Assessing Organic Water Pollution of Inland Wetlands with Remote Sensing and Field Data

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***Abstract*-The purpose of this paper was to assess and monitor water pollution using satellite images, orthophotos, analytical data, and fieldwork in a group of Spanish wetlands located in central Spain. The increase in large-scale irrigation schemes, intensive exploitation of water resources, and the water pollution in this area has seriously impacted these habitats.**

A multi-temporal analysis carried out from 1989 to 2013 showed the improvement or deterioration in water quality of seven of these wetlands. The water quality was determined using analytical and remote sensing data (vegetation index, and spectral and spatial profiles). Two case studies were presented: one wetland showed a remarkable improvement in water quality, with high eutrophication levels reduced as part of a clear decontamination process; the waters of the other wetland remained unaffected by eutrophication processes throughout the study period.

Remote sensing techniques only detect the presence of algae in wetlands, and analysis of the water is needed to confirm pollution. The integrated use of both methods would enable consultants and wetland managers to manage these areas more effectively and mitigate pollution problems.

Key words- Monitoring wetlands; Water pollution; Remote sensing; NDVI.

I. INTRODUCTION

Small, shallow water bodies are less stable than larger lakes, and are thus very sensitive to human intervention. Pollution from agriculture and wastewater has a significant negative impact on water quality and aquatic biota in wetlands. It causes eutrophication problems that entail harmful algal blooms, kills fish, and causes many related problems in fresh waters that are adjacent to areas with large human populations[1]. Traditionally, these ecosystems have been studied using analytic data and multi-temporal aerial photographs. Remote sensing techniques currently offer suitable methods for the identification, demarcation, and monitoring of wetlands, and have been discussed in prominent papers and projects [2, 3, 4, 5, 6, 7, 8, 9].

The wetlands of La Mancha Húmeda Biosphere Reserve (MHBR, UNESCO, 1981) in central Spain have reached high levels of urban pollution due to contamination by untreated wastewater from neighboring towns [10, 11]. Although wetlands are known to act as filters in hydrologic systems and retain and transfer nitrogen and phosphorus from water systems, increased added nutrients modify biological communities and ecosystem functions[12, 13, 14]. Nitrogen and phosphate nutrient intakes in wetlands also produce excessive algae growth, causing eutrophication of their waters. Algae growth in wetlands can be analyzed using remote sensing techniques [15, 16, 17].

The water bodies investigated in this study are situated in an area that has recently undergone sudden agricultural development; the use of irrigation on nearby farmland has proved detrimental to the groundwater, causing temporary water pollution from fertilizers and groundwater exploitation. The extent of the problem is so great that the excessive groundwater extraction has rendered the drainage aquifers of La Mancha unsustainable, and their subsequent disconnection from the fluvial aquifer network has altered the natural balance between surface and ground water, as well as the wetland ecology [18, 19, 20].

As more wetlands deteriorate in La Mancha, increasing pressure is put on plant and animal life. Direct drainage and eutrophication of the water bodies are factors that most affect the growth of flora and vegetation associated with wetlands [21]. Meanwhile, untreated wastewater is currently a serious threat to the local waterfowl population with botulism, endemic in La Mancha, and frequent bird mortality episodes resulting from tuberculosis.

Since the early 1990s, municipal wastewater treatment plants have been installed, and the water quality has improved. However, low surface water mobility in the wetlands and seasonal agricultural run-off prevent the complete recovery of the water quality.

To date, most water eutrophication studies in the MHBR wetlands have been carried out using field data and satellite imagery. However, there are no studies in the literature that have combined the two techniques.

The interpretation of high spatial and spectral resolution satellite images, information provided by the infrared channels of the electromagnetic spectrum, allows detection of water quality indicator parameters (color, turbidity, chlorophyll activity, masses of vegetation, etc.). This process can also identify the eutrophication of water bodies and precisely map the extent, intensity, and space-time variability of the pollution process. Examining the images captured on different dates also facilitates an understanding of how the pollution evolves, and allows the determination of the wetland response to restoration and conservation measures[20, 22]. Nevertheless, the information obtained through satellite images must be verified with the ground truth.

The aim of this paper was to apply remote sensing techniques to assess and monitor organic water pollution derived from domestic, industrial, and agricultural waste in MHBR wetlands. A multi-temporal water analysis of some water bodies was carried out, supported by field data. The improvement or deterioration over the last twenty-four years was studied and mapped [10, 11, 14, 23]. The goal was to provide the relevant agencies with a simple tool to control water quality of inland wetlands using satellite images.

II. STUDY AREA

The UNESCO Mancha Húmeda Biosphere Reserve is located in the center of the Iberian Peninsula on the south central meseta. The MHBR covers approximately 418,087 ha and extends into the provinces of Ciudad Real, Toledo, Cuenca, and Albacete (39°20'9.317"N 3°13'21.536"W, Figure 1). The main rivers flowing through this region are the Guadiana, Gigüela, Riánsares, Záncara, and Córcoles.

