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Mediterranean Agronomic
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ETC UMA

TOOLS AND INDICATORS FOR INTEGRATED WETLAND MONITORING

Case study, Fuente de Piedra Wetland, Andalusia, Spain

Master on: Integrated Plannification for Rural Development and Environmental Management

MALAGA

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Autor: Matilda Merkohasanaj
Supervisors: Dania Abdul Malak
Ece Aksoy

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ABSTRACT

Wetland ecosystems are important for the welling of the people as they provide a wide range of ecosystem services; however they are suffering several pressures coming from land use changes.

This study focused on identifying pressures and changes in the Fuente de Piedra wetland ecosystem (Malaga, Andalusia) by using latest Earth Observation and GIS techniques. The major drivers of pressures on this rural area have been identified being land use land cover changes, intensification of agricultural practices namely by conversion to irrigated crops as well as soil erosion.

Several topo-climatic variables have been analyzed in order to valuate past changes and present risks of the Fuente de Piedra wetland.

A number of indicators are used to assess spatial and temporal changes namely remote sensing based Normalized Difference Vegetation Index (NDVI) indicator was used to discriminate land use patterns, in particular agricultural crops focused in cereals and olive groves between 1985 and 2015. The mean NDVI values show high potential to distinguish between different LULC classes and their changes in time, but mostly prove to be an accurate tool to monitor the intra-annual distribution and seasonality between cereals and olive groves.

Wetland surface and flooding processes are monitored by using Normalized Difference Water Index (NDWI) derived from satellite images and Topographic Wetness Indicator (TWI) extracted from digital elevation model. The NDWI indicator shows to be an adequate tool for water surface discrimination and the temporal change detection in the wetland surface.

As a potential risk in the area, soil erosion was analyzed through statistical Regression analysis. Results reveal that high soil erosion rates come as a result of different spatial-temporal variables, affected mainly by precipitation and slope, but also show that the rate of soil erosion is greatly affected by the agricultural practice and type of land cover.

Namely techniques and indicator can provide to wetland management and decision makers accurate and precise data for a continuous monitor of their territory in order to improve planning of rural areas and conservation of wetland ecosystems.

RESUMEN

Los ecosistemas de los humedales son importantes para el bienestar humano por los distintos servicios ecosistémicos que ellos aportan, sin embargo, están sufriendo una serie de presiones ambientales que provienen principalmente de los cambios de uso de suelo.

Este estudio está centrado en la identificación de las presiones y cambios en la laguna de Fuente de Piedra (Málaga, Andalucía) mediante el uso de las últimas herramientas de teledetección y SIG. Los principales impulsores de las presiones en esta área rural se han identificado dichos cambios de uso del suelo, la intensificación de la agricultura principalmente de cultivos intensivos en regadío y la erosión del suelo.

Una serie de variables topo-climáticas relacionadas han sido analizadas con el fin de valorar los cambios pasados y los riesgos presentes en la laguna de Fuente de Piedra.

Se han utilizan una serie de indicadores para identificar distintos cambios espaciales y temporales basadas en teledetección. Principalmente, el índice diferencial normalizado de vegetación (NDVI) se ha utilizado para discriminar los patrones de uso de suelo, en particular los cultivos agrícolas como los cereales y olivares entre los años de estudio 1985 y 2015. La media de NDVI muestra un alto potencial para distinguir entre diferentes clases de uso de suelo, sino que más bien ofrece una alta precisión a la hora de detectar cambios intra-anuales y estacionales entre los cereales y los olivos.

Además, para analizar las dinámicas de superficie de agua del humedal, se ha utilizado el índice diferencial normalizado de agua (NDWI), derivado de imágenes de satélite, y el índice topográfico de humedad (TWI), extraído a partir de un modelo digital de elevaciones, los cuales muestran una alta potencialidad en la discriminación de la superficie del agua y el cambio temporal en la superficie de humedal.

Como riesgo potencial en el área, la erosión del suelo se ha analizado mediante un análisis estadístico de regresión. Los resultados muestran que los valores elevados de erosión de suelo son el resultado de diferentes variables espacio-temporales, principalmente la precipitación y la pendiente, pero también muestran que el nivel alto de erosión del suelo se ve afectado en gran medida por las prácticas agrícolas y el tipo de cobertura del terreno.

