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# ANALYSIS OF ENVIRONMENTAL FRAGILITY USING MULTI-CRITERIA ANALYSIS (MCE) FOR INTEGRATED LANDSCAPE ASSESSMENT

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**Abstract:** The Geographic Information Systems brought greater possibilities to the representation and interpretation of the landscape as well as the integrated analysis. However, this approach does not dispense technical and methodological substantiation for achieving the computational universe. This work is grounded in ecodynamics and empirical analysis of natural and anthropogenic environmental Fragility and aims to propose and present an integrated paradigm of Multi-criteria Analysis and Fuzzy Logic Model of Environmental Fragility, taking as a case study of the Basin of Monjolinho Stream in São Carlos-SP. The use of this methodology allowed for a reduction in the subjectivism influences of decision criteria, which factors might have its cartographic expression, respecting the complex integrated landscape.

**Keywords:** Environmental fragility. Multi-criteria evaluation. geographic information systems



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## INTRODUCTION

If in Brazil instruments are institutionalized to holistically understand the environment (such as environmental zoning and methods to evaluate environmental impacts) many works, as confirmed by Vettorazzi (2006), whether in the academic, public or private sector, have a bias concentrated on inventory of physical, biotic, social and economic data, considered by experts in the area, but with little or no integrated analysis.

The question is more critically situated in the elaboration of environmental diagnosis and clarity of the factors that guide the delineation of zoning units, with rules to identify highly qualitative zoning units, and charged with subjectivism, often susceptible to the perceptions of the team involved in the study.

Leyton (2004) presents five facts leading to this: (i) uncertainty cannot be modeled, (ii) qualitative facts are transformed into quantitative facts without adequate criteria, (iii) the environment is a complex system, (iv) information loss, and (v) the lack of rigorous mathematical calculations.

Geographic Information Systems (GIS) provide support to integrated analysis and the resolution of the five points listed by Leyton (2004). However, devoid of a clear methodology and a truly inclusive perspective, the outcome is an Advanced Digital Cartography or a repository of computer formatted maps.

Such systems have become essential tools for manipulating and processing geographic data. Buzai & Baxendale (2006) stated that these tools promoted not only a technological revolution, but also intellectual, with the former producing methodological and technical procedures to process spatial data, and the latter, important to discuss the environment. Hence, it changed the way reality is conceived, as it brings the question of interdisciplinary and new spatial awareness.

However, what regards the discussion and practice to be developed using the Geographic Information Systems is that, if on the one hand one of its functions is to integrate large volumes of data (derived from Remote Sensing, field surveys, secondary data and integration of factors) of different natures, such as socioeconomic and physical-territorial, on the other hand many works, especially those related to Environmental Analysis, remain under the auspices of automated digital mapping methods, or guided by the simple integration of cumulative data.

Thus, terminology is necessary to avoid overlapping simplistic data when addressing factors and criteria. *Factor*, according to Houaiss (2001), is “any element that concurs with a result”. Besides the concept of the dictionary, from the theoretical rationale presented, this factor is understood as the study subject. Thus, each Thematic Map is a factor that presents its compartmentation in the Landscape through Thematic Classes. Regarding the term criterion, according to Houaiss (2001), it is a “standard of comparison, evaluation and choice; foundation, a basis for choice and/or decision”. Thus, the criteria are defined by the individual studying the case in order to represent the environmental complex, expressed in the Landscape, using mathematical models.

To integrate environmental factors, the Boolean model is still the most widely used, due to the implementation of such tools in the software, or because of the ease of use and access to the information. However, the use of this model requires allocating fixed weights to the factors, resulting in delimited cartographic regions with static or rigid boundaries between the environmental zoning classes (Cereda Junior, 2006; 2011).

Thus, models that improve the performance in the representation of the forms arise, considering that the weights of the factors derived from the results of decision support techniques, whose limitations, inherent in the Boolean model, are outlined mainly by the use of numerical surfaces of decisions that best represent the gradual transitions between events represented in thematic maps. Among the data integration methods that enable this approach, seeking such reintegration, are the multi-criteria methods.

In the *Boolean Model* the combination of thematic maps that represent the criteria (physical, environmental, social or any other) are obtained using conditional operators, with each theme represented in a layer (information plan), combined according to a logical sequence that supports a hypothesis or proposition defined with the factors employed (Burrough, 1989). In the *Fuzzy Model* the thematic maps can be integrated through a combination that is based on multi-criteria analyzes performed by fuzzy operators, in which the factors are estimated by statistical analysis based on the knowledge of experts and compared against each other (Eastman, 2006).

Thus, by introducing a model adjusted to deal with inexact concepts, the classes (or zones) will be better represented, as it is better adapted to the gradual transitions between the spatial occurrences of the real world, through numerical surface decisions (Cereda Junior, 2011).

The use of multi-criteria analysis, according to Eastman (2006), is considered a significant advance over the conventional crossed referenced procedure and algebra information plans for defining areas of interest, one of the techniques used for decision making and its integration with Geographic Information Systems.

