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Spatial Evaluation of a Management Policy by Comparing Decision Maps

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Abstract: Spatial analysis has always been a valuable tool for strategic decision-making. However, Geographic Information Systems (GIS), the tools par excellence for representing and spatializing information, are not always, in their basic version, equipped for effective spatial assessment. Faced with a given spatially-referenced problem whose situation is materialized by an initial decisional map, a management policy is generally applied, resulting in a new final decisional map. How can the impact of this management policy be assessed? The aim of this work is to develop a mathematical and computer model for comparing decision maps in order to assess the impact of a management policy. To this end, a methodology based on a strategy of full integrating of Multiple Criteria Decision Making (MCDM) models for the comparison of decision maps in a Geographical Information System (GIS) is proposed and implemented. As decision maps are made up of spatial units, the proposed decision map comparison models are assumed to be independent of the location or geographical contiguity of these spatial units. However, the generic nature of the proposed integration strategy also makes it possible to integrate decision map comparison models into the GIS that take into account the location or geographical contiguity of spatial units. The effectiveness of the proposed model is illustrated through the case study of the evaluation of water resource management policy in Burkina Faso between 1992 and 2002. The results of the assessment showed, globally, a deterioration of water resources on the national territory between 1992 and 2002 with mainly a reduction in Forests (conserving water) in favor of agricultural land (consuming water). The GIS-MCDM integration model proposed for comparing decision maps could be applied in general to situations involving the spatial assessment of management policies (*e.g.*, policy to combat the proliferation of a given disease in an area, policy for managing degraded soils in an area).

Keywords: MCDM, GIS, Decision Map, Spatial Evaluation, Management Policy

1. Introduction

The spatial dimension present in problems such as land use planning, natural resource management and the organization of municipal and health services means that they can be described as problems with a spatial reference. To process them, decision-makers need tools capable of analysing and aggregating heterogeneous and conflicting information in order to facilitate decision-making. Geographic Information Systems (GIS) are tools par excellence for managing the spatial dimension but are limited when it comes to aggregate heterogeneous and conflicting data. However, Multiple Criteria Decision Making (MCDM) tools are capable of aggregating several heterogeneous and conflicting criteria. This is why we find in the literature the joint use of GIS and MCDM for the resolution of problems that have a spatial reference [1–4]. One of the results of the joint use of GIS and MCDM is the production of a decision map which will serve as a basis for a decision-making aid [3]. A decision map is a classic geographic map enriched with the decision maker's (DM) preferential information. Such a decision map may be the distribution of natural resources or the state of degradation of the resources of a given region [5]. Faced with a given problem with spatial reference whose situation is materialized by an initial decision map, a policy management is generally applied which gives rise to a new final decision map. How to evaluate the impact of this management policy? A start of answer to this question was made by Metchebon et al. [6, 7] with the proposal of mathematical models for comparing decision maps. However the question of their operationalization through a GIS had arisen. More recently, the possibilities of combining the powerful capabilities of machine learning with spatial analysis in a GIS have opened up innovative avenues for spatial assessment [8, 9]. But this machine-learning-based spatial analysis, in its current form, is not yet easy to implement in a GIS in the context of decision map comparison.

The objective of this work is to develop a mathematical and computer model, based on simple but efficient MCDM models, for comparing decision maps in order to evaluate the impact of a management policy. To do this, a methodology based on a tool integration strategy of Multiple Criteria Decision Making (MCDM) in an open source GIS will be designed and implemented. The rest of the paper is structured as follows. Section 2 presents some mathematical models for comparing decision maps [6]. Section 3 is dedicated to the integration and implementation strategy of these mathematical models for comparing decision maps in an open source GIS. In section 4, the efficiency of the comparison models integrated into GIS are illustrated in the comparison of decision maps for water resources management from 1992 to 2002 in Burkina Faso. From this comparison we deduce the spatial assessment of the impact of the water resources management policy between these two dates. Finally, we conclude our paper by putting forward perspectives for future work.

2. Some Models for Comparing Decision Maps

2.1. Formalization of the Decision Map Comparison Process

We consider a geographic map partitioned into spatial units labeled (identified) each by its spatial coordinates. Each spatial unit is associated with a characteristic vector including the measurement of its surface as well as its evaluations in relation to a set of criteria. The performances or evaluations of each spatial unit allow the assignment of said spatial unit to one of the predefined categories as defined below. We adopt the following notations in this work:

1. $\mathfrak{C} = \{C_1, C_2, ...C_n\}$ denotes the set of categories to which spatial units may belong. $\mathfrak{C}$ is ordered according to the preferences of the DM. Category C_i is better than category C_{i+1}. So the relation (1) holds, where the symbol $\succsim$ represents the preference relation between categories:
$$C_1 \succsim C_2 \succsim ... \succsim C_n. \quad (1)$$
2. n denotes the number of categories.
3. $\mathfrak{E}$ denotes the set of labels or spatial units

A decision map is an assignment of each spatial unit to a category. Formally, a decision map is defined as follows:

Definition 2.1. A decision map is any application A defined from the set of labels $\mathfrak{E}$ to the set of categories $\mathfrak{C}$ by:

$$A\colon \mathfrak{E} \to \mathfrak{C}$$
$$s \mapsto A(s).$$

In practice, s will denote a spatial unit and $A(s)$ the category to which it belongs. We denote by $\mathfrak{D}$ the set of decision maps. The objective is to create in $\mathfrak{D}$ a preference relation which represents the preferences of the DM. The symbols $\succsim$, $\succ$, $\sim$ will be used to represent broad preference, strict preference and indifference respectively between two decision maps.

