

AEROSPACE MONITORING OF ECOSYSTEM DYNAMICS IN DANUBE DELTA

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ABSTRACT:

Authentic barometers of environment health status, delta and coast wetlands represent research subjects for remote sensing applications. The Danube Delta contains a wide variety of ecosystems and species, many of them are seriously threatened throughout the rest of Western Europe, making an area of unique ecological significance. Efforts to exploit the Danube Delta for mechanized agriculture and aquaculture have reduced or eliminated natural water flow in many areas, severely disturbing aquatic ecosystems.

The paper presents aerospace monitoring of simple ecosystem dynamics based on a comparison of aerial and Landsat-MSS (acquired on July 24, 1975), Landsat-TM (acquired on June 28, 1984) and Spot-HRV (acquired on April 27, 1993) space multispectral images, over an eighteen years period, between 1975 and 1993. During this period, the environmental stresses on delta's ecosystems have increased markedly, caused by man's intervention over the entire hydrographical basin of Danube and inner Danube Delta.

After an individual preprocessing, a hybrid classification has been realized for each of the three multispectral images. Firstly, an unsupervised classification based on classic composite images (near IR, red, green - MSS 7, 5, 4; TM 4, 3, 2; XS 3, 2, 1) have been made, followed by a supervised hybrid classification process using a parallelepiped and maximum likelihood method for eight major classes. The dynamics of single ecosystems are described by linear or more commonly, non-linear exponential or parabolic functions. The study highlighted accentuated dynamics of alteration in Danube Delta's ecosystems and proved that medium resolution Landsat-TM and Spot-HRV are efficient means for ecosystem dynamics estimation. Old Landsat images revealed their utility for early times of remote sensing.

1. INTRODUCTION

Although second in Europe and the twenty-third in the world, the Danube Delta contains a wide variety of ecosystems and bird species, many of which are seriously threatened throughout the rest of Western Europe, making an area of unique ecological and phanistic significance. In addition to providing transportation and drinking water for inhabitants along its course, the Danube's water is tapped for hydroelectric power, industrial processes, irrigation of agricultural land, and disposal of municipal and industrial waste. The complex and varied ecosystems of the Danube Delta have remained unspoiled for centuries, natives integrating in the maintenance of natural balance. Environmental stresses on delta wetlands have increased markedly in the past 3 - 4 decades, caused by man's intervention, which became more and more actively over entire hydrographical basin of Danube and inner delta.

After 1990, the romanian region of Danube Delta, together with the lacustrine complex Razim-Sinoie has been declared a Biosphere Reserve. First of all, any agricultural and hydrological developments have been stopped. Over 50% of the reservation has been declared World Heritage Site by UNESCO. Experts of UNESCO among well-known commander Jacques Yves Cousteau (in 1991) have visited and studied Danube Delta. Due to their specific techniques for data recording and analysis, photogrammetry and especially remote sensing are exquisite means in change detection at the level of

principal morphohydrological elements and vegetation in the delta's ecosystems.

2. STUDY ZONE AND DATA SOURCE

2.1 Aerospace monitoring of the ecosystems

The reasonably extended ecological facies, the land use classes and areas with destroyed ecosystems are also successfully identified on space photographs with a spatial resolution of 50m or better. From these imageries, aerospace monitoring of the dynamics of areas can be realized, but only for those ecosystems where the probability of correct recognition approaches 98-100% (as a rule not below 96%, as otherwise the errors of identification can exceed the dynamics of change. Stable ecosystems, that is, with area changes of less than 0.5% per year, require a revision not less than once in 8-10 years. Highly dynamic ecosystems (more than 4% changes) require inspection every year (*Vinogradov, 1988*).

There are several developed technologies that can be used for comparing successive photographs for the detection of the ecosystem changes. The comparisons are executed either visually or using digital processing. By visual comparison, using known identification keys, the identification of images from two different date missions and the results are then compared. The main advantages of this visual method are the possibility of using all the tone, texture and other photographic

indication and also the possibility of controlling all natural and technical survey condition. Among automated methods of detection of changes the digital processing and analysis are used. Sometimes the systems work by recognizing the differences between compared images before classification of detected differences; and other times, in contrast, images are first automatically classified to produce ecological classes and then subtracted. The second method (post classification comparison method) is the most commonly used.

