of the consensus convergence model (CCM) (Regan et al. 2006) in aggregating weights of factors across groups of experts. In this way we developed LSMI based on the consensus of experts. Using those maps, policy-makers had a helpful and trustful foundation for defining final group priorities (rankings) of districts for IR development.

The motivation for presenting this methodology for land evaluation for IR is based on four key points:

- The main differences between previous cases of land evaluation for IR and our approach is the outcome of land evaluation processes. In previous cases, the outcome evaluates how suitable a plot of land is for IR with the following values: highly suitable, moderately suitable, marginally suitable, currently unsuitable, and permanently unsuitable. However, for our case study this approach is not precise enough. So in our case, the outcome needs to be an answer to the question: ‘What areas should have the highest priority for IR development?’

- We think that using a combination of GIS and AHP methods when relying on only one expert evaluating factor is problematic (this was the case in previous land evaluations for IR), because of the complexity of the decision-making problem and the necessity to include all interested participants in problem solving.

- Clearly, the commitment of the group of experts to the implementation of the outcomes depends upon the level of consensus achieved by the group (Pedrycz et al. 2011).

- Finally, we think that sometimes experts’ opinions are not comprehensive enough (expert opinions are usually based on scientific facts whereas real-life decision-making is often based on economic or political factors). Often policy-makers have some additional information (unknown to experts) and this is the reason why we also included a group of policy-makers in our methodology.

The structure of the paper is as follows. Methodology for land evaluation is the next section, followed by the obtained results. Then, the Discussion section deals with the uncertainty and the benefits of applying the presented methodology, followed by concluding remarks.

**METHODOLOGY**

To evaluate land suitability for IR in Vojvodina Province and to define priority areas (districts) for IR development, we applied the two-stage methodology presented in Figure 2. This consists of Stage A (Experts’ approach) and Stage B (Policy-makers’ approach). In Stage A experts selected factors for land evaluation and defined their weights using the AHP and CCM. These factors are then analyzed using GIS to develop LSMI, the ultimate outcome of this stage. Based on data from Stage A (LSMIs and suitability areas per districts) and their individual preferences (which include social, political, and other factors that cannot all be presented mathematically and scientifically), policy-makers in Stage B evaluate districts using Borda count and approval voting to define the final group priorities (rankings) of districts for IR development. The presented methodology (across both stages) has five steps which are described in the rest of this section.

**Step # 1: Experts use AHP**

The AHP method requires a well-structured problem represented as a hierarchy. The hierarchy of the decision problem is defined through discussion with three academic professors and one expert: DM1–professor of IR and drainage at the Faculty of Agriculture; DM2–professor of hydro-technical subjects at the Faculty of Technical Sciences; DM3–professor of land reclamation at the Faculty of Agriculture; and DM4–expert for water management at public water company (PWC) Vode Vojvodine. In Vojvodina Province there is only one university and one PWC. The university has two departments which deal with water management problems and we included the most eminent experts from them in our process.

Since Saaty (1998) claimed that it is very hard for the human brain to compare more than nine elements, and that even nine is too high, all identified factors were clustered into five major factor groups: SO, Climate (CL), Economy (EC), IN, and EN (Table 3).

In this specific case (Figure 3), at the top of the hierarchy is the goal; the next level contains the criteria (factor groups), while sub-criteria (factors) lie at the bottom of the hierarchy (due to lack of alternatives).
Then, each decision-maker (DM) verbally expressed their preferences among the set of factor groups and factors by employing pairwise comparisons of the hierarchy elements at a given hierarchy level in relation to the elements in the higher level by using Saaty's importance scale (Table 4). Value 1 corresponds to the case in which two elements contribute in the same way to the element in

Table 3 | Factors selected for land evaluation for IR

<table>
<thead>
<tr>
<th>Factor groups</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO</td>
<td>SL, DR, soil suitability for IR, GM, AW</td>
</tr>
<tr>
<td>CL</td>
<td>WD, DV</td>
</tr>
<tr>
<td>EC</td>
<td>FP, LU, PM, DL</td>
</tr>
<tr>
<td>IN</td>
<td>DW, DN, LC</td>
</tr>
<tr>
<td>EN</td>
<td>SW, UW</td>
</tr>
</tbody>
</table>

Figure 2 | Diagram of presented two-stage methodology for land evaluation for IR.