The climate is typically Mediterranean, with < 400 mm annual precipitation. The lowest mean monthly rainfall occurs in summer, coinciding with the highest temperatures (up to 43º C) and maximum evapotranspiration. The landscape is very flat, with 75% of its surface area between 625-700 m as with low drainage density. Surplus water and subsequent runoff is weak and only occurs during short periods, and most rainfall infiltrates the soil before reaching wetland depressions[24]. The lithology of the area is predominantly clay sediments, limestone, and saline deposits.

The study area includes more than 100 wetlands of different types considered as ecologically relevant, ranging from lakes to floodplains, episodically flooded to permanent, subsaline to hypersaline, and natural to artificial, which provide crucial nesting and feeding grounds for European migrating bird populations and homes to rare animal and plant species[14, 20].

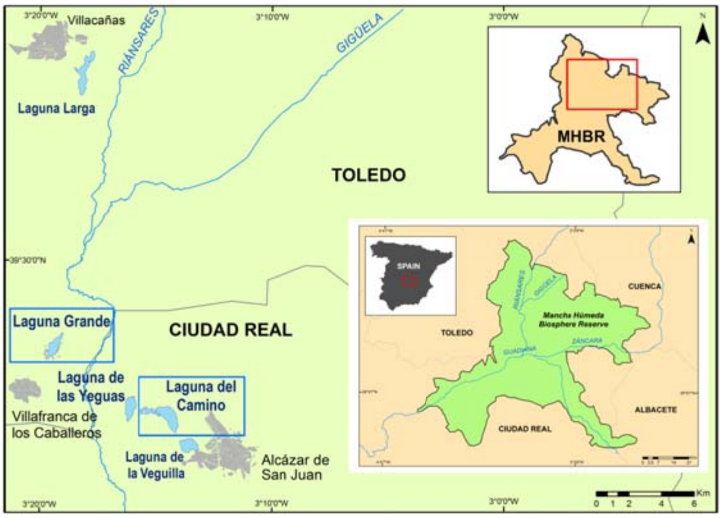


Fig. 1. Study Area: Mancha Húmeda Biosphere Reserve in Spain; selected wetlands are in blue squares

III. MATERIAL AND METHODS

The first stage of this research was to update the MHBR wetland inventory using different bibliographic [20, 25]and cartographic sources (1:25,000 and 1:5,000 scale), and high and medium spatial resolution satellite images. This photographic information was used to update the detailed spatial information for the wetlands. When satellite images were used together with cartographic sources, full details of urban wastewater discharge channels running into the wetland basins and new wetlands that had not yet been inventoried were revealed.

In addition to the information in natural colors provided by aerial photographs, Landsat and SPOT satellite images were used. They provided additional information from other regions of the electromagnetic spectrum, mainly from near and mid infrared, which was very useful in showing the characteristics of water, soil, and vegetation.

Landsat images are composed of between 6 and 11 spectral bands with a spatial resolution of 30 meters, except in thermal infrared (120 m in Thematic Mapper sensor and 60 m in Enhanced Thematic Mapper Plus sensor). Spot images have higher spatial resolution (10m), but spectral resolution is reduced to 4 bands (green, red, near infrared, and short-wave infrared). The main characteristics of Landsat and Spot images are summarized in Table 1.

TABLE 1. CHARACTERISTICS OF LANDSAT AND SPOT SATELLITES: SPECTRAL RANGE AND WAVELENGTH, SPATIAL RESOLUTION, AND NUMBER OF SPECTRAL BANDS

		Landsat			***SPOT***	
Spectral Range	*Wavelength*	*L5 & L7*	*L8*		*5 HRV*	
		Bands	Bands	Spatial Resol.	Bands	Spatial Resol.
(0.43 - 0.45)	Coastal aerosol		1	30		
(0.45 - 0.52)	Blue	1	2	30		
(0.52 - 0.60)	Green	2	3	30	1	10
(0.63 - 0.69)	Red	3	4	30	2	10
(0.76 - 0.90)	Near Infrared 1 (NIR 1)	4	5	30	3	10
(1.55 - 1.75)	Short-wave infrared (SWIR 1)	5	6	30	4	10
(2.08 - 2.35)	Short-wave infrared (SWIR 2)	7	7	30		
(10.4 - 12.5)	Thermic Infrared (TIRS)	6&8	10&11	120/60		

More than 60 images from different years, dates, and seasons were analysed to know the greatest inter- and intra-annual variability of the water layer. Most of the images were chosen from summer seasons because it was the most suitable period to detect pollutants in the wetland basin due to the water level being the lowest in this season[26]. Spring images were also included to detect possible pollution in the wetlands as a result of leaching of the irrigated fields. Eight Landsat and three SPOT images from various dates in different seasons were selected because they ensured maximum variability of water content and solute concentration (Table 2). They were compared to carry out a multi-temporal analysis of the wetlands, covering a period of more than twenty years (1989-2013) with similar rainfall characteristics. The current status of the wetlands was assessed based on the latest satellite images (2011 and 2013) and field data.

