Food and Agriculture Organization of the United Nations

"Senegal Land Cover Mapping"

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1 - Executive Summary

The GLCN activities for the Senegal Land Cover mapping have been finally concluded. The preliminary and the final interpretation work were carried out in the GLCN office at Centre de Suivi Ecologique (C.S.E.), in Dakar (Senegal). In addiction, within the LADA framework, an analysis of land cover changes in Senegal was performed and reported in "Senegal Change Assessment". The analysis covered all the classes present in the Senegal 2005 Land Cover legend; particular attention was given to the more sensitive areas such as Forest, Agricultural land and Urban areas using images taken in two dates: 1990 and 2005. Both the final Land Cover revision/accuracy assessment and the analysis of land cover changes in Senegal, were carried out at the GLCN office in Florence (Italy).

The land cover legend of Senegal, consisting of 55 classes, was set up using the F.A.O. LCCS methodology. The analysis was based on a set of corrected Landsat ETM images dated 2005. To affine the interpretation, a set of aerial photos donated by USGS and the high resolution images of Google Earth have been used. The mapping scale used for the Land Cover visual photo-interpretation was 1:100.000. Senegalese full resolution Land Cover dataset consists of 23,922 polygons, covering an area of 19,659 thousands ha.
During the fieldworks carried out all across the country, 170 field forms have been compiled; moreover, about 700 field extra observations (GPS coordinates, a photo and a short description/code for each point) incremented the field work data which have been afterwards hot-linked in an interactive database.

Capacity building was one important aspect of this project since it will contribute to develop further land cover activities in Senegal. The technical staff involved received regular training during the different phases of the project, resulting in highly experienced image analysts. Further, the software provided and the methodology applied, will constitute an important resource for the future updates of Senegal's land cover.

2 - Ancillary Data

This section gives an overview of the ancillary data collected for the photo-interpretation work, providing at the same time a deeper technical insight to the approach developed for Senegal land cover photo-interpretation activities.

The initial steps were all focused to enable the working group being as much as possible independent in the visual photo-interpretation work and to get a good understanding of both the methodology and the working chain steps. The images used to carry out the interpretation work were:

- A set of 12 Landsat ETM scenes of 2005;
- A set of 13 Landsat ETM scenes of 1999-2001;

The spatial resolution is 30 meters. Figure 1 shows the acquisition dates for each image used for the visual photo-interpretation.

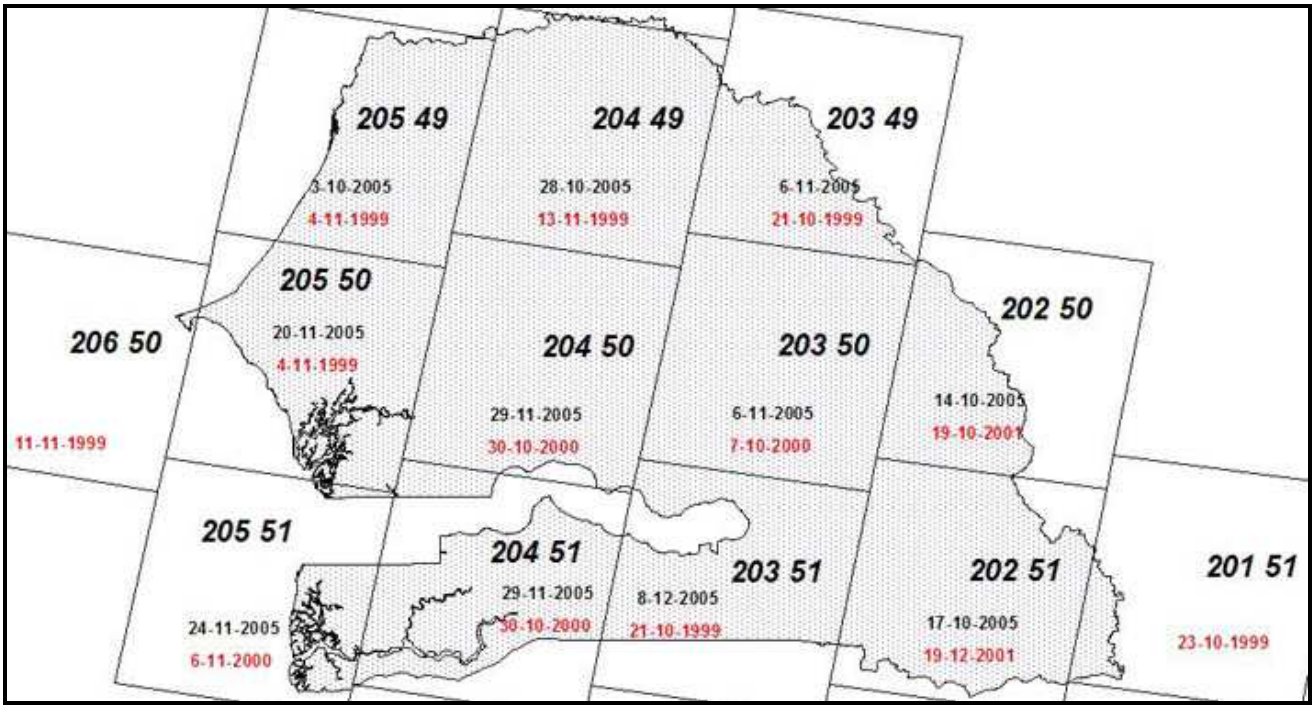

Fig. 1 – *Scheme of the Landsat images used for the interpretation with the acquisition dates of 2005 (black) and 2000 (red).*

With the Landsat ETM (432 RGB composit) scenes covering Senegal were prepared two mosaics in Radex format, a particular format developed by Terranova the software-house who also implemented GeoVIS, the software used for the visual interpretation.

The Radex format strongly reduces the image size keeping the same resolution of the original images. So, it make possible to work on mosaics of several Landsat images, avoiding to slow down the work progress owing to the greater weight of the Tif format images. Given that Senegal falls inside 2 UTM zones (28 and 29 North), it was necessary to create 2 Radex for each UTM zone of each date. In addition to the two Radex mosaics, one more mosaic of the eleven 2005 Landsat images in Tif format was also produced to display the satellite images with other GIS software (Arc View, Arc GIS, etc.)

In addition to the two Radex of the whole Senegal, Centre de Suivi Ecologique (CSE) made available to the project aerial photographs of Tamba, Kolda, Salemata and Ouli regions. With the aerial photos of these regions four Radex mosaics have been prepared and used during the interpretation work.

The photo-interpretation shapefiles of Tamba and Kolda regions (given to the project by CSE), have been used as starting points for the interpretation of these areas. The legend of the former interpretation was translated in the respective LCCS classes and the polygons smaller than 5 ha have been eliminated, since the smaller Minimal Mapping Area was fixed to 10 ha.

The Tamba and Kolda shapefiles displayed a shift with the 2005 images, used as reference base for the interpretation. So they have been corrected, and georeferenced again in order to reduce as much as possible the shift, giving a reliable base for a further interpretation. The result is shown in below Figure 2.

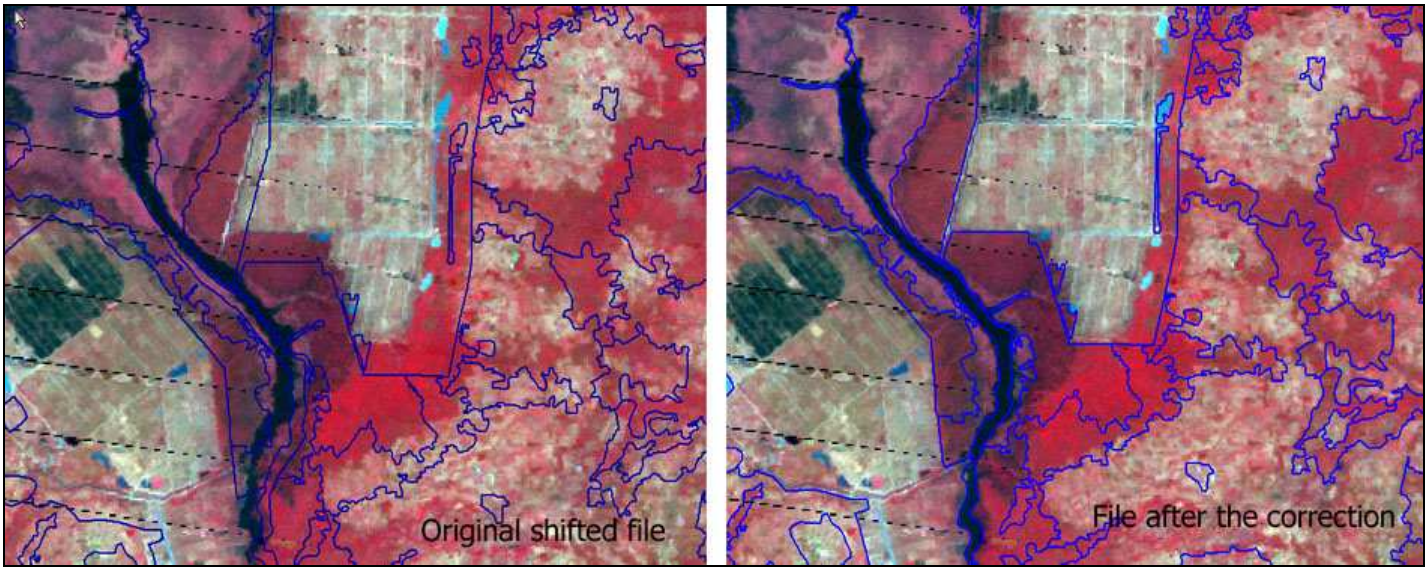

Fig. 2 – *An example of the shift displayed from a portion of the Kolda shapefile. On the left the original file as it used to appear, and on the right the result of the new georeferenced file after the correction.*

Some more shapefiles, covering the Dakar area, have been given by CSE; among them, the land cover interpretation referred to the years: 1978, 1986, 1995 and 1999. The land cover shapefile of 1999 has been used as the base for the interpretation of the Dakar area and no correction was needed. The codes have been translated in LCCS classes and the very small polygons eliminated.

The ancillary data given to the project by USGS consist in 758 geocoded aerial photographs, covering all Senegal and Gambia. They were taken during the 1994 country aerial survey campaign. The aerial photos became one reliable reference point for the photo-interpretation work, since they have been linked with the points in order to give the photo-interpreter a straightforward overview of the ground truth as seen from the plane. Aerial photographs give a better perspective compared to the one taken on the field, since they show effectively the spatial distribution and the coverage of the features.

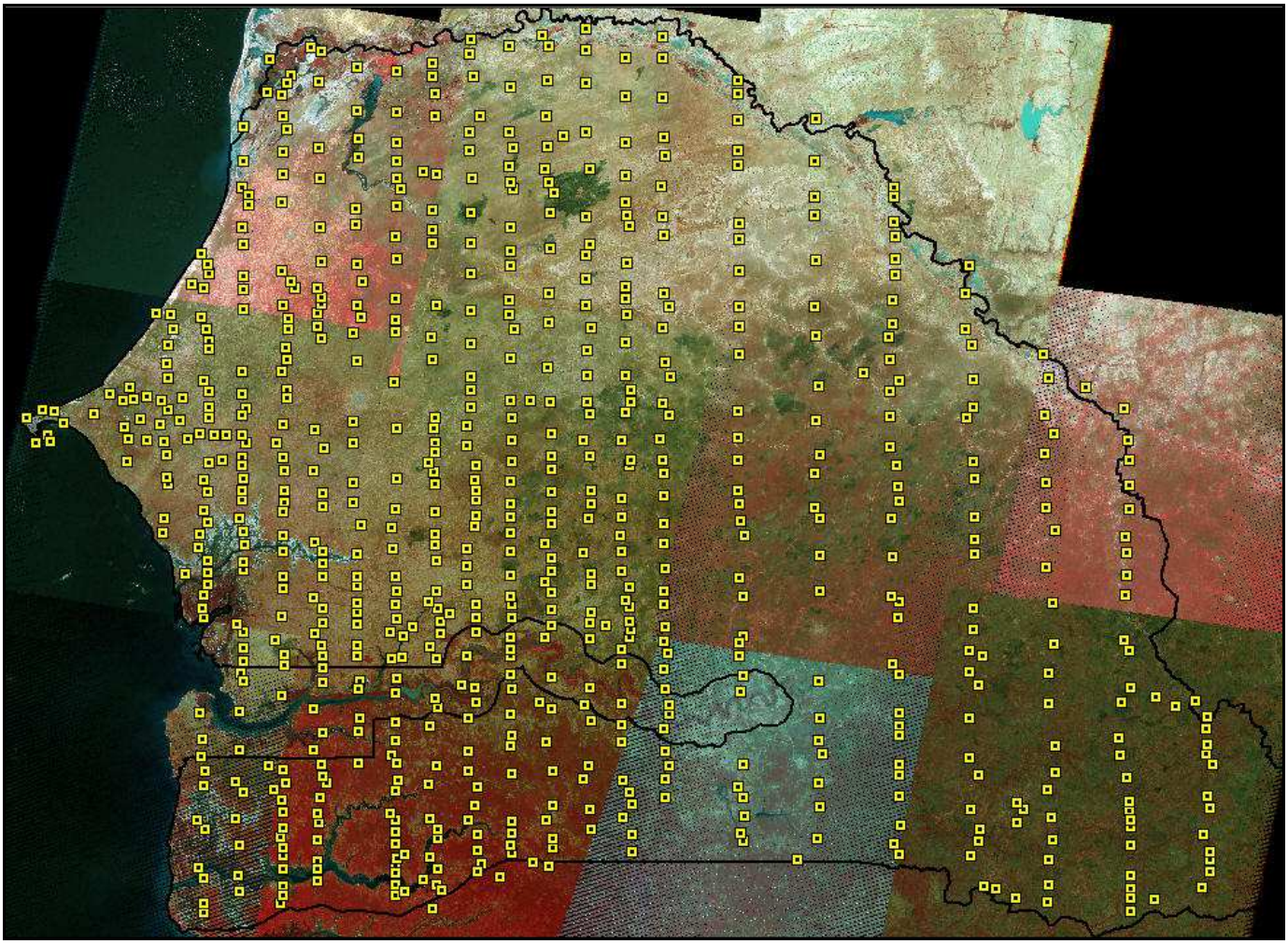

Fig. 3 – *USGS Aerial Photograph distribution.*

The output of these aerial photos is an Arc View shapefile where the points are coded and linked with photographs. This way, a further interpretation device was given to the photo-interpreters. Actually, just clicking with the hot-link tool on the point falling on the area to investigate, the corresponding aerial photo appears. Therefore, it helps to find interpretation keys and to have a better perception of reality as it appears on the satellite image, comparing it directly with an overview of the field truth. An example is showed by the figure below:

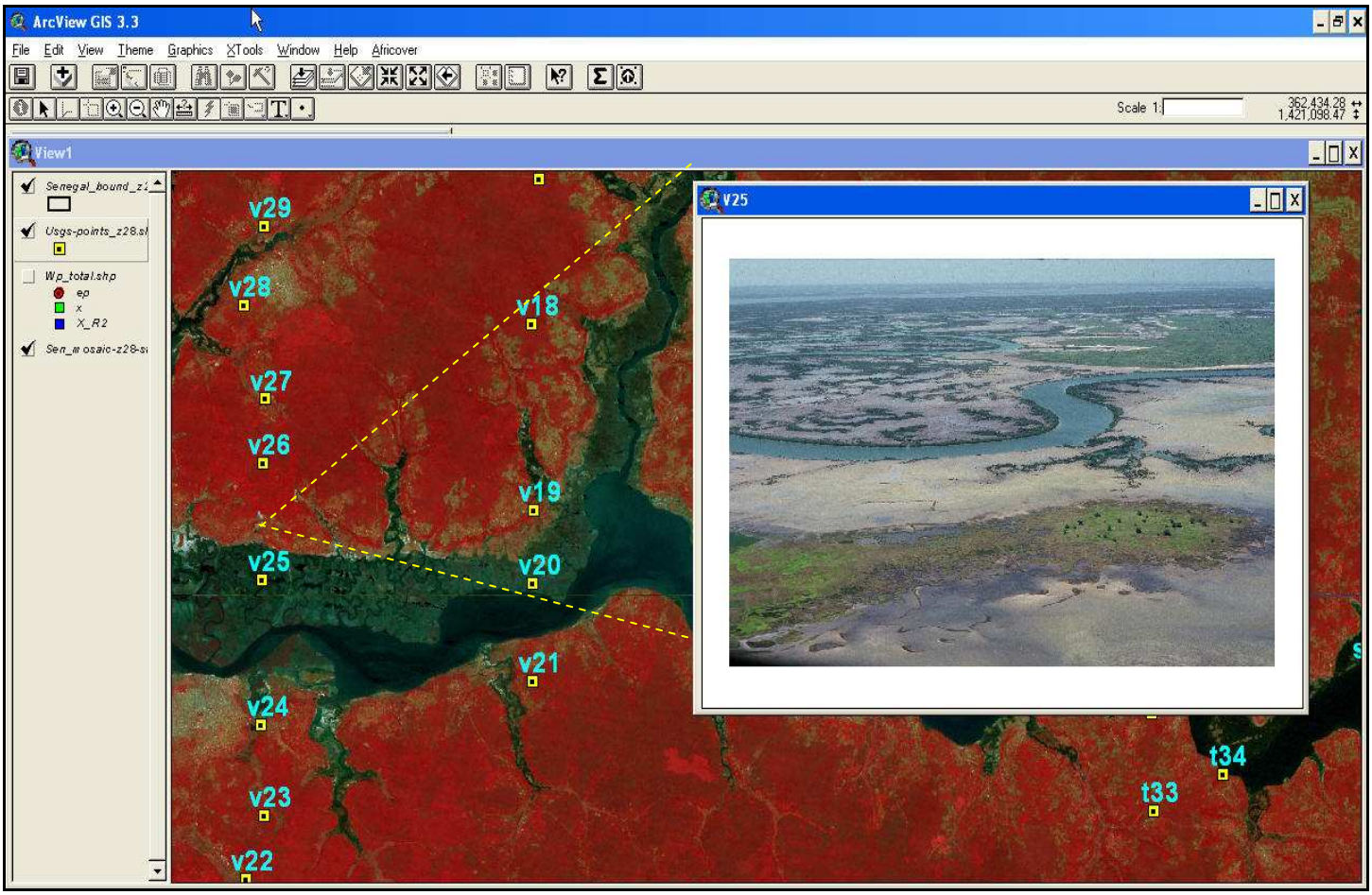

Fig. 4 – *An example of the hot-link between the points and the photos taken during the 1994 USGS aerial survey of Senegal. Clicking on any yellow point ("v25" in this case) the corresponding picture appears.*

The original classes of the former 1984 Senegal Land Cover map (scale 1:1.000.000) have been grouped in major land cover classes. The vector shapefile has been converted in a raster file and georeferenced in order to give one more interpretation tool to the photo-interpreters; in fact this map shows the distribution of the main types of vegetation covers according to the climatic zones.

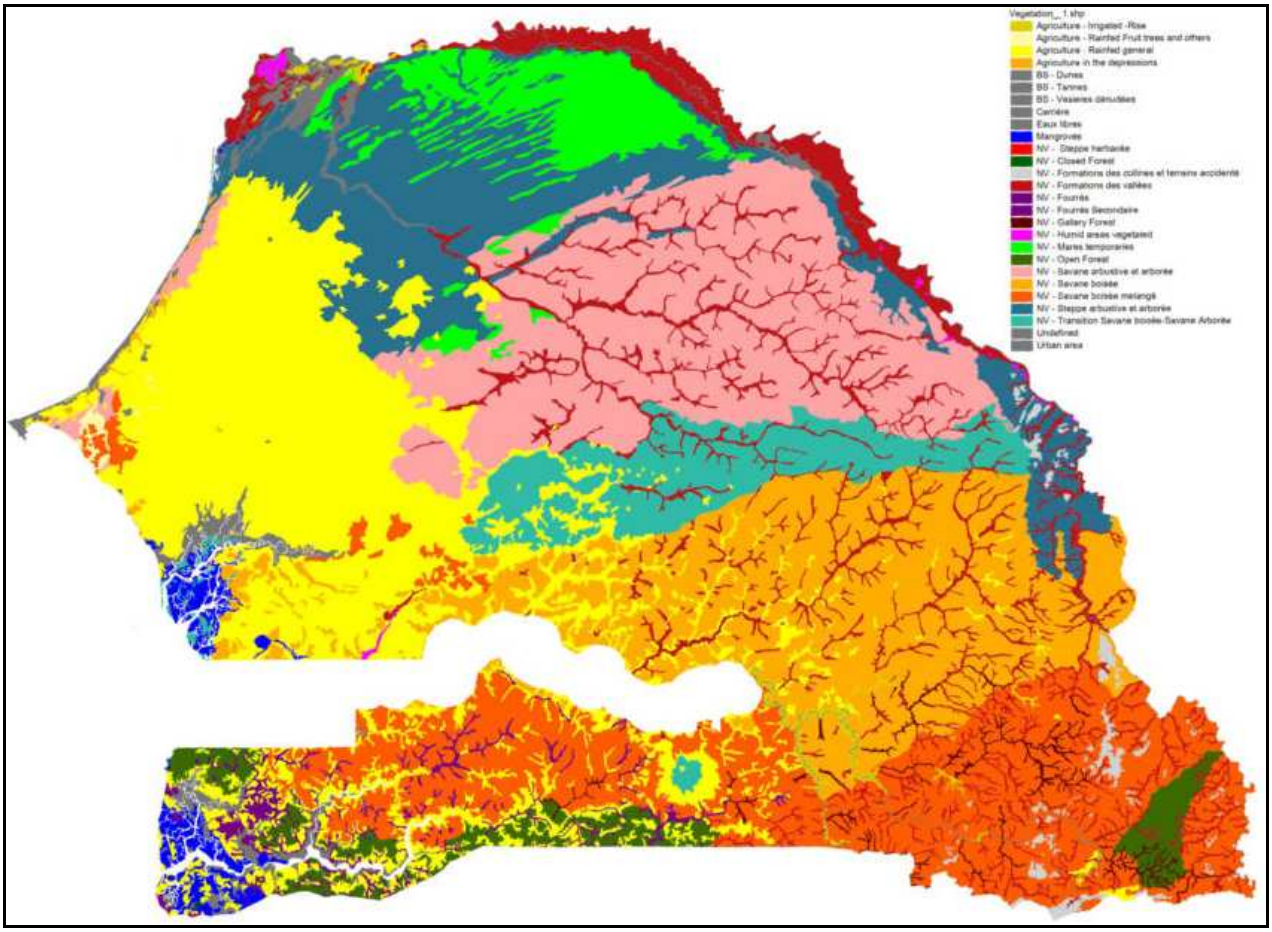

Fig.5 – *The 1984 Senegal Land Cover map.*

3 - Photo-interpretation

The implementation of Senegal Land Cover map is based on the multi-phase image interpretation approach, which was successfully used by FAO in a number of projects. The visual on-screen interpretation was carried out using the GeoVIS software (http://www.geovis.net/). GeoVIS is a vector-based editing system specifically designed for thematic interpretation. It is a user-friendly system that embeds the main tools of vector drawing and editing, including topological functions, with advanced capabilities of raster management (Radex) and a direct link with LCCS (Land Cover Classification System) software.

The analysis was based on a set of corrected Landsat ETM images dated 2005. To affine the photo-interpretation was used the set of above described ancillary data. The mapping scale used for the Land Cover visual photo-interpretation was 1:100,000.

In agreement with the Senior Mapping Expert it was decided to map always using the GeoVIS "Multiple Windows" tool, in order to visualize at the same time the Radex mosaic of both dates 2000 and 2005, during the digitization. It was also decided to use as digitization base the 2005

images even if they show, in some portions, black strips due to the Scan Line Corrector failure affecting Landsat satellite sensor from 2003 onward (Fig.6 and Fig.7). Whenever the noise caused by the black strips made difficult the interpretation of the 2005 image, then the 2000 one was used as reference base.

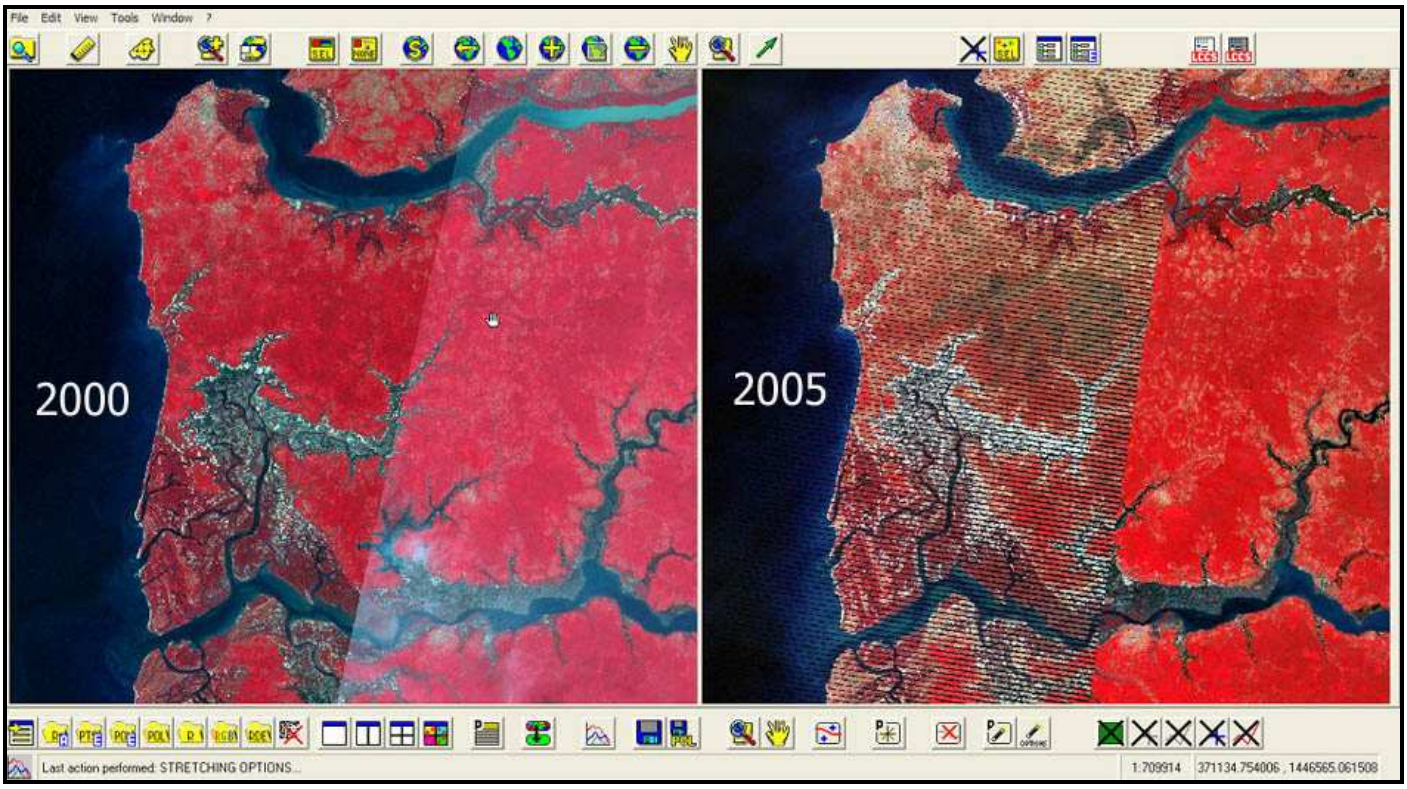

Fig. 6 – *The GeoVis multiple window tool. On the right side the 2005 image with black strips due to Landsat sensor problems.*

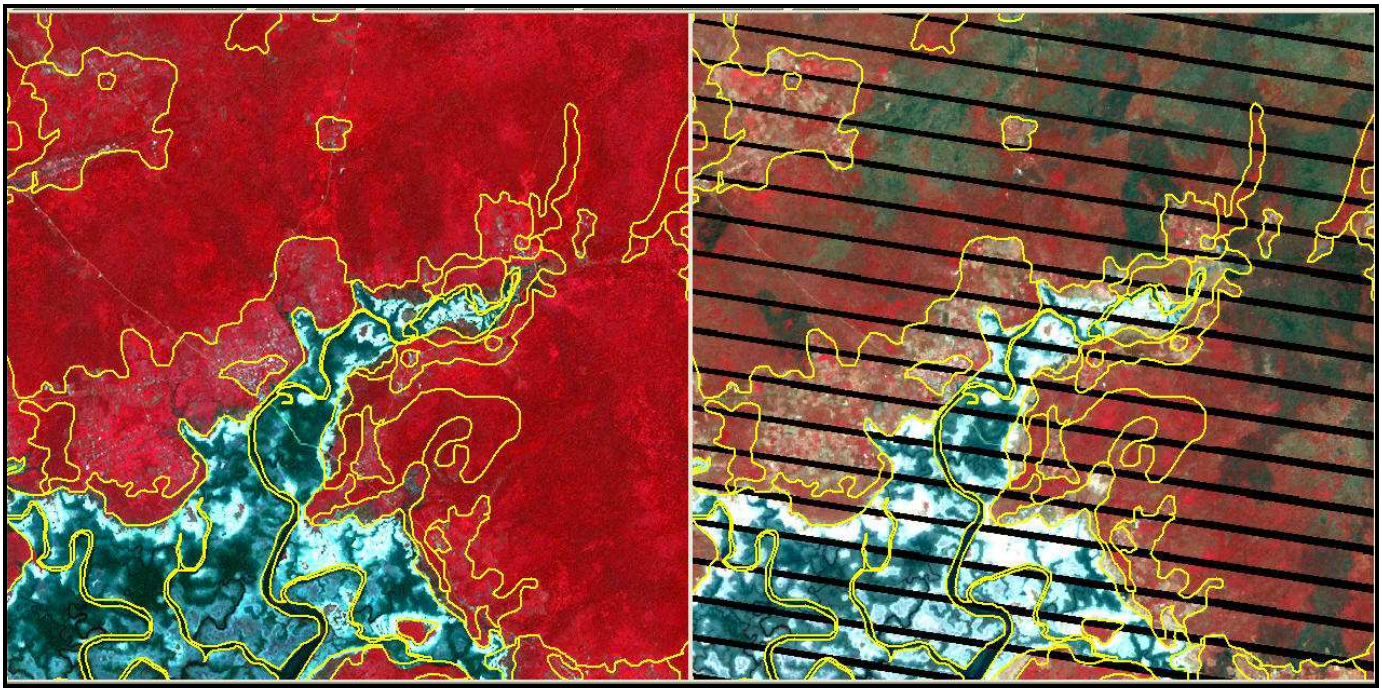

Fig. 7 – *The left window shows the 2000 Landsat image; the right window shows the same portion of image dated 2005. The latter is affected by black strips noise due to Landsat sensor problems. The scale is 1:100 000.*

As concern the visual interpretation, it was agreed to give more weight to the image showing the driest situation, in order to avoid an overestimation of the vegetation cover, getting a more reliable interpretation. Actually, the herbaceous layer presents during the wet season most of the time covers the reflectance of trees and shrubs, making sometime a difficult task to separate the different natural vegetation classes. Usually the November date is the best one, since it shows the dry situation after the rainy season (i.e. the herbaceous component is already almost dry, while the trees and shrubs component still shows their typical dark red reflectance).