Figure 3 | Decision problem hierarchy.
the higher level. Value 9 corresponds to the case in which one of the two elements is significantly more important than the other. The results of the comparison are placed in comparison matrices. After all judgments are made, the local priorities (weights) of the hierarchy elements are calculated from related comparison matrices. This procedure of computing weights is usually called prioritization. It is important to mention that though there are different methods which can be used for prioritization (e.g., see overview in Srdjevic (2005)), Saaty (1980) proposed the principal eigenvector of comparison matrix $A$ as the desired priority vector $w$, which can be obtained by solving the linear system:

$$Aw = \lambda w, \quad e^T w = 1,$$  \hspace{1cm} (1)

where $\lambda$ is the principal eigenvalue of $A$.

The synthesis process, as the final stage of AHP, is performed by multiplying the local weights of factors at the bottom level with the corresponding weights of factor groups at the higher level (see illustrative example in Table 5). The output of the synthesis is the final individual weights of all 16 factors, which are used as the inputs to Step 2 in order to derive the consensus weights of factors.

The consistency of matrices is presented through the consistency ratio (CR), which is defined as the quotient between the consistency index (CI) and the random index (RI) as follows:

$$CR = CI / RI.$$  \hspace{1cm} (2)

The CI is determined using the following equation:

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1},$$  \hspace{1cm} (3)

where $n$ is the number of compared elements (dimension of the matrix) and $\lambda_{\text{max}}$ is the maximal eigenvalue.

The RI is obtained from Table 6, established by Oak Ridge National Laboratory, for a matrix with dimensions from 1 to 15 (Saaty 1980). If the CR is less than 0.1, inconsistency among DMs is at an acceptable level (Saaty 1980).

### Step # 2: Achieving consensus

After individual weights of factors are obtained in Step # 1, it is necessary to get the final group weights of all factors. There are several procedures that can be used in AHP for that purpose. Aggregation of individual judgments (AIJ) and the aggregation of individual priorities (AIP) are the two most used procedures (Forman & Peniwati 1998; Ishizaka & Labib 2011). For AIJ, the DMs use the weighted geometric mean procedure to aggregate individual judgment matrices to obtain a group judgment matrix. Then, the selected prioritization method is used to derive a group priority vector from the group matrix. For AIP, the individual priority vectors for DMs are derived from individual judgments.
judgment matrices using a selected prioritization method. Then, the group priority vector is obtained through use of the weighted arithmetic mean AIPs.

Group priorities can also be obtained in a third way by combining AHP with compatible ‘soft’ consensus models (Dong et al. 2010). The central idea here is to generate advice on how the DMs with the highest inconsistencies with the group decision should change their preferences in order to increase their group consistency. The main problem with the above consensus models is that they automatically modify DMs’ opinions to reach consensus, and sometimes DMs do not want to change their opinions even if he/she has the highest inconsistency with the group decision.

The fourth procedure for group aggregation is the CCM (Lehrer & Wagner 1981). This model requires DMs in the group to assess all other DMs and then assign a weight to each DM according to their degree of respect for or agreement with that DM’s expertise or views on the issue at hand. This approach is infeasible for a number of reasons. For example, DMs may feel reluctant to explicitly quantify degrees of respect for other DMs, or reveal their true weight of respect (weights of DMs), as it could lead to rifts and ill-feelings within the group (more examples are shown in Regan et al. (2006)). Thus, Regan et al. (2006) have adapted the original CCM to use a weight of respect (weights of DMs) based on the strength of the difference in the factor (or criteria/sub-criteria) weights assigned by all DMs. In this model, by repeatable mathematical procedure and through mutual respect the DMs not only achieve consensus on the issue under consideration but also agree on the overall relative weight of each DM (Srdjevic et al. 2013).

Also, in AHP group decision-making there are many other preference aggregation procedures worthy of further exploration. For example, Madani & Lund (2011) used the probability distribution to describe the DMs’ preferences and integrated Monte Carlo simulation into AHP to inform the DMs’ of the effects of the existing uncertainty on the results.

As we mentioned, it is clear that the commitment of the group of experts to the implementation of the final weights of factors depends upon the level of consensus achieved by the group. This is the reason why we decided to use the CCM instead of AIJ, AIP, and other consensus models that automatically modify DMs’ opinions to reach consensus.

Below we go into more details about the mathematical model of CCM and its advantages.