TABLE 2. SATELLITE IMAGES USED[27, 28]

Satellite	**Sensor**	**Date**	**Scene**
	5-TM	05-05-1989	
	5-TM	08-26-1995	
LANDSAT	7-ETM	04-25-2000	200/032
	5-TM	06-18-2005	
	5-TM	05-28-2009	
	5-TM	07-28-2010	
	L8	08-11-2013	
SPOT		08-24-2010	271/036
	5-HRV	05-29-2009	
		15-04-2011	201/032

The images were processed with ERDAS Imagine 10 and the mapping was geo-referenced to UTM coordinates with 17 control points (error <0.07). All images were cropped to fit the study area of approximately 267,830 ha.

Visual and digital processing was carried out to study possible eutrophication in the wetlands and to assess the extent. In the visual analysis, different bands of the electromagnetic spectrum in all Landsat images were combined to obtain the aquatic biomass response of the vegetation mass. These bands were assigned and displayed in red, green, and blue, thus creating a RGB composite. E.g., ‘Natural color’ Red-Green-Blue shows objects in the colors normally perceived by the human eye; ‘False color’ Near Infrared-Red-Green colors are assigned to any three bands with different wavelengths that the human eye may not distinguish [29]. The normalized difference vegetation index (NDVI) was also obtained from Landsat images of contaminated wetlands, and maximum values were measured where the highest reflectivity was observed in the water bodies. This index, often used to assess vegetation and its relationship with different environmental variables [15, 30, 31, 32], was calculated from the NIR – RED/NIR + RED quotient spectral channels. Positive NDVI values usually correspond to terrestrial vegetation and negative values to an aquatic environment.

Using digital analysis, spectral profiles of the wetlands were generated in all images at the point of maximum NDVI value.

Spatial profiles were studied in each wetland on every study date, with longitudinal sections of the wetland basin for Near Infrared (Channel 4), since this discriminated the vegetation best. For Landsat 8 images, Near Infrared corresponds to Band 5.

Finally, visual and digital processing were completed with spectral, spatial, and radiometric enhancement(Principal Components, Kernel 3x3 High Pass,3x3 Low Pass, and Histogram Equalization, respectively) to enhance the physical characteristics of the wetlands and detect their spatial-temporal variability, which is not possible with conventional aerial photography.

The SPOT images and orthophotos were analysed visually to detect possible anthropogenic waste fed into the wetlands through drains or irrigation ditches, as well as changes in environmental characteristics.

As a necessary complement to remote sensing studies, a monitoring study of water pollution was conducted in two wetlands in the MHBR (Figure 1).Two lakes were selected, one saline (Laguna del Camino de Villafranca) and the other brackish (Laguna Grande de Villafranca). The wetland water quality was analysed in situ in May 2011 and readings were obtained for ammonium, nitrate, nitrite, phosphate, pH, salinity, conductivity, total dissolved solids, and temperature. VISOCOLOR® colorimetric test kits were used to obtain results of the nutrients in the samples (ammonium, nitrate, nitrite, and phosphate) and determined by a method described by Rodier[33]. HI929898, HANNA Instruments®, multi-parameter probe was used to measure the other parameters (pH, salinity, conductivity, total dissolved solids, and temperature)by immersing electrodes directly into the samples [33]. Analytical methods, ranges, and sensitivity are shown in Table 3. Water analysis conducted in all the study dates were carried out with the same techniques.

TABLE 3. ANALYTICAL METHODS, RANGE, AND SENSITIVITY[33]

	Analytical methods	*Range*	*Sensitivity*
Ammonium	colorimetric	0.03 - 2.5 (mg/l)	0.03
Nitrate	colorimetric	0.30 - 3.5 (mg/l)	0.3
Nitrite	colorimetric	0.04 - 1.1 (mg/l)	0.04
Phosphate	colorimetric	0.05 - 5.0 (mg/l)	0.05
pH	multi-parameter probe	0.00 - 14.00	0.01
Salinity	multi-parameter probe	0 -70.00 PSU	1
Conductivity	multi-parameter probe	0 - 200 mS/cm	1
Total dissolved solids	multi-parameter probe	0 - 400000 ppm	1
Temperature	multi-parameter probe	"-5º to 55ºC"	0.1

The type of natural vegetation border and the presence of algae and/or hygro-halophyte vegetation within each wetland were detected in situ, to compare actual information with that obtained from satellite images.

The water quality of the wetlands analysed in situ was compared with the data obtained more than twenty years ago by Peinado (1994) and Pérez (1995). These results were then contrasted with the hydrogeological and environmental studies available to date [18, 20]and with recent satellite images, to find possible groundwater inputs into the wetlands and their conservation status.

IV. RESULTS

The wetland water quality and possible eutrophication were analysed by processing and interpreting the images both visually and digitally, and by testing water samples. For all dates studied, the best combinations of spectral channels in Landsat images were ‘natural’ color and ‘false’ color near- Infrared-Red-Green[2, 3]. The false color image was selected as it offered better enhancement of aquatic surfaces with high vegetation density[8].

