Influence of human uncertainty in the elaboration of fuzzy reference databases for the accuracy assessment of land cover maps

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Abstract

Reference databases for the accuracy assessment of land cover maps are assumed to represent the true land cover in a set of selected locations. Although, the elaboration of reference databases through field visits or photo interpretation of aerial images is a hard and difficult task due to uncertainty in the assignment of the most correct land cover class at each sample location because of landscape fragmentation. To capture the diversity of land cover in each pixel of the reference data, a linguistic scale composed by five linguistic values is used in this paper and a methodology to translate the linguistic values to fuzzy intervals is proposed, based on the responses of the photo interpreters to a set of chosen pixels. These fuzzy intervals are then used to build a fuzzy confusion matrix and fuzzy thematic accuracy measures are derived. The main goal of this study is to quantify the differences of perception of photo-interpreters when assigning a linguistic scale to the sample pixels of the reference database. The proposed approach is tested on a case study where the accuracy assessment of a map of Continental Portugal with five land cover classes, derived from MERIS images, is made.

Keywords: reference database uncertainty, photo-interpretation, linguistic scale, fuzzy confusion matrix, fuzzy intervals.

1. Introduction

Reference databases for the accuracy assessment of land cover maps are composed by a set of sample observations selected over the study area. The information about land cover is collected through ground visits or photo-interpretation of aerial images. Generally, at each sample site of the reference database the land cover class that best describes that area is collected. Although, this approach has limitations since many times it is difficult for the photo-interpreter to choose the land cover that best represents the landscape. This uncertainty may arise due to the characteristics of the land cover, such as the existence of more than one land cover class in a certain location or because land cover classes are blended, forming a natural continuum instead of presenting abrupt transitions between classes.

An alternative approach for collecting the reference information that addresses uncertainty was first developed by Gopal and Woodcock (1994). The authors developed a linguistic scale with five linguistic values (absolutely wrong; understandable but wrong; reasonable or acceptable answer; good answer; absolutely right), that translate the degrees of membership of the sample observations to the land cover classes.

The aim of this study is to present a methodology to build fuzzy intervals corresponding to each of the linguistic values, using a set of chosen sites where the percentage of coverage of each class is evaluated, and quantify their impact in the accuracy assessment of land cover maps. These fuzzy intervals serve as the input in a fuzzy confusion matrix and thematic accuracy measures are derived and analyzed. The proposed approach is tested on a case study where a land cover map for Continental Portugal derived from MERIS (Medium Resolution Imaging Spectrometer) images is evaluated. The results obtained for two photo-interpreters are used in the study and the differences in the results analysed.

2. Methodology

The proposed methodology for the accuracy assessment of land cover maps starts with the definition of the linguistic scale. As in the approach of Gopal and Woodcock (1994) the linguistic scale used is composed by five linguistic values: Absolutely wrong (W); Understandable but wrong (U); Reasonable or acceptable (A); Good (G); Absolutely right (R).

Analysing the assignment of the linguistic values to each class for each of the chosen testing sites, where the area occupied by each class is known, enables the identification of the maximum and minimum proportion of area occupied by the several classes when each value of the linguistic scale was used by the photo interpreter. These values are used as, respectively, the maximum and minimum value of the support (region of the universe that is characterized by nonzero membership in a fuzzy set) of the fuzzy intervals corresponding to each value of the linguistic scale, except for the linguistic values Absolutely wrong and Absolutely right, where, for the first, the minimum of the support is always considered to be zero, and for the second the maximum of the support is always considered to be 1. The minimum and maximum value of the core (the core of a fuzzy set is the set of elements with full membership in the set) of each fuzzy interval corresponds respectively to the maximum of the support of the previous fuzzy interval and the minimum of the support of the following fuzzy interval, except for the linguistic values Absolutely wrong and Absolutely right, where, for the first, the minimum of the core is zero (coincident with the minimum of the support) and for the second the maximum of the core is one (coincident with the maximum of the support).

A fuzzy reference database is elaborated assigning at each sample observation, a linguistic value to each one of the land cover classes of the legend. This fuzzy reference database is then compared with the information of the map in a fuzzy confusion matrix, and overall, user's and producer's accuracy are derived accordingly with the methodology proposed in Sarmento *et al.* (2010). To allow a comparison with the traditional accuracy measures, the fuzzy accuracy measures derived from the fuzzy confusion matrix are defuzzified using the first of maxima (fom), centroid and last of maxima (lom) defuzzification methods (Ross, 1995) to obtain crisp thematic accuracy measures similar to overall, user's and producer's accuracy. Two traditional accuracy measures are also computed, namely MAX and RIGHT (Gopal and Woodcock, 1994). MAX considers a match when the map classification agrees with the land cover class that has the highest linguistic value at a certain sample observation of the reference database. On the other hand, RIGHT considers a match when the map classification agrees with the land cover classes that have the highest or second highest linguistic value at a certain sample observation of the reference database.