### Mathematical model of CCM

The main use of the CCM (Regan et al. 2006) is to calculate the weights of respect \( (W^{(k)}) \) based on the strength of differences in weights assigned to factors by DMs (Srdjevic et al. 2013). In this model, \( w^{(k)}_{ij} \) indirectly describes the respect that DM \( i \) has for the opinion or expertise of DM \( j \) in the context of the \( k_{th} \) factor. If initial weights for the \( k_{th} \) factor of \( m \) DMs are \( p^{(k)} = (p_1^0, p_2^0, \ldots, p_m^0)^T \), then:

\[
w^{(k)}_{ij} = \frac{1 - |p_i^0 - p_j^0|}{\sum_{j=1}^{m} 1 - |p_i^0 - p_j^0|},
\]

where \( i \) refers to the DM who is assigning the weights and \( j \) refers to the DM being assigned a weight. The weights of respect for the \( k_{th} \) factor are used to create matrix \( W^{(k)} \) with dimensions \( m \times m \). The consensual vector of \( k_{th} \) factor weights is obtained by the iterative equation:

\[
P_c^{(k)} = W^{(k)} P_{c-1}^{(k)}.
\]

The procedure is repeated until the values of the weights of the \( k_{th} \) factor in vectors \( P_c^{(k)} \) and \( P_{c-1}^{(k)} \) are equal within a tolerant error limit. This method is easy to implement and it does not require that all members of the group reach an agreement (which is common in group decision-making) (Regan et al. 2006). Readers are referred to Lehrer & Wagner (1981) for full details and mathematical proofs of the CCM.

### Advantages of CCM

Advantages of CCM are presented in detail in Regan et al. (2006) and so we will only touch upon the two most important advantages:

(a) For AIJ and AIP, all DMs are treated as if they have equal weights which will not be the case in many
group decision-making scenarios. Also, it is possible to apply AIJ and AIP when DMs do not have equal weights. However, these methods (AIJ and AIP) require consensual weights of DMs, so the problem is merely shifted from providing weights of factors (or criteria/sub-criteria) to consensual weights of DMs. On the other hand, CCM has the advantage of placing weights on the differences in opinion behind the factor-weights assignments rather than on the individual assigning the weights. In this way chances for conflict among DMs are minimal.

(b) For AIJ and AIP, individual decisions are aggregated into group decision using a simple central tendency measure such as an arithmetic mean (for AIP) or geometric mean (for AIJ). Arithmetic and geometric means are inappropriate descriptors of data that are multi-modal or have extreme outliers (Regan et al. 2006), especially if someone who expresses extreme views is factored in along with everyone else in the group. The important question is what makes someone an outlier in a group. According to Regan et al. (2006), extreme views might be caused by three potential situations:

1. outliers know more than the other group members,
2. outliers know considerably less, or
3. outliers are deliberately misrepresenting their views to push the central tendency towards their own more moderate position.

CCM is able to penalize the second and third situations, while AIJ and AIP are not able to do the same. In CCM, cooperation is rewarded and non-cooperation yields the risk of being excluded from the process, or having very little impact on the group decision as a result of being assigned low respect weightings.

Step # 3: GIS analysis

After consensual weights of factors are obtained in the previous step of the methodology it is necessary to represent all factors as GIS raster layers. Since factors for land suitability for IR are of heterogeneous types (qualitative and/or quantitative), different forms (continuous or discrete), and different domains of measurement, it is crucial to standardize all factor layers by bringing them into a common domain of measurement (Anane et al. 2012). Therefore, different ratings (values) were assigned to each cell (in all 16 layers) on a scale from 1 (low priority for IR) to 5 (very high priority) according to experts’ experience and domestic and international references. Also, all layers need to be identically geo-referenced and with the same pixel resolution, which enables GIS overlay analysis. Then, we multiply the cell values in each of the factor layers by the corresponding final (consensual) weights of the factors and summarize weighted cell values using raster calculator in GIS software. In this way we developed the final LSMI in GIS environment. The purpose of this map is to help policy-makers in Step # 5 to identify districts where funds will be allocated for reconstructing existing, and installing new, IR systems.

Step # 4: Sensitivity analysis

In Step 4, sensitivity analysis is performed to check the influence of different factor groups on the result, the outcome of which is the generation of two more LSMIs. This is performed by changing the weights of the main factor groups according to the two following cases:

- Case 1. Only SO, CL, and EN factor groups will have influence on land suitability for IR, while Economic and IN resource factor groups will be excluded. This will enable policy-makers to recognize districts with the highest natural resource potential of land for IR (in Step # 5).
- Case 2. Only Economic and IN resource factor groups will have influence on land suitability for IR, while SO, CL, and EN factor groups will be excluded. In this way policy-makers in Step # 5 can find out what districts need minimum investments for IN and where transport costs will be lower (agricultural products to the markets, etc.).

