

# New Method to Predict the Volumetric Changes in the Odiel Marshes (Huelva, Spain)

Emilio Ramírez Juidías, *Member, IAENG*, Meritxell Justicia Segovia, and Antonio Madueño Luna

**Abstract**—The Odiel Marshes, Nature Landscape and Reserve of the Biosphere by UNESCO, is a natural area located at the mouth of the Odiel river (Huelva, Spain), being, in size, the second largest wetland in the province of Huelva after Doñana. Due to its special topography, as they are characterized as salt-marshes, their characterization, both altimetric as volumetric, is quite complex. In this research, 40 Landsat satellite images from the United States Geological Service (USGS) were analyzed for the 1975 to 2010 period, each of which was examined and classified in a certain period of time in order to characterize right way the dynamic changes in the Odiel Marshes. Likewise, the Landsat satellite images were integrated into a GIS in order to obtain suitably using iterative processes the flood depth depending on rainfall data estimated for a period of 110 years (from 1900 to 2010). As regards temporal characterization was obtained a map of changes detected in the marshes by difference between the NDVI values of the image corresponding to the end date and the start date of each period. The results show how the greater integration of remote sensing and GIS technologies, with regression model, was most useful to describe, analyze and predict the volumetric change process in the Odiel Marshes.

**Index Terms**—historic flood, Odiel salt-marshes, periodogram, remote sensing.

## I. INTRODUCTION

ACCORDING to [1], wetlands are ecosystems that tend to disappear in an evolutionary process of silting. Nevertheless human activity has caused hitherto the acceleration of this process as well as other also negative, so that it has lost much of its original area. Other authors, such as [2] and [3], consider that wetlands are likely the kind of ecosystem that has undergone significant transformation by anthropic action. In fact the existing estimates until now, [3] and [4], specify that have disappeared between 75% and 80% of European wetland surfaces.

It is possible that the effects of recent climate change on wetlands are masked by the more recent impact of our activity. Therefore, for a full analysis of Odiel Marshes'

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volumetric evolution, it is necessary choose a time period long enough to analyze the regression of this marsh and its relationship to change in climate variables, which have affected irreversibly in their both filling and emptying cycles.

The marsh flatness has always been subjected to a variable flooding regime according to rainfall, the flow rates supplied by water avenues and the tidal regime. Flooding processes in marshes spaces are substantially controlled by their altimetric characteristics, in appearance simple or without reliefs, in addition to the effect of subsidence processes and/or upper-level, which are often insufficiently reflected in conventional contour lines mapping [5].

For this reason, the aim of this paper is to use satellite imagery and Geographic Information Systems (GIS) to obtain a method capable of calculate the different levels in Odiel salt-Marshes. Besides this method has to useful to predict the volumetric change process by regression models from climatic data, which are necessary to estimate the appropriate periodogram.

## II. MATERIALS AND METHODS

### A. Study Area

The Odiel Marshes are located in the Southwest of the Iberian Peninsula (province of Huelva), associated to Odiel river mouth (Fig. 1). Their total area is  $7185 \times 10^4 \text{ m}^2$ .

These marshes are constituted by a set of islands crossed by numerous natural pipes. They are divided into the north marsh, comprising the Occidental, Central and La Yegua islands, and the south marsh, formed by Bacuta, De Enmedio and Saltés islands.

The area consists of several Quaternary formations (Holocene) of sands, silts and clays, integrated in a complex system of estuaries of recent sedimentation influenced, in their genesis, by level changes of Earth's crust [7]. All set is

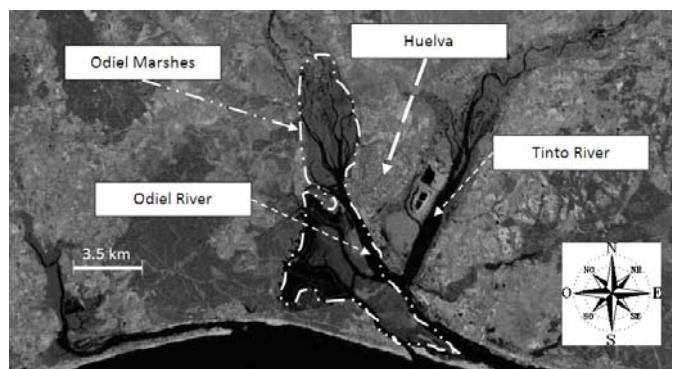


Fig. 1. Location of study area [6].

surrounded by Tertiary formations (Neogene) of yellow silt and Miocene marls, Pliocene sands and marls, and remains of a Pleistocene erosive glacis. In the marshes are given simultaneously both sedimentation and erosion processes that vary in space and time, creating a lot of temporary or permanent physiographic characteristics giving rise to a considerable variety of habitats. The tidal movement is the main determining factor in shaping of these ecosystems.