According to Vilas Boas (2005), the multi-criteria approaches are forms to model decision-making processes, which include: (i) a decision to be made, (ii) unknown events that may affect the results, and (iii) the possible courses of action and the results themselves. These models reflect, in a sufficiently stable manner, the assessment of the decision makers. However, its goal is to assist the manager to analyze the intensely complex data in the environmental field and seek the best strategy for managing the environment.

As multi-criteria analysis methods for this study, the following will be used: Weighted Linear Combination – WLC, and Ordered Weighted Averaging – OWA, in order to carry out the Environmental Fragility Mapping based on the ecodynamics of Tricart (1977) and Ross (1990 and 1994). Both methods are grounded on the integrated analysis of the environment and with the landscape as an integrated unit, through the non-Boolean multi-criteria analysis methods, which combine a broad set of variables, associated with a Geographical Information System, translating the theoretical and methodological essence of Environmental Fragility Mapping. This study also compares the results obtained by the multi-criteria methods, as well as the result analysis and environmental information suppositions generated by the studies.

The Weighted Linear Combination is a method in which the factors to be integrated receive weights and are combined by a weighted average. The result of the interaction between factors and their degree of relevance to one of the fuzzy classes is the Synthesis Map, no longer with rigid limits, but in a numerical surface, by grouping the data into thematic classes, according to methodological criteria (Malczewski, 2002). In this article the result is an Environmental Fragility Map obtained by Multi-criteria Analysis according to a Fuzzy Model, where each cell (pixel) represents the Fragility Class in which it belongs to and is expressed in the Landscape.

Thus, the limitations inherent in the strict limits of the Boolean Model are bypassed, for example, by numerical decision surfaces that best adapt to the gradual transitions between the occurrences represented in the thematic maps (Jiang & Eastman, 2000; Cereda Junior *et al.*, 2008). The Ordered Weighted Average differs when considering a second set of ordered weights, enabling the Model a better fit.

## MATERIALS AND METHODS

To compare and criticize the results - and not only the involved techniques - the studies were applied in a real region which forms part of the Basin of the Monjolinho stream in San Carlos - SP, as defined by Liporaci (2003) and also worked for Cereda Junior (2006, 2011).

With a population of approximately 220 000 inhabitants in 2010, São Carlos (interior of São Paulo state) has the advantages and challenges of a mid-sized city, including environmental problems. The occupation of areas with subdivision restrictions, which should be destined to other uses due to its characteristics, on account of pressures by the supposed development, as well as the needs of the public and private sector, eventually direct investments and planning models that ignore the physical aspects and its complex interrelationship (Cereda Junior, 2011).

Spörl (2001) states that by mapping environmental fragilities one can identify and analyze the environments, mapping their degrees and different levels of fragility, thereby enabling actions that are technically more suitable to these conditions.

The fragility factors and indices (herein treated as weights) used as a methodological framework in this work are supported in Ross (1990, 1994), hereinafter called Environmental Fragility Model. The factors used in this model are (i) Hierarchical Categories of Slope Classes, (ii) Fragility Classes for Soil Types, (iii) Degrees of Protection from the Type of Cover Vegetation, and (iv) Hierarchical Levels of Rainfall Behaviors.

The model proposed here differs subtly from Ross (1994), because Potential Fragility mapping is considered an intermediate phase not required for implementing the non-Boolean multi-criteria techniques. This paper considers that in areas already occupied the Potential Fragility of the land was changed, even when considering the Slope Physiographic Factor and its anthropogenic modifications.

The Hierarchical Levels of Rainfall were included in Model, as Spörl (2001) proposed, allowing the quantification of empirical risk and their association to landscape zones (as a fragility degree) to which this is subjected, since situations of high intensity rainfall promote the development of morphogenetic processes, while low rainfall annual situations lead to states of lower risk (Crepani *et al.*, 2000).

To implement the Environmental Fragility Model and its thematic cartographic products, was employed the Multi Criteria Evaluation module of the IDRISI 15 Program (The Andes Edition) developed by Clark Labs.

The factors used in the integrated analysis of the Landscape are of different natures. While the Hierarchical Categories of Slope Classes, for example, are a priori quantitatively expressed, the information regarding the Protection Degrees of Vegetation Cover Types is qualitatively expressed.

Therefore, to obtain not only comparability, but also fit the data to a common work scale required for Multi-criteria Analysis, it is necessary to standardize (or reschedule) the factors of each of the Model Environmental Fragility criteria, based on Degrees of Fragility proposed by Ross (1994) and Spörl (2001).

Thus, fuzzy standardization was performed for the slope factor, using an increasing monotonically sigmoidal function, taking as a control point $a$ = 0% and the control point $b$ = 30%, obtaining the Slope Factor Map with its fuzzified factors.