Step # 5: Policy-makers use voting methods

With the completion of Step # 4 the experts are no longer involved in the decision-making process. It would probably benefit the process overall if experts are at the same time policy-makers, but in many countries this is not the case,
and often policy-makers are politicians. Also, sometimes the opinions of experts are not comprehensive enough, as they are usually based on scientific facts whereas real-life decision-making is often based on economic or political factors. In many cases, policy-makers do not want to use sophisticated multi-criteria methods and sometimes just want to approve some solution or eventually rank them with no specific explanation. The main reason for this attitude is that politicians sometimes make decisions on some criteria which are not public and transparent (because of lobbying, corruption, and individual political interests). For those kinds of group decision-making problems, preferential and non-preferential voting methods are commonly used, especially in cases of large groups. However, even in smaller groups, some of these methods produce trustful results (Srdjevic 2007). Here, Borda count preferential method and the approval voting non-preferential method are used.

In this step, based on LSMIs from Steps # 3 and # 4 (and corresponding information such as the suitability of areas per district) and their individual preferences (which include social, political, and other factors that cannot all be presented mathematically and scientifically), seven policy-makers evaluated seven districts in Vojvodina Province using the Borda count and approval voting method. In the Borda count, each district gets 1 point for each first-place vote received, 2 points for each next-to-first-place vote received, and so on. The district with the lowest total score is selected as the winner. Through the approval voting method, the policy-maker can vote for as many districts as they wish. Each approved district receives one vote and the district with the most votes wins. In this way policy-makers identified districts where funds will be allocated for reconstructing existing, and installing new, IR systems.

RESULTS

Step # 1 and # 2: Experts use AHP and achieve consensus

DMs gave their opinions on the importance of factor groups and factors by using AHP methodology. First, they compared five factor groups (Appendix, Table A1, available with the online version of this paper) and then compared the levels of importance of factors regarding all factor groups (Appendix, Tables A2–A6, available online), both in a pairwise manner. The individual weights of all factor groups, partial individual weights of factors and CR of all pairwise comparison matrices are given in the Appendix, Tables A1–A6.

The CR values of all comparisons were higher than 0.1 only in three cases: when DM3 compared economic resource factors (CR = 0.180; Appendix, Table A4) and when DM1 (CR = 0.221) and DM3 (CR = 0.117) compared IN factors (Appendix, Table A5), but they (DMs) stated that they had logical explanations concerning their inconsistencies and did not want to change their comparisons (evaluations). It was also incredibly important that the overall CR for all DMs was acceptable, being less than 0.1.

The weights of factors are calculated individually for each DM by multiplying corresponding weights of factor groups and local factor weights. For example, DM1’s factor weight for SL equals 0.449 \times 0.078 = 0.035 (weight of factor group Soil (SO) \times local weight of factor Land slope (SL)); these values are listed in the Appendix, Tables A1 and A2. The final individual weights of factors are presented in Table 7.

The four sets of individual factor weights (values for DM1–DM4 in Table 7) served as input in the CCM. Computed consensual weights of factors are shown in Figure 4.

Table 7: Individual weights of all factors

<table>
<thead>
<tr>
<th>Factor groups</th>
<th>Factors</th>
<th>DM1</th>
<th>DM2</th>
<th>DM3</th>
<th>DM4</th>
</tr>
</thead>
</table>
| SO
  | SL      | 0.035| 0.023| 0.010| 0.032|
  | DR      | 0.131| 0.093| 0.026| 0.032|
  | Soil suitability for IR | 0.161| 0.093| 0.119| 0.229|
  | GM      | 0.047| 0.084| 0.042| 0.118|
  | AW      | 0.076| 0.084| 0.119| 0.093|
| CL
  | WD      | 0.092| 0.029| 0.065| 0.026|
  | DV      | 0.184| 0.029| 0.013| 0.077|
| EC
  | FP      | 0.063| 0.032| 0.026| 0.057|
  | LU      | 0.017| 0.032| 0.083| 0.026|
  | PM      | 0.016| 0.011| 0.008| 0.010|
  | DL      | 0.008| 0.032| 0.014| 0.010|
| IN
  | DW      | 0.063| 0.085| 0.236| 0.029|
  | DN      | 0.017| 0.085| 0.068| 0.012|
  | LC      | 0.005| 0.085| 0.033| 0.005|
| EN
  | SW      | 0.043| 0.103| 0.118| 0.204|
  | UW      | 0.043| 0.103| 0.020| 0.041|
Step # 3: GIS analysis

After consensual weights of factors are obtained in the previous step of the methodology, all factors are then represented as GIS raster layers. As we mentioned in the Methodology section, all layers are standardized, by bringing them into a common domain of measurement. Therefore, different ratings (values) were assigned to each cell (in all 16 layers) on a scale from 1 (low priority for IR) to 5 (very high priority). Factor (GIS layers) standardization is listed below.

