Follow-up and modeling of the land use in an intensive agricultural watershed in France

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ABSTRACT

In intensive agricultural regions, monitoring land use and cover change represents an important stake. Some land cover changes in agro-systems cause modifications in the management of land use that contribute to increase environmental problems, including an important degradation of water quality. In this context, the identification of land-cover dynamics at high spatial scales constitutes a prior approach for the restoration of water resources.
The modeling approach used to study land use and cover changes at a field-scale is adapted from a vector change analysis method generally applied to assess land cover changes from regional to global scales.
The main objective of this study is to identify vegetation changes at the field scale during winter, in relation with crop successions. Magnitude and direction of the vector of changes with remote sensing data and GIS, calculated on a small watershed located in Western France for a six-year period (1996-2001) indicate both intensity and nature of observed changes in this area. The results allow to qualify accurately (i.e. at the scale of the field) the type of changes, to quantify them and weigh up their intensity. Then, all the results are integrated in a probabilistic model to build-up a short time land use prediction.

Key words : Remote sensing, Change Vector Analysis, GIS, land use and cover change modeling.

1.INTRODUCTION

Land use and cover changes (LUCC) monitoring is a central issue for sustainable development. LUCC significantly modify earth-atmosphere interactions, and consequently bio-diversity and biogeochemical cycles of the earth. Furthermore, they contribute to the climate evolution as numerous studies proved it since several years in predicting the impact of land cover changes in global climate models. Thus, the implications of land use changes on the environmental processes are now considered in research programs on Global Change as the International Geosphere-Biosphere Program (IGBP). Nevertheless, beyond global scale vegetation maps, detailed and local information on LUCC are needed to validate observed changes at a global scale and also to identify any changes that are not perceptible at this spatial level. Also a comprehensive approach of LUCC monitoring implies the understanding of land use dynamics, spatial and temporal vegetation cover variations and needs to define human and environmental factors that locally motivate changes (Land Use/Cover Change Project – Reference LUCC Science Plan, IGBP/IHDP). Those factors strongly depend on agricultural techniques and land use management, which are highly linked with social, economical, political and environmental context.

In intensive agricultural regions, detailed monitoring of land use and land cover change represents an important stake. Some land management changes, in relation with industrial agro-systems, cause modifications that contribute to the increase of environmental problems: degradation of water quality is one of those. Thus, the knowledge of spatial and temporal variations of land use and land cover changes constitutes an important key for water quality action programs. For instance, winter land use evolution in the fields has an impact on pollutant flow transfers, that acts either as an accelerator when soils are bare or as a brake when covered with vegetation.
The follow-up of the evolution of land use and land cover changes is generally realized with remote sensing data like NOAA AVHRR, or more recently with SPOT VEGETATION images (resolution of 1km), to produce maps at regional or global scales (Lambin *et al*[1], Dubreuil *et al*[2], Champeaux *et al*[3]). These studies are often validated by using higher resolution data like Landsat TM or SPOT XS/Xi data. In some cases, the identification of land-cover dynamics at high spatial scales requires the elaboration of original methods or at least adaptation of methods used for global monitoring.

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The objective of this study is to follow-up LUCC and to model its winter behavior in an intensive agricultural region. In this paper, we focus on the Change Vector Analysis (CVA) method developed by Malila[4] in 1980 and refined by Colwell and Weber, in 1981, and latter by Lambin and Strahler[5]. This approach offers the opportunity to optimize the radiometric characteristics of each image, and then, to qualify and quantify the observed changes by calculating the magnitude and the direction of changes.

The originality of this study is the adaptation of the CVA to model the land use and land cover changes at the field scale in a region characterized by high spatial and time variations of the vegetation cover. The main objective of this study is to identify vegetation changes at the field scale during several winter seasons in relation with crop successions in order to define spatial and time trajectories that will improve the knowledge of the land use and cover evolution and its impact on the water quality.

2. CHANGE VECTOR ANALYSIS METHOD

For three decades, a wide range of methods and techniques have been proposed to model and monitor LUCC using remotely sensed images. Most of them can be grouped in two general classes (Johnson and Kasischke[6]):

- Change analysis by comparing raw data (method based on the exploitation of the radiometric value of each image)
- Change analysis by comparing classified data (intersection between classifications).