The control point indicates when the pertinence function begins to take on values greater than 0 (zero), and the control point $b$ indicates when the pertinence function reaches the threshold 1, in a standardized scale of real numbers ranging from 0 to 1. **Figure 1** shows the increasing monotone sigmoidal function graph under consideration.

The fuzzy standardization of the Fragility Classes factors for Soil Types, Degrees of Protection for Vegetation Cover Types, Hierarchical Levels of Rainfall Behaviors are in agreement with the Fragility Indices attributes proposed by Ross (1994) and Spörl (2001), according to **Tables 1** to **3**. Thus, for fuzzy standardization, a best suitable fuzzy function was used for such data types, which considers the experience of the researcher, as defined by Openshaw & Openshaw (1997).

The definition of the relative importance criteria between each factor for applying the Weighted Linear Combination method and Ordered Weighted Average Method was set according to a scale of values between 1 and 9. Saaty (1991) proposes the Analytic Hierarchy Process (AHP) as a technique for assigning weights, in which the different weights for each variable expresses the potential for a given variable studied. A numerical scale can be used as reference to classify, starting from 1 to those data with equal importance, ranging from extremely less important to extremely important. Next, the factors are classified in pairs with the importance comparison, in which the lowest limit (1) means that the importance among the criteria is equivalent.

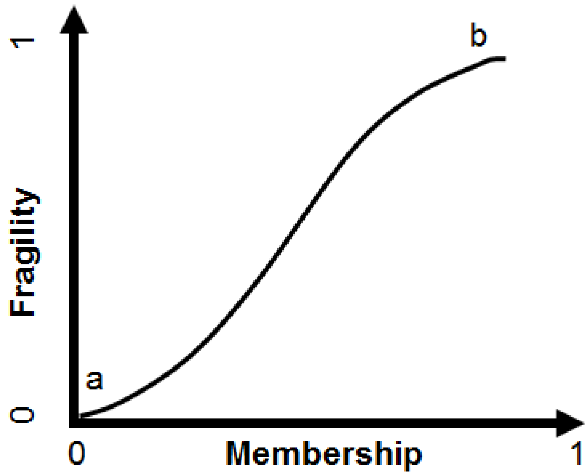



**Fig. 1** Fuzzy standardization of hierarchical categories for slope classes.

**Table 1.** Fuzzy standardization of hierarchical categories for soil classes

| Fragility | Soil types | Fuzzy classes |
|---|---|---|
| Very Low | Purple latosol, Dark red latosol | 0.0 |
| Average | Red yellow latosol | 0.5 |
| Very Strong | Podzolized with gravel, Litolics and quartz sand | 1.0 |

Source: Fragility adopted as Ross (1994).

**Table 2.** Fuzzy standardization of hierarchical categories for degrees of protection with type of vegetation cover

| Degrees of protection | Vegetal cover types | Fuzzy classes |
|---|---|---|
| Very High | Forests, natural forests, planted forests with biodiversity. | 0.0 |
| High | Natural shrub formation with dense herbaceous stratum. Dense shrub formations (secondary forest, dense savanna, dense brushwood). Homogeneously dense pine forest. Cultivated pastures not trampled by cattle. Long cycle crops such as cocoa. | 0.25 |
| Average | Long cycle cultivation in curve levels, coffee terrace, orange with fodder between rows. Grassland with low trampling. Eucalyptus forestry with native sub-forest. | 0.5 |
| Low | Long cycle low-density crops (coffee, black pepper, orange), exposed soil between rows, short cycle crops (rice, wheat, beans, soy, corn, cotton) with contour cultivation level/terrace. | 0.75 |
| Very Low and Nule | Deforested and recently burned areas, exposed soil by plowing/gradation, exposed soil along paths, roads, short cycle crops with no conservation practices. + | 1.0 |

+ Urbanized areas are included in this class, as they have no degrees of vegetal cover protection
Degrees of Protection adopted as Ross (1994).

**Table 3.** Fuzzy standardization of hierarchical categories for rainfall behaviors

| Levels Hierarchical Levels | Rainfall characteristics | Fuzzy Classes |
|---|---|---|
| Very Low | Rainfall situation with regular distribution throughout the year, with annual volumes not higher than 1000 mm/year. | 0.0 |
| Low | Rainfall situation with regular distribution throughout the year, with annual volumes not higher than 2000 mm/year. | 0.25 |

Hierarchical Levels adopted as Spörl (2001).