SO factors

SL influences runoff and DR as well as the erosion hazard to which the field is exposed. Moreover, farmland management and IR techniques depend on the SL. Values assigned to different classes of slope depending on their significance towards the suitability for IR are presented in the Appendix, Table A7 (available with the online version of this paper) and their spatial distributions are presented in Figure 5(a). DR is divided into five classes (according to Miljkovic (2005)). The classes are defined according to the risk of sufficient water (Appendix, Table A7; Figure 5(b)). Soil suitability for IR is divided into five classes (Miljkovic 2005). The classes are defined according to the degree of SO limitations (Appendix, Table A7; Figure 5(c)). SO limitations represent the ability to irrigate without deterioration of the SO over long periods of time. For GM, different ratings are assigned to six geomorphologic units (Appendix, Table A7; Figure 5(d)). AW was determined as a difference between the water content at field capacity and wilting point in the root zone. In Vojvodina, the topsoil depth varies from 0.1 to 1.5 m, the water content at field capacity ranges from 0.09 to 0.4 m$^3$m$^{-3}$, the water content at wilting point ranges from 0.03 to 0.27 m$^3$m$^{-3}$, and the range of total available water in the root zone ranges from 5 to 200 mm (Bezdan et al. 2012). Taking into account suitability for IR, AW is divided into five classes and ratings are assigned as shown in the Appendix, Table A7 and Figure 5(e).

CL factors

For the purpose of quantifying climatic influences on the suitability for IR development (priorities in sustainable IR implementation), different climatic indices can be selected. In order for the indices to be easily interpreted by an expert, we proposed two very basic indices:

WD (= potential evapotranspiration – precipitation) [mm]: The most common way of elaborating IR necessity is by analyzing the WD during the vegetation period. The WD here is calculated based on monthly precipitation data from nine principal meteorological stations in Vojvodina from 1971 to 2011 and potential evapotranspiration
(ETP) (Thornthwaite 1948). Ratings assigned to different WDs (Appendix, Table A8, available with the online version of this paper) and their spatial distributions based on IDW (inverse distance weighted) interpolation are presented in Figure 5(f).

DV: There are a number of drought indices. One of the most frequently used is the standardized precipitation index (SPI) (McKee et al. 1993) - the calculations of which only require precipitation data. Bezdan et al. (2012) used monthly precipitation data from nine principal meteorological stations in Vojvodina from 1971 to 2011 in order to calculate the SPI on a 3-month scale (SPI3) for each month. Authors also analyzed the stochastic behavior of drought in Vojvodina by applying the four state first-order homogeneous Markov chain model to the time series of SPI3. The DV map based on stochastic Markov chain modeling of SPI3 for Vojvodina is presented in Figure 5(g) (IDW interpolation). Value 1 represents the least vulnerable class while value 5 represents the most vulnerable class (and also the most suitable for IR).
**EC factors**

FP: According to Zivkovic et al. (1972) and Bezdan et al. (2012) FP is divided into four classes (Appendix, Table A9, available with the online version of this paper; Figure 5(h)). LU: LU map is derived from CORINE Land Cover 2006 database. The input map was reclassified into four classes regarding IR suitability (Appendix, Table A9; Figure 5(i)). PM: Based on city population, different values are assigned to each of the cities (Appendix, Table A9) and then spline interpolation is done (Figure 5(j)). DL: Using the number of livestock in districts and the equation for livestock units given in the last column of the Appendix, Table A10 (available with the online version of this paper) (equation is given by animal science experts from Faculty of Agriculture) different ratings are assigned to the districts (Figure 5(k)).

**IN factors**

DW: Four buffer zones are drawn around water bodies each at a distance of 2 km (Appendix, Table A11, available with the online version of this paper; Figure 5(l)). DN ranges from 0 to 73 m/ha and is divided into three classes (Appendix, Table A11; Figure 5(m)), which is important to note because in Vojvodina drainage canals could also be used for IR. LC is a planned readjustment and rearrangement of land parcels and their ownership. It is usually applied to form larger and more rational land holdings. LC can be used to improve the rural and INs. Here, 5 is assigned to areas where LC is done and 2 where it is not (Appendix, Table A11; Figure 5(n)).