The main limitation of the classification approach lies on the increase of errors due to mis-classifications. Moreover, it gives little information about the LUCC dynamics (Malila[4]). On the other hand, the change analysis method, that uses raw data, may be applied with multiple approaches to detect the change between two images such as band differencing (Weismiller *et al*[7]), transformed band differencing as vegetation indices (Nelson *et al*[8]), regression (Singh[9]), rationing (Howarth *et al*[10]), CVA between multispectral data (Malila[4])…This last method offers several advantages : a more complete use of the data since all radiometric values for each pixel are taken into consideration; a more accurate result with the identification of the magnitude and direction of the land cover changes; a more adaptable method according to the objectives of the study thanks to the scalability of the CVA (Lambin[11]).

"CVA is a multivariate method, which takes n bands, transforms, or spectral features as input from each pair of scene"(Johnson, Kasischke[6]). The method is based on the measure of the radiometric changes to follow-up of the LUCC. The measure of the radiometric change is evaluated with two components:

- The Euclidian distance that separates radiometric values of the same pixel at two dates; it characterizes the magnitude (M) of change and measures its intensity.
- The angle of the direction (D) of change that indicates the nature of the land cover change.

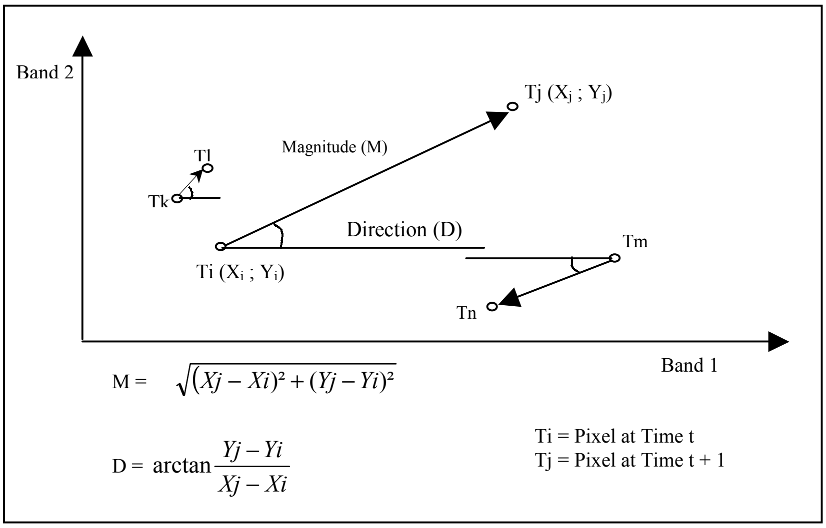


Figure 1. Change vector representation in a two-band radiometric space

The **figure 1** shows a naive simulation of the evolution of two pixels (Ti and Tj) represented in a two-dimension space. Bands 1and 2 may be used as a composition of bands like a vegetation index (NDVI, TSAVI…) as well as an orthogonal transformation (Principal Component Analysis), or red and near-infra red bands… The magnitude value that measures the intensity of change for the pixels Ti and Tj is calculated with the radiometric values of each pixel. Since the magnitude depends on the evolution of the two pixels over the time, the magnitude is high for [Ti-Tj] and low for [Tk-Tl]. “The direction of the change corresponds to a diagonal connecting the origin with the opposite corner of the parallelepiped defined by the vector” (Lambin *et al*[1]). The angle of the vector between the two dates characterises the direction of the change, illustrating for instance gain or loss of vegetation. On the figure 1, the angle of [Tn-Tm] may characterise a loss of vegetation and the angle measured on [Ti-Tj] a gain of vegetation.

Since CVA consists in the comparison of radiometric values for each band, high-quality data pre-processing are required. Radiometric and geometric corrections are essential when the purposes of the image processing are:

- To get physical values (by transforming numeric value to reflectance value)
- To make multidate comparison between images coming from the same or any sensor.

3. WINTER VEGETATION COVER MONITORING

3.1 Study area and data

The CVA was applied on a watershed, the Yar (61,5 km2) located on the western coast of Brittany (West France). Intensive farming combined with wet and warm autumns produce significant amounts of nitrogen before winter infiltration of water. For several years, high nitrogen rates are observed in rivers, mostly due to an excess in fertilization. Another effect is the euthrophization phenomenon, which occurs in the shape of algae bloom in spring on the coastal area, and that is extending from year to year. Consequences on environmental and tourist activities have lead local authorities to take decisions to restore water quality. In this area, crops cover approximately 60% of the total vegetated areas. Main crops are produced in relation with industrial breeding, principally corn, wheat and artificial meadows. During winter, which means a rainy season, most of fields remain traditionally without any vegetation cover after harvesting corn. In this area, nitrogen inputs are still too high, especially on bare soils that follow and precede corn implementation during the winter. The follow-up of LUCC is particularly difficult in this region, since spatial and time land cover variations are often high and the driven factors of changes are multiple.