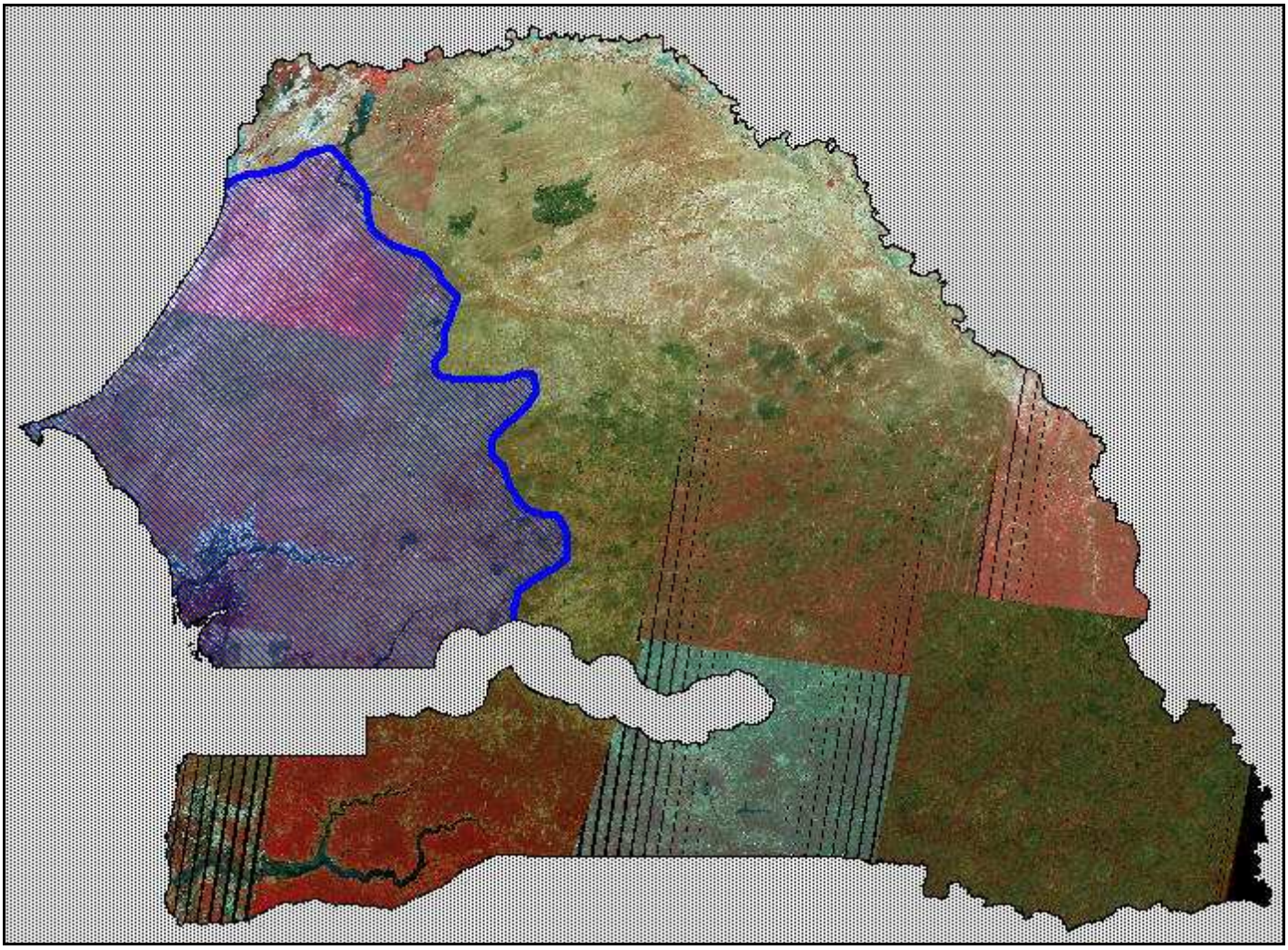

Fig. 8 – *In blue colour is highlighted the approximate area of the Peanut Basin.*

Concerning the agricultural areas falling inside the so called Peanut Basin (Fig.8), it was decided to map the agriculture present in both dates. So, the agricultural classes displayed on the final interpretation of this area will show the sum of the agricultural areas of the period 2000-2005. Actually, the whole Peanut Basin is a big agricultural area, where fields may have a fallow period that, in this case, was considered no longer than 5 years. During the fallow period the cover consists mostly of grass and light bush vegetation. Natural vegetation mapped inside this area was detected both in 2000 and 2005 image.

In addiction to the ancillary data collected, the **Google Earth** freeware (http://earth.google.com/) gave an extraordinary chance to photo-interpreters to detect the land cover feature. Almost one third of Senegal (Fig.9) is covered by high resolution satellite images which can be freely displayed. For this reason all the photo-interpreters computers have been provided with an internet connection and the Google Earth software.

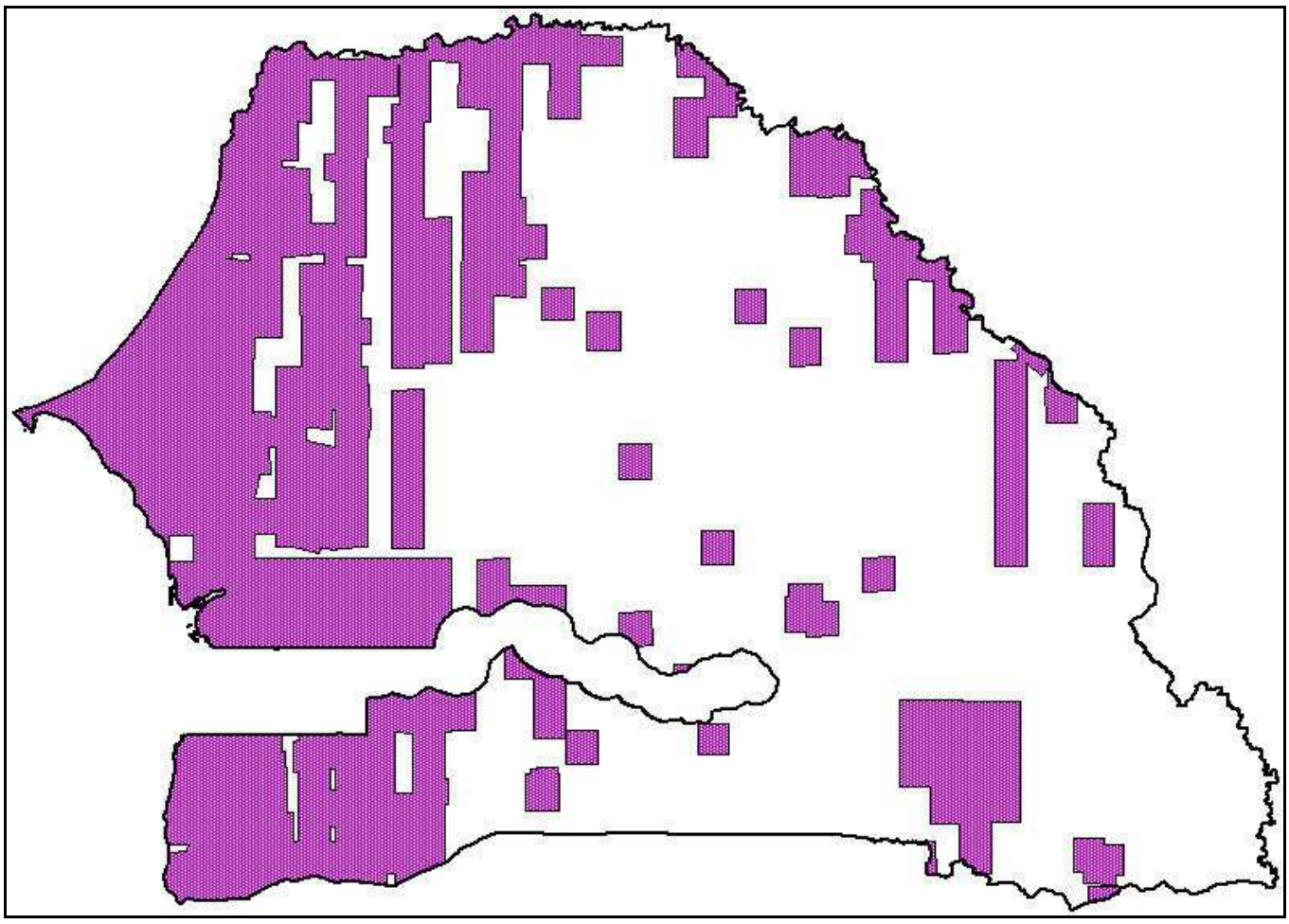

Fig.9 – *Violet colour represents the Senegal areas covered by Google Earth high resolution satellite images.*

Without taking anything away from the credits of the powerful Google Earth tool, in same cases its use produced controversial interpretations, due to the drastic changes in vegetation cover caused by seasonality. This change is especially marked in woody vegetation (shrubs and trees) which in Senegal normally is broadleaved deciduous. It means that woody vegetation, during the dry season, is leafless so if the acquisition date of the image analyzed corresponds to the dry season, the woody vegetation almost disappears. Therefore, the use of the Google Earth high resolution images imply a good knowledge of the area seasonality, i.e. when both dry and wet season occur, in order to give a correct interpretation of the vegetation cover.

Fig.10 – *Examples of seasonal changes affecting woody vegetation on Google Earth high resolution images.*

The same difficulties to give a correct visual interpretation was encountered analysing and comparing Landsat ETM images with different acquisition dates; in fact, as it was explained at the beginning of this paragraph, the black strips problem of the 2005 Landsat ETM images was overcome using Landsat images dated 1999, 2000 and 2001 whenever it was needed. On the reverse, the analysis of images with different acquisition dates gave sometimes the chance to estimate the water persistence in flooded areas.

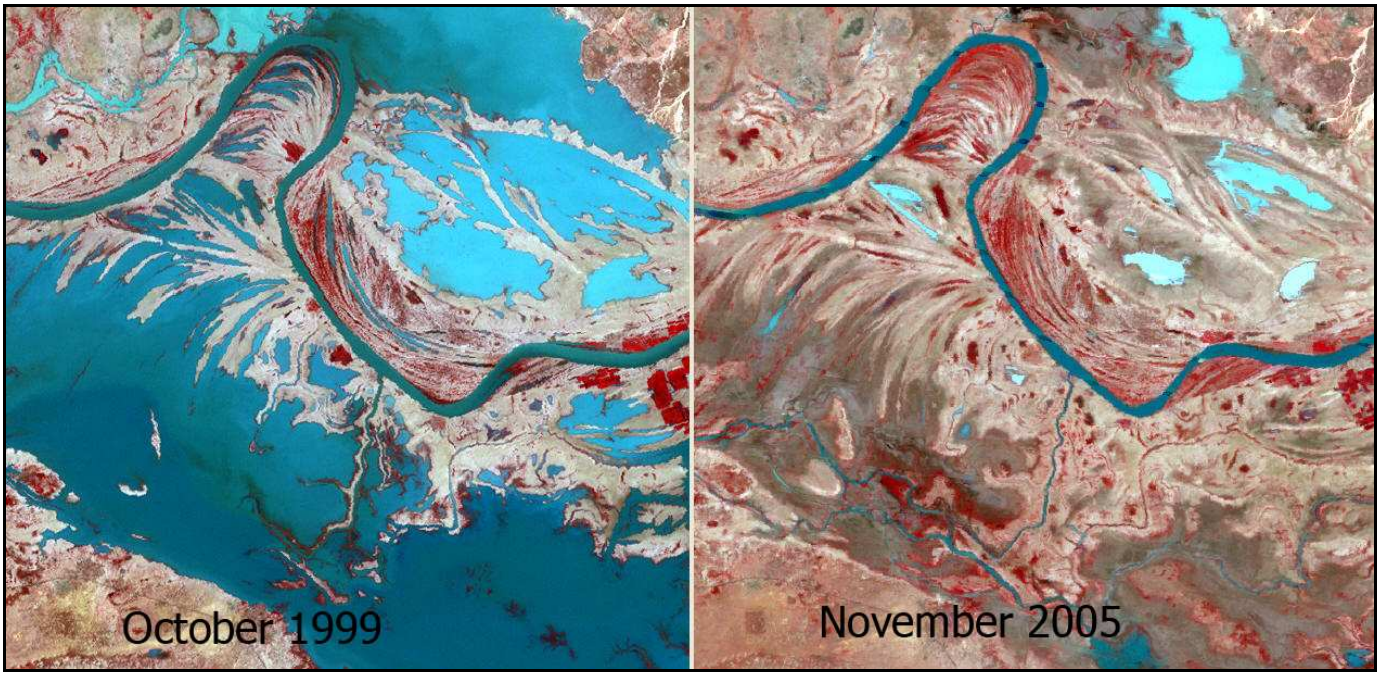

Fig.11 – *Examples of seasonal changes affecting flooded areas on Landsat ETM images.*