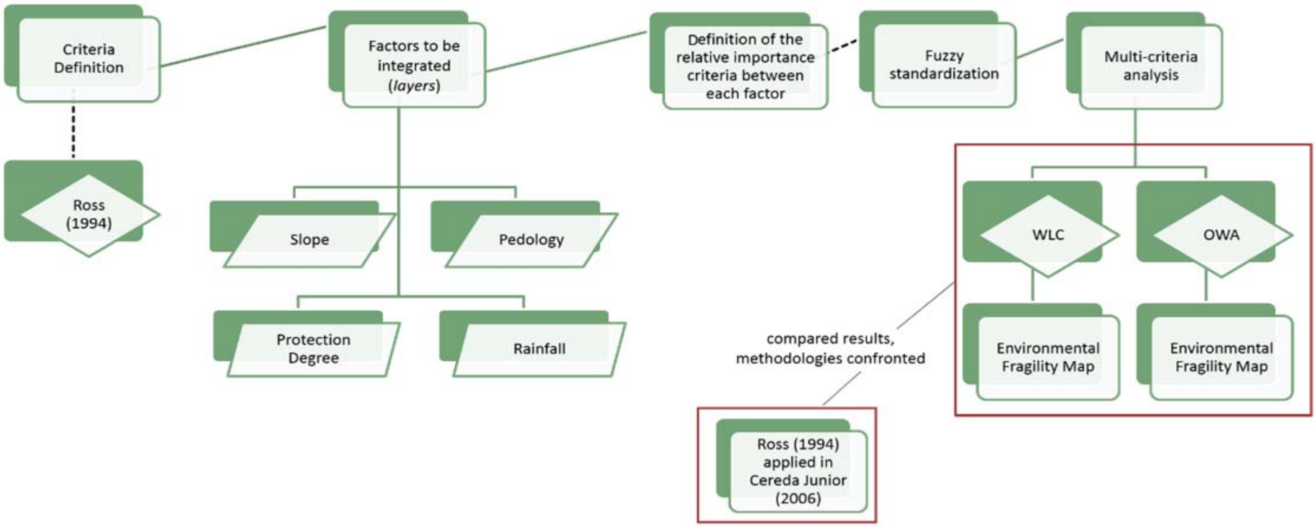



**Fig. 2** Schematic of methodological approach.

The relative importance among the criteria expresses the Level of Compensation, that is, the extent to which one factor can offset another; which is a process controlled by a set of weighted factors, after assigning the weights, the sum of all must be equal to 1 (Eastman, 2006). In the present study, to avoid the influence of one factor or another one, as in the original proposal by Ross (1994) that emphasizes the Slope, it is proposed that the relative importance of each factor is 1, that is, the environmental nuances already judged in the standardization of the data contribute equally to the objectives (Saaty, 1991) according to **Table 4**.

With the paired comparison, the Consistency Ratio value of 0.0 was obtained. According to Carvalho & Riedel (2005), the closer to 0 the more consistent the model is. The sum of the calculated weights must be equal to the unit, and it is recommended that this value always be less than 0.1. After the weights are calculated, the Weighted Linear Combination and Ordered Weighted Average are implemented.

The methodological approach is shown in **Fig. 2**, with its methodological and operational referential, as well the factors of the Environmental Fragility Model.

## DISCUSSION OF RESULTS

The Weighted Linear Combination is characterized by a combination of factors leading them to a medium risk, as it is exactly between the minimization process (AND) and maximization (OR) of risk. Thus, the Weighted Linear Combination will, with the maps of each factor, multiply the cell (pixel with resolution of two meters in this work), by its weight and then add up the results. Vettorazzi (2006) explains that because the weights have to totalize, the final product will have a range of values similar to those of the standardized maps. Then, after incorporating the factors, the final map is multiplied by each of the restrictions.

It should be noted that the standard reference for the size of a cell (grid) resolution for a cartographic basis is the cartographic accuracy standard, which if it is A, indicates that the lowest possible element is of 0.2 mm in the Source scale. Thus, in a 1:10 000 map, the resolution to be assigned is of $2 \times 2$ and in 1:50 000 it is of $10 \times 10$, therefore proportional.

The weights characterize the importance of each factor in relation to the others and define how they are offset. In the case of Environmental Fragility, high fragility factors in a particular location offset other factors in the same location with low fragility. As a result, **Fig. 3** shows the Environmental Fragility Map, considering the values in **Table 4**.

To integrate the factors using the Ordered Weighted Average procedure, the methodological route is similar to the Weighted Linear Combination, but with the inclusion of the Ordered Weights (order of weights), these being the same number of factors applied according to its position. By aggregating the factors, the different risk situations that may involve an undertaking can be analyzed (Yager, 1988).

As a first approximation (scenario 1) for the Ordered Weighted Average Method, the maximum possible value equal to 1 was set for the Ordered Weight I, taking the analysis toward a minimum value for the factors in each location, that is, totally averse to risk which, as shown earlier, behaves like an AND intersection operator, in which total weight is assigned as the criterion with the minimum value. As there are no other spatial ordering criteria, there is no trade-off, and the minimum value determines the final analysis.