Change detection method must be used according to the regional context and must provide a fine change detection in order to be a powerful decision tool for the actors of the water restoration quality program. For winter trajectories, the detection of change should point out, at the field scale, the evolution between two years, at two levels: vegetation cover conversions (e.g. bare soils in T1 to cover soil in T2 and *vice-versa*), the rates of soil cover and their evolution between two years as far as transfer flows are concerned. To reach these objectives, CVA method has been adapted to the field scale.

A set of 12 remotely sensed images (11 SPOT images and 1 IRS-LISS III -2 per year over 6 years from 1996 until 2002) is used for this study. The 5S model has been used for its relative simplicity to correct atmospheric effects (Tanré *et al*[12]). All the images have been then normalised with a “reference” image, the scene that has the widest radiometric dynamic range (winter 1999/00). Furthermore, geometric corrections are applied for each scene (with at least six ground control points) and data are registered in a geographical referential (Lambert 2 Conforme), with a low RMS error (<0.5 pixel). Then, all the scenes can be used for multispectral processing.

Field characteristics have been regularly collected on the field to validate image processing.

3.2 CVA processing procedure

The follow-up and the modelling of the land use changes have been carried out in two steps:

- 1) the crop successions from winter 1996/97 to winter 2001/02 have been defined with supervised classifications (with the classical maximum likelihood method). The fields limits were updated each year from satellite data and the results were integrated into a GIS (L. Hubert-Moy *et al*[13]). At this step, the objectives are to quantify and localize the bare soils on the whole watershed. Though in this way, some fields may be detected as bare soils whereas it is a young crop (wheat for example); with the knowledge of the following spring and summer land cover, it is possible to know if the field was really a bare soil during all winter or if, *a contrario*, a winter inter-crop has been sown. Even if the classification method does not allow to quantify precisely the vegetation cover, it gives a good idea of the global winter inter-crop coverage during the winter season. On the **table 1**, we can note that the evolution of bare soils is very low between two winters even if during the winter 2000/01, the proportion is slightly lower (4.1%). Agricultural policies now encourage the farmers to cover their fields in winter, the results on the winter 2001/02 will confirm this evolution or will show that we were in the cycle of crop successions.

Winter 1996-1997	**Winter 1997-1998**	**Winter 1998 1999**	**Winter 1999-2000**	**Winter 2000-2001**
330 ha	331 ha	314 ha	331 ha	253
5.4%	5.4%	5.1%	5.4%	4.1%

Table 1. Bare soils in winter between two crops, by ha and % of the total surface (1996-2001)

Multi-temporal classification allows to localize the "sensitive" fields that are not covered with vegetation during four or more winters since 1996 and to establish a diagnostic about the crop succession evolution.
Nevertheless, in relation with research on pollutant transfers (like nitrogen flows), a finest study of the cover soil and its evolution is required for a more realistic modeling of LUCC in relation with the water quality.

- 2) CVA proves its greatest utility when full-dimensional radiometric change information is required (Johnson *et al*[6]). In this study, where all changes between winters are potentially interesting to map, CVA appears well adapted since it can capture change information through spatial and time land cover and land use trajectories.
For instance, see figure 2 for the follow-up of the land use changes flowchart for the winters 2001 and 2002:

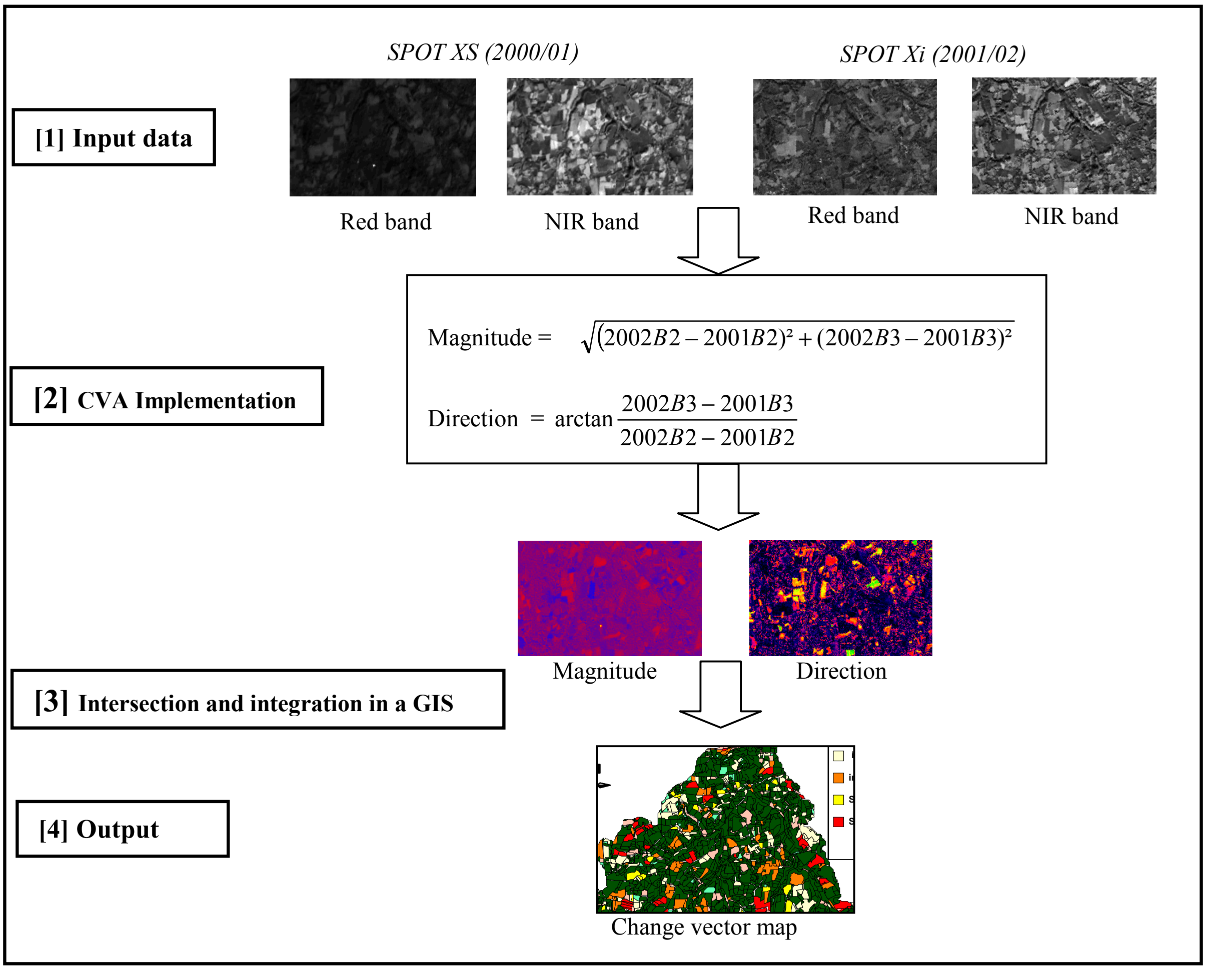


Figure 2. Change vector determination for winter vegetation covering at the field scale (1996/2002)

The Figure 2 shows the different steps of the application of the CVA on the Yar watershed. For the application of the CVA, the red and near infrared bands are selected for their radiometric characteristics **[1]**. Since the near infrared is sensitive to the vegetation and the red band is sensitive to the bare soil, exploitation of these bands allows to identify the rate of vegetation in the fields with a good accuracy. Then, The magnitude and direction formulas **[2]** are applied. The resulting images give the intensity of the change (Magnitude) and the type of the change (Direction). A threshold (**Table 2**) is applied to each image **[3]** and, the two resulting images are mixed and the resulting values are affected within the fields' boundaries into a GIS **[4]**.

Magnitude	**Direction**
1: no change [0; 5]	1: No change [-2; 5]
2: low change [6; 10]	2: Gain of vegetation [6; 31]
3: High change[11; 20]	3: Loss of vegetation [-27; -3]
4: Very high change[21; 57]	

Table 2. Threshold of the Magnitude and Direction images

4. RESULTS

Figure 3 illustrates the CVA results. Analysis by CVA shows that the watershed is concerned by few changes between those two winters (See **Table 3**), 4484 ha (out of a total area of 6150 ha) are classified in the class "no change". They correspond essentially to forest or fallow land. The surface affected to the "very high change" class totalizes only 239 ha (81 ha with a loss of vegetation and 158 ha with a gain of vegetation).