In another vein, the climate in the study area can be defined as Mediterranean maritime, with an insolation grade exceeding 3000 h/year. In the winter season, short and smooth, are produced most of the rains. By the other hand, the summers are dry and long though smoothed out by the proximity of the ocean, not exceeding, usually, the absolute maximum temperature of 40 °C. The average annual rainfall is 506.6 mm, being concentrated in the months of December and January, presenting, likewise, a dry season with deficient water balance between the months from May to September.

Both tides and rainfall oscillations give rise to a dense drainage net, consisting of a set of subterranean natural pipes and estuaries. The marshes' natural drainage is a complex system of tidelands through which circulates the tidal flow, whose oscillation gives rise to sediment deposition and, both organic matter and nutrients redistribution in the soil [8].

#### B. Data and Methodology

In this study, 40 orthorectified Landsat satellite images available from the United States Geological Service (USGS) Earth Explorer archive were obtained for the 1975 to 2010 period. Each satellite image was examined and classified in a determined period of time (1975/1990, 1990/2000, 2000/2005 and 2005/2010) in order to characterize right way the dynamic changes in the Odiel Marshes. All images (Path 218 Row 34 "WRS-1" and Path 202 Row 34 "WRS-2") were acquired during the month of March. Post-classification processing was necessary in order to avoid to certain details were classified as water. Odiel Marsh surfaces extent was calculated in Ilwiss GIS by multiplying the number of water pixels in each image by the spatial resolution of the original satellite imagery (30 m for Thematic Mapper and Thematic Mapper Plus).

Each Landsat satellite image was enhanced, and then using the nearest neighbor algorithm, achieving to maintain unchanged the original brightness of the pixel values according to [9] and [10].

In order to detect changes in the reflective surfaces that make up the study area, a radiometric correction was conducted using the method specified by [11]. After obtaining the regression equation of the model undergone some study and to estimate both filling and drying processes of the Odiel Marshes, it was come to perform a process of overlapping images with Ilwiss GIS, which helped to obtain the volume change water stored in Odiel Marshes, and the most likely water sources that contribute to the filling process.

For the purpose of to be able to generate a height map of study area was used the Digital Terrain Model of Andalusia (DTMA) in order to have a basis to obtain, by iterative

processes, the average depth of water, of Odiel Marshes, in each pixel of satellite image.

In another vein was carried out a deep literature review aimed to determine the possible existence of a temporal record of precipitation in the Odiel Marshes broad enough to obtain results, discussions and conclusions coherent with the present study. In this regard were analyzed precipitation data from meteorological stations located in Lepe, Moguer, Almonte and Doñana Marshes in order to predict the precipitation data in Odiel Marshes from 1900 to 2010 (Fig. 2) starting from the correlation among the different meteorological stations ( $r = 0.92$ ).

### III. RESULTS AND DISCUSSION

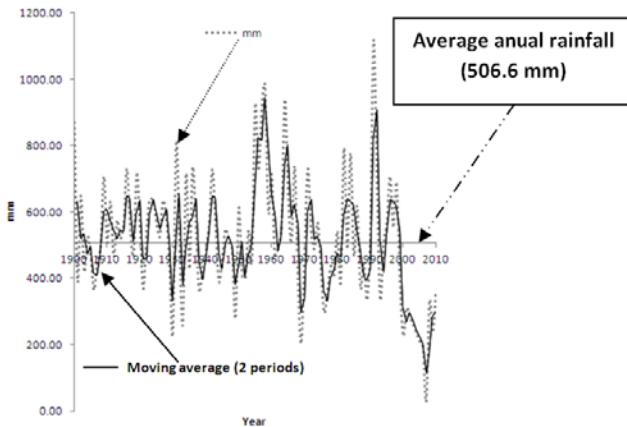


Fig. 2. Estimated rainfall in the Odiel Marshes from 1900 to 2010.