Definition 2.2. We call distribution $x(A)$ into categories of a decision map $A \in \mathfrak{D}$ the vector $(x_1(A), ..., x_i(A), ..., x_n(A))$, where $x_i(A)$ denotes the proportion of spatial units of A assigned to the categorie C_i. Hence the relations (2) and (3):

$$0 \leq x_i(A) \leq 1, \quad (2)$$

$$\sum_{i=1}^{n} x_i(A) = 1. \quad (3)$$

If there is no ambiguity, a distribution $(x_1(A), ..., x_i(A), ..., x_n(A))$ will simply be denoted by $(x_1, ..., x_i, ..., x_n)$.

2.2. On Construction of Decision Maps

Obtaining a decision map means assigning spatial units to categories ordered according to their aptitude or suitability for a given phenomenon (resource degradation, disease prevalence, crime, etc.). The methods used to construct such decision maps generally belong to the field of operational research, and more specifically to that of multi-criteria decision making, where we have the so-called multi-criteria sorting methods (ELECTRE Tri [10], UTADIS [11]). Multi-criteria sorting methods are used to assign alternatives to ordered categories by optimizing several criteria. When only one criterion is taken into account and the assignment categories are not ordered, the problem to which this situation refers in operational research is called the assignment problem [12].

2.3. Comparison Independent of Geographic Location

In this context, comparing two decision maps amounts to comparing the category distributions of these two maps without taking into account the geographical location of the spatial units. In this paper, we work under the hypothesis that the methods for comparing decision maps are independent of the geographical location. Two maps A and B having the same distribution of space units in each category will be considered indifferent. Under the previous hypothesis we formalize the following axiom:

Axiom 2.1. The preference relation on the set $\mathfrak{D}$ only depends on the distributions, *i.e.*,

$$\forall A, B \in \mathfrak{D}, x(A) = x(B) \Leftrightarrow A \sim B.$$

Remark 2.1. In what follows, a decision map A can be designated indifferently by its distribution $x(A) = (x_1(A), ..., x_i(A), ..., x_n(A))$.

2.4. Models for Comparing Distributions

These models can be used to compare two vectors in the presence of a preference order [6]. In This section we will present five simple but practically useful methods namely direct and inverse lexicographic order, stochastic dominance, weighted sum and a particular utility model in threshold k ($k \in \mathbb{N}$).

2.4.1. Lexicographic Order

Definition 2.3. A distribution $x = (x_1, ..., x_i, ..., x_n)$ respects the lexicographic order if the proportions of geographical units belonging to the categories satisfy the following preference order:

$$x_1 \geq x_2 \geq ....x_{n-1} \geq x_n. \tag{4}$$

Definition 2.4. Let $x = (x_1, x_2, ..., x_n)$ and $y = (y_1, y_2, ..., y_n) \in \mathfrak{D}$, we say that x is preferred to y by lexicographic direct order, denoted by xD_Ly if $\exists\, i \in \{1, ..., n\}$ such that:

$$x_1 = y_1, ..., x_{i-1} = y_{i-1}, x_i > y_i. \tag{5}$$

Interpretation: the best categories are considered first. The aim is to have a maximum number of spatial units in these categories.

Definition 2.5. Let $x = (x_1, x_2, ..., x_n)$ and $y = (y_1, y_2, ..., y_n) \in \mathfrak{D}$, x is preferred to y by lexicographic inverse order. Denoted $xD_{Li}y$ if $\exists\, j \in \{1, ..., n\}$ such that:

$$x_j < y_j, x_{j+1} = y_{j+1}, ..., x_n = y_n. \tag{6}$$

Interpretation: The worst categories are examined first. The aim is to minimise the areas in these categories.

2.4.2. Stochastic Dominance

The Stochastic dominance, denoted D_s, is an order relation between two probability distributions. A distribution X is preferred to a distribution Y in the sense of stochastic dominance if the cumulative distribution function of X is always greater than or equal to the cumulative distribution function of Y.

Definition 2.6. Let $x = (x_1, x_2, ..., x_n)$ and $y = (y_1, y_2, ..., y_n) \in \mathfrak{D}$. We say that x stochastically dominates y, denoted xD_sy, if and only if the following condition (7) are satisfied:

$$\forall j \in \{1, 2, \ldots, n\}, X_j \geq Y_j \text{ with } X_j = \sum_{k=1}^{j} x_k \text{ and } Y_j = \sum_{k=1}^{j} y_k, \exists i \in \{1, 2, ..., n\}, X_i > Y_i. \tag{7}$$

Here the elements of the vectors x and y are considered as random variables.

Interpretation: All categories are taken into account. To be preferred, you must be cumulatively at least as good in all categories and strictly good in at least one cumulative frequency.

2.4.3. The Weighted Sum

Definition 2.7. A preference relation $\succsim^0$ can be represented by a weighted sum if: $\exists\ w_1, ..., w_n \in \mathbb{R}^+$ and $\forall\ x = (x_1, x_2, ..., x_n),\quad y = (y_1, y_2, ..., y_n) \in \mathfrak{D}$,

$$x \succsim^0 y \quad if \quad \sum_{i=1}^{n} x_i w_i \geq \sum_{i=1}^{n} y_i w_i, \tag{8}$$

under constraints

$$\sum_{i=1}^{n} w_i = 1 \quad and \quad w_1 \geq ... \geq w_n. \tag{9}$$

Interpretation: The decision-maker must express his/her preferences on each category C_i in the form of weights w_i. The preference depends on the value of the weighted sum.