Using the independent channels of the electromagnetic spectrum also allowed the authors to distinguish the presence of vegetation (green algae) on the surface wetland water, mainly using near-infrared in high-medium resolution satellite imagery[4]. Once green algae were detected in the satellite imagery, in situ analysis was used to confirm the pollution.

The wetlands in these case studies that do not receive additional nutrients maintained negative or very low NDVI values and had unpolluted waters. Nevertheless, when the water sheet of shallow wetlands contained natural green algae and/or organic matter due to excess nutrients, the near-infrared reflectivity values increased and the NDVI index was positive.

Two case studies were presented where the evolution of water quality in the wetland area was clearly detectable. The first wetland was in the process of decontamination (Laguna del Camino de Villafranca, Figure 2a),and the second was an unpolluted wetland surrounded by natural vegetation(Laguna Grande de Villafranca, Figure 2b).

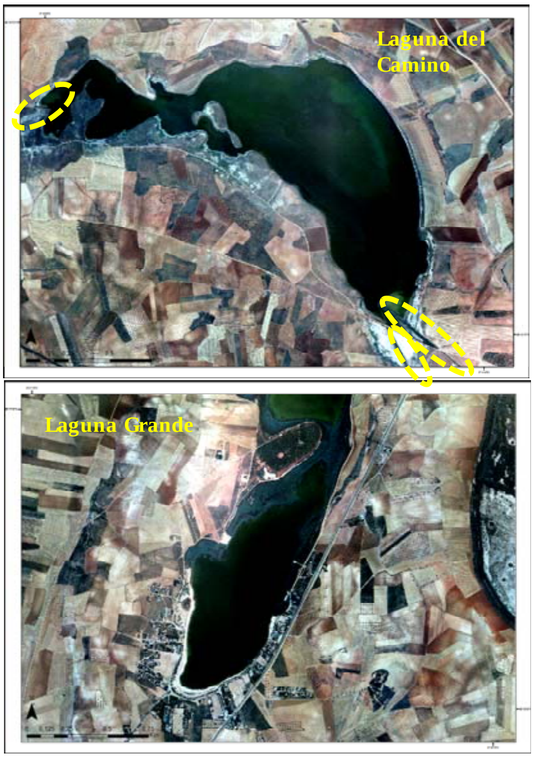


Fig.2.Orthophoto of Laguna del Camino de Villafranca with detail of drainage channels marked in yellow ellipses (top) and Laguna Grande de Villafranca (bottom)[34]

A. Laguna del Camino de Villafranca

The false color image showed a uniform pink spot covering the wetland basin from a large invasion of vegetation at the water surface in 2005(Figure 3). The pink (NIRed-Red-Green combination) was due to the spectral response of the infrared channel, which differentiated the vegetation perfectly. The spatial profile and spectral response indicated that virtually all of the wetland had been invaded and algae were present. Nevertheless, on the edge of the wetland there were typical Mediterranean emergent plants associated with this ecosystem, such as Cladiummariscus, Phragmitesaustralis, Shoenusnigricans, Carexhispida, Scirpuslacustris, and Scirpuslittoralis, which unlike algae, do not invade the wetland basin.

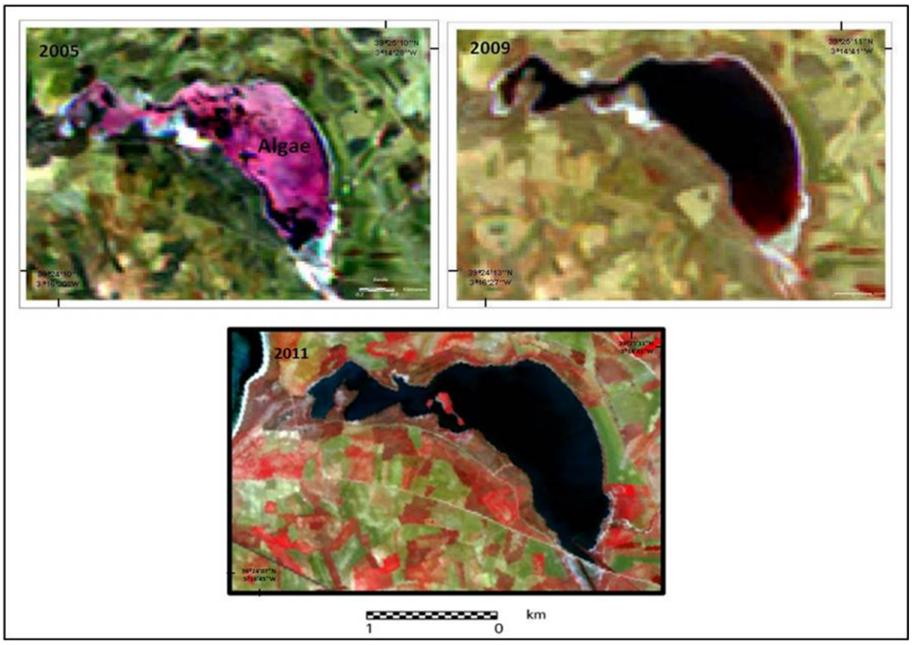


Fig. 3. False color images of Laguna del Camino with the same water level. In 2005 (above left) markedly eutrophicated (pink color shows the large expanse

of algae); in 2009 (above right) and 2011 (below) with less pollution (black color indicates water free of algae and a sharp decrease in pink is observed)

