STUDY AND ACCURACY ASSESSMENT OF REMOTE SENSING DATA FOR ENVIRONMENTAL CHANGE DETECTION IN ROMANIAN COASTAL ZONE OF THE BLACK SEA

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ABSTRACT:

Environmental studies are a constant subject of research and have a permanent place in the international policy of sustainable development and ecosystem preservation. An important aspect is resource management and environmental change detection.
Environmental aspects in coastal zones of the Bleck Sea are very important because the high population density and the intense economic and tourist activity make them extremely vulnerable. An integrated approach, using remote sensing and “in situ” observations, with the help of 2D-GIS data tools is the adopted solution in this work.
In this paper we use the SPOT HRV , Landsat TM and SAR satellite image data over the costal zone of Black Sea. The mean of reducing feature space dimensionality of data uses the orthogonal transform like: Principal Components Analysis for replace the feature set with a derived feature set. The pre processing and processing of the image data are made with ERDAS IMAGINE. Assessing the accuracy of change detection products is an important step for the integration of remote sensed data to environmental management system as a decision support tool.
In this paper we present the influence of accuracy and classification performance based of the confusion matrix and derived; overall classification accuracy, producer’s accuracy and kappa coefficient in change detection studies, the factors that are influencing the accuracy assessment and the accuracy assessment aspects for change detection and classification, with and without test data and cross-validation methods, for the Romanian coastal zone of the Black Sea from Mangalia to Sulina.

RÉSUMÉ

Les études du milieu constituent un constant sujet de recherche et ont une place permanente dans la surveillance internationale du développement soutenu et dans la conservation des écosystèmes. Un important aspect est le ménagement des ressources et la détection des changements d’environnement. Les aspects de l'environnement dans les zones côtiers de la Mer Noire sont très importants à cause de la grande densité de la population et du développement économique soutenu et ainsi à cause de l’activité touristique qui font ces zones très vulnérables. Un abordage intégré sur la base des données de télédétection et des observations “in situ” dans le cadre d’un système d’information géographique en deux dimensions est la solution retenue dans cette étude. Dans ces travaux on utilise l’imagerie HRV(p), TM et SAR sur la côte de la Mer Noire. Dans le but de réduire les dimensions spectrales des données a été utilisée la transformation orthogonale en composantes principales pour remplacer le set original de donnes. Le traitement et pré traitement des images a été effectué à l’aide du logiciel ERDAS et EACI PACE. L’établissement de la précision des changements des produits est un pas important de l’intégration des données de télédétection dans un système de ménagement du territoire comme support technique aux décisions administratives. Dans ces travaux on présente l’influence de la précision de la classification et du coefficient kappa dans les études de la détection des changements et ainsi que les facteurs qui influencent dans l’établissement des aspects liés aux détections des changements et dans la classification, sans l’utilisation des données test ou méthodes de validation concernant la côte de la Mer Noire à partir de Mangalia à Sulina.

INTRODUCTION

The environmental policies at the international level are related to such issues as pollution, natural resource management, sustainable development and global climate change. The role of remote sensing data in this context is to define and support information systems for environmental purposes, with the aim to detect air and water pollution, soil degradation, vegetation and environmental change.
As a component of the environmental studies, the land cover change is an important aspect of resource management and environmental mitigation, being a complex indicator of the effects of the local, national and international policies regarding the environment.
The late development in the satellite and sensors capabilities can be identified as a response to the high request for increased accuracy in spatial, radiometric and temporal domain.
The most used technique for land cover change detection is the merging of two images from different dates; the resulted overlay indicates the areas that appear to be changed and the nature of change also. In such an analysis the results are dependent of the accuracy of the two images used.

Techniques developed for accuracy assessment must take into consideration the factors that are sources of error in image and the methods used for assessing accuracy in a single image and for a pair of images.

Serious erosion processes affect the coastal areas. Erosion monitoring can be best performed using change detection techniques.

The coastal erosion is a natural phenomenon by which the coast line advances into the shore, under the continues influence of the natural factors, (climatic factors and the configuration of the coastal currents, the winds and hydrological regime and the waves and also the pollution), the hydro technical and protection constructions in the coastal aria modified the current's regime re-directing them and producing an deceleration of the erosion phenomena in the related zone but in exchange adjacent areas can be subject to increased erosion phenomena due to the change in marine currents regime. These processes have a variable evolution speed in time and space and are a continuous threat for the human establishments from the coastal aeries, and also for the ecosystem.