The main task in comparing the images of different years and in discovering changes in the areas of ecosystems is to determine the common basis of these changes, that is, the ecological trend. This trend is defined as a translational change of a system whereby its state on any time scale is not repeated and the direction of its drift is constant within the investigated time limits. The main purpose is to measure and describe the ecological trend in terms of area change, using aerospace images. It should be excluded the influences of different short-terms fluctuations (for example hydrometeorological variability in different years). Distinguishing ecological trends at this level involves great difficulty and only a rigorous mathematical expression is sufficient to allow scientific ecological prognoses.

2.2 Research sites

2.2.1 Caraorman–Dunavăț site: As study sites has been selected Delta's representative areas, both for flora and fauna diversity and for dynamic changes from the past decades. The site has a square form of 30.72 km side and is placed in central-western of Danube Delta and contains the following ecosystems: **ecosystem of dry land** - in the south-western of site, including surroundings of Murighiol, Dunavățu de Sus and Dunavățu de Jos villages; **ecosystem of running water** - including Sulina and Sf. Gheorghe branches, Dunavăț, Tătaru and Crișan channels; **ecosystem of stagnant water** - including lakes ponds, and plugged channels; **ecosystem of river banks and marine levees** - Ceamurlia, Lat and Caraorman, which had been the domain of all kind of trees, broke up in their greatest part and replaced with Canadian poplars. On Caraorman bank still exists a large abandoned sand-mining; **ecosystem of marshy and flooding surfaces** - is dominated by emerged vegetation prevalent constituted of common reed and a mixture of common reed- mace reed. Floating reed islet formation, which is a mixture of reed roots herbs and soil, usually floating or fixed on the bottom of depressions, has a peculiar place within the ecosystem; **ecosystem of polders** - include fish ponds, agricultural and forest polders; the zone in the north of Sulina branch is declared area for ecological restoration.

2.2.2 Sulina site: The site has a square form of 24.1 km side and is placed in central-eastern Danube Delta. This includes in addition to Caraorman- Dunavăț site, **marine ecosystem** - include Black Sea coastal area. Sea proximity creates a series of special problems. It is very important to underline that water level variance in ecosystem of marshy and flooding surfaces is dependent on water flow variance on Danube branches. This ecosystem acts as a large buffer lake, which attenuates water flow variance. Water levels difference in inner delta from april to june has a 60-70 cm maximum.

2.3 Data sources

The study was based on available satellite images (Landsat MSS, July 24, 1975; Landsat-TM, June 28, 1984 and SPOT-HRV, April 27, 1993), aerial photographs at 1:45,000 scale acquired in 1984, ground radiometric measurements realized in

some representative areas of Caraorman Dunavăț site, near the Remote Sensing Laboratory of Technical University of civil Engineering-Bucharest, at 54 km on the Sf. Gheorghe branch, in 1984 and 1993, with a four-channel Exotech 100 AX portable radiometer using Landsat-TM channel filters (to facilitate the object classes separation and point out the atmospheric effects) and complementary data (topo-hydrographic maps, main ecosystems map, Danube Delta vegetation and soils maps, etc). Using Landsat-MSS images (characterized by a lower resolution) the study period extends at 18 years.

3. METHOD

3.1 Preliminary processing

One of the most important temporal reasons for change-detection applications is the acquiring month of the imagery. Images acquired during the period with power sun light, present a very good contrast between various details (Jansen, 1983). For example, in this case, the contrast from covered with vegetation soil and uncovered is very strongly. Using the scene acquired in the same year's period is suggested to change-detection with purpose to reduce the problems which appear because sun-angle difference, vegetation-phenology changes and differences in soil-moisture. (Hall et al., 1991; Jansen et al. 1993). SPOT HRV image was used as a reference image to ensure compatibility of multitemporal data.

Due to lack of information regarding atmosphere characteristics radiometric calibration has been realized for every site based on 15 invariant or quasi-invariant in time objects (Chavez, 1989): darker zones (great lakes water and Black Sea without turbid water), or brighter zones (Caraorman bank and beaches sand). Landsat- MSS and TM images normalization has been done, for every channel, using a nonlinear regression equation:

$$y(i) = ax(i) + b \quad (1)$$

where: $y(i)$ -is radiometric value of pixel from reference image; $x(i)$ -is correspondent radiometric value of pixel from corrected image.