The images from 2009 and 2011, using the same NIRed-Red-Green combination, showed a decrease in algae mass and a resulting improvement in water quality. These algae, located on the surface of the water, were easily identifiable in satellite images because the water in these wetlands was shallow. In August 2013, this wetland presented more water than in previous years, which complicated the visual interpretation. Nevertheless, the image showed a reduced extension of the algae.

The images obtained using the NDVI index for the same dates showed how the area covered by hydrophytic vegetation had changed. The pale shades and positive high values typical of eutrophicated waters covered the whole basin in 2005.However, in the 2009 and 2011 images, there was a sudden reduction of NDVI values, characteristic of cleaner waters (Figure 4).

The sample NDVI values from1989 - 2011 illustrated the reduction in algae mass, with high positive values until 2005, and current values showed a sharp decrease, which is typical of clean waters (Table 4). The image from the summer of 1995 gave negative NDVI values because the wetland bed was dry and covered by saline efflorescence[23].

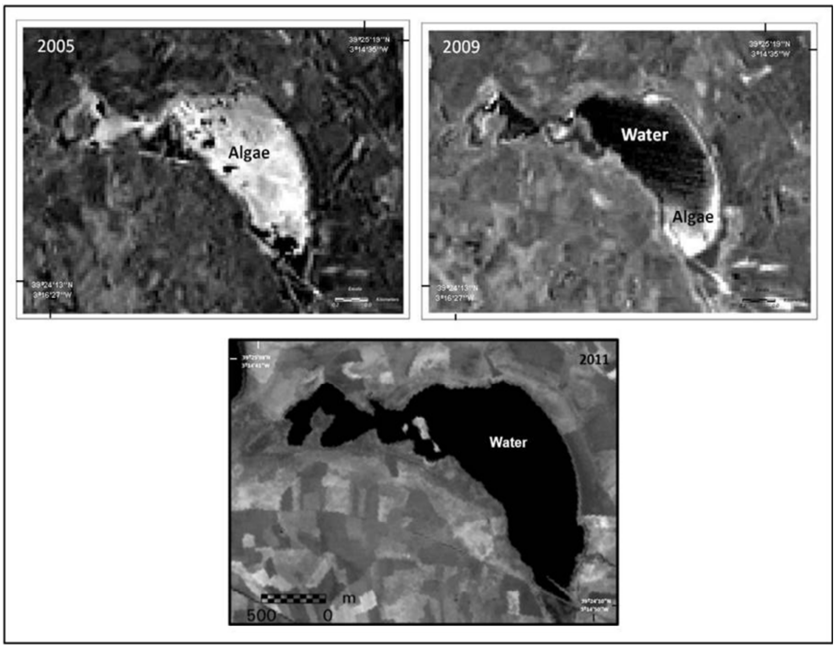
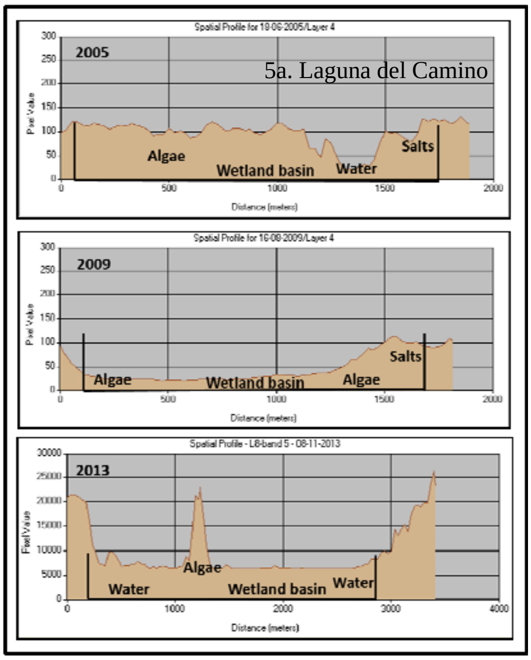


Fig. 4. NDVI of Laguna del Camino:2005 (above left) shows high chlorophyll activity throughout the whole wetland basin (white shades);2009 (below) and 2011 (above right) show high absorption of spectral values, typical of water (very dark shades)

TABLE 4.MAXIMUM VALUES OF NDVI INDEX INSIDE THE WETLANDS (A: LAGUNA DEL CAMINO; B: LAGUNA GRANDE). POSITIVE VALUES (IN BOLD) INDICATE VEGETATION AND NEGATIVE VALUES OR NEAR 0 INDICATE ONLY WATER