3. Case study

3.1. Data and methods

To test the proposed methodology of accuracy assessment of land cover maps a map for Continental Portugal of 2005 was used (Carrão *et al*., 2010). The land cover legend is composed by five land cover classes (urban areas (UA); agriculture (AG); natural vegetation (NV); forest (F) and water and wetlands (WW)), that resulted of the generalization of the LANDEO nomenclature (Carrão *et al*., 2007) originally with 16 land cover classes. To elaborate the reference database, a sample with 250 observations was selected through a simple random sampling design. To assign at each sample observation a linguistic value for each one of the land cover classes of the legend, using the linguistic values indicated in section 2, a photo-interpretation of a set of aerial images with a spatial resolution of 0.5 m and four spectral bands was made.

To build the membership functions for each value of the linguistic scale, a set of 32 sample observations was selected deterministically and overlaid with the aerial images. To evaluate the proportion of the pixel area corresponding to each class, a set of 100 points were distributed systematically over each sample observation and each one of those points was photo-interpreted. Counting the proportion of points corresponding to each class at each sample observation, enables an estimation of the proportion of area that each land cover class occupies within each sample observation.

The results obtained for two photo interpreters are analysed in the following section.

3.2. Results

The membership values obtained for each one of the linguistic values and for each photo-interpreter are shown in Table 1, Figure 1 and Figure 2.

Considerable differences can be seen between the results obtained for the two photo interpreters, namely in the amplitudes of the cores and supports of several linguistic values.

The fuzzy intervals obtained for the photo-interpreters 1 and 2 for overall accuracy are shown in Figure 3 and the defuzzified values in Table 2. The values obtained for lom for photo-interpreter 1 and 2 are very similar (69% and 67% respectively) and also very close to the value obtained for MAX (65%) (Table 2). Although, the core's amplitude (i.e. the values between fom and lom) vary substantially between the two photo-interpreters, being about 15% larger for photo-interpreter 1 (Table 2).

Table 1: Support and core of the fuzzy numbers corresponding to each linguistic value for photo-interpreter 1 and 2, expressing the normalized proportion of land cover coverage.

Photo-interpreter	Linguistic values	Support of the fuzzy number	Core of the fuzzy number
1	Absolutely wrong (W)	[0,0.17]	[0,0.11]
	Understandable but wrong (U)	[0.11,0.38]	[0.17,0.30]
	Reasonable or acceptable (A)	[0.30,0.56]	[0.38,0.45]
	Good (G)	[0.45,0.82]	[0.56,0.77]
	Absolutely right (R)	[0.77,1]	[0.82,1]
2	Absolutely wrong (W)	[0,0.17]	[0,0]
	Understandable but wrong (U)	[0,0.41]	[0.17,0.22]
	Reasonable or acceptable (A)	[0.22,0.68]	[0.41,0.48]
	Good (G)	[0.48,0.92]	[0.68,0.80]
	Absolutely right (R)	[0.80,1]	[0.92,1]

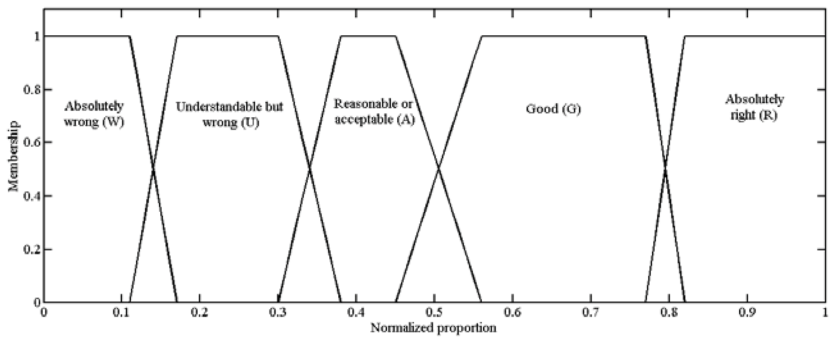


Figure 1: Membership functions obtained for the linguistic values for photo-interpreter 1.