During the registration process, have been used two reference images, based on aerial photos at 1:45,000 scale, representing the geometric fundament for images registration (Rignot et al. 1991). Geometric corrections applied to photos and satellite images have been based on 34 ground control points for Caraorman-Dunavăț site and on 28 ground control points for Sulina site. These points have been determined, using software PAT-MF for Aerotriangulation with independent models, at Wild Aviolyt BC2 in the Photogrammetry, Remote Sensing and GIS Laboratory of Moncton University, Edmundston center, Canada.

It has been realized a resample of 4x4 for MSS and 1,5x1,5 for TM because different sensor resolutions (80m for MSS, 30m for TM and 20m for HRV). For low-resolution images resampling (Landsat MSS) it has been used the nearest neighbour-method, which does not alter the digital number of the original image pixels. For Landsat-TM images transformation have been used three-degree polynomials, followed by a cubic convolution. The resample function included 16 pixels surrounding the processed pixel, allowing local modeling of image by a polynomial surface. Transformation accuracy varies according to resample images. The root-mean-square (RMS) error is $\pm 0,436$ pixel for

MSS image, $\pm 0,813$ pixel for TM image and $\pm 0,275$ pixel for HRV image.

3.2 Composite images generation

Theoretically, vegetation, water and uncovered soil have very different behaviors in visible and especially in IR range. In this last range the separation of the three classes is easily done. A realistic interpretation proves to be very complex. For example, in range of 550 nm wavelength of visible spectrum, turbid water and uncovered soil can be mistaken.

Multispectral images allow different color combination, through which are selectively pointed out study objects. In most cases a very expressive standard false color composite is realized if a combination between channels near IR, red, green - MSS 7, 5, 4; TM 4, 3, 2; XS 3, 2, 1 is chosen (Thomson, 1990). It can also be realized a principal standardized components analysis, to confirm the three channels that will be used. This method brings a significant improvement of the SNR (Signal to Noise Ratio). In this case for color composite image generation it has been used two principal component of PCA with Normalized Difference Vegetation Index (NDVI). Adding this index allows a preferential enhancement of the areas covered with vegetation versus the built urban areas or uncovered soils.

Examining channels histograms for satellite images can be seen that only a small part of sensor range is covered. As a result a contrast enhancement is needed. For linear contrast enhancement with point's saturation, are used low values of enhancement (2.5-3.5%) with purpose of optimal use of unsupervised classification. The nonlinear contrast enhancement offered better results (histogram equalization) by enhancing the contrast for the densest domain of reflectance values from the original image. (Deutsch, Heydt, 1987; Singh, 1989). There also been used Laplace filters techniques for directional and nondirectional edge enhancement (used for linear details - channels, shore line).

The wider colors range on realized images allows distinguishing waters, vegetation and soils classes. Main morpho-hydrographic features as shore line, fluvial and continental plains, running, stagnant and marine ecosystems, past meanders remains, agricultural lands and villages parceled structure, uncovered soils and different vegetation types (compactly common reed, mixture common-mace reed, forest vegetation, grass vegetation) are revealed. Digital processing has been done with IDRISI 32 Release 2 software.

3.3 Multispectral classifications

For multispectral classification it has been used a hybrid method. First, unsupervised classification of the color composite image SPOT HRV has been realized (ISODATA algorithm), where the selected 16 classes are defined (Lee and Marsh, 1995). Several confusions occurred: for example in some areas of image forest vegetation class and compactly common reed class overlapped, or stagnant water class and remind water class. In order to improve classes definition have been used radiometric measurements, taken in 1984 and 1993 and a vegetation map at 1:100.000 scale, realized in 1993. After classes regrouping followed a hybrid supervised classification for 8 classes: running water, stagnant water, compactly common reed, mixture common reed-mace reed, forest vegetation, grass vegetation, uncovered soil and agricultural soil for Caraorman-Dunavăț site and sea water, stagnant water, running water, compactly common reed, mixture common reed-mace reed, forest vegetation, grass vegetation, uncovered soil+ urban area. Classification merges the parallelepipeds and

maximum likelihood methods to remove problems caused by nonnormalised distribution of used image (Jansenand et al. 1993). This last classification served for MSS and TM classifications checking (Kartikeyan and Gopalakrishna, 1994). The accuracy classification for the three dates was estimated using the standard, single-data, qualitative accuracy assessment procedures for each image. Producer and user accuracy were calculated for each change class, along with the overall accuracy (error matrix and Kappa Index of Agreement analysis) (Congalton and Green, 1998). Global accuracy for obtained classifications varied between 89.56% and 95.73%. Kappa coefficients varied between 0.82 and 0.91.