NDVI maximum values inside the wetland A: Laguna del Camino B: Laguna Grande								
Year	April		May		June		August	
Wetland	A	B	A	B	A	B	A	B
1989			**0.43**	**0.14**				
1995							-0.13	-0.03
2005					**0.32**	**0.38**		
2009			-0.2	0.04			-0.064	**0.28**
2011	-0.3	**0.2**						

The spatial profiles of the wetland in 2005, 2009, and 2013 with Landsat Channel 4 and 5 (sensor TM and L8, respectively) allowed the surface area occupied by algae to be distinguished(Figure 5a), as well as those areas not containing algae. The peak spectral values corresponded to the salts that were present around the edge of the wetland, with a high reflectivity rate in all the channels. In the 2013 spatial profile, the very high near-infrared values indicated that the algae cover had decreased in size, covering only a small central portion of the lake.



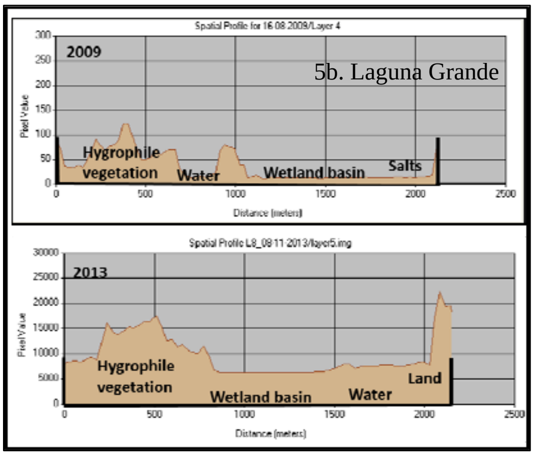


Fig. 5a.Spatial profiles of Landsat for near-infrared in 2005, 2009, and 2013 of Laguna del Camino(left) in which algae, clean water, and salts from the edge of the wetland are differentiated. The algae peak in 2013 was due to the presence of the irrigation channel. The sudden reduction of eutrophicated water should be noted.

Fig. 5b. Spatial profile of Landsat for near-infrared in 2009 and 2011 of Laguna Grande(right)with specific hygrophile vegetation and widely flooded area free of algae

In the SPOT image from 2011, several existing channels used for recharging and discharging water into nearby wetlands were shown in red (Fig. 3). These channels, currently used as green filters, showed high NDVI values (white colors in Figure 4)and peaks in NIR values (Figure 5a). This behavior suggests the presence of organic pollution; therefore, water should be analysed to determine their effectiveness in removing pollutants.

The water analyses defined the wetlands in 1989 and 1990 as saline[10], and in 2011 as brackish as a result of increased water volume with a high alkaline pH(Table 5). Currently, nitrite and ammonium values remain below the normal limits, although nitrate and phosphate concentrations (2 mg/l) continue to be above the normal limits established for natural waters(1mg/l for nitrates and 0.1 mg/l for phosphates). Additionally, wastewater dumping has caused a gradual decrease in salinity. This situation is reflected in the obtained values of salinity, conductivity, and total dissolved solids, which fall with in the brackish water range (Table 6).Therefore, although the images showed a remarkable reduction of algae extension, after the implementation of municipal wastewater treatment in 1986, the wetland still contained significant levels of pollutants associated with springtime irrigation. As such, analytical data of water in 2011 showed high nitrate and phosphate values, which were above normal values for natural waters (2mg/l)(see Table 5).

B. Laguna Grande de Villafranca

The second case study focused on the other wetland in the MHBR, which maintains a large border of natural vegetation (emergent plants) and has not shown any signs of water contamination to date. This wetland has a permanent water table containing brackish water and is artificially regulated with river water, which alters its natural hydroperiod. The wetland also suffers considerable human impact from recreational bathing and fishing activities[10, 20].

TABLE 5.AQUATIC ANALYSIS IN 1989 [10]AND 2011 IN LAGUNA DEL CAMINO (A) AND LAGUNA GRANDE (B). VALUES IN BOLD REPRESENT VALUES ABOVE THE NORMAL LIMITS ESTABLISHED FOR NATURAL WATERS

Parameters	1989		2011		
	A: Laguna del Camino	B: Laguna Grande	A: Laguna del Camino	B: Laguna Grande	Limit (mg/l)
Ammonium (mg/l)	-	-	0.20	0.30	2
Nitrates (mg/l)	0.08	0.08	**2.00**	0.00	1
Nitrites (mg/l)	0.00	0.01	0.03	0.00	0.1
Phosphates (mg/l)	1.80	0.00	**2.00**	0.00	0.1
pH	8.70	7.80	8.57	8.20	
Salinity PSU	-	-	11.73	4.80	
Conductivity (µS/cm)	-	-	19,630	8,636	
Total dissolved solids (ppm)	62,312	7,772	9,815	4,318	
Temperature (º C)	15.50	17.00	20.44	25.28	

TABLE 6. SPECIFIC RANGES OF SALINITY, CONDUCTIVITY, AND TOTAL DISSOLVED SOLIDS[33]

Name	Fresh water	Brackish water	Saline water	Brine
Salinity (PSU)	< 0.5	0.5-30	30 - 50	> 50
Conductivity (μS/cm)	100 - 2,000	2,000 - 50,000	> 55,000	> 55,000
Total disolved solids (ppm)	< 1,000	1,000 - 10,000	10,000 - 100,000	> 100,000

Satellite images failed to show the presence of algae, although the natural color (Figure 6) and spatial profiles allowed a large amount of organic matter to be discerned on the wetland bed.