After analyzing all meteorological data were found that correlation between precipitation data from Doñana and Odiel were, by itself, sufficiently significant ( $\leq 0.001$ ) to obtain an equation to predict the data presented in Fig. 2. The equation is:

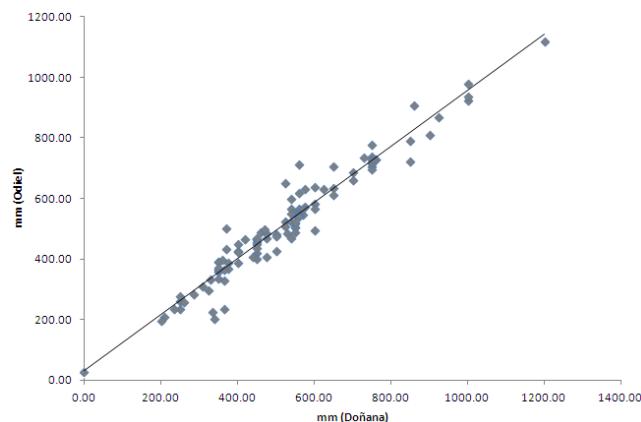


Fig. 3. Adjusted regression curve for rainfall data in Odiel Marshes.

$$y = 380.22 + 0.918 \times P - 0.177 \times A \quad (1)$$

$$r = 0.97$$

$$R^2 = 0.94$$

Where "y" is the prediction of rainfall in the Odiel

Marshes in mm, "P" is the rainfall data in Doñana Marshes in mm and "A" is the year.

After analyzing satellite images was obtained a progressive decrease in annual water surface in the Odiel Marshes, due to the increase of human activity around of study area, although should not be ignored, according to rainfall data, the cumulative decrease of rainfall in environment of Odiel (Fig. 2, 4, 5 and 6), which indicates that Odiel Marshes is under the influence of a dry period.

Due to space considerations, and according to [12], it was

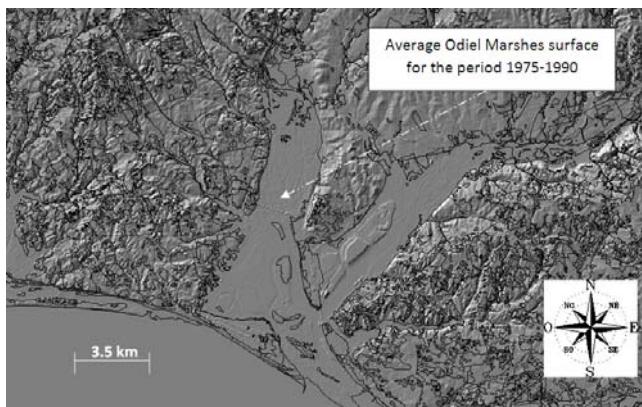


Fig. 4. Average extension of the Odiel Marshes water surface from 1975 to 1990.

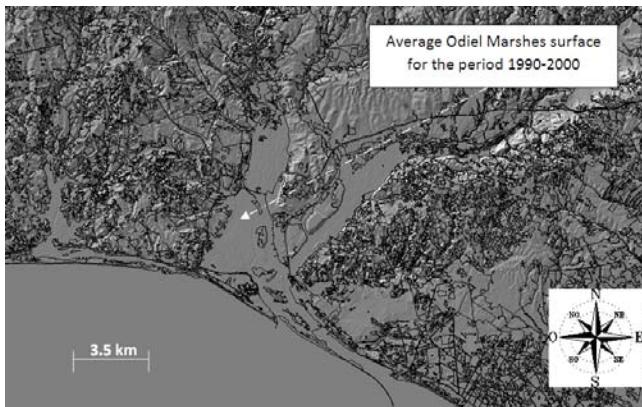


Fig. 5. Average extension of the Odiel Marshes water surface from 1990 to 2000.

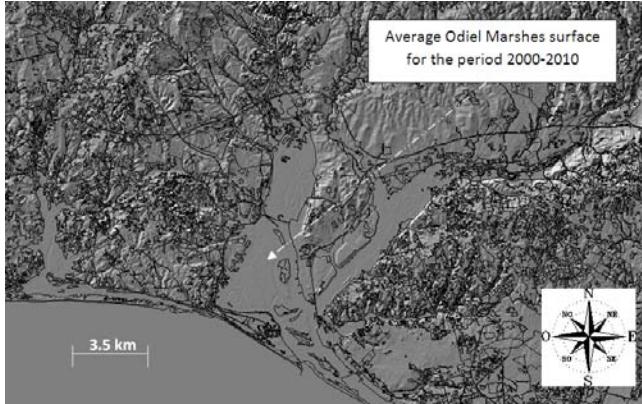


Fig. 6. Average extension of the Odiel Marshes water surface from 2000 to 2010.

determined that decadal summaries of the Odiel Marshes levels would be the most suitable method to visually present the results. The Odiel Marshes area analysis showed that decadal minimums/maxima (Fig. 4, 5 and 6) were

achieved in 1975/1990, 1990/2000 and 2000/2010. As can be seen the 1980s (Fig. 4) had the most water surface that 1990s and 2000s, and between these, 1990s and 2000s, the differences are no significant.