**EN factors**

IR water quality has many classifications. Here we used the US Salinity Laboratory Classification (USSL), which is based on considerations of the hazards of salinization and the alkalinization of irrigated SOs (US Salinity Laboratory Staff 1954). In this classification, values of electrical conductivity are seen as an indicator of salt concentration (low salinity water – C1, medium salinity water – C2, high salinity water – C3, and very high salinity water – C4; Appendix, Table A12, available with the online version of this paper) while SAR values are seen as an indicator of the relative activity of water soluble Na in the absorption reactions with SO (low sodium water – S1, medium sodium water – S2, high sodium water – S3, and very high sodium water – S4; Appendix, Table A12).

SW: The evaluation of water quality for IR included major water bodies that are considered characteristic of Vojvodina, based on (compiled in the course of) official monitoring programs in the period 2004–2009. During the observed period, water samples were taken 6–24 times per year depending on the water sampling point in question. The sampling included 58 points, located in the aforementioned water bodies. Different values are assigned to different water quality classes (Appendix, Table A12) and then spline interpolation is done (Figure 5(o)). UW: The sampling included 24 points. The process is the same as in SW (Appendix, Table A12; Figure 5(p)).

Finally, standardized cell values in each of the factor layers are multiplied by the corresponding final (consensual) weights of the factors (presented in Figure 4) and summarized into the final LSMI (lower part of Figure 6), where 1 represents low priority for IR and 5 represents very high priority. To get a better visual insight into the differences between DMs, individually obtained factor weights of all DMs (presented in Table 7) are multiplied with the cell values of corresponding layers and aggregated into the individual LSMIs (upper part of Figure 6).

Areas containing the most suitable land (ratings 4 and 5 represent the two optimal suitability zones) are summed for each district and presented in Figure 7. As districts did not have the same sizes (or areas), suitability percentages per district are calculated to provide equal treatment and equal opportunities to all districts. South Backa district is first with 213,635 ha in the first two suitability zones, second is Srem district with 179,303 ha while North Banat is last with 82,936 ha. On the other hand, when we look at percentages, North Backa district has 72% of the total area in the first two suitability zones, Srem and South Backa are similar with 55 and 54%, and South Banat is last ranked with 35%.

**Step # 4: Sensitivity analysis**

Here, as we mentioned in the Methodology section, we developed LSMIs for two cases. The first case investigates the potential of natural resource factors of different districts for IR, while the second case finds out what districts need minimum investments for IN and where transport costs will be lower (Figure 8).
South Banat, South Backa, and North Backa are the districts with the highest natural resource potential for IR (Case 1) with 219,289 ha, 208,335 ha, and 162,117 ha in the first two suitability zones (Figure 9). However, North Backa is dominantly first ranked with 91% of the total area in the first two suitability zones. According to the economic-IN resource map (Case 2), the South Backa district is first ranked with 297,556 ha while the Srem district has the highest percentages of areas in the first two suitability zones, 79%.

**Step # 5: Policy-makers use voting methods**

Based on the information from Figures 6–9 and their own preferences, seven-policy makers (PM1 and PM2 from the Provincial Secretariat for Agriculture, Water Management and Forestry; PM3 and PM4 from PWC Vode Vojvodine and PM5-7 from the Ministry for Agriculture, Water Management and Forestry) evaluated seven districts using the Borda count voting method (Figure 10(a)). PM1, PM4, and PM6 identified the North Backa district, PM2 and PM5 the South Backa district, while PM3 and PM7 identified Srem as having the highest priority in IR development. Within the group context (final decision), when individual rankings were summarized the priority order was: (1) North Backa (district with 14 total points, Figure 10(a)); (2) and (3) South Backa and Srem (17 points); (4) Central Banat (30 points); (5) and (6) West Backa and North Banat (39 points); and (7) South Banat.
(40 points). Even though North Backa is not the district with the biggest areas within the first two suitability zones, it has the highest percentages of the sum of the first two suitability zones (for final and natural resource factor maps). Second ranked were the South Backa and Srem districts with an equal score. When approval voting was applied (Figure 10(b)), the North Backa district was ranked first (received votes from five policy-makers: PM1, PM3, PM4, PM6, and PM7) but now South Backa was second (four votes) while the Srem district was third (three votes). In this step, approval voting is used as a control mechanism for results obtained through the Borda count method. Using the Borda count approval voting method, we were able to determine the accuracy of the rankings for the first, second, and third ranked districts; the latter two of which obtained the same score after the Borda count method was implemented.