Monitoring of these kind of phenomena can be done only with a database of an geographical information system (GIS), which should contain special data (satellite and aerial imagery, maps etc) and also geographical, geological, socio-economical information. The Romanian coastal aria stretches on a pretty long distance. Detecting the changes in the costal line is quite easy when utilizing images that come from a single sensor. Sensors operating in the field of microwaves have the advantage that they do not depend on the visibility conditions and the dry land and water surfaces appear distinct, each having a specific response. In the coastal areas the level differences are reduced, so the geometrical distortions are also reduced, remaining the ones characteristic to the data used.

CHANGE DETECTION

1. General characterizations of the Romanian Black Sea shore

Romania is placed in the Northwest side of the Black Sea, with a 243km shore.

The general orientation of the shore is to the North South, the northern limit being formed by the Chilia channel (45^{o}12' north and 29^{o}40'east), which makes the shared border with Ukraina and the southern limit with Bulgaria being formed by a conventional line, which passes south of Vama Veche (43^{o}44' north and 28^{o}35'). The open sea limit of the territorial waters is considered to be at a 12-mile distance to the shore line; in figure 1 is presented the physic-geographical maps of the Romanian Black Sea shore.

Genetically and especially morphological the Romanian seashore presents a variety of aspects. Northern sector is an accumulative shore, formed mainly by littoral lines, sandy and in submersibile. Southern sector the shoreline is obvious being formed by a high cliff, which is interrupted by parts, which are cut off the sea also by sand aeries. To the modification of the actual morphological aspects of the two existing sectors contributes in proportions and combinations, factors of different origins, such as litology the fluvio-marine accumulations, waves, currents, level fluctuations, seismically activity, winds, precipitations fauna and flora and also human activities.

The northern sector takes 68% from the Rumanian shore lying in the eastern extremity of the Danube Delta, between Gura Musura from the secondary delta, Chilia and Capul Midia.

The existence of positive eustatism of the Black Sea (0.5cm/year) gave birth to a slight sea transgression shown by swamps in the river marine movment resulted from the sediments of the delta deposits. At the moment, in the cordon/Sulina shore sector there is precise demarcation line because the pre/existing sandy aria is submersed under water (-0,80m). In the aria of the Sulina channel (behind the dams, the shore had a rapid forward movement, looking overlay like a spur adjacency into the sea. Between Sulina and Sf. Gheorghe there is a sandy belt area almost as a straight line (with different lengths), with a tendency to move towards west. South in the mouth of the Sf. Gheorghe channel is developing the island Sahalin (it appears for the first time on the 1830 and1857 maps, made by the representatives of the Delta Commission). In the last 40 years it stretched to the South and moved to the West, almost closing the Zatoane - Ciotic zone, transforming it into a lagoon. From Ciotic to Chituc there is a sandy belt/aria positioned between the sea and the lagoon complex Razelm-Sinoe, pierced by the Portita mouth through which the strong storms often produce ruptures in the littoral belt south to Portita. The littoral belts which border the Danube delta and the Ravel lagoon to the east are formed from instable dunes, with heights varying between 0.20m and 1.50m.These sand are often moved either by the sea waves which cross the belts during storms, or by the strong winds which blow in these parts. Generally the littoral belts have variable widths and are in a continuous displacement, which clearly show the tendency to move to the west. The southern sector contains 32% from the Romanian shore length and has the structural characteristics of a high cliff. This sector stretches south of Capul Media to the border with Bulgaria, the land configuration being determined by the morphology litology and structure of the deposits which form the Dobrogea Plateau. The shore in this sector has a great stability and undergoes a continuous but slow process of retreat because of the erosion accelerated by the action of atmospherical and biological factors and also of underground waters which are generating land slides with the aspect of false terraces. The solutions to diminish the erosion and slide processes are to build dams to consolidate the cliffs. Today the zone is characterized by a diminishing process of the beaches. The aspect of the shore in between Constanta and Vama Veche is given by the complex geological structure. The combined action of the waves and marine currents determined the apparition of small gulfs, which were separated from the sea by littoral belts.