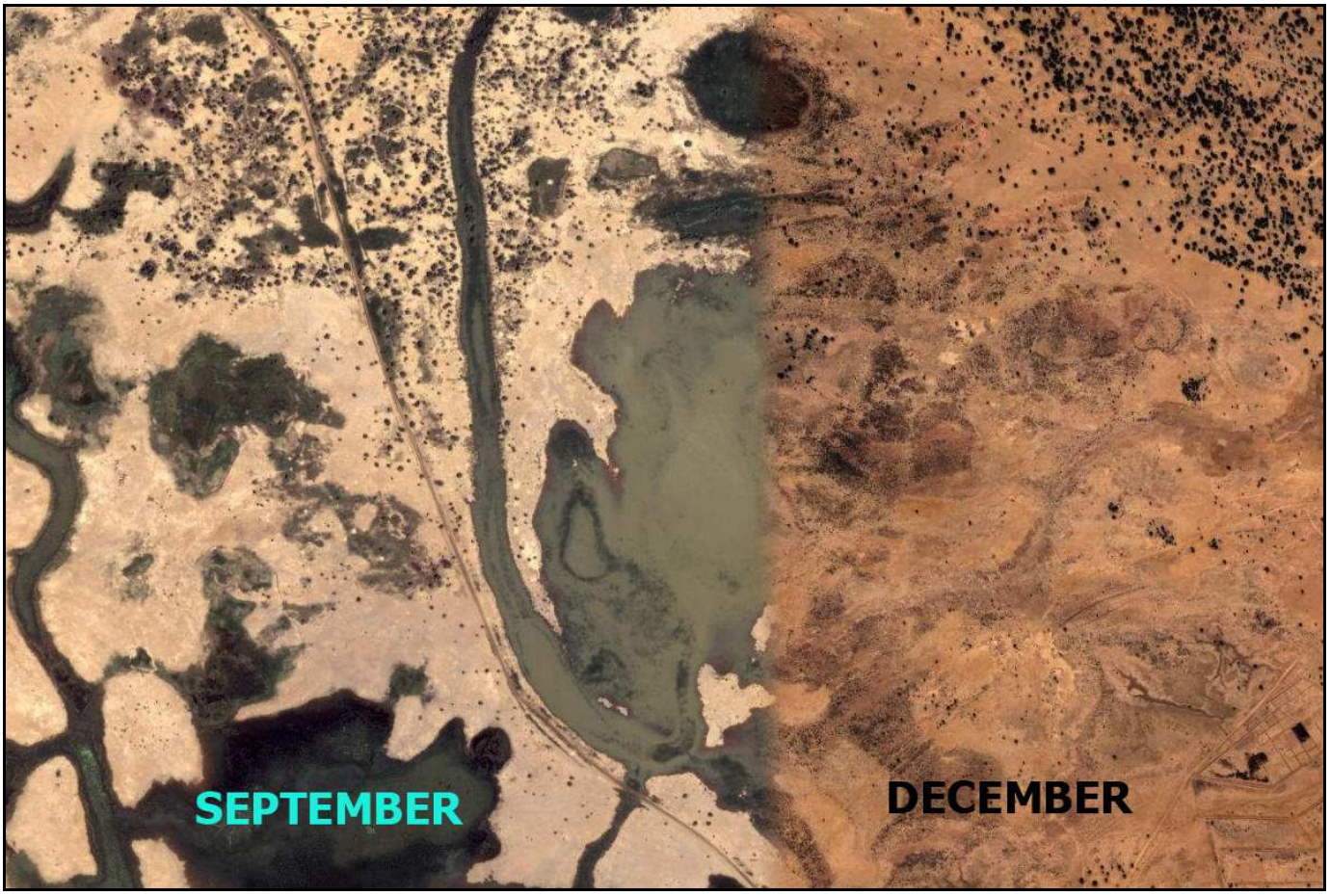

Fig.12 – *Examples of seasonal changes affecting flooded areas on a Google Earth high resolution image.*

The final Senegalese full resolution Land Cover dataset consists of 23,922 polygons, covering an area of 19,659 thousands ha.

4 - Field Verification campaign

The present paragraph gives an overview of the steps followed in order to bring the Senegalese working group to perform the field verification. The fieldwork campaign had the double purpose to further enrich the database, and to train on the job the staff on the field samples data acquisition procedure.

The steps followed to organize the field work campaign can be summarized as follow:

1. Detection of the unclear situations encountered during the preliminary photo-interpretation.
2. Identification the area to be checked and the route to follow, according to the accessibility of the points.
3. Preparation and printing of a series of maps highlighting both points to be checked and routes to follow.

4. Performing of the field work, compiling the Field Verification Form and taking extra field information.
5. Arranging of the data collected during the field work campaign, in order to be easily accessible for both the photo-interpreters and any final user interested.

During the preliminary interpretation, all the unclear situations were indicated creating a specific box in the extra layer. At the end of the preliminary interpretation, all the boxes have been collected in a single shapefile.

After a series of meeting with the GLCN staff, the areas to be checked were identified considering both the interpretation problems encountered and the lack of high resolution images (Google Earth mainly) on that areas. Overlapping the boxes indicating the unclear situations with the field work zones previously identified, two draft routes were sketched out. The two routes have been chosen considering also their accessibility and the polygons to be checked.

All the polygons with an uncertain interpretation but falling outside the routes have been replaced with polygons representing the same feature, intersecting (or nearby) the routes chosen. From the shapefile containing all the polygons to be verified, it was created a shapefile of about 200 points falling inside the polygons and next to the route to follow. These points (fixed points) have been then uploaded on the GPS, in order to facilitate the research of the polygon to check. The digital file of the Senegalese "Carte Routiere et Touristique – scale 1: 500.000" was georeferenced and its printout was used as base map during the field work campaign. Moreover, a dozen of specific printouts of the satellite images falling in the areas to be checked were used.

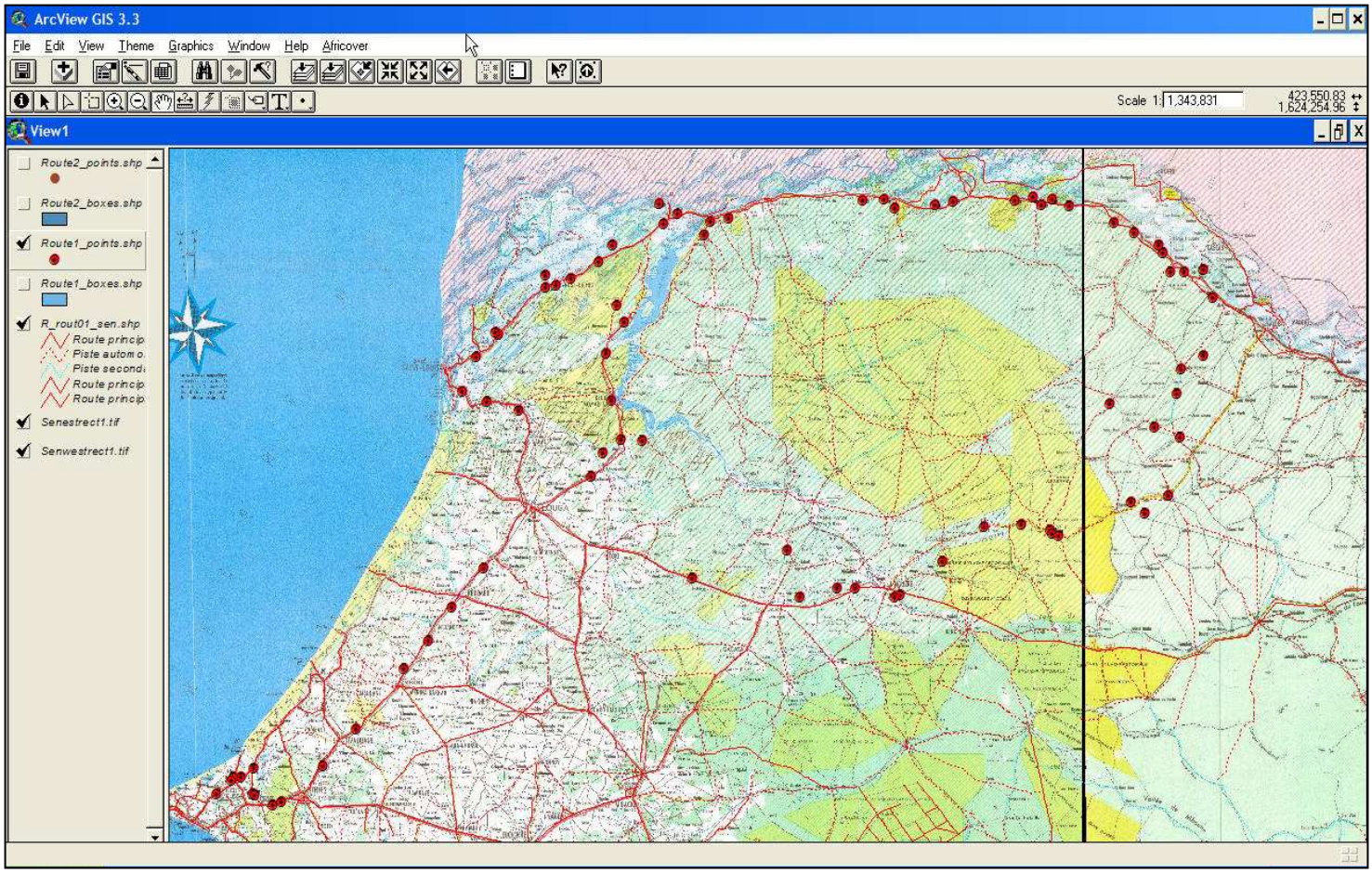

Fig.13 - *Route 1 – Area covered and distribution of the points to take.*

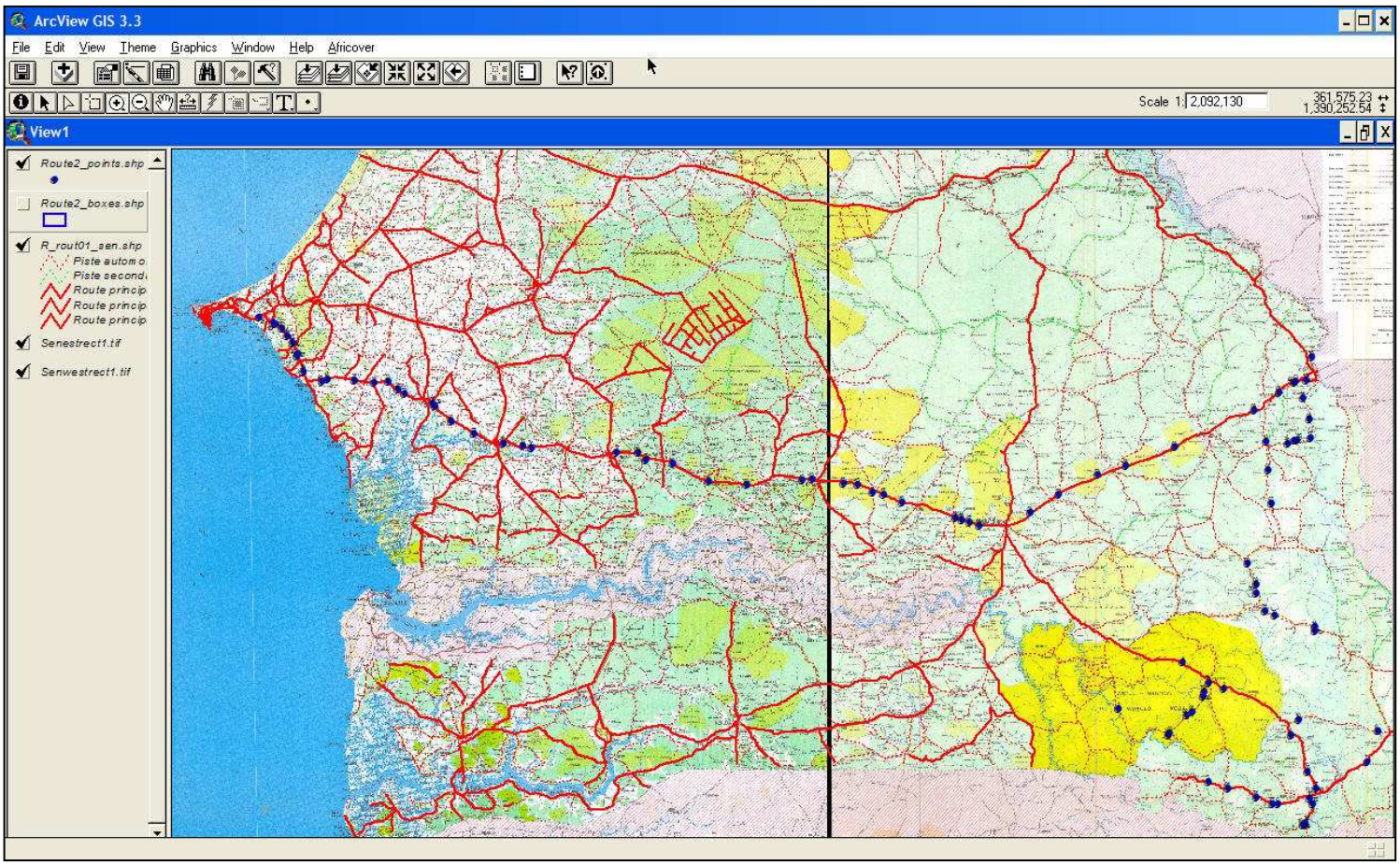

Fig.14 - *Route 2 – Area covered and distribution of the points to take*.

The field work was carried out from the 18th up to the 24th of May 2007.
Given the very limited time to carry out the campaign, the field work was performed by two separate groups of two photo-interpreters each in the same period. **Group 1,** formed by Mr. Ibrahima Dieme and Mr. Mamadou Lo, covered Route1; **Group 2,** formed by the reporter and Mr. Samba Ndao, covered Route 2.
Summarizing, the two routes passed from the following places:

- **Route 1:** Dakar – Thies – Kebemer – Louga – St. Louis – Richard Toll – Dagana – Salde – Linguere – Dara – Louga – Keur Momar Sarr - Dakar.
- **Route 2:** Dakar – M'Bour – Fatick – Kaolack – Koungheul – Tambacounda – Goudiri – Kidira – Saraya – Kedougou – Niokolo Koba – Tambacounda – Dakar.

Before the departure for the fieldwork campaign, the reporter carefully explained how to compile the Field Verification Form and the fieldwork procedure for each point to be verified, consisting in:

- Finding the better position in order to have a clear overview of the area, according to the polygon shape (visible on the printouts of the field maps);
- Storing the point in the GPS and writing down the ID number of the point;
- Taking at least 4 photographs (North, South, East and West);
- Writing down the photo numbers and the corresponding position in which they have been taken;
- A description of the situation encountered, compiling thoroughly the Field Verification Form.
- If needed, to improve the description of the area writing down some additional notes or observations.

It was also suggested to integrate the set of fixed points with some extra points, in order to have an overview of the main land cover features encountered all along the routes.

The extra points consist in GPS points taken from the car in movement, during the transfer from one fixed point to another; in correspondence of every GPS point recorded are also taken one (or more) photo and notes (sometimes simply the land cover class code) of the area crossed.

They allow getting a good overview of areas with a changing land cover, with the benefit of earning precious time. During the field work the time factor is very important, so it was indispensable to get as many information as possible in a very short time. Anyway, the extra points cannot be considered as reliable as fixed points, since the observations are made from the car in movement which means there is a portion of indeterminacy due to the fastness of the examination. Moreover, the land cover situation all along the routes can be disturbed by the presence of the route itself. Anyway, the code assigned to each extra point is linked to the perception of the class all around the point rather than to the photograph taken on that point.