Figures 1, 2 for Caraorman-Dunavăț site and figures 4, 5 for Sulina site present classification results for TM and HRV sensors.

3.4 Postclassification processing

The classified images were compared using a statistical analysis to reveal changes. Ecological changes are focused on emphasizing the habitat changes of Delta's ecosystems, depending on antropic interventions in these areas. Figures 3 and 6 present changes diagram in habitats of two sites.

It has also been calculated many vegetation indices types, in order to realize qualitative map of vegetation classes. Among these, Soil Adjusted Vegetation Index (SAVI) and Normalized Difference Vegetation Index (NDVI) proved to be the best. These have been calculated using the following equations:

$$NDVI = \frac{\text{channelIR} - \text{channelR}}{\text{channelIR} + \text{channelR}} \quad (2)$$

$$SAVI = \frac{(1+L) * (\text{channelIR} - \text{channelR})}{\text{channelR} + \text{channelIR} + L} \quad (3)$$

where coefficient $L=0.5$; Channel R is channel 5 for MSS sensor, channel 3 for TM sensor and channel XS2 for HRV sensor; Channel IR is channel 7 for MSS sensor, channel 4 for TM sensor and channel XS3 for HRV sensor. Figure 7 presents soil adjusted vegetation indices (SAVI) for the two sites

Analyzing these two images can be observed a significantly separation between running water (Danube's branches, channels) and stagnant water (lakes and past meanders remains) ecosystems and the rest of ecosystems, because of high absorption of red and infrared radiation by the liquid medium and its low chlorophyll plants constituent. Separation of different vegetation types is facile, both in ecosystem of marshy and flooding surfaces, and in ecosystem of river banks and marine levees or in ecosystem of polders.

For example, forest vegetation class from Caraorman bank, northern Cretan village and Isadora Lake are very well depicted apart the other vegetation types (common reed and mixture common reed-mace reed), because of its dominant spectral reflectance in near infrared range.

By comparing the results from multiple aerospace images analysis, the ecological trends in the changing areas of most Danube Delta ecosystems were seen to be nonlinear. During the study period (1975-1993) nonlinearity of the ecological trend is obvious (Figure 8). The nonlinear trend is a curve of the form:

$$Y = a + b(X_o - X_i)^\alpha + c(X_o - X_i)^\beta \quad (4)$$

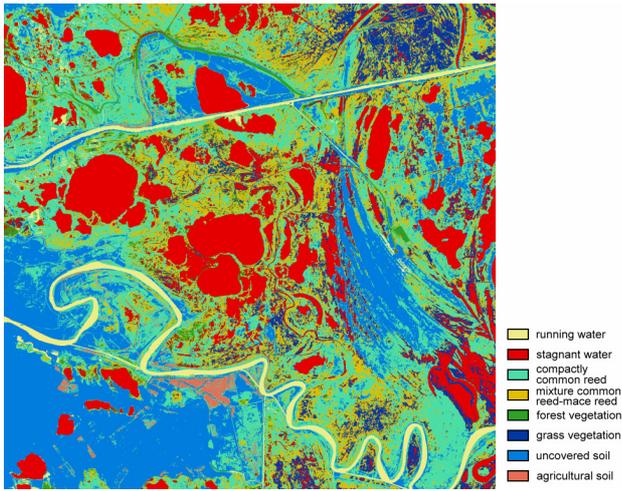


Figure 1. Classification of Caraorman site TM June 28, 1984

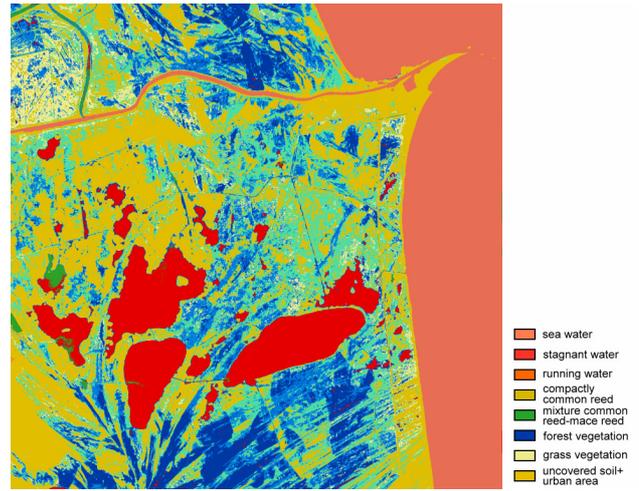


Figure 4. Classification of Sulina site TM June 28, 1984

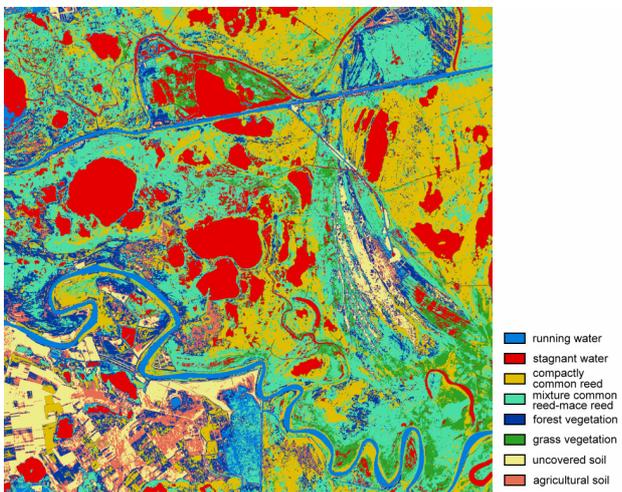


Figure 2. Classification of Caraorman site HRV April 27, 1993

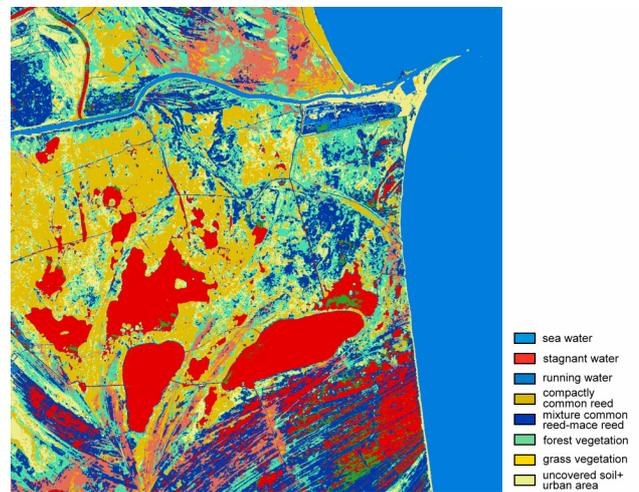


Figure 5. Classification of Sulina site HRV April 27, 1993