2. Accuracy assessment aspects for change detection

Accuracy is considered to be the degree of closeness of results to the values accepted as true. Some of the accuracy assessment methods are: the variance analysis, minimum accuracy value used as an index of classification accuracy, spatial error and class attribute errors, a probabilistic approach for change detection and land cover classes are abstraction and generalizations of the real world in order to provide discrete values for continues To obtain a robust change detection, some environmental factors and variables must be taken into consideration, such as atmospheric conditions, soil characteristics, vegetation cycles, hydrologic cycles and others.

Most of the environmental features are extremely dynamic; in most of the cases the temporal and geometric resolution of remote sensed data cannot cover the dynamic domain of the environmental parameters evolution (atmospheric conditions, soil moisture, and other environmental related phenomena). In change detection studies we should have in mind the differences in the phenological state of different varieties of the same species and the time the data sets were acquired (most suitable at the same date of the year).

Meteorological aspects and the hydrologic regime of the area along with the agricultural work schedule are important aspects also.

These aspects are predictable if we have appropriate geomorphologic analysis land cover and soil qualities are assessed for the zone in study.

The littoral belts from the South sector are not continuous and are made of fine and medium grain sands. The retreat of the rocky shore is caused by the marine erosion, which is; - very active in the Agiga, Eforie Constanta and North Mangalia zones (the materiel resulted from the cliff's erosion was taken away by waves and currents), - less active in the south zones of Tusla and 2 Mai.

3. Basic data utilized and methods

The Romanian side of the seashore goes over 32 maps at the 1:25 000 scale, designed between 1958 and 1964. These maps were utilized to create the reference situation in our studies. The maps were vectorised with the main topographical elements from the nearby neighborhood of the littoral belt within a SIG database. The satellite images that were used for the study are HRV (p) (spatial resolution 10m) from 23.05.1997 images 98/262 and 98/258. For the interest zone were used two TM images (spatial resolution 30m), images 1281/029 from 23.06.1997 and the images 181/128 from 23.06.1997. There were also used images SAR from 31 may 1998 orbit 16272/frame 0909 and 09 August, orbit 17274/frame 1891. (Courtesy of CRUTA and INMH). There were also used aerial photo grams from July 1983,1984,1986 and 2002 at the scale 1:6000, other cartographic documents, field determinations, meteorological observations regarding the direction, the size and waves speed, ground studies, surface waters, their hydrological regime and vegetation elements, the distribution of human establishments and the traffic infrastructure transportation network, GPS field measurements (which were introduced into the data base into separate levels for better analysis).

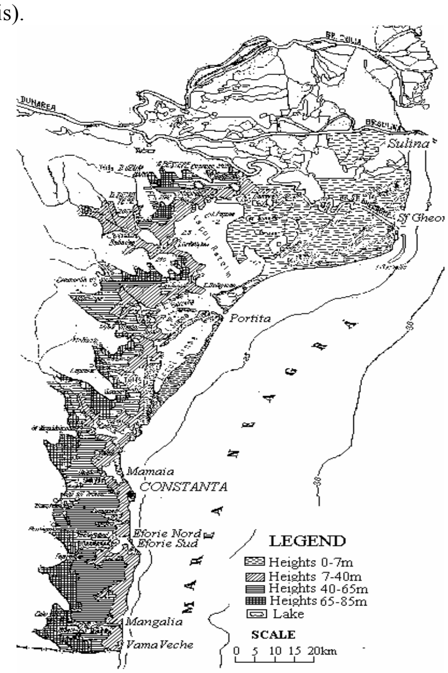

Figure 1. The Romanian Black Sea littoral.

In order to register the satellite images the digital elevation model of the field was derived, for a band of 50km from the littoral belt. The studies were made within a project having as partners UTCB, OPTOELECTRONICA, INMH and CRUTA Bucharest. The morphological modifications of the coastline were evidentiated by the registration of the satellite images over the reference vectorial database.

The interpretation of the data image was made with the ERDAS 8.3 software version, installed on a PC station and for the factorization of the maps ARC/INFO was used. The preliminary analysis and the interpretation of the image data had the steps shown in figure 2.