**DISCUSSION**

We compared the developed final LSMI (Figure 11(a)), where 1 represents low priority for IR and 5 represents very high priority, against the existing soil suitability map for IR (Miljkovic 2005), where 1 represents very severe SO limitation for sustained use under IR (see Appendix, Table A7) and 5 represents no limitation for sustained use under IR (which can be considered as highly suitable). As we mentioned before, SO limitations represent the ability to irrigate without deterioration of the SO over long periods of time. According to IR (Miljkovic 2005) in Vojvodina Province, 28% of total arable land is highly suitable, but the government of Vojvodina Province does not have enough funds to invest in all highly suitable land. On the other hand, we developed a final LSMI where 7.85% of total arable land does have very high priority for IR. This map can be more valuable to policy-makers than the
previous one, as the defined priority zones are more precise and allow for an optimization in investments.

Another important issue here is how to test the uncertainty of obtained LSMIs. To do that we need to include some quantitative information. We decided to analyze the compatibility of developed LSMIs against real-life data from the analyzed area. For that purpose we used a map of existing IR systems in Vojvodina Province (Figure 12).

Then, using this map (Figure 12) and the developed LSMIs (Figures 6 and 8), we calculated the total area (ha) and percentages of developed priority zones in lands under existing IR systems (Table 8). The obtained results were satisfactory. For the final LSMI (all factors are included, Figure 6) 68% of all land under IR systems were located in the two zones with the highest priority (the last row of Table 8). We found a similar outcome for the second LSMI (only natural resource factors are included, Figure 8, Case 1) where 62% of all land under IR systems was located in the two zones with the highest priority. The largest compatibility was within the third LSMI (only economic-IN resources factors).
are included, Figure 8, Case 2), where 82% of all land under IR systems was located in the two zones with the highest priority. These results lead to the conclusion that often economic factors had more influence on real-life decisions than other factors which are more important for experts. For example, in this case study we found the sum of all weights of economic–IN factors was only 0.288 (see Figure 4). This is why we think that sometimes experts’ opinions are not enough (expert opinions are usually based on scientific facts whereas real-life decision-making is often based on economic or political factors). This is the reason why we included Stage B (Policy-makers’ approach) in the presented methodology.

In our opinion, from the results of Step 5 the objective decision would be to rank South Backa as the district with the highest priority for IR development, because it has the largest area with a very high priority: 213,635 ha (Figure 7). However, policy-makers identified North Backa district as the first ranked district. Their explanation was that this district is less developed than South Backa district (for example, South Backa district is closer to Belgrade, the capital of Serbia; and Novi Sad, the biggest city of Vojvodina Province, is placed in this district). Also, they stated that PWC Vode Vojvodine is planning to invest funds in the

Table 8 | Total area (ha) and percentages of developed priority zones in lands under existing IR systems

<table>
<thead>
<tr>
<th>Priority zones</th>
<th>LSMI: final (all factors)</th>
<th>LSMI: natural resources factors</th>
<th>LSMI: economic–IN resource factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>778 ha (1%)</td>
<td>882 ha (1%)</td>
<td>62 ha (0.1%)</td>
</tr>
<tr>
<td>2</td>
<td>9,049 ha (12%)</td>
<td>15,311 ha (20%)</td>
<td>2,498 ha (3%)</td>
</tr>
<tr>
<td>3</td>
<td>14,383 ha (19%)</td>
<td>13,299 ha (18%)</td>
<td>10,985 ha (15%)</td>
</tr>
<tr>
<td>4</td>
<td>41,183 ha (55%)</td>
<td>34,383 ha (46%)</td>
<td>33,452 ha (44%)</td>
</tr>
<tr>
<td>5</td>
<td>9,920 ha (13%)</td>
<td>11,742 ha (16%)</td>
<td>28,317 ha (38%)</td>
</tr>
<tr>
<td>∑(4 + 5)</td>
<td>51,103 ha (68%)</td>
<td>46,1256 ha (62%)</td>
<td>61,769 ha (82%)</td>
</tr>
</tbody>
</table>
The presented methodology is more precise than those clearly, the commitment of the group to the implemen-
tation of the outcomes depends upon the level of consensus achieved by the group (Pedrycz et al. 2011). Due to this we decided to use CCM, where cooperation is rewarded and non-cooperation yields the risk of being excluded from the process or having very little impact on the group decision as a result of being assigned low weights to outliers (Regan et al. 2006). In this way the chance for consensus is higher. Consensual weights of factors obtained by CCM are the outcome of Step # 2.

- The presented methodology is more precise than those that have appeared in previous publications. In Step # 3, we developed a final LSMI where 7.85% of total arable land does have very high priority for IR, while in the existing map (Miljkovic 2005) 28% of total arable land is highly suitable. The developed map can be more valuable to policy-makers than the previous one, as the defined priority zones are more precise and allow for an optimization in investments (due to the lack of funds).