The result of the field work campaign can be summarized as follow:

- **Group 1**: 81 fixed points (Fig.15)
- **Group 2**: 90 fixed point + 706 extra points (Fig.16 and Fig.17)

Inexplicably, for each one of the 81 fixed points collected from Group 1 it was taken only one photo, instead of four. Furthermore, Group 1 did not record the GPS verification point of their position during the observations. The local staff members forming Group 1 explained that, for each point described on their Field Verification Form, they reached the exact position of the point uploaded initially on their GPS. So, a part the photos, there is not an instrumental evidence indicating the exact position of the observations made by Group 1, which somehow reduce the reliability of the data they gathered.

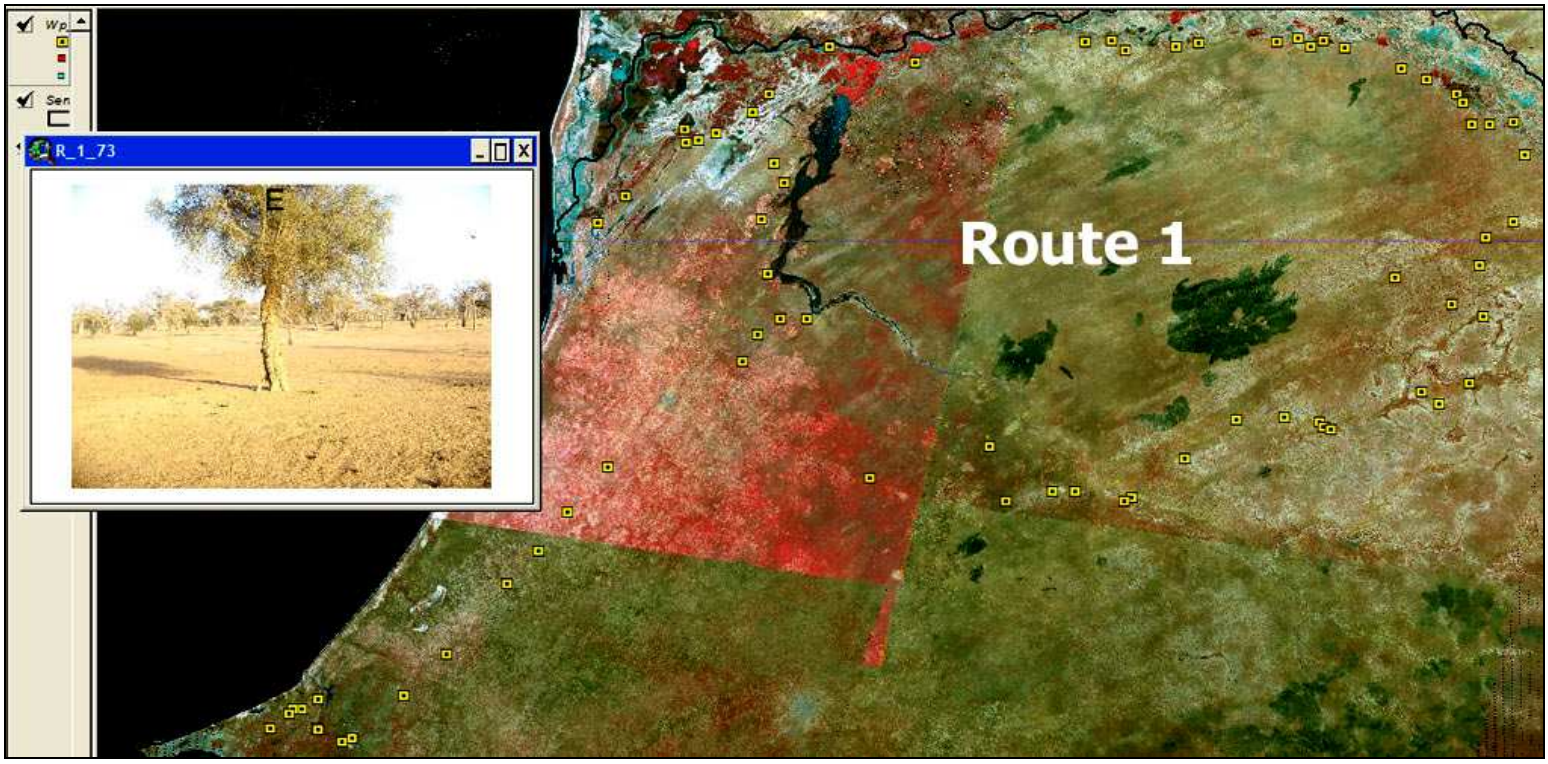

Fig.15 – *The yellow squares represent the locations of the points gathered from Group 1. They are all fixed points and are hot-linked with photos. Clicking on each point, a window showing the corresponding field photo pops up.*

The field work campaign output is an ArcView shapefile where both fixed points and extra points are coded, described and linked with photographs. It is a powerful interpretation device for the photo-interpreters since, clicking with the hot-link tool on any point, a photograph representing the field truth pops up. Therefore, it helps finding interpretation keys and having a better perception of reality as it appears on the satellite image, because it is possible to compare it directly with the field truth.

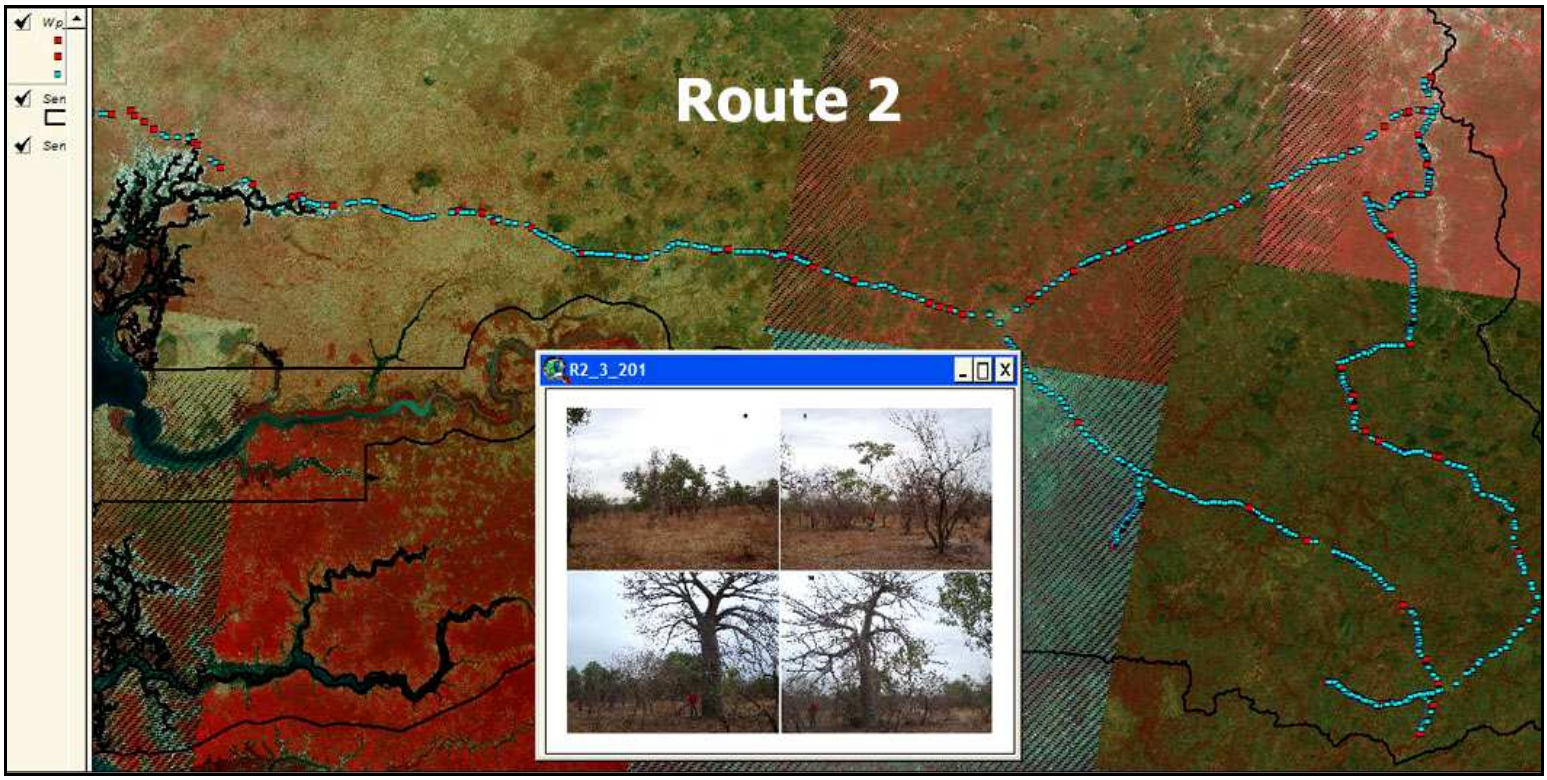

Fig.16 – *Locations of all the points gathered from Group 2. The red squares correspond to the fixed point while the light blue circles represent the extra points. They are both hot-linked with photos. Clicking on each point, a window showing the corresponding field photo pops up.*

The field point database could be further implemented in the future with new observation, points and pictures. It also can be consulted by any final user who needs to get field information of the areas crossed during the field verification campaign.

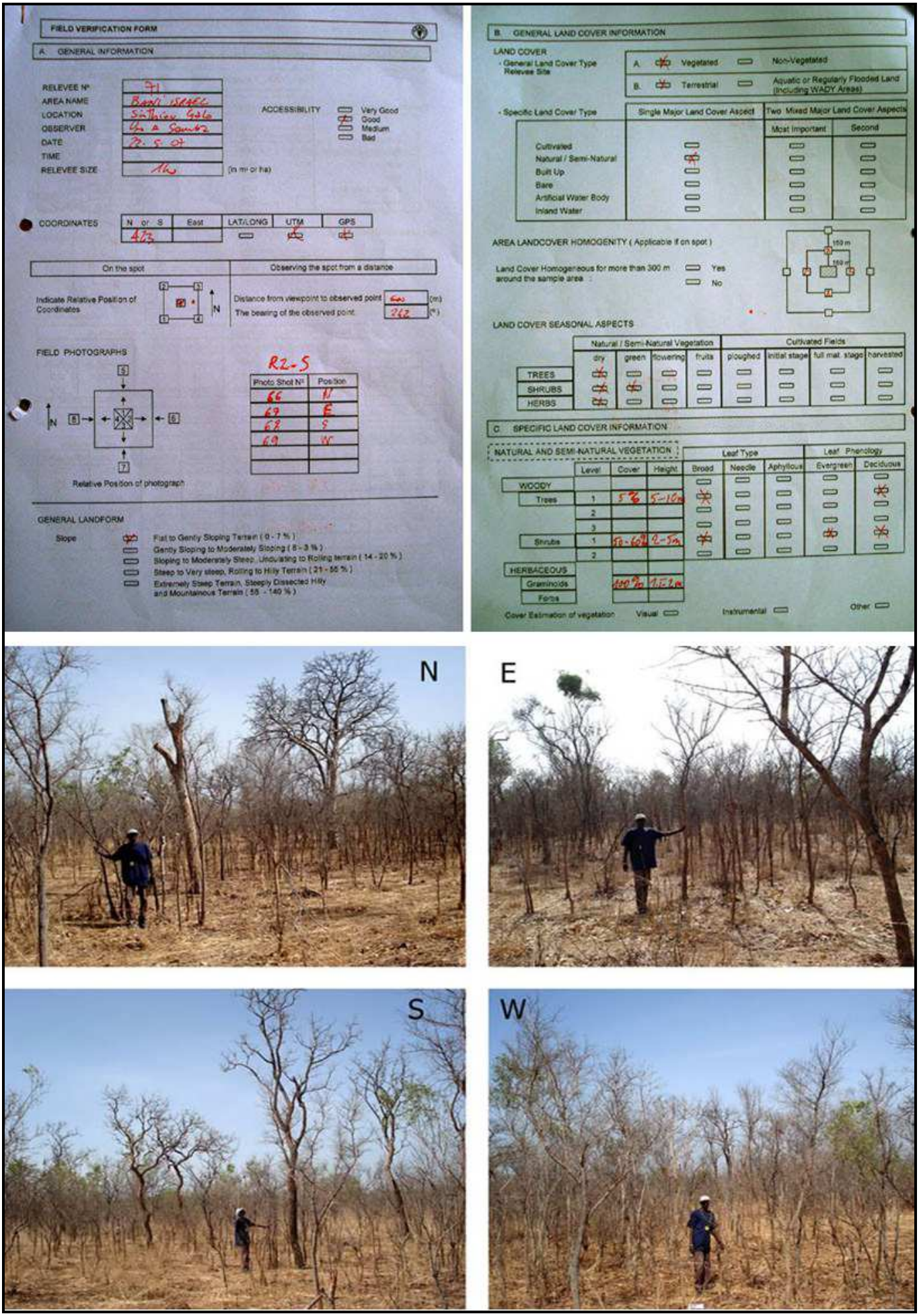

Fig.17 – *Example of Field Verification Form duly compiled and respective photos.*

5 - Legend

Senegal Final Legend consists of 55 classes (clicking on the link, a legend with a full LCCS description of every single class will appear). FAO, through Africover Project and Global Land Cover Network, has developed a comprehensive, standardized a priori land cover classifications system (LCCS) (http://www.fao.org/docrep/003/x0596e/x0596e00.htm); this methodology was applied to shape the land cover classes of Senegal listed below.