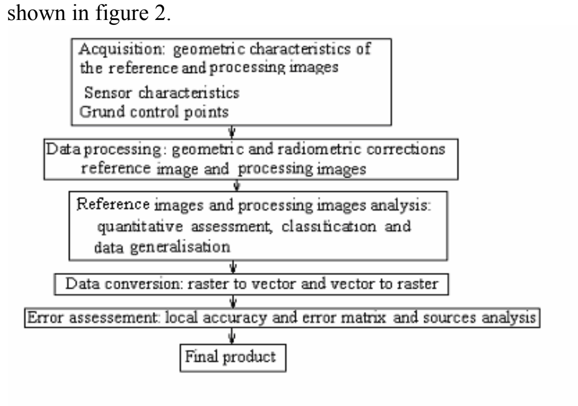

Figure 2. The steps in the image analysis.

3. Interpretation of the results

A judicious discerning radio metrical and geometrical analysis can improve the interpretative proprieties of spectral and spatial data. The radiometric analysis contained operations for the elimination of the noise present in the data, and also thickening the lines and limit marks. The geometrical analysis besides correcting the distortions connected to the aquisition of the image is also bringing into the system of the reference map in gauss projection, having as reference the Krasovski ellipsoid.

Considered to be a pre-analysis step, the rectification of the satellite images has as target the geometrical transformation of the images. Usually, this step means: finding the support and control points the calculation of the transformation parameters, the creation of the transformed image in the reference system imposed by one of the known resampling methods. The data administration within a GIS supposes: logical and physical independence, base access to recorded data, with the help of fast algorithms.

In figures 3 and 4, below, are presented the results of the spatial analysis on Landsat TM data compared with a vectorised map scale 1: 25.000.

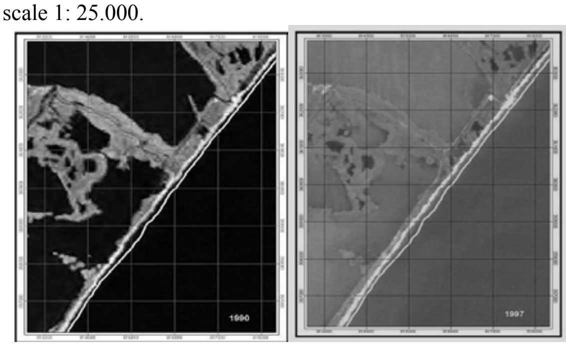

Figure 3. Coastline evolution: 1990-1997.Landsat TM superimposed on vectorised map (Images courtesy CRUTA)

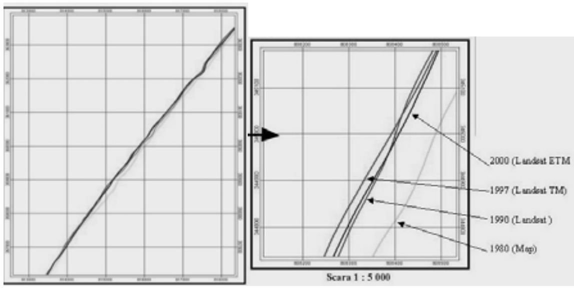

Figure 4. Shoreline evolution over 20 years as extracted from Landsat data.

3.1. The changes of the Romanian costal zone

The Rumanian coastal zone can be divided from the geomorphological point of view, in two main units. The northem unit and the southern unit. In the northern zone prevails the low relief, characteristic to the Danube Delta, with narrow blokes. Transported by the strong currents of that zone, the sands built a barrier in the Sf. Gheorghe zone. These barriers closed the Razelm Lake. The sediments form the modern times are made mainly from quartz sand (70% silicon). Heavy metals do not go over 3%. The transport of sediments that come from the regions north to the Danube Delta have higher silicon content, of almost 90%. The evolution of the delta zone started during the quarternary and was strongly influenced by the modifications into the sea level of that time.