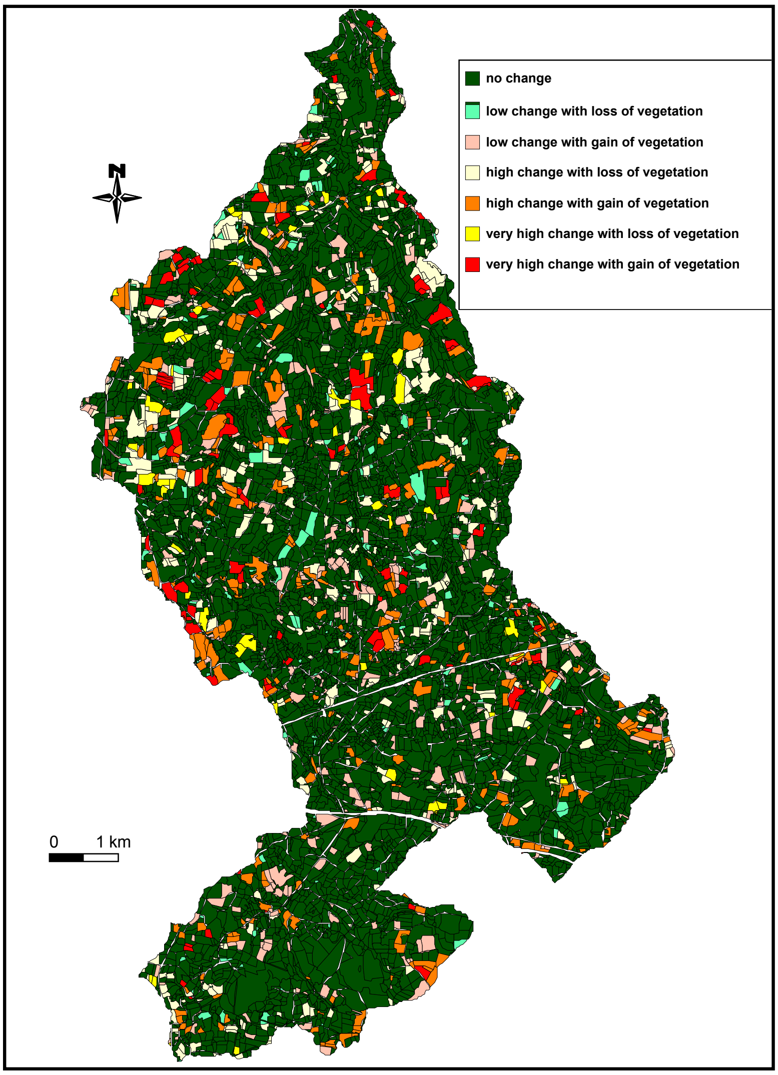


Figure 3. Winter vegetation covering change with CVA on the watershed of the Yar (winter 2000/01-2001/02)

The "very high change with loss of vegetation" class corresponds to fields that were totally covered during the winter 2000/01 and bared in 2001/02. The management of the fields depends on several factors and is very difficult to model ~~it~~. However, these types of dramatic changes are generally due to the cycle of the crop successions. The "very high change with gain of vegetation" class is more important than the class 6. Climatic conditions are in this case a determinant factor: the winter 2000/01 was very rainy and most of the farmers

couldn't sow inter-crops during the winter. On the contrary, the winter 2001/02 was dry and climatic conditions were not a restrictive factor for crop sowing.
Classes 4 and 5 ("high change with gain or loss of vegetation") represent a significant part of the watershed changes with a total of 759 ha. The changes of classes 4 and 5 are less radical than the ones of classes 6 and 7 but play a major role for the flows of nitrogen transfers since it represents 12.4% of the overall watershed surface. For the class "high change with loss of vegetation", it can correspond for example to a field that was either covered with vegetation during the winter 2000/01 and with few vegetation during the next winter or to a field partially covered with vegetation in 2000/01 and without any vegetation cover during the winter 2001/02.

The watershed upriver is characterized by little changes (presence of important forest areas). On the contrary, in the north of the watershed (more precisely the north-west), important changes can be noticed in relation with intensive agricultural practices occurring in this part of the watershed. The high rhythm of the crop successions induces strong changes between all winter seasons. However, the CVA allows to discriminate fields that have potentially a major role in the pollution flows, at a higher scale and it shows the global evolution of the land cover and its dynamics on the watershed.