1 - TERRESTRIAL AGRICULTURE :	
Code	***Class Name***
1APf-g-2	*Large to Medium Tree Plantation*
1APf-g-2	*Large to Medium Tree Plantation - Casuarina sp. Plantations*
1APf-p-1	*Small Tree Plantations*
1arV-g-Ir	*Large to Medium Irrigated Banana crops*
1AV-g	*Large to Medium Tree crops*
1AV-p	*Small Tree crops*
1H-g-Ir-suc	*Large to Medium Irrigated Herbaceous crops - Sugar Cane*
1H-g-Ir	*Large to Medium Irrigated Herbaceous crops*
1H-p-Ir	*Small Irrigated Herbaceous crops*
1H-p	*Small Rainfed Herbaceous crops*
1H-p-Is	*Small Rainfed Herbaceous crops – Isolated*
1H-g	*Large to Medium Rainfed Herbaceous crops*
1H-p+A	*Small Rainfed Herbaceous crops with a layer of Sparse Trees*
1H-p+A-Is	*Small Rainfed Herbaceous crops with a layer of Sparse Trees - Isolated*
1H-g+A	*Large to Medium Rainfed Herbaceous crops with a layer of Sparse Trees*
1H-p-de	*Small Post Flooding Herbaceous crops*
2- TERRESTRIAL NATURAL VEGETATION :	
Code	***Class Name***
2AF	*Closed Trees*
2AF-ga	*Closed Gallery Forest*
2AO	*Open Trees*
2AO-ga	*Open Gallery Forest*
2ATO	*Very Open Trees*
2ATO-m	*Very Open Trees in Mare Environment*
2arF	*Closed Shrubs*
2arO	*Open Shrubs*
2arOAE	*Open Shrubs with emergent Trees*
2arTO	*Very Open Shrubs*
2arTOAE	*Very Open Shrubs with emergent Trees*
2HOF	*Closed to Open Hebaceous vegetation*
2HOAarE	*Closed to Open Hebaceous vegetation with Sparse Trees and Shrubs*
3 - AQUATIC AGRICULTURE :	
Code	***Class Name***
3HH-g	*Large to Medium Rice crops*
3H-p	*Small Rice crops*

4 - AQUATIC NATURAL VEGETATION :	
Code	***Class Name***
4arOF-Pin-s	*Closed to Open Mangrove Shrubs*
4arOF-Sin	*Closed to Open Shrubs temporarily flooded*
4AO-Sin	*Open Trees temporarily flooded – Gonakie.*
4HF-Pin	*Closed Herbaceous vegetation permanently flooded*
4HOF-Pin-s	*Closed to Open Herbaceous vegetation permanently flooded with brackish water*
4HOF-Sin	*Closed to Open Herbaceous vegetation temporarily flooded*
5 - ARTIFICIAL SURFACES:	
Code	***Class Name***
5AE	*Airport*
5M	*Mines and Quarries*
5PT	*Port*
5U	*Urban Area(s)*
5U-ru	*Rural Settlement*
6 - BARE AREAS:	
Code	***Class Name***
6D	*Sand Dunes*
6S	*Sand*
6SN	*Bare Soil*
6S-Er	*Bare Soil affected by Water Erosion*
7 - ARTIFICIAL WATERBODIES:	
Code	***Class Name***
7S	*Salt Extraction*
8 - NATURAL WATERBODIES:	
Code	***Class Name***
8E-FL	*River*
8E-LP	*Lake*
8E-LP-s	*Salty Lake*
8E-Sin-s	*Non Perennial Salty Lake*
8E-T	*Tidal Area*
8SN	*Bare Soil temporarily flooded*
8SN/4arHE	*Bare Soil OR Sparse Shrubs and Herbaceous vegetation in temporarily flooded area*
8SN/4arHE-s	*Bare Soil OR Sparse Shrubs and Herbaceous vegetation in temporarily flooded area - Brackish water*

Each Senegal class is fully described in the attached document Senegal Classes Description, where are given examples showing Landsat ETM (432 RGB composit), the corresponding High Resolution satellite images (taken from Google Earth), Aerial Photographs (donated from USGS) and field photos taken during the field verification campaign. Moreover each class is hot linked with a Google Earth point, indicating an example where the class occurs.

The below list of single thematic classes of the full resolution Senegal database, shows their frequencies in the cartographic context as Single Unit or Mixed Unit:

GENERAL INFORMATION

Area: 196587466902.89
Number of polygons: 23922
Number of single classes: 48

SEN_LC_z28_ : LIST OF SINGLE THEMATIC CLASSES

CLASS	Single Unit	Mixed Unit			SUM
	Class 1	Class 1	Class 2	Class 3	
1APf-g-1	**51**	7	7	0	**65**
1APf-g-2	**23**	4	0	0	**27**
1APf-p-1	**6**	2	0	0	**8**
1arV-g-Ir	**18**	0	0	0	**18**
1AV-g	**41**	5	4	0	**50**
1AV-p	**33**	64	243	1	**341**
1H-g	**17**	9	0	0	**26**
1H-g+A	**107**	26	19	0	**152**
1H-g-Ir	**51**	4	1	0	**56**
1H-g-Ir-suc	**8**	0	0	0	**8**
1H-p	**32**	60	34	0	**126**
1H-p+A	**4283**	1245	598	5	**6131**
1H-p+A-Is	**0**	0	806	30	**836**
1H-p-de	**51**	37	57	0	**145**
1H-p-Ir	**118**	83	64	0	**265**
1H-p-Is	**0**	0	59	3	**62**
2AF	**512**	12	26	0	**550**
2AF-ga	**411**	21	14	0	**446**
2AO	**895**	200	182	2	**1279**
2AO-ga	**567**	263	188	3	**1021**
2arF	**56**	4	1	0	**61**
2arO	**86**	13	5	0	**104**
2arOAE	**673**	380	185	0	**1238**
2arTO	**102**	34	30	0	**166**
2arTOAE	**909**	956	589	0	**2454**
2ATO	**1114**	631	1311	0	**3056**
2ATO-m	**0**	18	231	55	**304**
2HOAarE	**1013**	1211	913	1	**3138**
2HOF	**107**	171	105	0	**383**
3H-p	**360**	35	46	0	**441**
3HH-g	**362**	7	1	0	**370**
4AO-Sin	**51**	77	132	2	**262**
4arOF-Pin-s	**306**	159	190	0	**655**
4arOF-Sin	**35**	81	283	0	**399**
4HF-Pin	**227**	45	53	0	**325**
4HOF-Pin-s	**22**	1	10	0	**33**
4HOF-Sin	**126**	273	215	3	**617**
5AE	**10**	0	0	0	**10**
5M	**41**	0	0	0	**41**

5PT	**2**	0	0	0	**2**
5U	**190**	49	48	0	**287**
5U-ru	**1436**	627	199	11	**2273**
6D	**4**	3	0	0	**7**
6S	**27**	26	67	0	**120**
6S-Er	**216**	412	416	2	**1046**
6SN	**35**	24	27	0	**86**
7S	**18**	0	0	0	**18**
8E-FL	**56**	10	6	1	**73**
8E-LP	**134**	31	9	0	**174**
8E-LP-s	**12**	3	1	0	**16**
8E-Sin-s	**3**	2	0	0	**5**
8E-T	**181**	155	59	0	**395**
8SN	**460**	298	344	0	**1102**
8SN//4arHE	**220**	0	0	0	**220**
8SN//4arHE-s	**326**	0	0	0	**326**

6 - Accuracy Assessment

On November 2008, in the GLCN office at the Istituto Agronomico per l'Oltremare (Florence, Italy), the Senegal Accuracy Assessment was carried out under the supervision of the FAO Senior Mapping Expert, Mr. Antonio Di Gregorio.

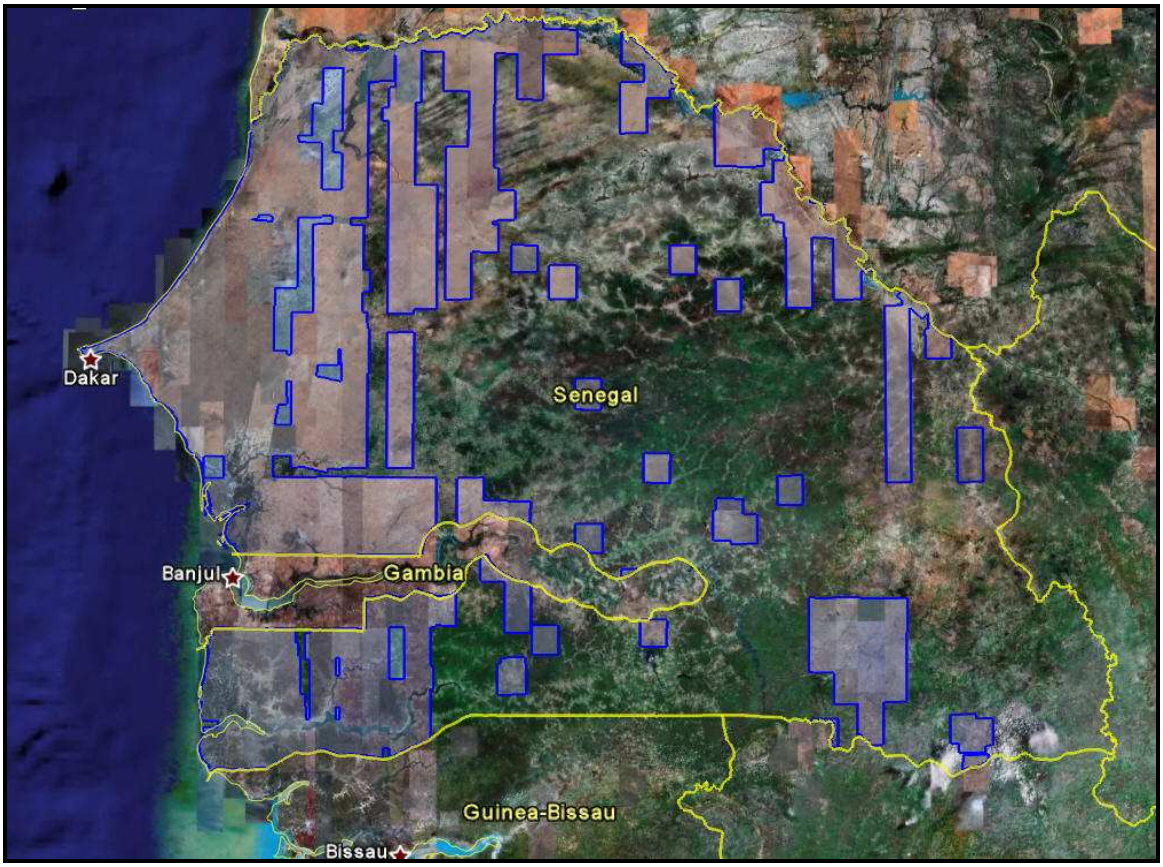

Fig.18 – *Senegal as seen with the Google Earth software. The areas outlined in blue colour are the one covered by high resolution satellite images.*

To perform the accuracy assessment task, the dedicated software GeoMAP (Mapping Accuracy Programme, http://www.geovis.net/) was used. The software extracts randomly the polygons (single units, NOT mixed units) to be checked; they are extracted according to the given area, the frequency of the classes present in the original shapefile and the minimum amount of classes for each stratum (class of group of classes) needed.
To evaluate the land cover mapping accuracy, the high resolution imagery available with Google Earth freeware were used as base images (Fig.18).

The total number of polygons extracted is 477 for a total of 39 strata. Only stratum N. 2 (Large to Medium Irrigated Banana crops) was not checked because no one of the 18 classes with this code falls inside the area covered by high resolution images.

The legend of the strata extracted is:

LEGEND

CLASS	DESCRIPTION
1. 11182-5671-S1099Zs1W7	"Permanently Cropped Area With Rainfed Needleleaved Evergreen Tree Crop(s) Dominant Crop: Wood and Timber - Other wood/timber - Casaurina sp. Crop Cover: Plantation(s)"
2. 11204-13227-S0604	"Permanently Cropped Area With Surface Irrigated Shrub Crop(s) Dominant Crop: Fruits & Nuts - Banana (Musa spp.)"
3. 11221	"Rainfed Herbaceous Crop(s)"
4. 11221 + 20227	"Herbaceous Crop(s) + Broadleaved Deciduous Sparse Trees"
5. 11229	"Permanently Cropped Area With Irrigated Herbaceous Crop(s)"
6. 11239-12635-S0915	"Permanently Cropped Area With Surface Irrigated Herbaceous Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop Sequentially) . Dominant Crop: Industrial Crops - Sugar Cane (Saccharum officinarum)"
7. 11241	"Small Sized Field(s) Of Rainfed Herbaceous Crop(s)"
8. 11241 + 20227	"Small Sized Field(s) Of Herbaceous Crop(s) + Broadleaved Deciduous Sparse Trees"
9. 11247	"Permanently Cropped Area With Small Sized Field(s) Of Post Flooding Cultivation Of Herbaceous Crop(s)"
10. 11453	"Permanently Cropped Area With Small Sized Field(s) Of Irrigated Herbaceous Crop(s)"
11. 20090	"Broadleaved Deciduous Trees"
12. 20090-13152(1)[Z1]	"Broadleaved Deciduous High Trees"
13. 20153	"Broadleaved Deciduous Thicket"

14. 21102-3012	"Broadleaved Deciduous (40 - (20-10)%) Shrubland with Herbaceous"
15. 211041-1	" Broadleaved Deciduous ((70-60) - 40%) Shrubland with Herbaceous and Emergents"
16. 21104-3012	" Broadleaved Deciduous (40 - (20-10)%) Shrubland with Herbaceous and Emergents"
17. 21102-1	"Broadleaved Deciduous ((70-60) - 40%) Shrubland with Herbaceous"
18. 21454-121340	"Herbaceous Closed to Open (100-40)% Vegetation"
19. 21642-121340	"Closed to Open (100-40)% Herbaceous Vegetation with Trees and Shrubs"
20. 22687-3011	"Broadleaved Deciduous ((70-60) - 40%) Woodland With Open Shrubs And Open Herbaceous Layer"
21. 22687-3011(1)[Z1]	"Broadleaved Deciduous ((70-60) - 40%) Woodland With Open Shrubs And Open Herbaceous Layer"
22. 22687-6021	"Broadleaved Deciduous (40 - (20-10)%) Woodland With Open Shrubs And Open Herbaceous Layer"
23. 3610-16-S0308	"Large To Medium Sized Field(s) Of Graminoid Crops With Sequential Cropping On Permanently Flooded Land (With One Additional Crop) (Herbaceous Terrestrial) Dominant Crop: Cereals - Rice (Oryza spp.)"
24. 3685-L13S0308	"Small Sized Field(s) Of Graminoid Crops On Waterlogged Soil Major Landclass: Level Land, Depression Dominant Crop: Cereals - Rice (Oryza spp.)"
25. 40047-L15L5N1110R1Zt2	"Woodland On Temporarily Flooded Land. Major Landclass: Level Land, Valley Floor, Slope Class: Flat To Almost Flat Soils: Subsurface: Fluvisols Water Quality: Fresh Water Floristic Aspect: Acacia nilotica"
26. 41899-67278-R2Zt3	"Closed to Open (100-40)% Broadleaved Evergreen Shrubs On Permanently Flooded Land (With Daily Variations) Water Quality: Brackish Water Floristic Aspect: Rizophora"
27. 41983-4786	"Closed to Open Medium High Shrubs On Temporarily Flooded Land."
28. 42348-4732-L15L5R1	"Closed to Open Medium Tall Herbaceous Vegetation On Temporarily Flooded Land Major Landclass: Level Land, Valley Floor, Slope Class: Flat To Almost Flat Water Quality: Fresh Water"
29. 5003-9	"Urban Area(s)"
30. 5003-9-A44Zp1	"Urban Area(s) Built-Up Object: Other - Rural Settlement"
31. 6006	"Loose And Shifting Sands"
32. 6009	"Shifting Sands / Dune(s)"
33. 8003-76	"Non-Perennial Natural Waterbodies (Surface Aspect: Bare Soil) (Water presence 3-1 months)"
34. 8004-18	"Tidal Area (Surface Aspect: Bare Soil)"
35. [Orchard Small & Large]	**11182 -W8*** - "Permanently Cropped Area With Rainfed Tree Crop(s) Crop Cover: Orchard(s) " **11192-W8** - "Permanently Cropped Area With Small Sized Field(s) Of Rainfed Tree Crop(s) Crop Cover: Orchard(s)"
36. [Plantation Small & Large]	**11182-W7 *** - "Permanently Cropped Area With Rainfed Tree Crop(s) Crop Cover: Plantation(s)" **11192-W7** - "Permanently Cropped Area With Small Sized Field(s) Of Rainfed Tree Crop(s) Crop Cover: Plantation(s)"
37. [Herbaceous Flooded with Fresh & Brackish Water]	**40055-4723-R1 *** - "Closed Tall Herbaceous Vegetation On Permanently Flooded Land Water Quality: Fresh Water" **42347-60686-R2Zt1** - "Closed to Open Herbaceous Vegetation On Permanently Flooded Land Water Quality: Brackish Water Floristic Aspect: allophitic sp."