2.4.4. Particular Utility Model in Threshold $k (k \in \mathbb{N})$

Definition 2.8. Let $x \in \mathfrak{D}$ and $k \in \{1, ..., n\}$. We define the polynomials M_k as:

$$\text{If} \quad k \neq n-1, n \quad M_k(x) = \sum_{j=1}^{k} \sum_{i=1}^{j} x_i + \sum_{j=k+1}^{n} (1 - \sum_{i=j}^{n} x_i), \tag{10}$$

$$M_k(x) = \sum_{j=1}^{k}\sum_{i=1}^{j} x_i + \sum_{j=k+1}^{n}\sum_{i=1}^{j-1} x_i. \quad (11)$$

$$\text{If} \quad k = n-1, \quad M_{n-1}(x) = \sum_{j=1}^{n-1}\sum_{i=1}^{j} x_i. \quad (12)$$

$$\text{If} \quad k = n, \quad M_n(x) = \sum_{j=1}^{n}\sum_{i=1}^{j} x_i. \quad (13)$$

$$Let \quad x, y \in \mathfrak{D}, \quad x \succsim y \quad if \quad M_k(x) \geq M_k(y). \quad (14)$$

Interpretation: The decision-maker must define a threshold $k, k \leq n$ of good and useful categories. The preference test is a function of these k categories as defined in relations (10), (12), (13).

In the next section, these models will be implemented and integrated into the GIS in the form of extension modules (plugins).

3. Methodology

3.1. Integration Strategy

In this work we have chosen the strategy of fully integrating [13] MCDM models into a GIS. These decision map comparison models will appear to the user as any other GIS functionality. The Figure 1 shows the three stages involved in integrating comparison models into a GIS.

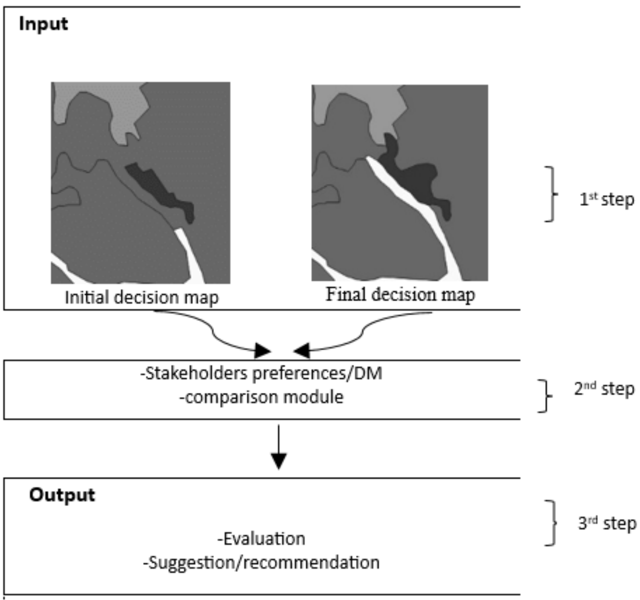

Figure 1. *Integration strategy.*

3.1.1. Step 1: Supplying and Importing Decision Maps

The analyst can help the DM design the two decision map into the GIS. One of the decision maps represents the initial state of a spatially-referenced problem. The application of a management policy gives rise to another decision map, called the final decision map. It is possible that the task of constructing the decision maps will fall to the expert in MCDM analysis.

3.1.2. Step 2: Modelling of DM Preferences and Definition of Comparison Model Parameters

The analyst defines how each comparison model works and specifies the parameters associated with each, taking into account the decision-maker's preferences.

3.1.3. Step 3: Reporting the Results

Once step 2 has been validated, we obtain the results of the spatial evaluation, *i.e.*, the comparison of the two decision maps. From these results, suggestions or recommendations will be made to the decision-maker. In this stage, the decision-maker examines and validates the results obtained from the models integrated into the GIS. This validation by the decision-maker ensures that the models meet his/her needs and expectations.

3.2. Choice of an Open Source GIS

In this work we opted to work with an open source GIS to have the freedom to use the software without restriction and also to be able to share our experience with the large and growing community of open source GIS software users. Another criterion that prevailed in the choice of a GIS software was the possibility of developing new GIS functions using an open-source programming language. Two open source GIS software, Geographic Resources Analysis Support System (GRASS) [14] and QGIS [15], are currently gaining in popularity thanks to their ability to develop new functions in their kernels using the open source programming language python. For reasons of continuity with our previous work [4, 16] carried out satisfactorily on Quantum Geographical Information System (QGIS) software, we have opted to use it for this work.

3.3. Plugin Design

A plugin is the visual result of implementing a module that integrates a new GIS functionality. In this case, the new GIS functionality is the module integrating decision map comparison models. The user will then be able to use this plugin like any other GIS functionality. Figure 2 illustrates the three main steps when designing the Plugin: Prerequisites and tools needed, Plugin structure and object or function of the plugin.