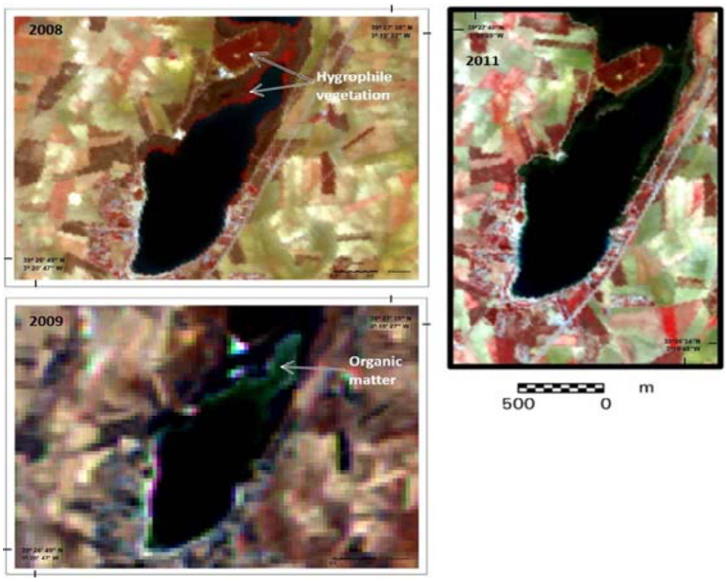


Fig. 6. Uncontaminated Laguna Grande, with a wide border of natural vegetation that slows and filters the seasonal agricultural pollutants. SPOT images in false color in 2008 and 2011 (above left and right, respectively) and Landsat image in natural color in 2009 (below)

The NDVI values for different dates, mainly in 2005, 2009, and 2011, show very pale shades, limited to the shore area of the wetland, due to the border of natural vegetation (Figure 7). Overall, there was no response to chlorophyll activity seen inside the wetland.

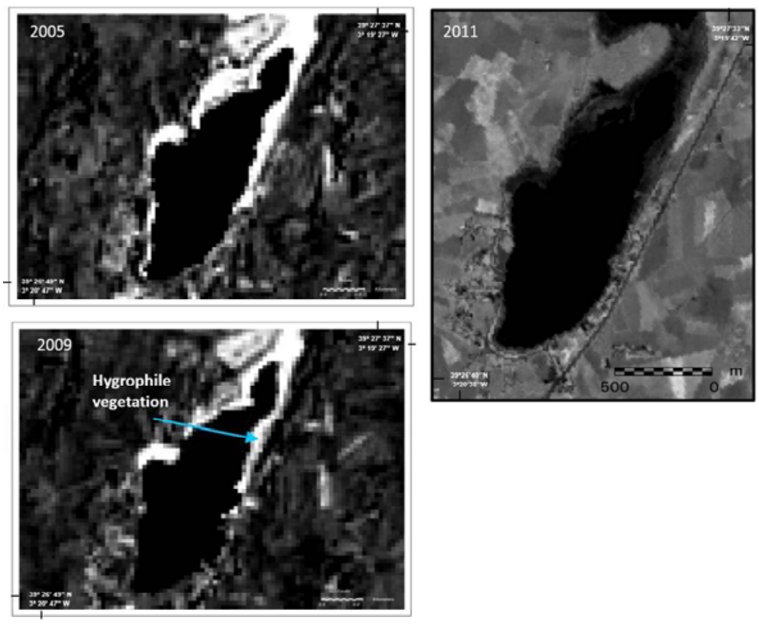


Fig. 7. NDVI index of Laguna Grande. In 2005 (above left), 2009 (below left), and 2011 (above right), clean waters are seen throughout the entire basin and significant presence of hygrophile vegetation on the flood edges from the northern section (white shades)

The maximum value of the NDVI index was tracked to determine whether the surface area contained the presence of algae (Table 2). The values obtained at different dates were positive and very high in 2005, 2009, and 2011, confirming the existence of chlorophyll activity within the wetland itself, except in 1995 when it was almost completely dry. Nevertheless, the different spatial pattern of the profile in the near-infrared channel highlighted the presence of specific natural vegetation masses (mainly Phragmitesaustralis and Cladiummariscus), but not algae in the wetland basin, with a wide flooded area free of them in both 2009 and 2013(Figure 5b). In 2013, the peak spectral values corresponded to the land adjacent to the edge of the wetland, with a high reflectivity rate in all the channels.