Of the  $7185 \times 10^4 \text{ m}^2$  of Odiel Marshes, the maximum area flooded is  $6.2 \times 10^7 \text{ m}^2$ , equivalent to a volume of  $110.28 \times 10^6 \text{ m}^3$  after performing the prediction (maximum volume of water marshes).

After to extrapolate data from satellite images to GIS, was calculated the depth of the marsh after carrying out a joint analysis with DTMA. Likewise, a significant ( $\leq 0.001$ ) relationship (2) was observed between the volume of water, the Odiel Marshes surface and the estimated depth (Fig. 7) in the total of two hundred random sample points selected in the satellite images. Fig. 8 shows estimated volume and area in Odiel Marshes.

$$y = -18.273 + 2.064 \times S - 4.205 \times ED \quad (2)$$

$$r = 0.96$$

$$R^2 = 0.93$$

Where "y" is the prediction of volume in the Odiel

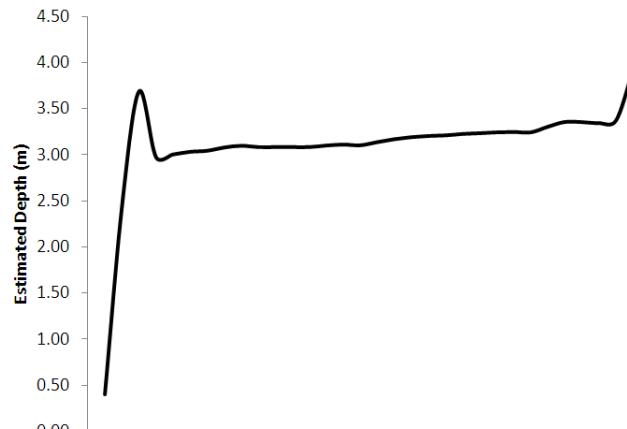


Fig. 7. Estimated depth in Odiel Marshes.

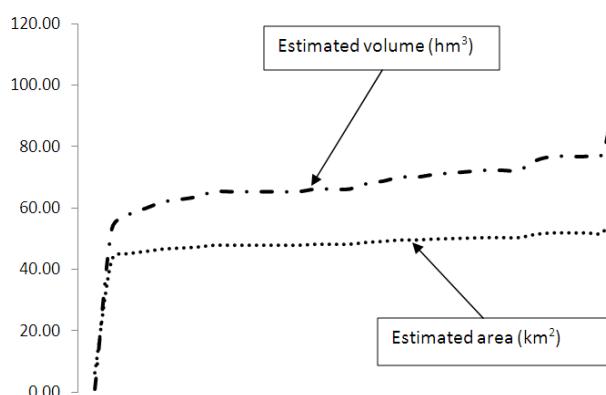


Fig. 8. Estimated area and volume in Odiel Marshes.

Marshes in  $\text{hm}^3$ , "S" is the estimated surface in Odiel Marshes in  $\text{km}^2$  and "ED" is the estimated depth in m.

Also was obtained a map of changes detected in the marshes by difference between the NDVI values of image corresponding to the end date and the start date of each period. The results are shown in the following figures (Fig. 9, 10, 11 and 12).

In Fig. 9, 10, 11 and 12, most areas will be grey,

indicating no change because each pixel has relatively the same value in start date and the end date. Areas that show up green were brighter in the start date (meaning more vigorous vegetation in this date), while areas that show up

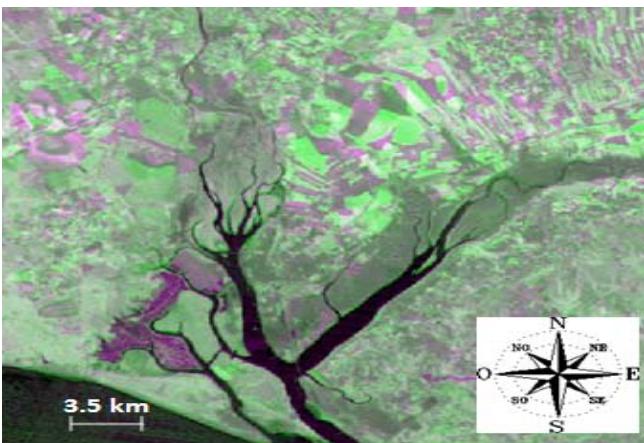


Fig. 9. Detected changes in Odiel Marshes between 1975-1990.