Classes	**Surface (ha)**
1: no change	4484
2: low change with loss of vegetation	103
3: low change with gain of vegetation	301
4: high change with loss of vegetation	392
5: high change with gain of vegetation	367
6: very high change with loss of vegetation	81
7: very high change with gain of vegetation	158

Table 3. Classes of change from CVA results (winter 2000/01 and 2001/02)

This application of the CVA method shows that it's become possible to follow-up the vegetation cover changes at a field scale. Also, it allows the identification of some spatial and temporal land use trajectories. On **figure 4,** some specific trajectories are defined:

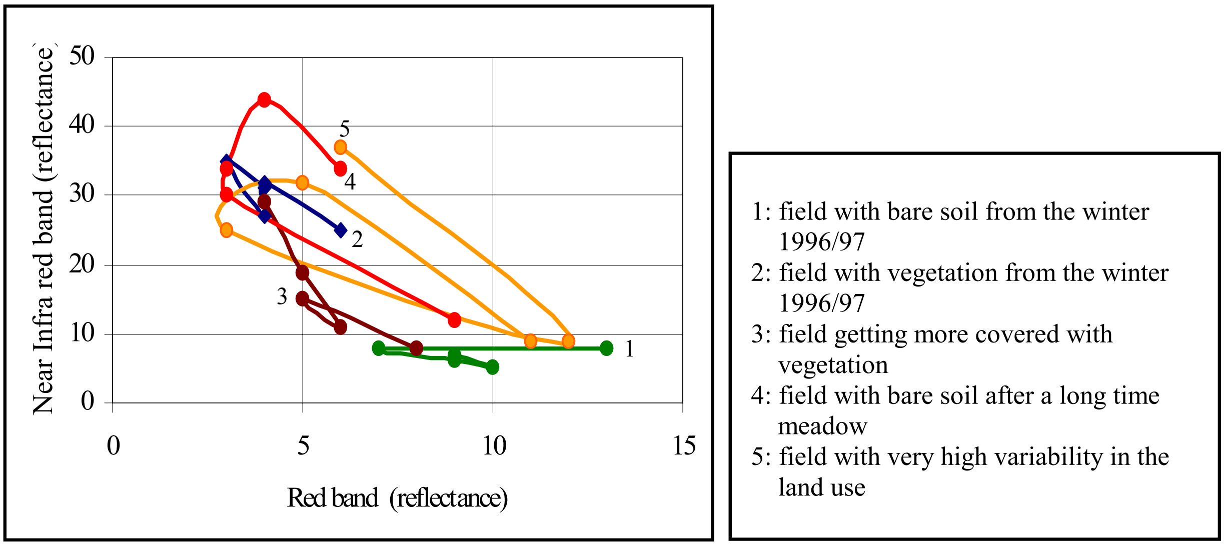


Figure 4. Determination of radiometric trajectories of five test fields (Yar's watershed, 1996-2001)

The fields, which have met little changes between two winters (curves 1 and 2), are characterized by short curves that illustrated short spatial-temporal trajectories. On the contrary, fields with high changes have a stretched curve due to significant radiometric changes between two successive winters.

Results of the intersection of the CVA resulting map and the occurrence bare soil map produced from the multitemporal image classification [Fig.5a; Fig.5b] are shown on **figure 5**. It allows to spatialize and discriminate the land use trajectories and their spatial and temporal evolution.
For instance, fields that are concerned with no or little changes between each winter (trajectory T2 and T2b on the Fig.5c and Fig.5d), correspond essentially to fields that belong to the category "bare soils" since the winter

1996 or, as well, to "forest areas" and "permanent meadows" located near the river stream. The fields covered with vegetation from 1996 to 2002 totalize 3914 ha. More than 2750 ha are characterized by low changes and 1164 ha by at least one important or high change during the 6 winter-period. Among these latest, 527 ha are detected with a gain of vegetation and 637 ha with a loss of vegetation.

On the other hand, some fields are concerned with high variations between each winter. For instance, the trajectory T1, shows that during the winter 98-97 and the next winter a high change with gain of vegetation has occurred, followed by a high change with loss of vegetation during the winter 99-98, followed by two winters with low changes gain and loss vegetation, and finally by a high change detected between the two last winters. In this case, 3 winters with the "bare soil" class are detected. The trajectories with high variations of land cover concern especially the fields where two to five "bare soil" situations have been detected since the winter 1996. They totalize 840 ha, 66% have met important or very important changes between the winters and only 274 ha with few or no changes. If we focus on the fields with 4 "bare soil" situations since 1996, almost 70% are concerned by trajectories where at least one winter with loss of vegetation is included and about 62 % of the changes are classified as important or very important.