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ACRONYMS

CAP: Common Agricultural Policy

DEM: Digital Elevation Model

EC: European Commission

EO: Earth Observation

ESA: European Space Agency

EU: European Union

GIS: Geographic Information System

IGM: Instituto Geográfico Nacional de España

LULC: Land Use Land Cover

MEDWET: Mediterranean Wetlands Initiative

MUCVA: Mapa de Uso y Cobertura Vegetales de Andalucia

NASA: National Aeronautics and Space Administration

NDVI: Normalized Difference Vegetation Index

NDWI: Normalized Difference Water Index

PNOA: Plan Nacional de Ortofotografía Aérea

REDIAM: Red de Información Ambiental de Andalucía

RS: Remote Sensing

SIOSE: Sistema de Información de Ocupación del Suelo de España

SWOS: Satellite based Wetland Observation Services

TWI: Topographic Wetness Index

SAC: Special Areas of Conservation

1. INTRODUCTION

Wetlands cover only 6% of the overall global surface (570million hectares) but they stand as one of the most diverse ecosystems in the planet, being particularly important for their valuable functions and for the services they provide to human beings. Wetland ecosystems are essential for humans, supporting them with provisioning services such as water purification and food supply, regulating services such as extreme event neutralizers, flood retention, as well as supporting and recreational services. More importantly, wetland habitats have large carbon sequestration and storage potentials, as they host plants and soils that support very slow decomposition rates of carbonic matter storing carbon for hundred or even thousands of years [1].

Wetlands are areas where water is the primary factor controlling the environment and the associated habitats including both land and water environments; in other words, water component has a significant function in wetland ecosystems, controlling its biophysical processes[2]. In wetland ecosystems, the complexity of the system, its water conditions and dynamics can vary tremendously, in terms of the timing and duration of the superficial water filling, as well as seasonal patterns of inundation or the transitional land between terrestrial and aquatic systems[3]. Wetlands have been subjected historically to many land use changes and anthropogenic transformations that have created pressures on the functional capacities[4]. Wetlands have suffered continuous pressures from continuous drainage and land use change shifting mainly from wetlands to agriculture land or to urban settlements and transport networks. Degradation and loss of wetland habitats are mainly caused from wetland or water drainage for agriculture practices, infrastructure and urban extension, water pollution, but also from water inflow deviation and over exploitation of groundwater resources in addition to global change effects [5][6].

These high pressures on the system have pushed for the need of assigning protection measures and awareness raising efforts to inform about their importance to human and to attempt to reduce the pressures on them[6][7].

The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that deals particularly with wetland ecosystems providing the framework for national action and international cooperation for their conservation and wise use of their resources [8]. The Ramsar Convention, adopted in the Iranian city of Ramsar in 1971, calls for "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world". The Convention's member countries cover all geographic regions of the planet.

Throughout these years, these efforts in improving knowledge and management, raising awareness, and effectively conserving wetlands showed clearly the impacts suffered by these ecosystems and proved their importance to human beings. At present, the linkage between wetlands conservations, spatial monitoring at local and global scales for a better and appropriate conservation of natural recourses and a better environmental management on different levels is one of the important aspects countries should consider within the management of their resources. In practical terms, a good understanding of the regional specifications, the historical changes, and the management regimes are essential to understand the situation, the gaps and the best practices within the management of a region. In addition, based on the identified gaps, specific tools can be developed to support management and policy in the form of recommendations towards better Sustainable Rural Development for regional and national development purposes.

In Europe and the Mediterranean region, wetlands are among the world's most threatened ecosystems, where around 50% of all wetlands having disappeared in the last century [4]. Spain is one of the Euro Mediterranean countries with the highest number of wetlands registered around 2500 wetlands, 320 catalogued in the Spanish inventory in a total surface of 170.806 hectares; 117 (37%) of them are in the region of Andalusia covering 56% of total national wetland extension. Almost 60% of Spanish wetlands were lost in the last 50 years due to increased agricultural practices, urban expansion and tourism developments[9][10].