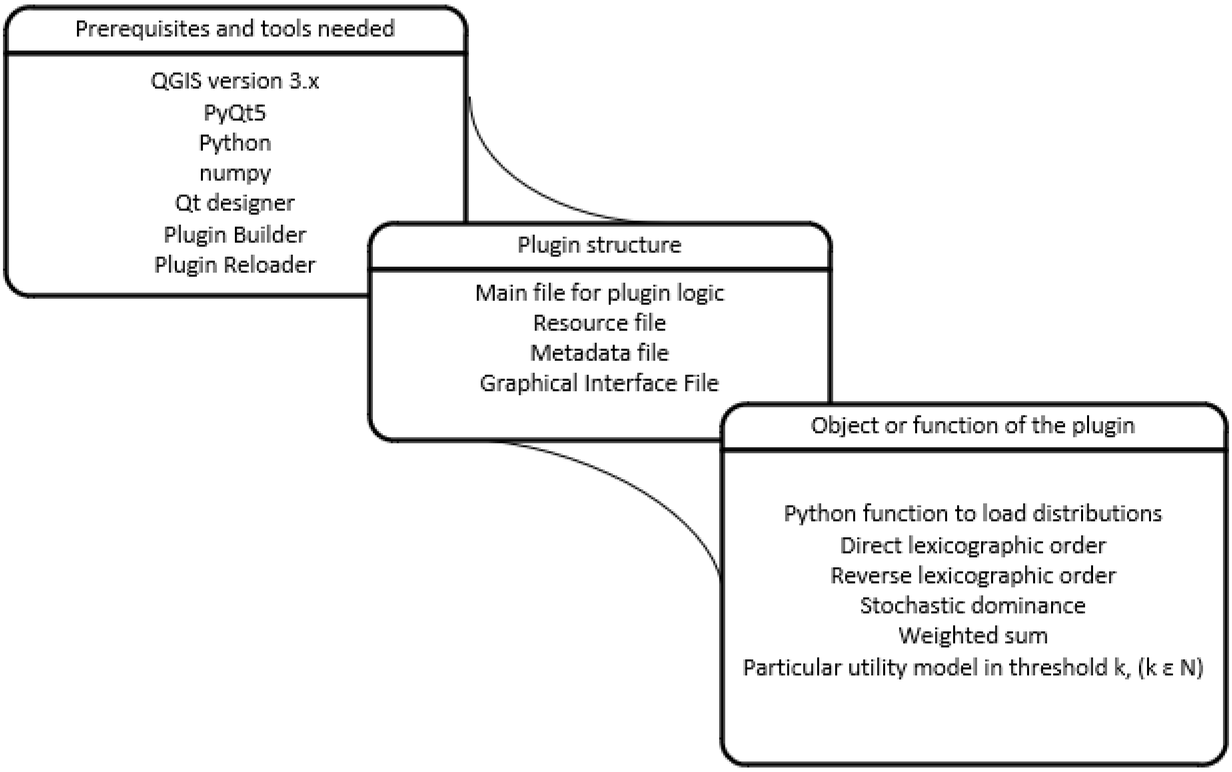

Figure 2. *Plugin design.*

3.3.1. Prerequisites and Tools Needed

To design the plugin in QGIS, you need to have the following software and modules or libraries installed on your computer:

1. in this work we used QGIS version 3.14;
2. PyQt5 [17]: The library used to create graphical objects in QGIS;
3. Python [18]: This is the programming language used to implement functions in QGIS.
4. Numpy: a python library dedicated to mathematical functions;
5. Qt designer: a tool for creating or modifying graphical user interfaces;
6. Plugin Builder: a QGIS extension that makes it easy to create the structure of a plugin in QGIS;
7. Plugin Reloader (optional): a QGIS extension that allows plugins to be loaded into QGIS without restarting it.

3.3.2. Plugin Structure

The plugin structure created by Plugin Builder is a folder containing several files with a particular structure. The most important of these files are:

1. a python file containing the plugin's main class;
2. a resource file containing the plugin's resources (icons, images, XML forms, etc.);
3. a metadata file containing plugin information (such as name, description, author, etc.);
4. a file for the graphical user interface.

3.3.3. Plugin Object or Function

Once the structure had been created, we added the following python functions to the file containing the plugin's main class:

1. a python function that retrieves the distribution of spatial units into categories for each decision map loaded into the QGIS project (this function takes as input the attribute tables of each decision map loaded and returns its distribution in categories);
2. functions implementing algorithms for the five decision map comparison methods;
3. a function that links the above-mentioned functions with the user interface.

Figure 3 shows the Python function implementing the lexicographic order-based decision map comparison model and which is a part of the file containing the plugin's main class. We can see in the third line of this python code the method "self.charge.Info()" which retrieves the distribution of spatial units into categories for each decision map loaded into the QGIS project.

```python
def lexicograph(self):
    nb_cat=eval(self.spinBox.text())
    x,y=self.chargeInfos()
    res=" The decision maps A and B are indifferent "
    res_i=" The decision maps A and B are indifferent "
    i=0
    while res== " The decision maps A and B are indifferent " and i<nb_cat:
        if x[i]>y[i]:
            res="Decision map A is preferred to decision map B"
        if y[i]>x[i]:
            res="Decision map B is preferred to decision map A"
        if x[i]==y[i]:
            i=i+1
    j=nb_cat-1
    while res_i== " The decision maps A and B are indifferent " and j>=0:
        if x[j]<y[j]:
            res_i = "Decision map A is preferred to decision map B"
        if y[j]<x[j]:
            res_i = " Decision map B is preferred to decision map A"
        if x[j]==y[j]:
            j=j-1
    self.tbInfos1.append(str(" Direct lexicographical order: {}".format(res)))
    self.tbInfos1.append(str(" Reverse lexicographic order: {}".format(res_i)))
    self.tbInfos1.append("*****************************")
```

***Figure 3.** Lexicographic order function.*

Note that "Plugin Builder" is used to create the plugin structure. This involves modifying the plugin's standard graphical interface to obtain the interface shown in Figure 4.