**Table 4.** Adopted weighting criteria according to SAATY scale

| | Slope | Pedology | Protection | Rainfall |
|---|---|---|---|---|
| Slope | 1 | | | |
| Pedology | 1 | 1 | | |
| Protection | 1 | 1 | 1 | |
| Rainfall | 1 | 1 | 1 | 1 |

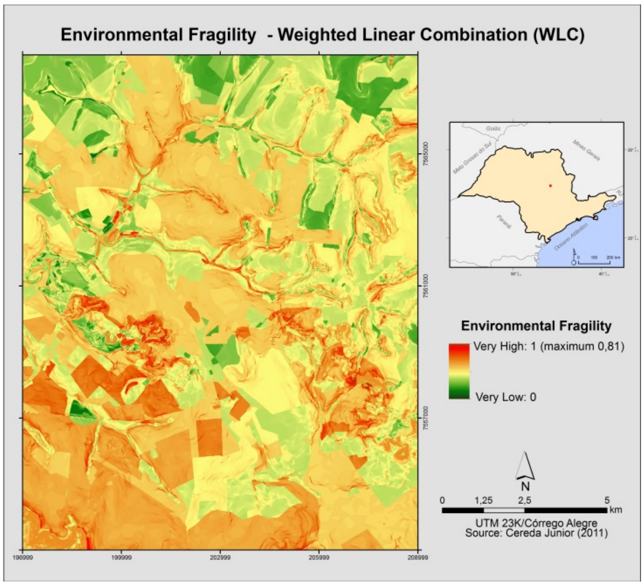



**Fig. 3** Environmental Fragility obtained by applying the Weighted Linear Combination.

As explained by Dalmas (2008), if the sum of all ordered weights must be 1, and when this value is assigned to the factor with less influence in the previous weighting process, there is a tendency for the analysis solution to have a low Risk (AND), in which the criterion is essential (but not sufficient on its own) in the final result.

A scenario 2 was also generated (term used for Ordered Weighted Average product) with the Ordered Weight 4, set as the unity, that is, the high ordered weight takes the analysis to a maximum value for the factors of each location represented in the pixel. A solution called totally pessimistic, with union operator OR, with the factor included in the set of decisions if at least one criterion is met.

For this case, Dalmas (2008) states that if the total value of the weights is assigned to the most influential factor in the previous weighting process, there is a tendency for the analysis solution to be high risk (OR) and each criterion is sufficient, on its own, to shape the final form.

Considering the Strategic Decision Space (**Fig. 4**) and the theoretical and methodological assumptions of the Environmental Fragility Model, the spatial weights were defined, as shown in **Table 5**, which represent low risk (pessimistic or conservative analysis), and extreme risk (optimistic analysis and no trade-off). The weighting factor is used for the Weighted Linear Combination technique, according to **Table 4**. Map 5a and 5b (**Fig. 5**) shows the cartographic map products.

Scenario 1 shows that the Environmental Fragility peaked at 0.25, which means that the entire area is included in the Low Fragility Class, with minimal risk and with no trade-off. Scenario 2 shows the values reaching the entire range of classes (0 to 1), noting that most of the area is in the High Fragility Class, with maximum risk and with no trade-off.

Not only for a better understanding, but also to extract the Ordered Weighted Average method, its main feature – the control level of ANDness – three additional alternative scenarios were generated, as shown in **Fig. 6** and **Table 6**.