In Spain, unsustainable agricultural practices have high negatively impact wetland ecosystems in rural areas. In these regions, the use of fertilizers, the change in agricultural practices namely the introduction of irrigation and the change of major crop types, have increased the pressure on wetlands shrinking their areas, affecting their hydrological processes and decreasing the quality of their waters as well as increasing soil erosion over times[11][12].

This thesis is developed in the frame of European Horizon 2020 project called SWOS (Satellite based Wetland Observation Services) project that was launched in June 2015 to support the monitoring of wetland ecosystems. The thesis builds on the knowledge developed during the last years on the importance of wetlands, and selects one of SWOS Mediterranean wetlands, namely the Fuente de Piedra wetland in Southern Spain as its working area.

An integrated assessment of the situation of the whole Fuente de Piedra wetland ecosystem, very particular for its hyper saline environment, is developed. The research provides on the one hand, knowledge about the situation of the wetland, and on the other hand, tests some tools based on GIS and RS (Remote Sensing) that can support management and monitoring efforts in the region. This work was developed to support advanced research studies in the framework of the rural planning and environmental management, focusing on the impacts of spatial and temporal changes in a typical Mediterranean rural environments, being an outcome of important socio-economical drivers that are impacting the "health" of wetland environments.

Main Objectives

This thesis has two main objectives: the first one aims to assess and understand past Land Use Land Cover (LULC) changes and environmental pressures on a Mediterranean inland wetland ecosystem; while the second one focuses on the use of relevant Earth Observation (EO) techniques and tools to support a more effective monitoring and management of natural resources in the wetland ecosystems.

The first objective aims at assessing the historical changes of LULC within Fuente de Piedra wetland ecosystem. The impact of these changes is studied individually on the study area in order to understand the significance of each simple topo-climatic variable on the shaping of the rural environment. At a later stage, the cumulative effects of the factors are evaluated in order to understand their relations and the dominant factors causing significant pressures on the territory. Such analysis improves the understanding of the level of influence of each topo climatic variable in the region and supports management efforts and decision making in the region.

The second objective tests the level of reliability of applying EO techniques and information management tools like GIS and Remote Sensing (RS) in supporting monitoring short term (seasonality) and long terms (annual) LULC change. Different types of satellite images are assessed, including the latest products of sentinel images of the Copernicus programme of the European Commission and Landsat images, and specific indicators are calculated and tested as tools to assess change detection.

The reliability of the integration of these tools for the wetland monitoring is then discussed as support tools for local and regional planning of rural areas.

More precisely, and whenever data were available, a better understanding of the effect of changing agricultural management practices, being a dominant land use in the study area, and their effects on the condition of this saline wetland catchment is developed.

The ultimate objective is to show the reliability of the use of GIS tools and RS techniques as supporting tools to local and regional wetland mangers in terms of providing accurate solutions for key policy questions and support all phases of environmental planning including the setting of future targets.

2. BACKGROUND

2.1. Wetlands Importance and Definition

Wetlands, called as ¨Ecological Supermarkets¨ are among the world's most productive environments. They are cradles of biological diversity, primary productivity upon which countless species of plants and animals depend for survival and the source of a wide range of public goods and services, including tourism and the supply of fresh water. Wetlands are also important storehouses of plant genetic material and important productive plants like ¨rice¨, which are a common wetland plant and the staple diet of more than half of humanity.

Despite the range of definitions, the most widely accepted definition is the one set out in the text of the Ramsar Convention on Wetlands, signed in Ramsar, Iran, in 1971, the first international effort made to protect these important habitats. According to Article 1.1 of the convention, wetlands are: *Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters¨*[13].

The Ramsar Classification System of Wetland Type includes 42 types of wetlands which belong to the three main categories:

- ✓ Coastal/Marine Wetlands,
- ✓ Inland Wetlands,
- ✓ Human-made Wetlands

Beside the multiple roles of wetland ecosystems and their values within a worldwide extension from the cold arctic to the hot tropics, they cover just approximate 3% of the total world land area but hold 30 % of all carbon stored on land as one of the most important climate change mitigation provided by wetland ecosystems[14]. Additionally different authors and studies suggest values approximated 3-6% or 7 to 9 million km^2 of the total world area [15] [16][17].