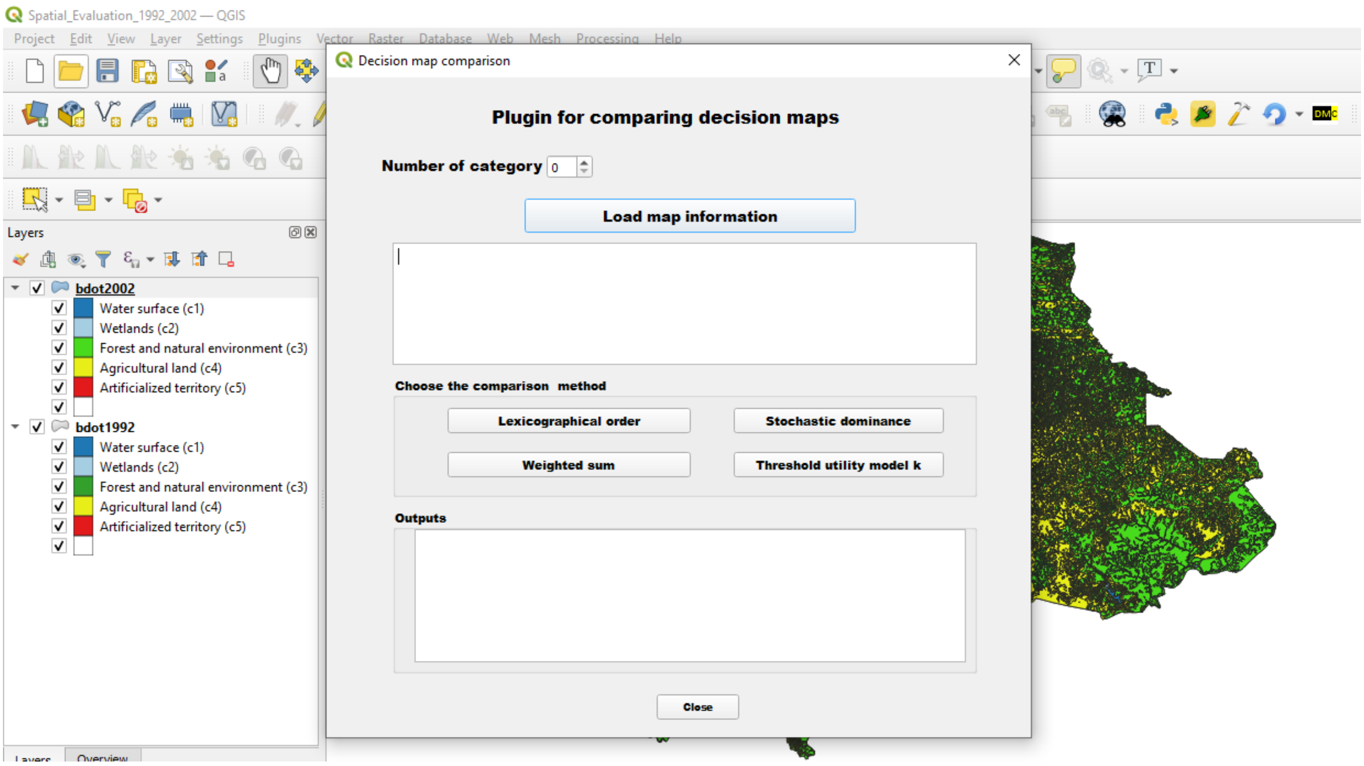

***Figure 4.** Plugin interface.*

3.4. Input and Output Data of Models for Comparing Distributions

3.4.1. Input Data for Lexicographic Order, Stochastic Dominance Model

To compare decision maps using lexicographic order, the user only needs to specify the number of categories in the decision map. The two decision maps to be compared have the same type and number of categories. When the decision maps are loaded in the GIS, our program calculates the category distribution of each decision map and compares them according to the lexicographical order, lexicographic inverse order or Stochastic dominance model.

3.4.2. Input Data for the Weighted Sum Model

In addition to supplying the number of categories making up the decision map, in order to use the weighted sum comparison model, the user must also supply the weights w_i for each category C_i such that relation (9) holds. When the decision maps are loaded in the GIS, our program calculates the category distribution of each decision map and compares them according to the weighted sum model

3.4.3. Input Data for the Particular Utility Model in Threshold $k(k \in \mathbb{N})$

Here, the number of categories in the decision map needs also to be provided. In addition, the user is prompted to specify the threshold k such that a category C_l, $l < k$ (respectively $l \geq k$) is considered bad (respectively good). When the decision maps are loaded in the GIS, our program calculates the category distribution of each decision map and compares them according to the particular utility model.

3.4.4. Output Data for Distribution Comparison Models

For each distribution comparison model, the output data consists of the category distribution of each decision map, the comparison indicator and the preference relationship between the two decision maps. For each comparison model, the Table 1 presents these output data in the context of our case study.

4. Results

In order to spatially evaluate the impact of water resource management policy on the entire territory of Burkina Faso from 1992 to 2002, we will use the decision map comparison plugin (see previous section 3) with input data: the 1992 and 2002 water resource management decision maps. These decision maps are based on land use databases (LUDB) obtained from the Burkina Faso Geographical Institute (IGB). Land use includes both physical and functional land use. The Land use database (LUDB) is a homogeneous inventory of biophysical land cover.

Note that the LUDB has been updated every 10 years since 1982. The 1992 and 2002 water resources decision maps were at the same scale (1/200000 with a spatial unit representing a 25-hectare portion of the territory), which made it possible to compare them spatially. However, the 2012 water resources decision map was available but was produced at a more precise scale (1/100,000 scale with a spatial unit representing a 5-hectare portion of the territory) and therefore different from the 2012 and 2002 decision maps. This made it impossible to compare the 2012 and 2002 or 2002 and 1992 decision maps. As for the 2022 decision map, it was not yet available.

4.1. Structuring Phase

4.1.1. Problem, Objective, Methodology and Actors

The problem of evaluating water resource management policy in Burkina Faso between 1992 and 2002 that we are dealing with does not, strictly speaking, have a Decision Maker. As an analyst with the assistance of an expert from the IGB, we are playing the role of Decision Maker. Our aim is to demonstrate the effectiveness of the decision map comparison tool that we have designed in solving a real problem. The issue of water resource management is of great importance for a country like Burkina Faso, most of which is located in what is known as a Sahelian zone. The Sahelian zones are known for the hydric stress that characterises them. The authorities in charge of regional planning are therefore implementing water resource management policies to alleviate the problem. By comparing the state of water resources between two different dates, we can get an overall idea of the impact of water resource management policy between these two dates. with decision maps representing the state of water resources at two distinct dates, the comparison of these decision maps will enable us to give an overall opinion on the impact of the water resources management policy applied during the period between these two dates.

Based on the LUDB, we need to construct decision maps of water resource management for the years 1992 and 2002. To do this we will:

1. divide the territory into spatial units,
2. assign spatial units into categories ordered according to their water conservation capacity.

It should be noted that such decision maps were obtained by using the ELECTRE Tri [13] and KEMIRA-Sort [16] MCDM sorting methods integrated into QGIS when solving a problem of landscape degradation (soil and vegetation).