38. [Bare Soil & Bare Soil Eroded]	**6005 ***- "Bare Soil And/Or Other Unconsolidated Material(s)" **6005-Q3U1** -"Bare Soil And/Or Other Unconsolidated Material(s) Erosion: Water Erosion Scattered Vegetation: Scattered Vegetation Present"
39. [Bare Soil or Sparse Vegetation Flooded with Fresh & Brackish Water]	**8003-3-V1 // 40451 *** - "Non-Perennial Natural Waterbodies (Flowing) (Surface Aspect: Bare Soil) Salinity: Fresh, < 1.000 ppm of TDS // Sparse Shrubs With Sparse Herbaceous Vegetation On Temporarily Flooded Land" **8003-8-V3 // 40449-4891-R3** - "Non-Perennial Natural Waterbodies (Standing) (Surface Aspect: Sand) Salinity: Moderately Saline // Sparse Shrubs With Sparse Herbaceous Vegetation On Permanently Flooded Land (With Daily Variations) Water Quality: Saline Water"

The first step was to extract randomly, with GeoMAP software, the polygons to be checked, according to the area covered by high resolution images. All the polygons extracted were exported and converted in Kml Google Earth format (Fig.19).

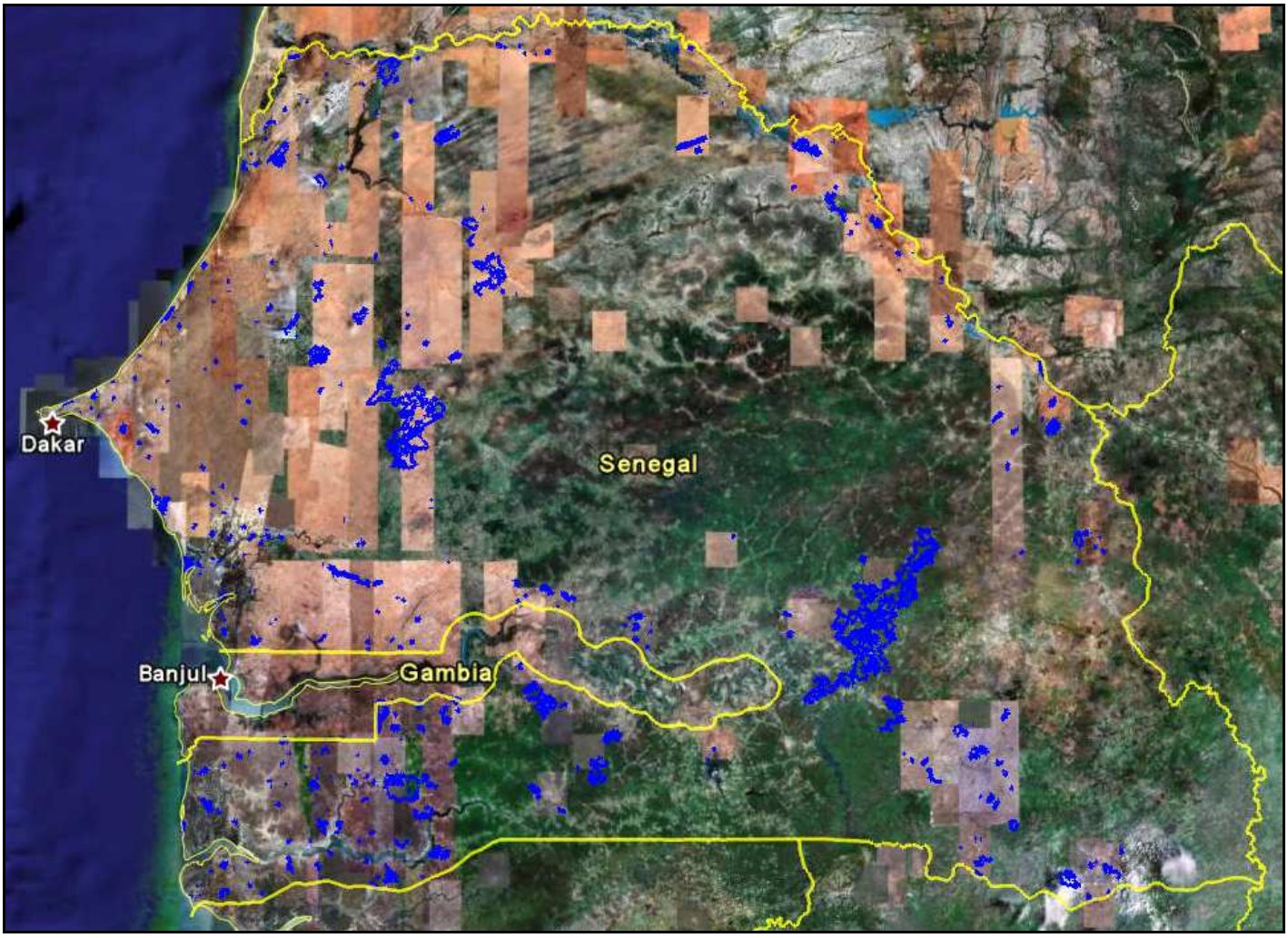

Fig.19 – *Senegal as seen with the Google Earth software. In blue are shown the polygons extracted for the accuracy assessment. They fall inside area covered by high resolution images.*

Afterwards, the procedure followed was:

a) the polygon to be checked was visualized on one screen, with GeoMAP software; the base image was the Landsat ETM used for the original interpretation.

b) the polygon to be checked was visualized on a second screen, with Google Earth software; the base image was a high resolution image (from 1 to 2,5 meter per pixel resolution).

After a careful control of the polygon code correctness, through the analysis of the high resolution satellite image, the assessment was carried out. There were three possible cases:

1. the interpretation of the polygon was considered correct, then in GeoMAP evaluation windows, the "Correct" key was selected. An example of this case is given in Fig.20.

2. the interpretation of the polygon was considered partially correct, then in GeoMAP evaluation windows, the "Split" key was selected. Clicking on the "Split" key of the GeoMAP window, one new window pops up, giving the chance to cut the polygon with a "Split polygon" tool. This way, a portion of the polygon with the correct code is separated from the portion of polygon with a different land cover type from the one codified. The correct portion keeps the original code while to the wrong portion is given the code of the corresponding land cover class. Most of the time, the split tool was used to correct polygons with a bad delineation. Note that when the area of one or more parts of the split polygon were smaller or equal than 20% of the total area of the polygon, the split was not done. An example of this case is given in Fig.21.

3. the interpretation of the polygon was considered wrong, then in GeoMAP evaluation windows, the "Wrong" key was selected. Clicking on the "Wrong" key of the GeoMAP window, a bar with all the Senegal classes appears; from the list was selected the correct class belonging to the checked polygon. An example of this case is given in Fig.22.

The GeoMAP software stores all the data coming from the accuracy assessment work, in order to calculate statistics for each polygon checked.

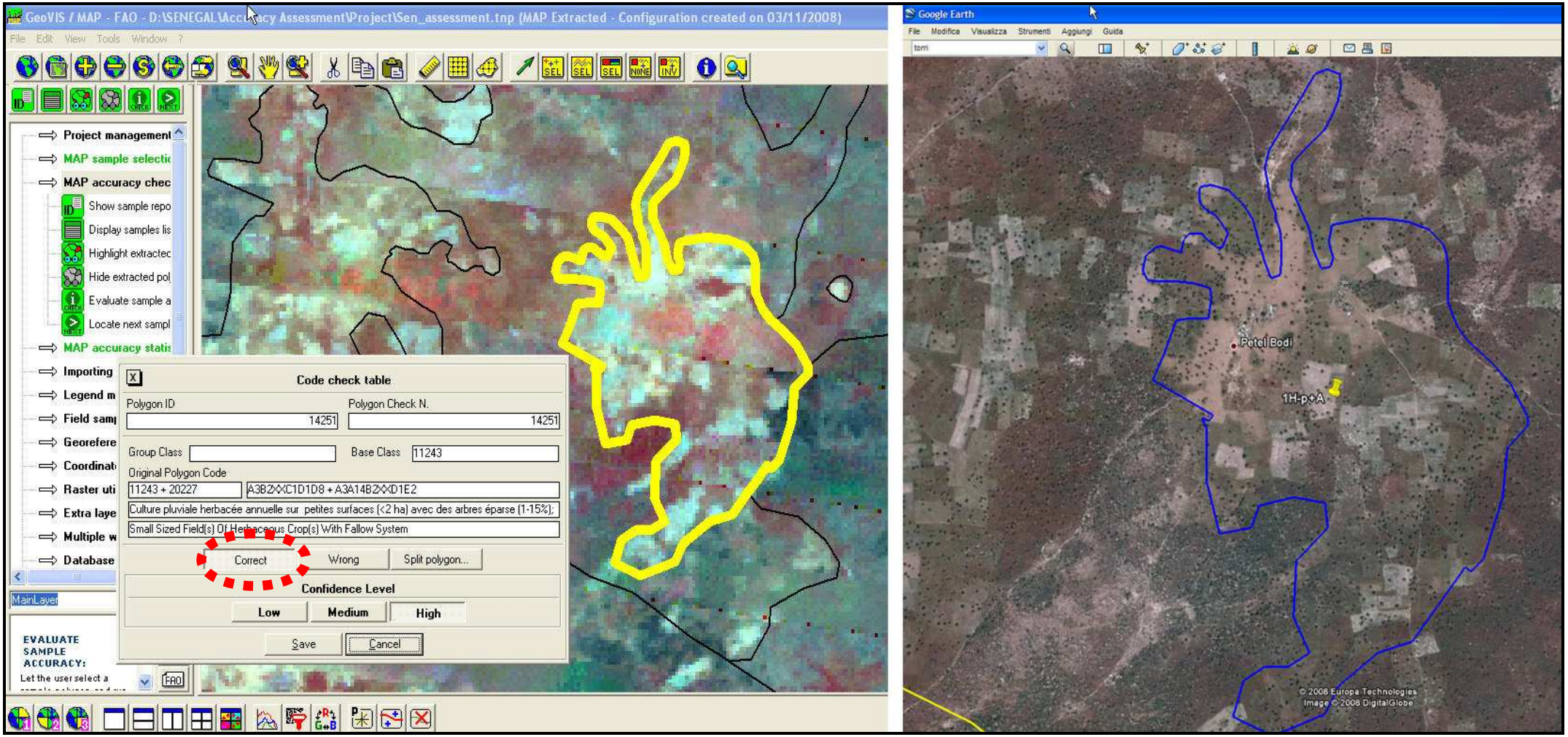

Fig.20 – *Example of correct photo-interpretation. On the Left figure the polygon is checked and evaluated with the GeoMAP software; in this case the code (1H-p+A = Small Rainfed Herbaceous crops with a layer of Sparse Trees) is correct as can be seen on the right figure, where the polygon to be checked is visualized on a Google Earth high resolution image. So clicking on the "Correct" key of the GeoMAP window (red dotted frame), the assessment of the polygon is finalized.*

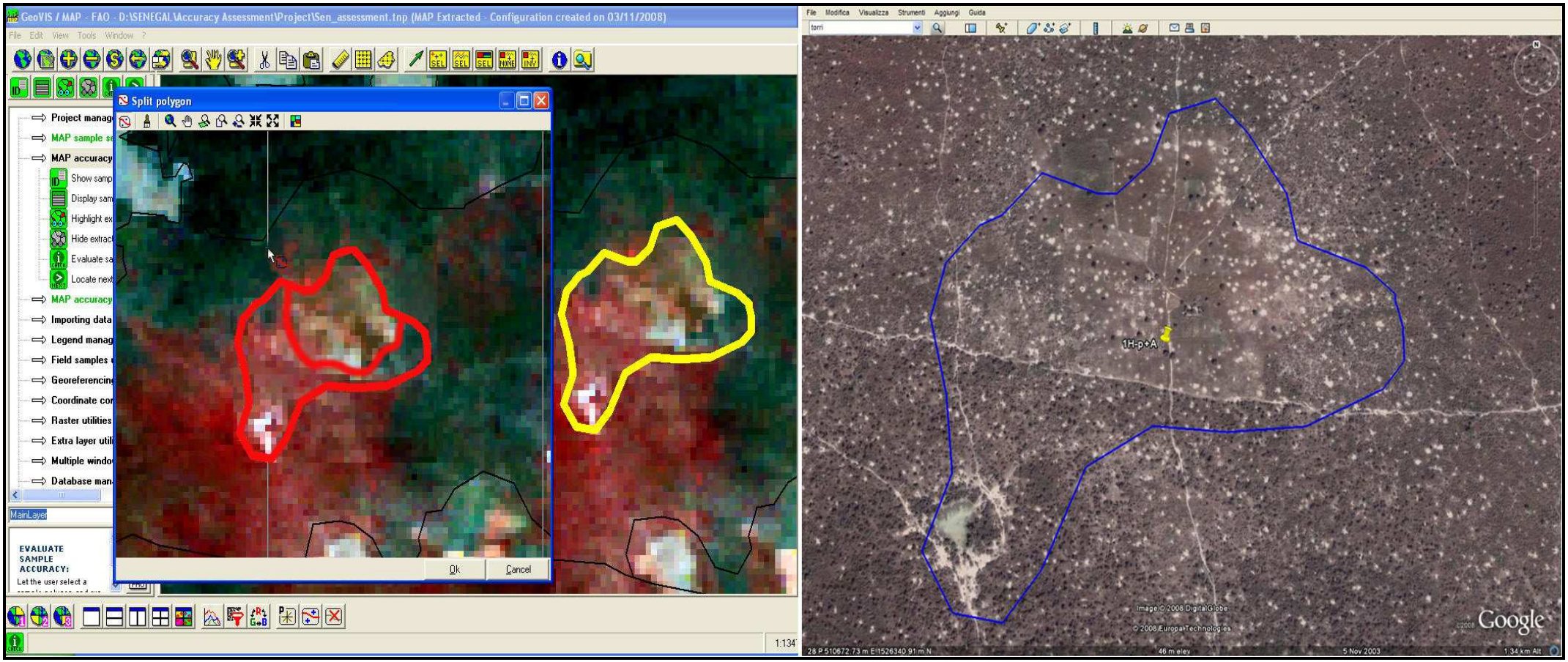

Fig.21 – *Example of partially correct photo-interpretation. On the left figure, the polygon is checked and evaluated with the GeoMAP software. In the example a portion of the polygon is not correct, as it is shown on the right figure, where the polygon to be checked is visualized on a Google Earth high resolution image. Clicking on the "Split" key of the GeoMAP window (not present in the figure) one new window pops up; on this latter window (the one with the red polygon in the left figure) is possible to cut the polygon with the "Split polygon" tool, separating the correct portion from the wrong one. The correct portion keeps the original code while to the wrong portion is given the code of the corresponding class.*