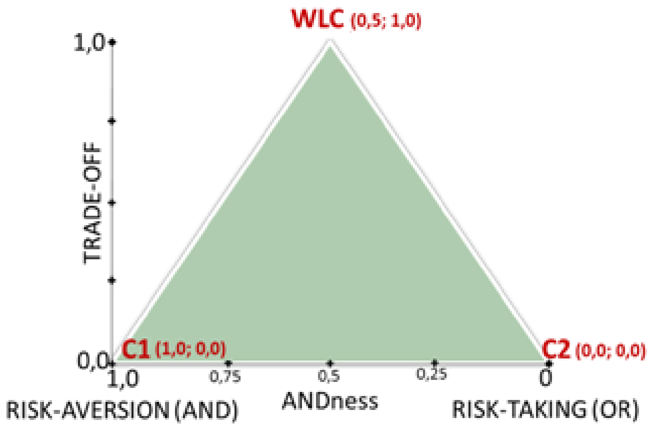



**Fig. 4** Ordered weights ordination within strategic decision space.

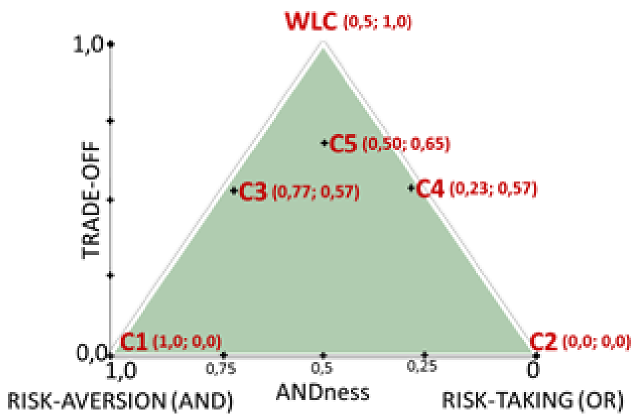
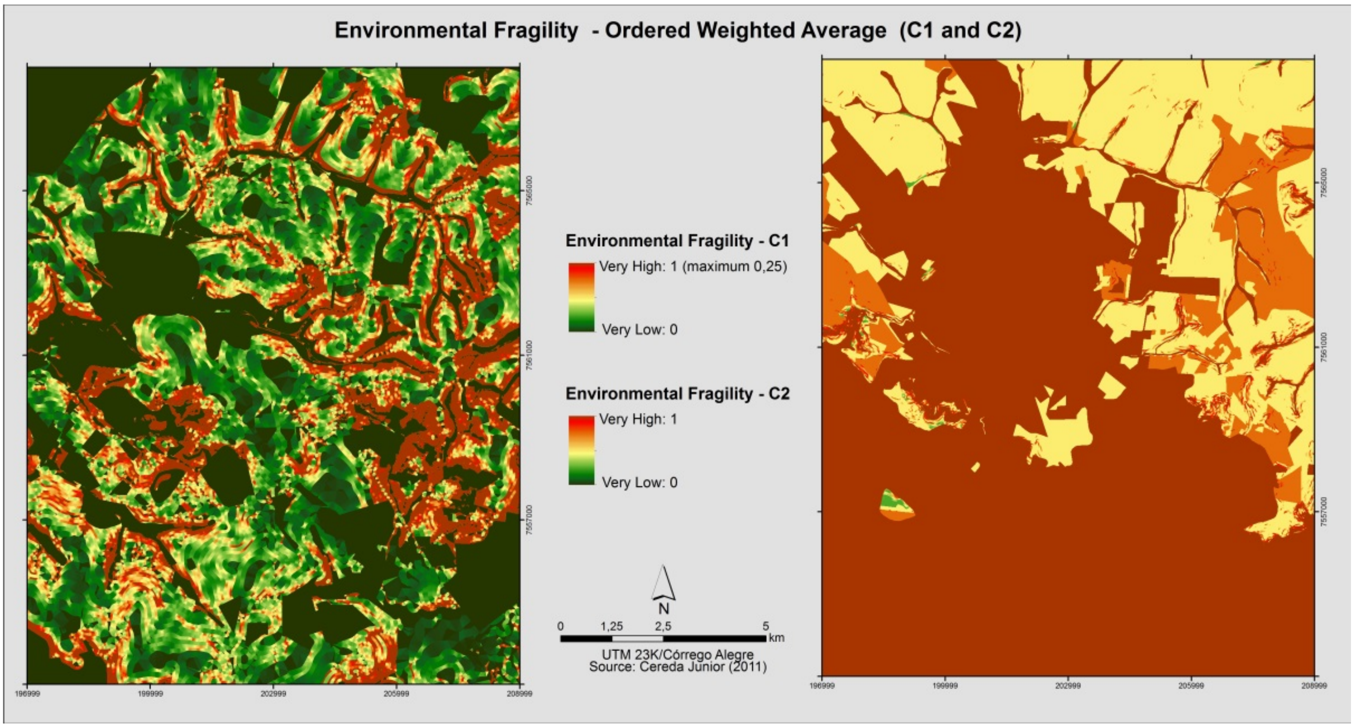



**Fig. 6** Ordered Weights within the strategic decision space.

**Table 5.** Ordered weights for scenarios C1, C2 and WLC

| Scenario | Ordered Weights | | | | ANDness | Trade-off |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | |
| C1 (AND) | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 |
| C2 (OR) | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| WLC+ | 0.25 | 0.25 | 0.25 | 0.25 | 0.50 | 1.00 |

+ Presented in the table as a reference, as it is the very WLC, with average risk and total trade-off