The Delta was formed during the period of the sea level retreats through the alternate developing of the river Danube, each developing it's own deltaic structure. Presently there are three Danube branches active and only Chilia is still developing it's own deltaic structure. The other coastal sectors are retracting, being influenced by the decrease in the Danube sediments over the last century. The long term studies shown a decrease of the Black Sea level of almost 2.5mm/year in the Vama Veche region, while other measurements evidentiated the rising of the sea level of 1.2 to 1.8 mm/year at Sulina and almost 3.3mm/year at Constanta. The ground in the delta zone is going down with 1.3-2mm/year because of the sediments phenomenon and the zone's tectonics. The tide phenomenon in the Romanian coast not is easily detected because of other fluctuations. The other fluctuations of the Black Sea level are caused by the dynamics in the river's debits that go into the Sea, modifications of the water flow in the Bosfor straits and the precipitations/ evaporations relation in that zone. One of the most important factors that influence the hydrological budget of the Black Sea is the volume of water, which goes through the rivers that form the hydrological pool of the Black Sea. The Danube River has the highest volume between April and June. The building of many dams over the Danube River and it's affluents considerably reduced the transport of sediments.

Another important factor is the winds and waves regime. The average wind speed in the NV region of the Black Sea is between 6.5 and 5m/s. The main directions of the wind is N,V and S, a greater weight having the NV direction. During the summer months the predominant direction is S-SE. The storms have a predominant N direction, with an average wind speed of 9.8m/s, during a period of time of 8 to 22 hours. There is a 50% probability that aver one year to have waves higher than 0.2m. The retreat of the coastline with almost 10m/year is more obvious along the Sakhalin barrier and south to Ciotca, and also between Portita and Chitiuc. Then the coastline advances immediately south of Sulina where it is accompanied by the presence of some very shallow waters. See figure 5

4. Sources of error in change detection

A first approach to classify errors in environmental change analysis with remote sensed data is dividing the sources of error in instrumental errors and method errors. A more detailed description of errors can include the data acquisition errors, data processing, data analysis and data conversion errors .

In the process of error assessment, several errors can occur: positional errors, registration, differences, data entry error for reference data, interpretation and delineation of reference data, reference data and remote sensed data are not simultaneously collected, classification errors. The results are affected by different errors, at different levels and the positional and the thematic information obtained from the two data sets is not of the same precision. From the merging of the two data sets will result an unknown precision of the final product.

4.1 Positioning error

The resulted thematic classification assigned to each identified class a spatial location on the image. During this process a generalization operation is performed. The class boundaries are also affected by misclassification of the marginal pixels.

Horizontal accuracy for map products at scales greater than 1:20 000 must be less than 10% of tested points to have a greater error of 0.85cm, measured at the map's scale. For maps at scales 1:20 000 or smaller, the admissible error is 0.51 mm. The horizontal components are defining standard position error in which are contained 90% of point coordinate discrepancies. Another accuracy criteria is the map standard deviation.

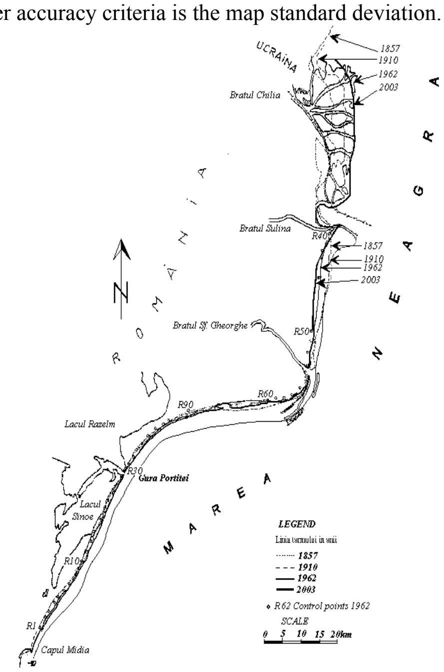

Figure 5. The dynamics of the littoral corridor between year 1857 and 2003.

Standard deviation for tested points must not have a value over the value calculated :

$$d = \sum_{i=1}^{n} \left[\frac{l_i}{n} \right]^{0,5} \quad (1)$$

where d = standard deviation
li= point error
n = number of points

Figure 6. Change detection using two images within a time lapse of 10 years. Bright details are subject of change

If we assume that two points taken into consideration are independent and their specific accuracy is different, the relative position error can be calculated from the square sum of the two values for the positional accuracy:

4.2 Classification data error

Another source of error is the thematic classification of data.

A method to empirically assess the classification accuracy is to select several classes and to compare them with the reference data. Reference data is usually named "ground truth". By comparing the data sets, the percentage of the pixels correctly classified can be estimated.