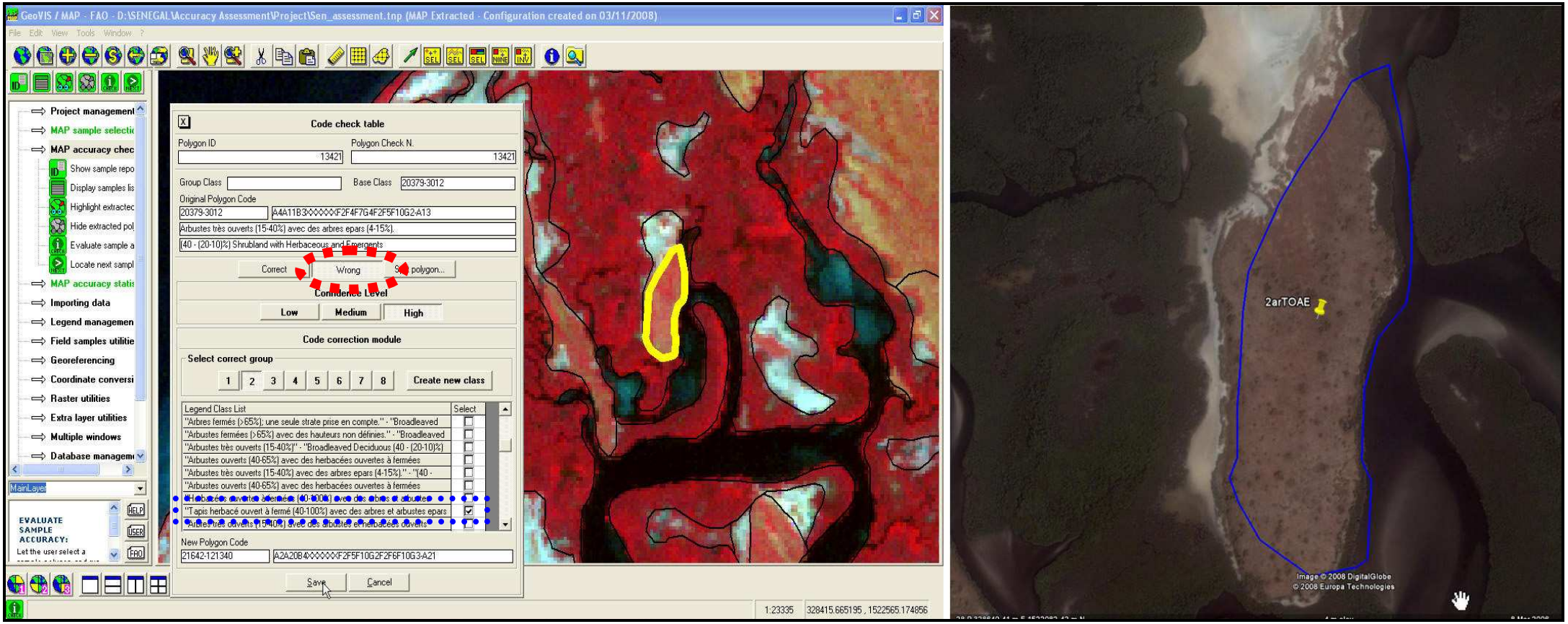

Fig.22 – *Example of wrong photo-interpretation. On the Left figure, the polygon is checked and evaluated with the GeoMAP software. In this example the original polygon's code (2arTOE = Very Open Shrubs with emergent Trees) is wrong, as can be seen on the right figure, where the polygon to be checked is visualized on a Google Earth high resolution image. Clicking on the "Wrong" key of the GeoMAP window (red dotted frame) a bar with all the classes pops up. From the bar is selected the correct class (red dotted frame) which is given to the polygon checked.*

The results of the accuracy assessment for each stratum are summarized in the below table:

STRATUM (CLASS OR GROUP)	Correct Photointerpretation						Total Checked	
	MAP Approach				SURFACE Approach			
	Number		Area				Number	Area
11182-5671-S1099Zs1W7 - Permanently Cropped Area With Rainfed Needleleaved Evergreen Tree Crop(s)Dominant Crop: Wood and Timber - Other wood/timber - Casaurina sp.Crop Cover: Plantation(s)	5	100,00%	20.427.781,79	100,00%	20.427.781,79	100,00%	5	20.427.781,79
11204-13227-S0604 - Permanently Cropped Area With Surface Irrigated Shrub Crop(s)Dominant Crop: Fruits & Nuts - Banana (Musa spp.)	0	0,00%					0	0,00
11221 - Rainfed Herbaceous Crop(s)	5	100,00%	11.043.751,68	100,00%	11.043.751,68	100,00%	5	11.043.751,68
11221 + 20227 - Herbaceous Crop(s) + Broadleaved Deciduous Sparse Trees	2	66,67%	8.329.535,85	94,04%	8.329.535,85	94,04%	3	8.857.461,85
11229 - Permanently Cropped Area With Irrigated Herbaceous Crop(s)	4	80,00%	8.366.878,02	98,84%	8.425.553,48	99,53%	5	8.465.165,02
11239-12635-S0915 - Permanently Cropped Area With Surface Irrigated Herbaceous Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop Sequentially) .Dominant Crop: Industrial Crops - Sugar Cane (Saccharum officinarum)	5	100,00%	45.410.720,36	100,00%	45.410.720,36	100,00%	5	45.410.720,36
11241 - Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	2	40,00%	4.654.224,76	28,06%	13.238.765,17	79,81%	5	16.588.034,00
11241 + 20227 - Small Sized Field(s) Of Herbaceous Crop(s) + Broadleaved Deciduous Sparse Trees	97	88,99%	10.749.690.098,02	99,86%	10.757.434.980,04	99,93%	109	10.765.124.732,79
11247 - Permanently Cropped Area With Small Sized Field(s) Of Post Flooding Cultivation Of Herbaceous Crop(s)	7	70,00%	4.585.618,38	44,33%	6.447.619,48	62,33%	10	10.344.895,34
11453 - Permanently Cropped Area With Small Sized Field(s) Of Irrigated Herbaceous Crop(s)	3	100,00%	26.508.935,15	100,00%	26.508.935,15	100,00%	3	26.508.935,15
20090 - Broadleaved Deciduous Trees	9	69,23%	131.567.491,63	92,65%	136.473.895,48	96,10%	13	142.008.503,64
20090-13152(1)[Z1] - Broadleaved Deciduous High Trees	8	80,00%	129.498.397,78	97,23%	132.197.579,83	99,26%	10	133.187.916,62
20153 - Broadleaved Deciduous Thicket	7	70,00%	19.212.698,19	76,79%	19.463.084,42	77,79%	10	25.020.522,97
21102-3012 - Broadleaved Deciduous (40 - (20-10)%) Shrubland with Herbaceous	2	66,67%	4.553.140,76	87,79%	4.553.140,76	87,79%	3	5.186.422,98
211041-1 - Broadleaved Deciduous ((70-60) - 40%) Shrubland with Herbaceous and Emergents	14	87,50%	144.020.672,87	99,37%	144.309.284,75	99,57%	16	144.932.013,81
21104-3012 - Broadleaved Deciduous (40 - (20-10)%) Shrubland with Herbaceous and Emergents	20	86,96%	278.270.852,94	98,48%	281.109.031,02	99,48%	23	282.566.116,29
21102-1 - Broadleaved Deciduous ((70-60) - 40%) Shrubland with Herbaceous	9	90,00%	44.271.752,68	96,44%	44.683.715,46	97,34%	10	45.906.083,21
21454-121340 - Herbaceous Closed to Open (100-40)% Vegetation	5	50,00%	10.269.788,29	44,69%	12.729.072,57	55,39%	10	22.980.215,87
21642-121340 - Closed to Open (100-40)% Herbaceous Vegetation with Trees and Shrubs	16	64,00%	63.281.834,77	84,67%	70.303.371,82	94,06%	25	74.740.538,84
22687-3011 - Broadleaved Deciduous ((70-60) - 40%) Woodland With Open Shrubs And Open Herbaceous Layer	17	73,91%	621.675.460,84	97,50%	628.222.845,37	98,53%	23	637.624.558,53
22687-3011(1)[Z1] - Broadleaved Deciduous ((70-60) - 40%) Woodland With Open Shrubs And Open Herbaceous Layer	12	85,71%	16.068.178,97	93,92%	16.369.026,78	95,68%	14	17.107.499,92
22687-6021 - Broadleaved Deciduous (40 - (20-10)%) Woodland With Open Shrubs And Open Herbaceous Layer	22	78,57%	94.171.797,33	95,12%	95.809.232,27	96,77%	28	99.006.779,36
3610-16-S0308 - Large To Medium Sized Field(s) Of Graminoid Crops With Sequential Cropping On Permanently Flooded Land (With One Additional Crop) (Herbaceous Terrestrial)Dominant Crop: Cereals - Rice (Oryza spp.)	9	100,00%	11.252.248,26	100,00%	11.252.248,26	100,00%	9	11.252.248,26
3685-L13S0308 - Small Sized Field(s) Of Graminoid Crops On Waterlogged SoilMajor Landclass: Level Land, DepressionDominant Crop: Cereals - Rice (Oryza spp.)	8	88,89%	4.528.659,75	70,78%	5.026.781,65	78,57%	9	6.397.879,41
40047-L15L5N1110R1Zt2 - Woodland On Temporarily Flooded Land.Major Landclass: Level Land, Valley Floor, Slope Class: Flat To Almost FlatSoils: Subsurface: FluvisolsWater Quality: Fresh WaterFloristic Aspect: Acacia nilotica	2	100,00%	353.349,60	100,00%	353.349,60	100,00%	2	353.349,60
41899-67278-R2Zt3 - Closed to Open (100-40)% Broadleaved Evergreen Shrubs On Permanently Flooded Land (With Daily Variations)Water Quality: Brackish WaterFloristic Aspect: Rizophora	8	100,00%	11.304.841,18	100,00%	11.304.841,18	100,00%	8	11.304.841,18
41983-4786 - Closed to Open Medium High Shrubs On Temporarily Flooded Land.	2	100,00%	2.184.193,09	100,00%	2.184.193,09	100,00%	2	2.184.193,09
42348-4732-L15L5R1 - Closed to Open Medium Tall Herbaceous Vegetation On Temporarily Flooded LandMajor Landclass: Level Land, Valley Floor, Slope Class: Flat To Almost FlatWater Quality: Fresh Water	8	38,10%	5.609.528,72	52,80%	7.708.771,65	72,56%	21	10.624.371,52
5003-9 - Urban Area(s)	4	80,00%	7.717.514,03	98,86%	7.717.514,03	98,86%	5	7.806.400,03
5003-9-A44Zp1 - Urban Area(s)Built-Up Object: Other - Rural Settlement	32	88,89%	8.284.947,53	91,14%	8.378.108,27	92,16%	36	9.090.601,16
6006 - Loose And Shifting Sands	2	100,00%	797.973,90	100,00%	797.973,90	100,00%	2	797.973,90
6009 - Shifting Sands / Dune(s)	2	100,00%	1.903.486,05	100,00%	1.903.486,05	100,00%	2	1.903.486,05
8003-76 - Non-Perennial Natural Waterbodies (Surface Aspect: Bare Soil) (Water presence 3-1 months)	10	83,33%	6.197.041,84	90,23%	6.702.008,45	97,58%	12	6.867.926,34

8004-18 - Tidal Area (Surface Aspect: Bare Soil)	4	80,00%	5.674.197,19	83,84%	6.176.870,15	91,27%	5	6.767.704,84
Orchard Small & Large (Defined in 11182-W8 - Permanently Cropped Area With Rainfed Tree Crop(s))	2	100,00%	787.238,90	100,00%	787.238,90	100,00%	2	787.238,90
Plantation Small & Large (Defined in 11182-W7 - Permanently Cropped Area With Rainfed Tree Crop(s)Crop Cover: Plantation(s))	2	100,00%	857.984,02	100,00%	857.984,02	100,00%	2	857.984,02
Herbaceous Flooded with Fresh & Brackish Water (Defined in 40055-4723-R1 - Closed Tall Herbaceous Vegetation On Permanently Flooded LandWater Quality: Fresh Water)	4	66,67%	972.186,39	70,05%	1.271.391,60	91,61%	6	1.387.897,70
Bare Soil & Bare Soil Eroded (Defined in 6005 - Bare Soil And/Or Other Unconsolidated Material(s))	5	83,33%	26.986.475,31	95,64%	27.536.914,85	97,59%	6	28.216.345,68
Bare Soil or Sparse Vegetation Flooded with Fresh & Brackish Water (Defined in 8003-3-V1 // 40451 - Non-Perennial Natural Waterbodies (Flowing) (Surface Aspect: Bare Soil)Salinity: Fresh, < 1.000 ppm of TDS // Sparse Shrubs With Sparse Herbaceous Vegetation On Temporarily Flooded Land)	9	69,23%	13.843.159,13	73,56%	14.370.644,48	76,36%	13	18.819.636,25

The above table summarizes the results according to two different approaches: a Map approach and a Surface approach.

In the **Map approach** the polygon is the accuracy's unit of measurement, while in the **Surface approach** the area checked is the accuracy's unit of measurement, i.e. in the Map approach a polygon with a bad delineation is considered wrong, even if only a portion of it is wrong; on the reverse, the Surface approach takes into account also the right portion of polygon with a not precise delineation.

The above percentages have the following meaning:

Blue (map accuracy based on number of fully correct polygons) = percentage of correct polygons against the total amount of polygons checked.

Green (map accuracy based on number of fully correct polygons) = percentage of polygons' correct area against the total polygon's area checked; in this case, even if a portion of the polygon has a correct interpretation, the area of the whole polygon is considered wrong.

Red (surface accuracy based on ratio between correct and total surface checked) = percentage of correct area against the total area checked; in this case the total amount of correct surface is taken into consideration, also the portion of correct area of polygons with a not precise delineation.

The classes N.18 and N.28 show a low general accuracy. For this reason a further revision of the land cover interpretation was carried out. Particular attention was given to classes showing low accuracy, and a specific check was done for classes N.18 and N.28. At the end of the final revision, an additional accuracy assessment was performed specifically for the two classes quoted above, with the following result:

STRATUM (CLASS OR GROUP)	Correct Photointerpretation						Total Checked	
	MAP Approach				SURFACE Approach			
	Number		Area				Number	Area
21454-121340 - Herbaceous Closed to Open (100-40)% Vegetation	7	70,00%	13.906.431,59	89,96%	14.261.107,57	92,25%	10	15.459.007,02
42348-4732-L15L5R1 - Closed to Open Medium Tall Herbaceous Vegetation On Temporarily Flooded LandMajor Landclass: Level Land, Valley Floor, Slope Class: Flat To Almost FlatWater Quality: Fresh Water	8	80,00%	8.477.478,37	91,94%	8.792.447,58	95,36%	10	9.220.308,50

An extensive description (class by class) of the accuracy assessment is in ANNEX 1 – Accuracy Assessment Statistical Report

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