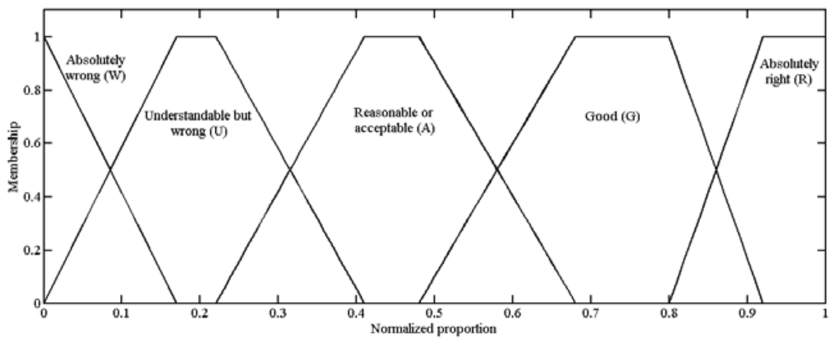


Figure 2: Membership functions obtained for the linguistic values for photo-interpreter 2.

This difference is due to the wider amplitude of the cores of the fuzzy intervals obtained for each linguistic value for photo-interpreter 1 (Table 1 and Figure 1) which means that there is less uncertainty.

The user's and producer's accuracy was computed for all classes, but only the results for the user's accuracy for classes AG and NV are presented in this paper. Figure 4 shows the results of fuzzy user's accuracy obtained for both photo-interpreters.

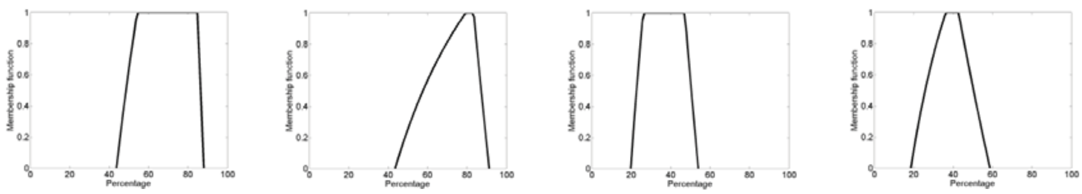
a) b)

Figure 3: Fuzzy interval representing overall accuracy for: a) photo-interpreter 1; b) photo-interpreter 2.

Table 2: Defuzzified overall accuracy in percentage of the considered land cover map for photo-interpreters 1 and 2.

Photo-interpreter	Defuzzification methods			Traditional methods	
	fom	*centroid*	*lom*	*MAX*	*RIGHT*
1	54	61	69	65	80
2	61	63	67		

Table 3 shows the defuzzified values and the results obtained for MAX and RIGHT. Even though the supports of the obtained fuzzy numbers are similar, as for the overall accuracy, the amplitude of the cores for both classes is much wider for photo-interpreter 1 than for photo-interpreter 2. For example, for the class agriculture these values are respectively 30% for photo-interpreter 1 and only 3% for photo-interpreter 2.



a) b) c) d)

Figure 4: User's accuracy of agriculture and natural vegetation for photo-interpreters 1 and 2. a) user's accuracy of agriculture for photo-interpreter 1; b) user's accuracy of agriculture for photo-interpreter 2; c) user's accuracy of natural vegetation for photo-interpreter 1; d) user's accuracy of natural vegetation for photo-interpreter 2.

Table 3: User's accuracy of agriculture and natural vegetation for photo-interpreters 1 and 2.

Photo-interpreter	Land cover classes	Defuzzification methods			Traditional methods	
		fom	*centroid*	*lom*	*MAX*	*RIGHT*
1	***AG***	55	67	85	88	96
	NV	27	37	47	46	64
2	***AG***	80	71	83	88	96
	NV	37	38	43	46	64

The results also show that the values obtained with MAX are very similar to the ones obtained for the last of maxima (lom), for both land cover classes. Although, the values obtained for the first of maxima (fom) are very different for the two photo-interpreters. The values fom and lom only translate the amplitude of the cores of the fuzzy interval, although the centroid defuzzification method has all values of the membership function under consideration. An interesting characteristic that the results show is that the centroid takes similar values for both classes, even though the obtained fuzzy intervals have considerable differences.

4. Conclusion

The methodology proposed in this paper allows the inclusion of human uncertainty in the elaboration of reference databases in the accuracy assessment of a land cover map. The construction of fuzzy intervals for each value of the linguistic scale for each photo-interpreter enables the modeling of uncertainty associated with the assignment of the linguistic values at each sample observation of the reference database. The construction of fuzzy confusion matrixes and the computation of fuzzy accuracy indices enable the propagation of uncertainty in the reference data to the accuracy indices and the defuzzification methods allow a direct comparison with the traditional accuracy indices. Further research is however necessary to establish clear rules to assign the linguistic values.

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