If we compare the two water resource management decision maps from 1992 and 2002, an effective water resource management policy between these two dates would result in an overall increase in the categories of spatial units conserving the most water to the detriment of those conserving the least water.

4.1.2. Construction of Decision Maps

1. *Map scale*: The map scale used is 1/200000, which means that one centimetre on the map corresponds to two hundred thousand centimetres, or two kilometres on the ground.
2. *The spatial unit:* This is the area of the smallest zone to be mapped. It is 25 hectares for all zones except urban areas and bodies of water, where the minimum area to be

mapped is 5 hectares. For linear areas (roads and other straight objects), only those with a minimum width of 100 metres are mapped [19].

3. *The nomenclature of land use categories:* The nomenclature is a set of themes used to characterise the different types of land use in Burkina.
The LUDB nomenclature is organised into four levels representing 44 different types of use. In this work we will focus on the first level, made up of 5 main classes or categories. These are the 5 categories of water resources to which the spatial units will be assigned: water surface (C_1), wetlands (C_2), forests and natural environments (C_3), agricultural land C_4 and artificial land (C_5). Taking into account the capacity of each category to conserve water, we have the preference relation (15) between the five categories:

$$C_1 \succsim C_2 \succsim C_3 \succsim C_4 \succsim C_5. \quad (15)$$

Figure 5 shows the two decision water resource maps for the years 1992 and 2002.

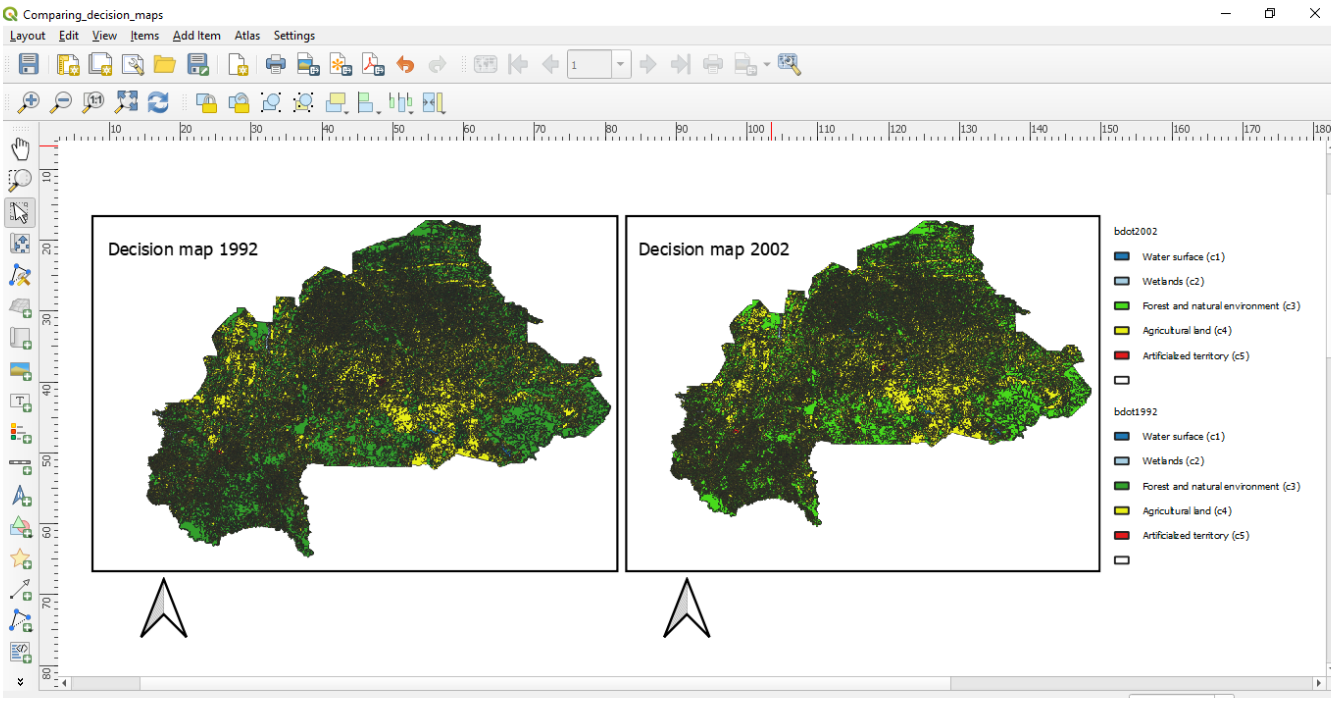

Figure 5. *Decision maps of water resources in 1992 and 2002.*

Table 1. *Model comparison results.*

Models	**Distribution associated with the 1992 decision map (A)**	**Distribution associated with the 2002 decision map (B)**	**Comparison indicator**	**Preference relations**
Direct lexicographical order	(*0.0046*, 0.004, 0.533, 0.4561, 0.0023)	(*0.0018*, 0.0039, 0.4964, 0.4965, 0.0013)	*0.0046 > 0.0018*	The 1992 map is *preferred* to 2002 map.
Reverse lexicographical order	(0.0046, 0.004, 0.533, 0.4561, *0.0023*)	(0.0018, 0.0039, 0.4964, 0.4965, *0.0013*)	*0.0013 < 0.0023*	The 2002 map is *preferred* to 1992 map.
Stochastic dominance	(0.0046, 0.004, 0.533, 0.4561, 0.0023)	(0.0018, 0.0039, 0.4964, 0.4965, 0.0013)	the vector sum of cumulative frequencies of the 1992 map is: (0.0046 0.0086 0.5416 *0.9977* 1.) and that of the 2002 map is: (0.0018 0.0057 0.5021 *0.9986* 0.9999)	The 1992 map is *incomparable* to that of 2002 *i.e.* not ($A \succsim B$) and not ($B \succsim A$)
Weighted sum	(0.0046, 0.004, 0.533, 0.4561, 0.0023)	(0.0018, 0.0039, 0.4964, 0.4965, 0.0013)	Weight vector: (0.434 0.211 0.14 0.132 0.082). Weighted sum of the 1992 map = *0.138* and that of the 2002 map = *0.137*	The 1992 map is *preferred* to the 2002 map.
Particular utility model in threshold $k = 3$	(0.0046, 0.004, 0.533, 0.4561, 0.0023)	(0.0018, 0.0039, 0.4964, 0.4965, 0.0013)	utility of the 1992 map = *2.0941* utility of the 2002 map = *2.0105*	The 1992 map is *preferred* to the 2002 map.