Thus, the combination of the classification method with the CVA provides a finest change detection. Also, the classification results quantify the land cover evolution (follow-up of the bare soil in winter since 1996). The CVA proved to be a robust method for qualifying the changes (in the determination of the land cover rates and their evolution between from a winter to another) and the combination of the two methods allows, at a field scale, to produce land use trajectories for a better understanding of the LUCC.

With the help of these information, a model based on a probabilistic theory (Dempster-Shafer theory) has been successfully applied to predict a short time bare soils evolution (Hubert *et al*[14]).

5. CONCLUSION AND FUTURE WORK

In this study, the follow-up of the land use and cover had to identify the land cover dynamics at field scale, in the context of a water quality restoration program. A classic approach is first applied with the determination of the crop successions issued from supervised classification of the satellite data. Then, a characterization of the land use for each winter and its evolution is achieved. Nevertheless to characterize and weigh up the evolution of observed changes in winter, a finer method is required. The Change Vector Analysis has been chosen for its ability to using the radiometric data of each image. In several studies, the CVA has already shown its advantages to capture all changes, but most of them were achieved at regional scale. The application of the CVA on the Yar's watershed has required an adaptation of the method to manage, to qualify and identify the changes at field scale. The combination of the two techniques produces spatial-temporal trajectories for each field. All those data represent parameters to integrate in a flow nitrogen model (INCA) that predicts the water quality at the downstream of the river. Thus, the CVA provides an important source of information that can be used in multiple applications.

All the data yielded are intended to be integrated in flow nitrogen's model (INCA: Integrated in Nitrogen Catchment Area, UE, 5th Framework Program, USARQ-INRA/COSTEL). They represent one of the parameters integrated in the model to measure the evolution of the water quality in this region and elaborate predictions. Moreover, the results are integrated in a probabilistic model (that use the Dempster-Shafer theory) to perform short time predictions of the land use and cover in winter.

[1]

Fig. 5a

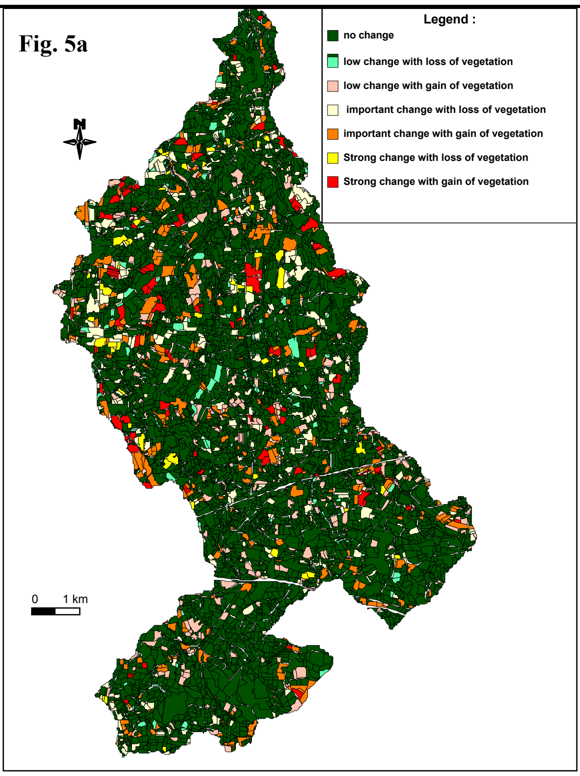
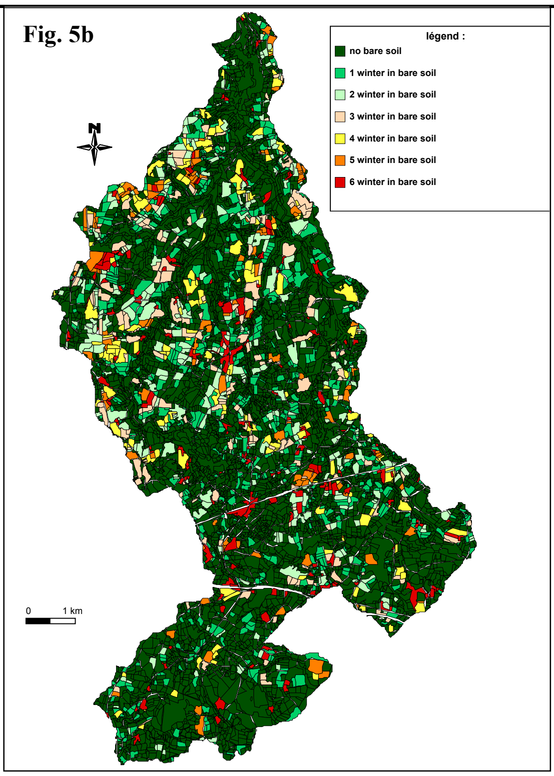