Finally, sometimes experts' opinions are not comprehen-
sive enough on their own to obtain an objective decision because they are based on scientific facts whereas real-life decision-making is often based on economic or political factors. This thesis was true in this case study, because experts gave weights of only 0.288 to economic-IN factors, and compatibility of land under existing IR systems was the largest (82%) within the LSMI developed in Step # 4 (where only economic-IN resource factors were included). On the other hand, they gave weights of 0.711 to natural resource factors, while compatibility within the LSMI (where only natural resource factors are included) was only 62%. The main reason for this is that often policy-makers have some additional information (unknown to experts), and this is the reason why we include them in Step # 5. After all, in many countries, policy-makers have the power to make decisions without taking into account the opinions of experts.

**CONCLUSION**

The primary objective of this paper was to establish a transferable and transparent procedure for group evaluations of land suitability for IR and selecting or ranking the district(s) to which funds for IR infrastructures should be assigned. For this purpose, this two-stage methodology was developed. In the first stage, the expertise of a few qualified individuals, with support of computerized decision-making tools (here AHP and CCM), was used to derive individual preferences of judged decision elements and then to come up to consensual group weights of 16 factors relevant in validating the land suitability for IR. Consensual weights were then used to develop an initial map of land suitability in the GIS environment. As a part of the sensitivity analysis, for which the weights of the main factor groups were changed iteratively, two more maps were developed showing land suitability regarding natural resource conditions and the existing and perspective economic-IN resources. Based on output information obtained during the first stage (three maps and corresponding data) and individual preferences of policy-makers (which include social, political, and other factors that cannot all be presented as maps because of...
data limitations), during the second stage a voting process was simulated in order to allow involved policy-makers to rank the districts. The preferential Borda count method was used first, and then the results were checked by the approval voting method which belongs to so-called non-preferential voting environments.

We see the advantages of not exclusively using the opinion of policy-makers in the proposed approach. This is important because individual judgments of policy-makers could be subject to/be the result of lobbying, corruption, and individual political interests. To preserve objectivity and limit the possibility of manipulation or abuse, we propose to organize and perform activities in the initial stage of decision-making process by consulting expert knowledge to generate a trustful database about land suitability for IR. This means that policy-makers will make decisions based on objectively derived information on land suitability for IR and because of this it is expected that they will not make contradictory decisions. While developing the offered approach, we were aware of the fact that the described decision problem may not be solely treated by using GIS-created land suitability maps (for IR) because there are factors that cannot be presented in a mathematically and scientifically justified way, such as: (1) the ability and/or willingness of districts’ authorities to provide financial support to projects towards the development of IR; (2) areas and/or regions from where a young population leaves due to a lack of opportunities (e.g., employment); (3) social structures within populations, etc. All of these problems are usually taken into account by policy-makers when they make decisions, and this usually cannot be easily recognized or contrasted (mainly because of data limitations). Therefore, policy-makers must have a certain degree of freedom and autonomy in exposing their preferences, and the proposed approach accounts for that.

Worthy of mention is that the results of the decision-making process were presented to both groups of participating individuals, i.e., experts and policy-makers. No significant complaints by experts were made about the consensual weights of important factors relevant in evaluating land suitability for IR. Rather, they agreed that the three GIS developed maps satisfactorily represent their individual land suitability for IR. Rather, they agreed that the three sensual weights of important factors relevant in evaluating significant individuals, i.e., experts and policy-makers. No complaints derived from the final decision.

Based on results obtained in the described case study example, we think that the proposed approach could be extended to other group spatial decision-making problems. In particular, the agenda for future research could be to undertake land suitability analysis and evaluation for smaller areas (e.g., municipalities) located in districts that are already recognized as having the highest suitability for IR. Local stakeholders should participate in defining a decision problem and a related hierarchy, then evaluate criteria and sub-criteria that correspond to the real-life local situation and proceed with the next steps (appropriately adjusted) of the described methodology.

ACKNOWLEDGEMENTS

This work was supported in part by the Ministry of Education, Science and Technological Development of Serbia under the grant 174003 (2011–2014) – Theory and application of AHP in multi-criteria decision making under conditions of risk and uncertainty (individual and group context).

REFERENCES


Miljkovic, N. 2005 Meliorative Pedology (Meliorativna pedologija). Faculty of Agriculture, Novi Sad, Serbia (in Serbian).


US Salinity Laboratory Staff 1954 Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook 60. US Government Printing Office, Washington, DC, USA.

First received 2 March 2015; accepted in revised form 14 September 2015. Available online 22 October 2015