4.2. Evaluation Phase and Results

The results of the comparison of the two decision maps of 1992 and 2002 using the comparison models presented in section 2.4 and integrated into QGIS as a plugin are presented in Table 1.

4.2.1. Weighted Sum Model

Figure 6 illustrates the result of using the plugin when choosing the weighted sum model.

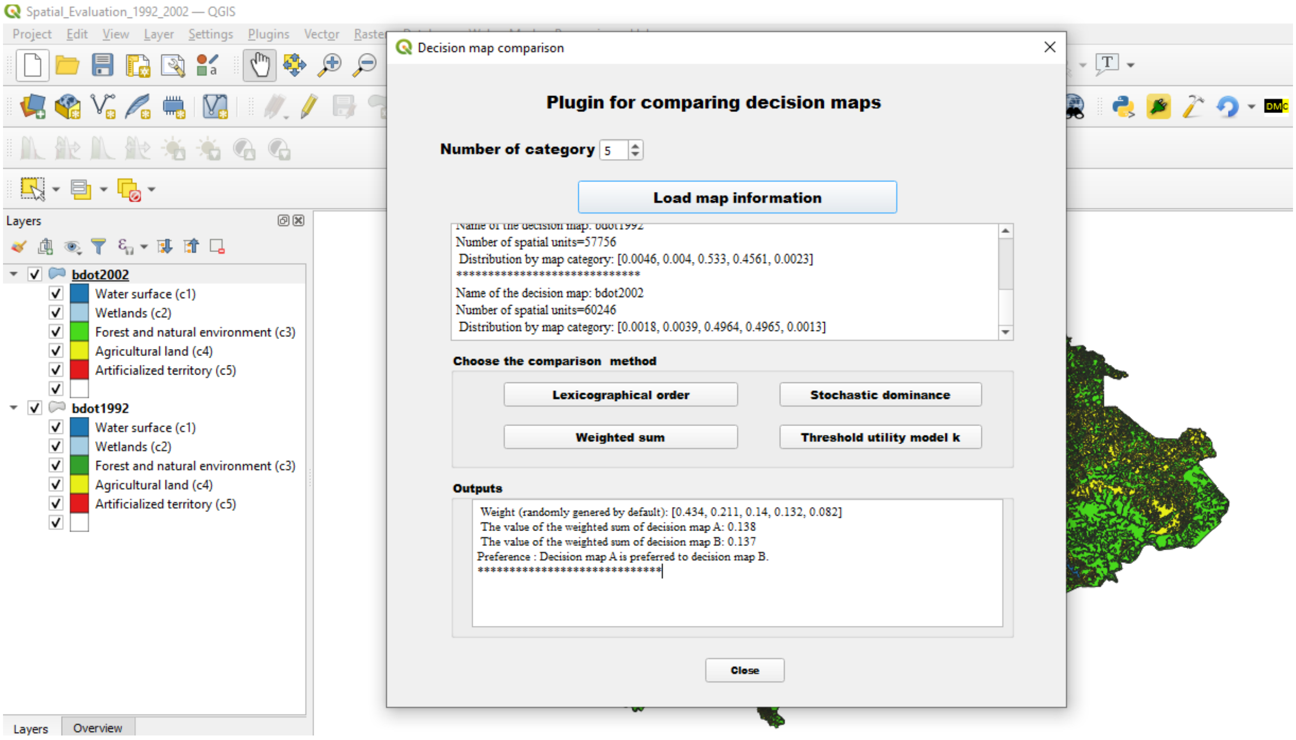

Figure 6. *Weighted sum comparison model.*

The components of the weight vector $(w_1, w_2, w_3, w_4, w_5) = (0.434, 0.211, 0.14, 0.132, 0.082)$ satisfying the relations (8) and (9) were respectively associated as weights of the categories C_1, C_2, C_3, C_4, C_5.

We then have the distribution of spatial units in the categories of the 1992 and 2002 maps respectively (0.0046, 0.004, 0.533, 0.4561, 0.0023) and (0.0018, 0.0039, 0.4964, 0.4965, 0.0013). This means that water surface cover 0.46% of the national territory in 1992, compared with 0.18% in 2002. 0.4% for wetlands in 1992 compared with 0.39% in 2002. Forests and natural environments, which accounted for 53.3% of the total in 1992, fell to 49.64% in 2002. The proportion of agricultural land increased from 45.61% to 49.65%. There was 0.23% artificial land in 1992, but this had fallen to 0.13% by 2002. Overall, the weighted sum of the 1992 map is equal to 0.138 and that of the 2002 map is equal to 0.137. The 1992 map is therefore preferred to the 2002 map. This means that, overall, the water resource management policy implemented between 1992 and 2002 has not had a positive impact. Although the water resource management policy was not effective between 1992 and 2002, it could be that locally, at the level of the categories, this management policy may or may not have been effective. The use of other decision map comparison models will enable us to address this concern.

4.2.2. Direct Lexicographical Order

According to Table 1, a comparison of the first two components of the distributions associated respectively with the decision maps shows a decrease in water surface from 1992 to 2002, *i.e.*, a deterioration in the best category C_1. This could lead us to say that the resource management policy has not been effective for the areas in this category C_1.