Map 5a Map 5b

**Fig. 5** Environmental Fragility obtained by applying the Ordered Weighted Average – Scenarios 1 and 2.

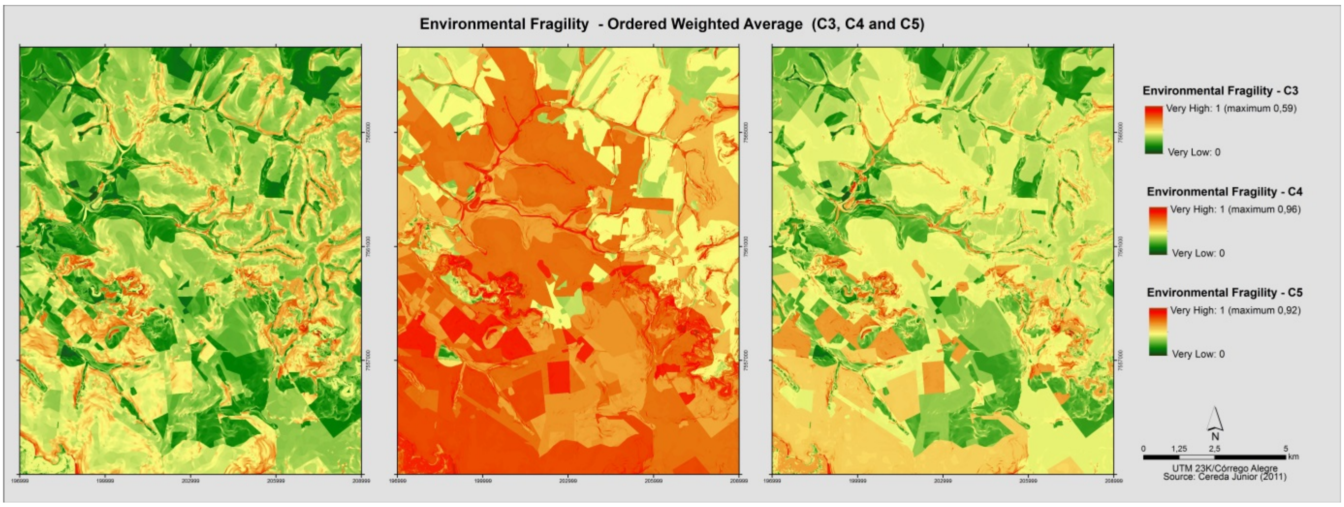
**Figure 7** shows the results for these three new scenarios (maps 7a, 7b and 7c). In the Weighted Linear Combination there is always full trade-off, that is, the variables cannot be controlled, thus trade-off scenarios are generated, but with different levels of ANDness.

## CONCLUSIONS

With the results obtained and presented in **Figs 3**, **5** and **7**, and also with the theoretical framework constructed, one can contrive not only the quantitative analysis of Environmental Fragility Indexes, but also the analysis from the point of view of integration variables, using the techniques applied.

The mapping product regarding the Weighted Linear Combination method shown in **Fig. 3**, applies trade-offs to the low fragility factors from those with higher rates, allowing the assumed interference of the model proposed by experts in the field – such as Ross (1994) – to be, if not eliminated, minimized by the average ANDness (0.5) and full trade-off (1.0), or the end of the triangle in the Strategic Decision Space (**Fig. 6**).

However, in this case, the weights of each factor considered extremely high or extremely low tend to approach a complete average, distorting variables that in fact can have differences in complex systems, such as environmental systems. For instance, in a given location with Average Protection Degree and Low Fragility Pedology, the full offset (trade-off = 1) would allow the Slope (with High Fragility) to continue to strongly influence the model.




Map 7a Map 7b Map 7c

**Fig. 7** Environmental Fragility applying the Ordered Weighted Average – Scenarios 3, 4 and 5.

**Table 6.** Ordered weights applied to Ordered Weighted Average - new scenarios

| Scenario | Ordered Weights | | | | ANDness | Trade-off |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | |
| C3 - low risk, partial trade-off | 0.55 | 0.25 | 0.15 | 0.05 | 0.77 | 0.57 |
| C4 - high risk, partial trade-off | 0.05 | 0.15 | 0.25 | 0.55 | 0.23 | 0.57 |
| C5 - neutral risk, partial trade-off | 0.1 | 0.4 | 0.4 | 0.1 | 0.5 | 0.65 |

Thus, with low risk analysis (ANDness greater than 0.5) there is minimized Fragility, since they must have high index values for all the factors involved. Taking into consideration high risk analyzes (ANDness less than 0.5) the Fragility Index is maximized because the highest value found in one of the criteria guides the others.

With the control allowed by the Ordered Weighted Average method, Scenario 1 with minimal risk is built, with ANDness = 1 (or ANDtotal) and no trade-off between factors (trade-off = 0). The result shown in Map 5a confirms the trend to analyze the environmental system where full solution AND takes the data to almost fully minimizes its characteristics expressed in the Landscape. For the study object, the highest Fragility Index calculated for the whole area was of 0.25 (very low risk), which was not confirmed during the field visits and bibliographic references, and also inconsistent with the Basic Maps, mainly Pedological and of Slopes.

Therefore, with the creation of Scenario 2, maximum risk, with ANDness = 0 (or ORtotal), the results presented confirmed the expectation of this model. As expected, with no offset between factors (trade-off = 0), it takes the data to the solution in which critical values elevate the final Fragility Index, shown in Map 5b. This scenario also confirms the initial hypothesis of this study, in which the Boolean algebra-based multi-criteria methods do not allow to fully apprehend the environmental complex.

This can be cartographically observed in the work of Cereda Junior (2006), generated by a Boolean model, with the Double Entry Table technique. This solution, considered suitable as it follows all the methodological principles of the initial Model, can be challenged due to the weighted control and ordered weights, as in the Ordered Weighted Average, because the displacement of Classes for close Fragility Indexes or exactly equal to 1 is now evident, expressed in the Landscape as critical areas, with very high Fragilities for areas that, confirmed in the field, do not have such characteristics.