The water analysis from 2010 (Table 5) showed brackish water with an alkaline pH. The nutrient values were very low or insignificant, as they were in 1990; hence, it could be deduced that these may be a limiting factor for the growth of aquatic life. The results obtained in 2011 for the parameters of salinity, conductivity, and total dissolved solids confirmed this wetland as brackish.

Increases in temperature were observed in both wetlands between 1989 and 2011 since they were years with contrasting meteorological conditions, 1989 being colder than the average and 2011 warmer than the average. Differences in salinity between both wetlands were due to their own origin and nature.

The use of various remote sensing techniques, along with aquatic analysis, allows this wetland to be classified as non-polluted. However, monitoring of the wetland is recommended since it receives water effluents from the Gigüela River and is surrounded by a developed area that uses septic tanks instead of a sewage system.

The study of the two wetlands, comparing satellite imagery, field work, and water analysis confirmed that one of these wetlands is not currently polluted (Laguna Grande de Villafranca) and the other shows a notable improvement following the installation of waste water treatment plants (Laguna del Camino de Villafranca).

V. DISCUSSION

The results of this study showed that visual and digital interpretation of satellite imagery can be very useful in detecting specific characteristics of inland wetlands in Spain including water extension and seasonality, turbidity, salinity, hydrophytic vegetation, artificial channel drainage, and the surrounding land use. These features were highlighted by Herrero and Castañeda[36]: "Remotely-sensed data were the primary, and in most cases the only available, source of consistent information, …and this technique can help planning and surveying for the implementation of wetlands protection measures in harmony with the conterminous agricultural areas." Therefore, wetland assessment using remote sensing facilitates the monitoring of improvement and conservation measures implemented in the wetlands (vegetation regeneration, green filters, waste water treatment, etc.)[4].

Spot and Landsat images also facilitate an understanding of how the aquatic vegetation masses in wetlands evolve. This result agrees with previous studies in which Landsat images were used to develop long-term records of eutrophication levels to identify trends[22, 30].

Of the different forms of spectral, spatial, and radiometric analysis, the NDVI index best demonstrates eutrophication in the shallow wetlands and is normally used to evaluate aerial vegetation and its correlation with different environmental variables[15, 30, 31, 32]. NDVI detects the presence of green algae masses in shallow wetlands that frequently produce eutrophication. This phenomenon takes place mainly in Mediterranean wetlands with very dry summers and drastic reductions in the water sheet (unless there are urban additions). Furthermore, these results are consistent with those obtained by Rivera,et al. (2013) in the monitoring of macrophytes in Utah Lake using Landsat imagery[9]. NDVI can also be used to identify the accumulation of organic matter in shallow wetlands. However, as in the second wetland case study here, the NDVI index results must be interpreted with caution. Positive and high NDVI values and very pale colors in the images confirm the existence of chlorophyll activity, which may mean the presence of algae mass or hygrophilous vegetation. Therefore, the spatial profile pattern is needed to differentiate between the two.

This spatial profile also enables comparisons between red and near-infrared in the electromagnetic spectrum, which allowed the researchers to locate and differentiate algae, natural vegetation, salts, and organic matter in the wetland basin.

Detection of algae masses and anthropogenic discharges(urban and agricultural) are indicators of possible water contamination. However, only analytical data can identify water pollution, intensity, and pollutant type.

This study demonstrated the effective potential use of remote sensing tools to describe and evaluate spatial changes in macrophytic vegetation in wetlands. This corresponds to the results reported by Marcus, et al.[4].

VI. CONCLUSIONS

The application of remote sensing in the study of wetlands facilitated the detection of water pollution and eutrophication; the summer satellite images were found to be the most suitable for detection due to the Mediterranean climate. The images in false and natural colors turned out to be very useful for differentiating the algae from natural hygro-halophytic vegetation.

Studies of multi-temporal images, together with water analysis, allowed the evolution of water quality in the wetlands to be determined, classifying them as eutrophicated or non-polluted.

NDVI index analysis, more commonly used in forestry and agricultural studies, proved very useful in shallow water bodies in detecting the presence of algae, always supported by spatial profile patterns. Positive values in the vegetation index may indicate a probable eutrophication.

However, it should be noted that although remote sensing techniques detect the presence of algae in the wetlands, water pollution can only be confirmed by chemical analysis of the water.

Currently, out of the two wetlands studied in MHBR, one shows eutrophicated water and the other shows no signs of water contamination.

Remote sensing tools, combined with field work, provide a permanent geographically located image database as a baseline for future comparisons. They also enable consultants and wetland managers to improve the management of these areas and mitigate their pollution problems.

It would be interesting to include remote sensing techniques in the surveying and monitoring of wetlands water quality data, instead of using both methods separately. The integration of both methods, along with future improvements in remote sensing data tools and availability and in methods for the use of current information, will result in a better understanding of wetland problems such as organic pollution.

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