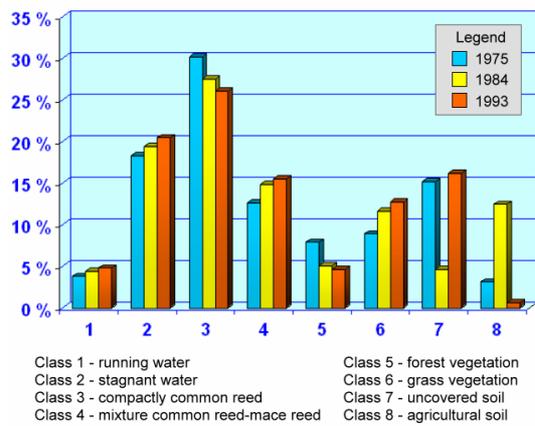


Figure 3. Change diagram of Caraorman site 1975-1993

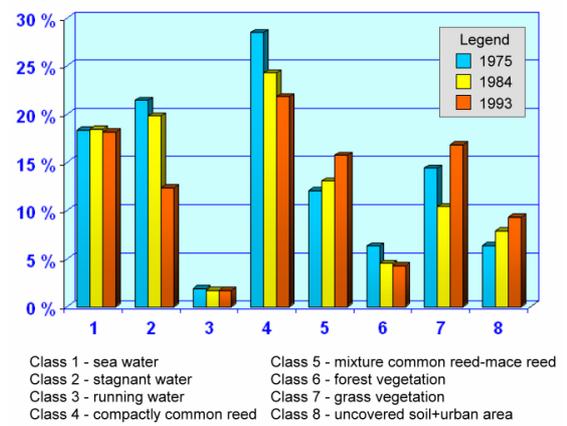


Figure 6. Change diagram of Sulina site 1975-1993

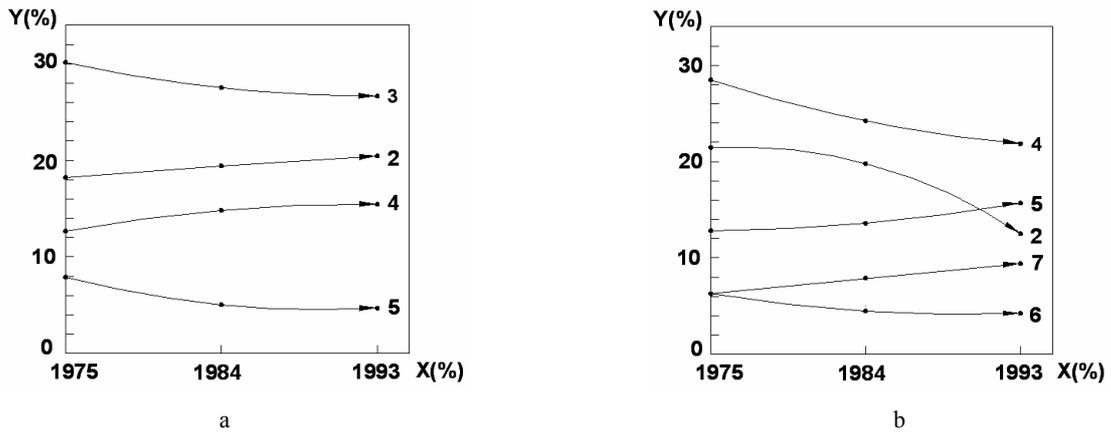


Figure 7. Trend in area change of ecological facies in Danube Delta: a) Caraorman-Dunavăț site; b) Sulina site

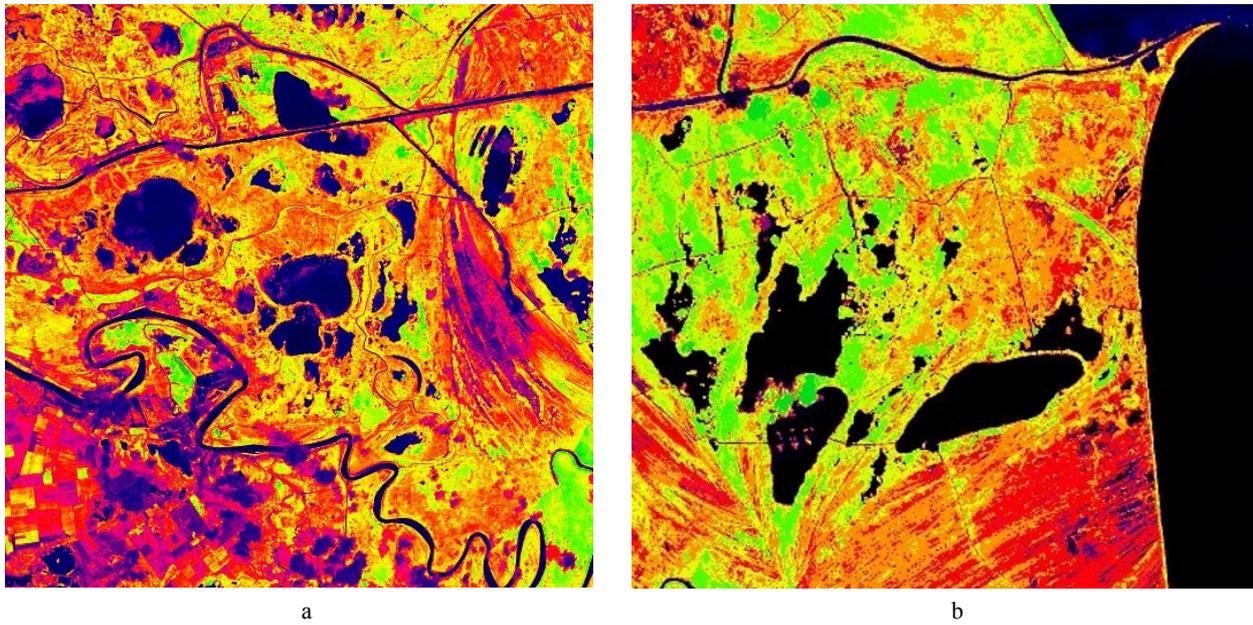


Figure 8. Soil adjusted vegetation indices (SAVI): a) Caraorman-Dunavăț site; b) Sulina site