The global extent of coastal and inland wetlands is estimated to be in excess of 12.8 million km^2, 5.7 million km^2 of them are inland natural freshwater wetlands (including 3.85-4 million km^2 of peatlands); and 1.3 million km^2 of rice ponds.

Open water wetlands (both natural and human-made) cover a seasonal maximum of 5.66 million km^2, while coastal wetlands area is smaller and include 0.5 million km^2 of major estuaries, 0.566 million km^2 of major deltas 0.147 million km^2 of mangroves[14].

Wetland ecosystems hold an important part of global biodiversity and ecosystems services that they provide, where from the 233 habitat types listed in Annex I of the Habitats Directive, 47 of them can be classified as wetland habitats. About 290 species covered by the Habitats Directive are linked to wetland ecosystems, while a simply comparison on the range of ecosystem services values provided by Coastal and Inland wetlands shows a value 6-8 time higher than the grassland and woodland[13].

Even so 50% of global wetlands and over 60% of European wetlands were lost seen the 1990s. The drainage of wetlands has been common practice in Europe for centuries, leading to a substantial decrease in the number, size and quality of wetland areas.

In this last year the increasing demand of water and over-use of it, jeopardizes human well-being and the environment to provide a safe water access, human health, food production, economic development and geopolitical stability, are made less secure by the degradation of wetlands driven by the rapidly widening gap between water demand and supply. Even with current attempts to maintain water flows for ecosystems, the capacity of wetlands to continue to deliver benefits to people and biodiversity, including clean and reliable water supplies, is declining.

2.2. Wetland Conditions and Pressures

The main causes of the degradation and loss of wetlands being: Land use change, especially increased agriculture and grazing, water diversion through dams, dykes and canalization; Infrastructure and urban expansion, in river valleys and coastal areas; Climate Change are main degradation effects.

In Europe, agricultural activities and the large-scale use of wood for construction and fuel, led to progressive deforestation, drainage of peatlands and embankment of floodplains for flood protection. These ever more intensive activities have resulted in massive losses of pristine wetland habitats and the development toward semi-natural ecosystems[18][17].

Between 1990 and 2006, from the wetland area converted to other land uses, 2 % were artificialized (e.g. urban areas), 7 % became agricultural, 12 % water bodies, and 79 % forest and semi-natural areas. For more the changes continue to increase the last 6 years with a 35 % of the change in wetland areas was due to conversion to agriculture and 49 % to forest creation and afforestation [19].

In the Mediterranean Region, there are 15 to 22 million hectares of wetlands a fourth of which are artificial, such as dam reservoirs and fish-farming ponds, which have a key importance for carbon sequestration. But they also provide a wide range of other services such as water provisioning, management and purification, flood defense and offer recreational and tourism opportunities that makes Mediterranean Region particular.

Mediterranean wetlands especially have been experiencing various kinds of pressure due to human activities. Agriculture has long had the most significant direct impact. In addition, there is now urbanization, mass tourism and infrastructure development, particularly along the coast and in river valleys. Pressure is increasing due to the growing number of inhabitants on the coast. River flow rates are falling almost everywhere, due to water extraction and retention by dams.

Meanwhile Climate change and climatic variability are also having a growing impact, by amplifying the severity of droughts and caused pressures to increase drainage. Moreover the sea level of the Mediterranean rose by 22 cm in the 20th century, with significant effects on coastal wetlands. This trend probably is going to worsen[20].

The quantity of water available for natural habitats, and wetlands in particular, has been falling, most dramatically in the south and east of the region. Water extraction is the greatest threat to wetlands; either water storage in the wetland catchment is required by the Water Framework Directive and regional programs. Irrigated agriculture is the greatest water consumer in the region, accounting for 2/3 of total consumption. Excessive pumping weakens wetlands and the water tables that depend on them, although irrigated surface areas now seem to have stabilized in the European Union.

On the other hand water quality has partially improved in Europe since the 1980s, due to the reduction of nutrients and heavy metals, although other pollutants (pesticides, drugs) are decreasing but sometimes stagnating or insufficiently monitored[21].