Fig. 5b



[2]

Fig. 5c

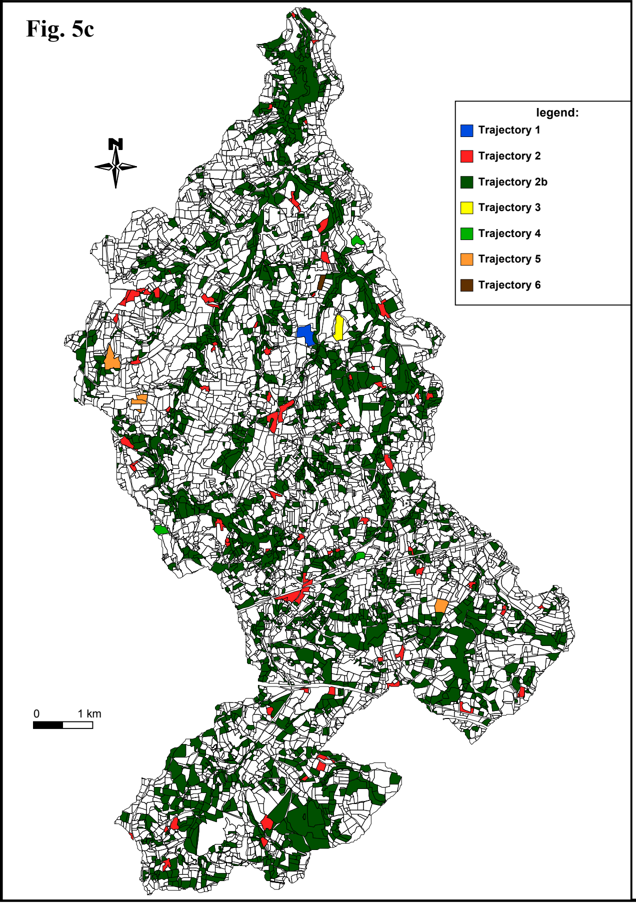
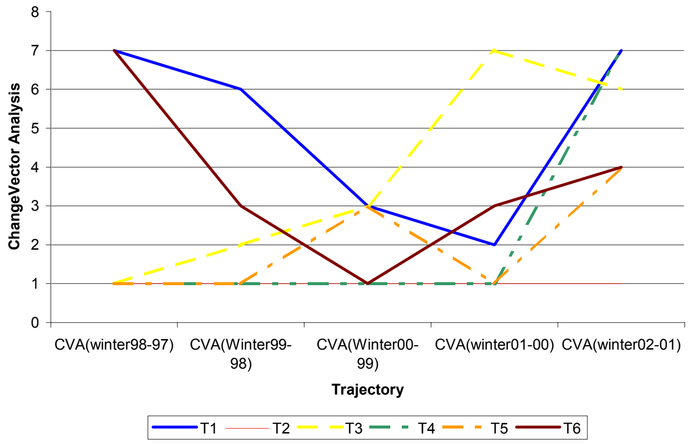


Fig. 5d



Change Vector Analysis

1 : no change
2 : low change with loss of vegetation
3 : low change with gain of vegetation
4 : high change with loss of vegetation
5 : high change with gain of vegetation
6 : very high change with loss of vegetation
7 : very high change with gain of vegetation

Trajectory

[T1] : land cover trajectory with 3 winters in bare soil
[T2] : land cover trajectory with 6 winters in bare soil
[T3] : land cover trajectory with 4 winters in bare soil
[T4] : land cover trajectory with 5 winters in bare soil
[T5] : land cover trajectory with 2 winters in bare soil
[T6] : land cover trajectory with 1 winter in bare soil

Figure 5: Determination of the land cover trajectories and their evolution; [1] Intersection of the CVA (a) and the bare soil occurrence map (b); 2] Spatialisation (c) and determination (d) of the land use trajectories at field scale

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