4.2.3. Reverse Lexicographical Order

Still analyzing the results of Table 1, the comparison of the last two associated components respectively to the decision maps of 1992 and 2002 show us a reduction in artificial land, *i.e.*, a reduction in the worst of the categories C_5. This could lead us to say that the resource management policy was effective for the areas in this category C_5.

4.2.4. Stochastic Dominance

Regarding the results of Table 1 neither of the two decision maps stochastically dominates the other; which could result in the fact that the cumulative improvements on the good categories (C_1, C_2, C_3) do not always compensate for the deteriorations on the worst categories (C_4, C_5).

4.2.5. Particular Utility Model in Threshold $k = 3$

We assume that $k = 3$, *i.e.*, the first three categories are judged to be the most useful and must be maximized while the last two categories must be minimized. Here again the utility of the 1992 map is higher than that of 2002. This generally reflects the inefficiency of the water resources management policy between 1992 and 2002.

Also, as shown in Figure 7, we generally note a deterioration of water resources on the national territory between 1992 and 2002 with mainly a reduction in Forests (C_3) (conserving water) in favor of agricultural land (C_4)(consuming water).

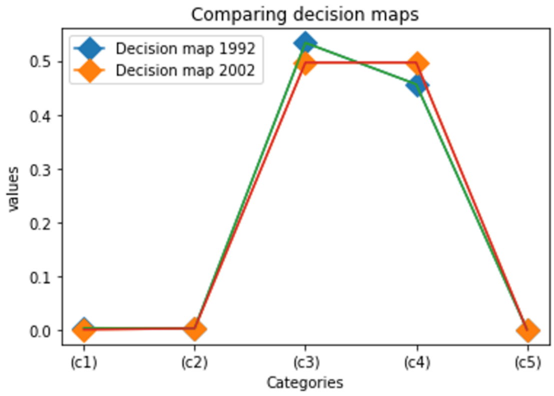

Figure 7. *Comparison graph.*

5. Discussion

The comparison of the decision maps made it possible to qualify and quantify the physical zones by their capacity to store water, to locate them spatially on the national territory, and to see the changes they may have undergone between 1992 and 2002. However, the situation observed between 1992 and 2002 could not only be the result of a water resources management policy. Indeed, others socio-economic factors not taken into account are likely to influence a water resources management policy in Burkina Faso [20, 21]. Taking these factors into account would make it possible to construct more realistic decision maps, the comparison of which would allow a more reliable spatial evaluation of the concerned management policy.

The decision map comparison models presented here consider as indifferent two decision maps with the same distribution of spatial units into categories. However, between two decision maps with the same distribution of spatial units in categories, we might prefer the one with spatial units dispersed in the categories to the one with spatial units grouped in the same categories. Thus, in this case, the comparison of decision maps depends on the geographical location or configuration of the spatial units and would now count.

This is the case, concerning the water resource management, where we might wish to have spatial units dispersed rather than grouped in the best categories. Indeed, having the spatial units dispersed in the best categories would ensure that the right water resource zones are spread across the territory and not grouped together in a single part of it. As a result, the whole territory would benefit more from water resources. The GIS would then need to include decision map comparison methods that take into account the geographical configuration of spatial units. A first model for comparing decision maps, taking into account the configuration of spatial units, was proposed in [7]. In this model, the Choquet integral [22, 23] was used to distinguish two decision maps with the same distribution of spatial units in the categories. In fact, the Choquet integral favors situations with grouped spatial units and disfavors situations with dispersed spatial units.

The proposed GIS-MCDM integration model for comparing decision maps could be applied to a number of spatial management policy assessment situations. Examples include the evaluation of a public health policy or a crime-fighting policy on the scale of a given territory. Here, a decision map would be the spatial representation of the initial risk of disease proliferation (respectively the crime rate) on the territory. A second decision map would spatially represent the risk of proliferation of said disease (respectively the crime rate) after a management policy has been put in place. A comparison of the two decision maps would give us an idea of the effectiveness or otherwise of the management policy implemented. In fact, an overall reduction in the risk of disease proliferation (or in the crime rate) observed when comparing the two decision maps would lead to a positive opinion on the effectiveness of the management policy implemented, or to an ineffective control policy in the opposite case.

6. Conclusion and Future Work

The integration of decision map comparison models into a Geographic Information System (GIS) is a significant advance for spatial decision making. It allows us to overcome the current limits of GIS and opens a new dimension to spatial decision support. More precisely, we proposed a mathematical and computer model (GIS-MCDM model) for comparing decision maps base on the full integration of four simple but efficient MCDM models (Lexicographic order, Stochastic dominance, The weighted sum, Particular utility model in threshold k ($k \in \mathbb{N}$) into QGIS software. The use of the new tool materializing the proposed GIS-MCDM model made it possible to effectively compare water resources management decision maps from 1992 and 2002 with the aim of spatially evaluating water resources management policy. Indeed, we observed an overall deterioration of water resources during the period 1992 to 2002; which mainly resulted in a reduction of forests in favor of agricultural lands. This successful application to a real-life case involving the evaluation of a water resource management policy demonstrated the effectiveness of the new tool proposed. This tool thus available in the GIS, here QGIS software, can be used to spatially evaluate other management policies (e.g., policy to combat the proliferation of a given disease). However, many challenges remain. For example, how can we develop decision map comparison models that take into account the geographic location or configuration of spatial units and integrated them in the GIS? We plan to tackle this challenge.

Abbreviations

DM	Decision Maker
GIS	Geographical Information System
GRASS	Geographic Resources Analysis Support System
IGB	Burkina Faso Geographical Institute
LUDB	Land Use Databases
MCDM	Multiple Criteria Decision Making
QGIS	Quantum Geographical Information System

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Conflicts of Interest

The authors declare no conflicts of interest.

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