To confirm or refute these statements, Scenarios 3 and 4 were generated, yielding the summary mapping products depicted in maps 7a and 7b of **Fig. 7**. Such scenarios were built, respectively, in order to obtain low risk, but with partial offset (ANDness = 0.77 and trade-off = 0.57), and also high risk but with partial offset (ANDness = 0.23 and trade-off = 0.57). The results confirmed the theoretical expectations of the model, in which by considering the ANDness in the Strategic Decision Space for a minimal risk or a maximum risk, but considering an average offset, the results exhibit tendencies toward extreme solutions, however offset by higher critical values.

Therefore, seeking a solution with an offset between the variables, but with a tendency toward intermediate solution (not extreme) for the Environmental Fragility Model, this study concludes that scenarios with ANDness values of 0.5 (or close to it, in other words neutral risk), and also offsets close to 0.5, are better adapted not only to the technical principles but mainly to the theoretical basis.

Therefore, the environment no longer classified with strict limits and environmental criteria that seeks to reintegrate the environmental complex under consideration, embodied in the landscape - not only due to the influence of pre-established criteria by the experts, but also adjusted by the Ordered Weighted Average method - provides control over the components and allows the spatial expression of the environment to be demonstrated in the analysis.

An offset value greater than 0.5 (but less than 0.75) was calculated so that the criteria with high values could have that characteristic preserved, but without deterministically interfering with the Model, that is, a slight offset tendency, hence obtaining 0.65 for the study area. For this, in the ordered weights distribution, it was defined that the extreme values (ordered weight equal to 1 and 4) would have a value of 0.1, while the central values would have 0.4, according to **Table 6**.

With no prior assumptions, only weights and spatial modeling, it was possible to construct a logical line of decision-making without direction or even automatic calculations by means of generic software, confirming the knowledge-driven concept for the Weighted Linear Combination and Ordered Weighted Averaging methods, resulting in Scenario 5, Map 7c of **Fig. 7**.

Comparing it with the results obtained by Cereda Junior (2006), it is observed that there was a reduction in the Very Strong Class, as shown in **Table 7**. The explanation is that the solution adopted was a ORtotal because there was no offset between factors (trade-off = 0), not only increasing, as shown earlier, but distorting the extreme critical values, especially the Pedology Criterion and Soil Protection Degrees.

To survey the results obtained, and its real expression in the landscape, fieldwork was conducted. The former ones for recognition and updating purposes, and the latter ones with photographic records with different Fragility values, which were called Photograph Control Points, totaling 80. One of the key findings in the field was the Soil Protection criterion, considered explicitly in the Model. Different from the initial proposal of Ross (1994,) in which the Degree of Protection is a tabular nuance (Cereda Junior, 2006), the Synthesis Map was achieved using the Ordered Weighted Average.

It was also noted that Slope and Pedology actually have a high degree of control over Environmental Fragility for the study area, but not deterministically. Several Fragility areas classified as Average or High require attention, due to the new occupations, which can change their condition.

As for the results, especially when compared with the direct and operational application found in Ross (1994), for the study area Cereda Junior (2006), using the multi-criteria operators, it enabled to decrease the influence of the Slope theme for the final Synthesis Map, in which the process via Double Input Table or Arabic Numerals shows the determinism of such criteria. The initial hypothesis of this study, that the multi-criteria methods enabled reintegrating the theoretical and methodological essence of Environmental Fragility mapping (as defined by Ross, 1994), in addition to producing new insights and perspectives on the use of computer systems, is confirmed with satisfactory results.

The Ordered Weighted Average method proved to be not only well suited to the variables of Model Environmental Fragility, as the experts involved provides control over the decision process completely, allowing the inclusion of new criteria, and responsibility of their control. This is a step towards the use of Geographic Information Systems (GIS) not only based on old paradigms with new visual presentation and still thought of as large repositories of maps, but, with GIS capabilities to provide better products for decision making – always the responsibility of specialists. The lack of widespread use of multi-criteria methods can be attributed in part to the fact that this method is absent in software packages (commercial, or free), except when additional components are used.

**Table 7.** Areas of Fragility Classes

| Fragility Class | OWA area ($km^2$) | Boolean Area (Double Entry Table) ($km^2$) |
|---|---|---|
| Very Weak | 7.7 | 0.1 |
| Weak | 75.55 | 0.3 |
| Average | 84.35 | 44.4 |
| Strong | 12.00 | 15.2 |
| Very Strong | 0.4 | 120.0 |

The opinion of Castillo (2009) is highlighted and confirmed, which states that the difference between Landscape and Geographical Space is fundamental to avoid overlapping the concepts. The Landscape, according to the author, should be considered as a material portion of the geographical space, but which is by no means autonomous as an explanatory dimension of Geography and devoid of the attribute of totality, with the extrapolation of this limit retraced to a formalism that has left its mark in the history of geographical thought.

More than area quantification or the accuracy of measurements, the cartographic products obtained from an Environmental Fragility outlook, with the application of multi-criteria methods, allow reviewing the study object, enabling to integrate new projects, upgrading and creating Master Plans, and also for other management purposes that include Integrated Analysis.

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