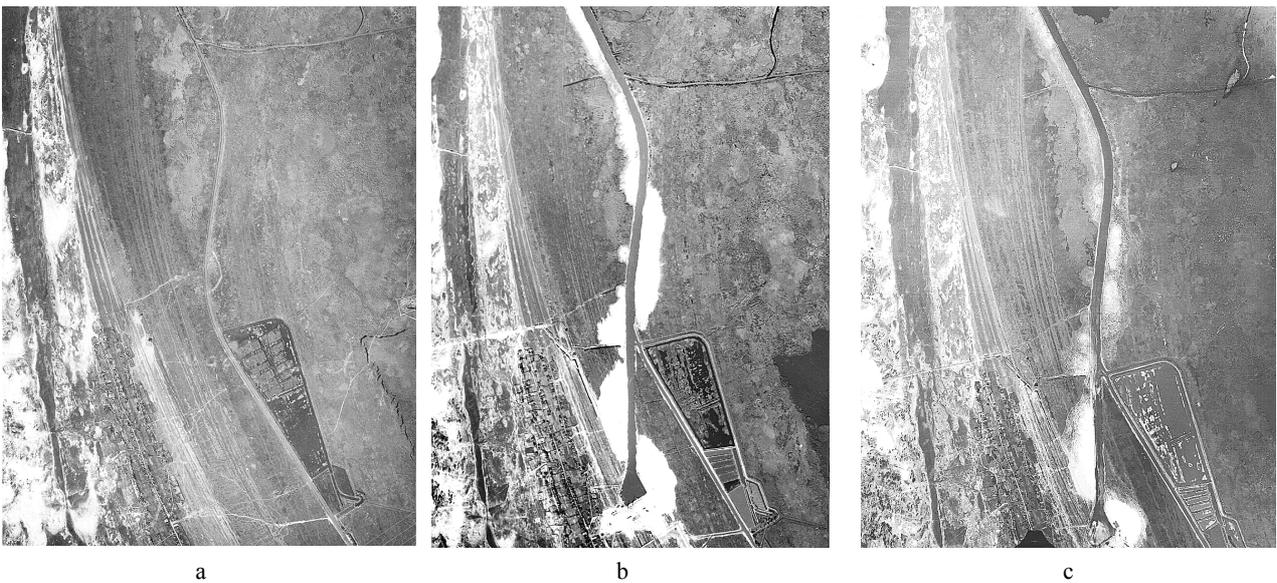


Figure 9. Ecosystem impact of abandoned Caraorman sand-mining a) 1973; b) 1983; c) 1990

Where Y is an area of delta occupied by investigated ecological facies; X_0 is the conventional year of the process beginning for facies area decrease; X_i is the year of aerospace images. The area dynamic trend is exemplified by the figure 8 for stagnant water, compactly common reed, mixture common reed-mace reed and forest vegetation habitats from the Sulina site.

4. CONCLUSIONS

Digital processing techniques in the two sites areas, during 1975-1993, highlight the following:

- The available satellite images allow a cinematic multisensor approach. Landsat-TM and SPOT-HRV medium scale images ensure a satisfactory level of accuracy for monitoring changes detection in Danube Delta areas. Although the Landsat MSS low resolution images extend study period, they add difficulties during processing and interpretation of results. In order to complete information for these images has to be utilized historical surveys from the same date.
- Applied techniques (preliminary radiometric and geometric processing, data compression, contrast and edge enhancement, multispectral classification, post-classification processing) assured the maximum accuracy in data processing (without altering the initial information) and in the results interpretation.
- The use of vegetation indices, merged with principal component analysis reveals very useful information regarding the area change percentage for different vegetation classes from Danube Delta ecosystems in the two sites.
- Alteration processes caused by antropic interventions in these areas were depicted: reduce of stagnant water ecosystem, compactly common reed, forest areas and increase of mixture common reed-mace reed, uncovered soil and urban areas (see figure 7) It is obvious the failure of economic exploit efforts such as fish ponds, agricultural and forest polders. After 1990, many of these projects were abandoned and ecological restoration projects were initiated. Figure 9 presents ecosystem impact of sand-mining abandoned construction from Caraorman bank. Even after 10 years the ecosystem have not restored.

The accuracy assessment resulted in a measure of the quality of the change information. Such measures are vital when important natural resource decision is based on satellite-derived information, as is the case with natural environment of Danube Delta.

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