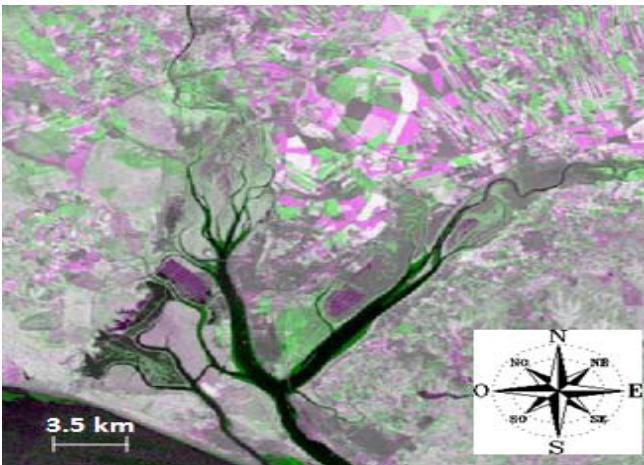


Fig. 10. Detected changes in Odiel Marshes between 1990-2000.

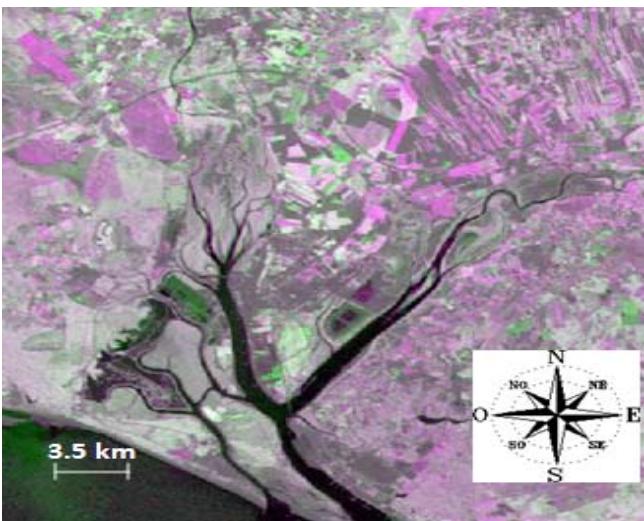


Fig. 11. Detected changes in Odiel Marshes between 2000-2005.

in magenta were brighter in the end date (meaning more vigorous vegetation in this date).

#### IV. CONCLUSION

The Odiel Marshes experience an annual filling process coinciding with the months of highest rainfall, and a water

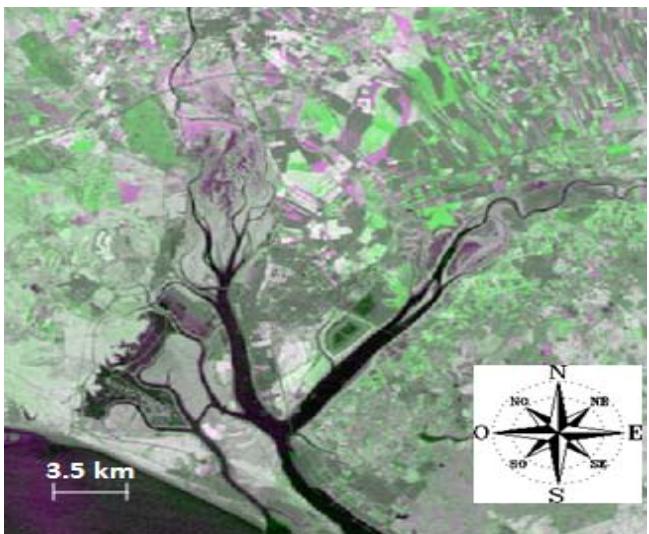


Fig. 12. Detected changes in Odiel Marshes between 2005-2010.

loss focused in the summer months. Comparing the occupied volume by water between 1975-2010, was observed a slight decrease of the annual water volume coming into this salt-marshes, which is consistent with an increase in temperature during the same period of time, causing an increase in the evaporation and thus an environmental impact to medium to long term.

The results obtained in the present study coincide with those performed by [3] in Doñana Marshes, in relation to the expectations, and [13] in his doctoral thesis, so it can be concluded that the methodology has been validated and is completely reliable.

According to [14], satellite remote sensing of surface water fluxes and storages in wetlands is an immature but rapidly growing field. This research showed that combined remote sensing and GIS approach was very successful in visualizing the differences in Odiel Marshes level throughout the analysis period. In addition, Landsat data were found to be very suitable for this analysis. Landsat data have been utilized for many different types of remote sensing applications. The long record of images available through the USGS Landsat archive [6] makes them ideal for historical time-series visualization projects.

The results shown that imagery can be used to effectively visualize water level fluctuations and display changes due to variations in climatic conditions on a decadal or longer term basis. This may be useful in creating public awareness of the problems caused by the global change.

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