From every class representative pixels are selected and compared to the reference data.

A statistical approach of this problem is to select random pixels from the thematic map and to compare them to the reference data. Here, the main impediment is that large classes have the tendency to be represented by a larger number of points and the small classes may be not represented at all. The solution to this problem could be the stratified random sampling, in this case, a set of strata are predefined and the random sampling is carried out in each of these collections. A regular grid can be used or a random selection of pixels in each class, in order to assess the class accuracy. A confusion matrix will result.

(Van Genderen, 1982) and (Rosenfield,1978) have, along with others, determined guidelines for the minimum sample size.

The estimated accuracy for a class can be calculated (Freund, 1962):

$$p\left\{-z_{\alpha/2} < \frac{x-n\theta}{\sqrt{n\theta(1-\theta)}} < z_{\alpha/2}\right\} = 1-\alpha \qquad (2)$$

x= number of correct identified pixels, n= total number of pixels in the sample, θ= the map accuracy, (1-α)= a confidence limit, imposed by the analyst.

The remote sensing characteristics that affect the change assessment accuracy are: temporal, spectral and spatial resolution, look angle.

In order to perform accurate change analysis, the data must be acquired at approximate the same time of the day and at significant calendar dates regarding the environmental changes that are under observation.

If data used to detect changes are from the sensors with the same IFOV (Instantaneous Field of View), it is easy to register the two data sets. Geometric rectification algorithms can be used to register the images to a standard map projection (most of the available software and maps are in UTM but for the specific case of Romania, a Stereographic 1970 map projection is necessary- for this, standard datum and standard geoid is provided).

4.3 Environmental considerations

To obtain robust change detection, some environmental factors and variables must be taken into consideration, such as atmospheric conditions, soil characteristics, vegetation cycles, hydrologic cycles and others. Most of the environmental features are extremely dynamic, in most of the cases the temporal resolution of remote sensed data cannot cover the dynamic domain of the environmental parameters evolution (atmospheric conditions, soil moisture, other environmental related phenomena). The atmospheric effect can be corrected with specific path radiance atmospheric correction models or an image-to-image normalization method.

Many factors, related to the specific phonological characteristics of the vegetation canopy must be taken into consideration. Attention must be given to differences in the phenological state of different varieties of the same species and the time the data sets were acquired . Meteorological aspects and the hydrologic regime of the area along with the agricultural work schedule are important aspects when change detection analysis is performed.

Depending of the meteorological conditions, the river network of the studied area can suffer changes and thus affect the soil humidity conditions. These aspects are predictible if we have appropriate geomorphologic analysis is and soil quality is assessed for the zone in study.

5. Image processing and change detection

In order to obtain environmental changes information, once we selected the appropriate data and classification scheme, special radiometric and geometric corrections must be applied, followed by change detection and classification techniques, creation of thematic products and finally the error assessment.

Image normalization reduces the pixel brightness variations. Using simple regression equations between the brightness values of radiometric normalization targets in the base scene and the scene to be normalized can perform image normalization.

Ground targets that spectrally invariant in the two images can be used to normalize multitemporale data sets to a single reference scene. The acceptance criteria for radiometric normalization are (Eckhardt, 1990):

The target must be at the same elevation, must contain as little vegetation as possible the terrain must be as flat as possible, the scene features must remain unchanged in both scenes.

This method calculates the additive term (path radiance correction) from a constant (D) and then obtains the multiplicative factor:

$$M = \frac{\cos\theta_{0\,ref}\left(\frac{1}{ES_{ref}^{\;2}}\right)A_{ref}}{\cos\theta_{0\,norm}\left(\frac{1}{ES_{norm}^{2}}\right)A_{norm}} \qquad (3)$$

$$C = D_{ref} - \left(D_{norm}\right) - \left(M\right)$$

where: 1/A= Radiance interval of brightness value, C= additive correction, θ_0= solar zenith angle, ES= Earth-Sun distance, Ref= reference scene, Norm= scene to be normalized, D= dark normalization target of brightness value. This approach ignores differences in atmospheric attenuation and phase angle between data sets. The radiation received is dependent of the relative orientation of the terrain from the Sun. All these methods require a DEM (Digital Terrain Model).The DEM and the image was registered and resample to the same spatial resolution as images. And then the value for each pixel is

processed in order to represent the amount of illumination it should.
The spatial registration of a remote sensed image to a map projection is necessary in order to locate with precision the changes occurred in the studied zone. Geocoded images are directly available from data distributors but additional registration must be necessary for zones with complex terrain configuration and when DEM used by data suppliers are not of confidence. A good way to perform geocoding was to measure ground control point in the field with GPS and use this data set to calculate the correct rectification. The ground control points are permanent, static features in the field and easily identifiable on the image.
The most used algorithms for change detection are (Jensen):
- Change Detection Using Write Function Memory Insertion.
This is an analog method for qualitatively assessing the changes in a region and do not provide quantitative information of the changes occurred.
- Multi Date Composite Image Change Detection. Multiple data sets are inregistred to a single database. This composite data set can be used to extract information by unsupervised classification techniques with a result of a class with change and a class with no change. Another method is the principal component analysis.
- Image Algebra Change Detection (Band Rationing and Band Differencing). Subtracting an image from the other one performs image differencing. The result is formed by positive and negative values in areas of radiance change:

$$D_{ijk} = BV_{ijk}(1) - BV_{ijk}(2) + C \qquad (4)$$

Where: D_{ijk}= change value pixel, $BV_{ijk}(1)$= brightens value at time 1, $BV_{ijk}(2)$= brightens value at time 2, C= constant used to transform the negative or positive results in positive results (normally the results are ranging in the interval –250 to 250)
i= line number, j=column number, k= band number.
The essential aspect of this process is the threshold selection of boundaries between change/no change zones.

5.1. Spectral Change Vector Analysis

Areas with changes have a different spectral response. The vector describing the direction and the amplitude of the change from image 1 to image 2 is the spectral change vector. The total change/pixel (CM_{pixel}) in n-dimension spectral space is :

$$CM_{pixel} = \sum_{k=1}^{n} \left[BV_{ijk(date2)} - BV_{ijk(date1)}\right]^2 \qquad (5)$$

where: $BV_{ijk(date2),\ ijk(date1)}$ = pixel values for date 1 and date 2 in band k .

5.2. Change detection error matrix

In order to assess the accuracy of the change detection procedures is recommended to generate an error matrix. The columns of an error matrix contain the reference data and the rows represent the results of the remote sensed classified data. This is an effective way to represent accuracy of each classified category :
The error matrix is a multidimensional table, its cells contain change data from a category to another. The statistical approach of the accuracy assessment consists of different multivariate stastitical analysis. A used measure is KAPPA (Cohen, 1960).
KAPPA is designed to compare results from different regions or different classifications.
The KHAT statistic is:

$$\hat{K} = \frac{N \sum_{i=1}^{n} X_{ii} \sum_{i=1}^{n} (X_i * X_{+i})}{N^2 \sum_{i=1}^{n} (X_{i+} * X_{+i})} \qquad (6)$$

where n is the number of rows in the matrix, X_{ii}=number of observations in the row i and column I, X_{i+}= the marginal totals of row i and column I, N=total number of observations.

CONCLUSIONS

Change detection is an important tool for environmental studies, assessing the accuracy of change detection products is an important step for the integration of remote sensed data to environmental management system as a decision support tool. In assessing environmental changes based on remote sensed data, the major impediment is that the estimate values are difficult to compute due to the complexity of the processes involved and more often the reference data is not available for computing accuracy. A specific attention must be given to different methodologies to detect changes and error matrix construction, as a function of change susceptibility of the studied area.
In order to improve results in change detection several aspects must be considered:
A budget of the sedimentary regime is needed; The shoreline topometry at several time interval, with the same precision of the measurements in order to obtain a dynamic 2D-3D model of the region to determine substrate variability and change detection at spatial and temporal scales of high resolution. It is also important to know parameters and boundary conditions controlling coastal evolution and geologic framework such as tectonics, sea-level movements, storm and other changes in sediment source and paleogeography; Constant in situ observations, correlated with remote sense data acquisition. In the space of two decades, application of this methodology of investigation allowed a better understanding of the coastal line evolution trends greatly improved understanding of the coastal zone dynamics.

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