Recent years GIS, EO and RS applications have demonstrate high abilities for worldwide ecosystem monitoring and especially on wetland ecosystem, combining previous existing information data, different thematic maps and satellite image on monitoring: habitats distribution, land use and land cover of the surrounding wetland area, land change, environmental hazards as fires and inundation etc. [12][13]. All these outputs are capable to provide a long observation, ranging from local to global scale to support decision makers in improving management issues and policies for a rational use and conservation of natural resources and wetland habits especially.

On one hand for inventorying and monitoring wetlands, satellite remote sensing has many advantages like: repeating coverage so that wetlands can be monitored seasonally or yearly, provide information on surrounding land uses and their changes over time but also they are data easy implemented in GIS processing. They are less time consuming and less costly.

But on the other hand they have several limitations. Not always the spatial resolutions is the adequate for the detections of small or elusive features; or the possibility to separate different vegetation classes or wetlands type is limited[24], so they need to be support buy ground verifications. For more procedural errors related to the ability to accurately recognize and classify wetlands [25] and natural conditions like climate (clouds) or natural hazard (fires) can affect them [26][27].

2.3. Wetland Conservation Policies

International cooperation is the key answer on the wetlands conservation and protection. As the main key factor the Convention on Wetlands was signed at Ramsar (Iran) in 1971 in order to protect them, while seen 2014, 168 countries have signed it, including all the Mediterranean countries. The number of "*Wetlands of International Importance*" in the Mediterranean Region, included in the Ramsar list, has more than doubled in the last decade.

The Convention defines the wise use of wetlands as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development. In this framework the convention of Ramsar and its wise use, it´s globally supported by International and National Policies, Programs and Directive[28].

Wetland protection in Europe may seem guaranteed with the appropriate legislation at three different levels, i.e. Ramsar, the EU directives and the national legislations in the various European countries governance.

The Habitats Directive together with the Birds Directive [29] part of Natura 2000 Network is one of the base conservation directives. It comprises Special Areas of Conservation (SACs), designated by Member States under the Habitats Directive. The development of national policies for conservation and biodiversity of wetlands, include National Biodiversity Strategies and Action Plans as EU actions to implement the Strategic Plan and achieve the 2020 Biodiversity Targets.

The Water Framework Directive is the concept of integration, seen as key to the management of water protection within the River basin and Wetlands. Some others important European directives related to Wetlands Water Conservation and protection are:

- ✓ The Nitrates Directive (91/676/EEC),
- ✓ The Groundwater Directive (2006/118/EC),
- ✓ The Urban Waste Water Directive (91/271/EEC),
- ✓ There is also the recently adopted Flood Risk Management Directive, which is directly relevant to wetlands.

The Mediterranean Initiative on the Ramsar Convention on Wetlands, or 'MedWet'[30] founded in 1991 with the aim of encouraging international collaboration among Mediterranean countries, specialized wetland centers and NGOs in protecting regional wetlands. In 2002, MedWet became a formal inter-regional structure for the implementation of the Ramsar Convention caring a specific mission, as to ensure the effective conservation of the functions and values of Mediterranean wetlands and the sustainable use of their resources and services. Amended in 1995 aims to prevent, reduce, fight and as far as possible eliminate pollution in the Mediterranean zone and protected Marine area [21].

- <u>Spanish Approach</u>

Spanish legislation establishes a number of legal instruments to ratify the strategic importance of wetlands and the need for conservation. Among the strategic and planning instruments with an explanation on wetlands conservation and protection are the *National Hydrological Plan and National Irrigation Plan*, different *Basin Hydrological Plans*, the *National Forest Strategy*, the *Spanish Strategy for the Conservation and Sustainable Use of Biodiversity*. As the main Strategic Plan the *"Spanish Strategic Plan for the Conservation and Rational Use of Wetlands"* it is establish by:

- Water Law 29/1985 establishes a definition of wetland, the need for inventory and delineation, development and management plans, delegated by the Real Decreto Legislativo 1/2001.
- Law 4/1989 of Conservation of Natural Areas and Wild Flora and Fauna also it provides the development of a national inventory of wetlands along protective measures.
- Coastal Law 22/1988, of 28/07/1988 for its impact on the conservation of coastal and inland wetlands [31].

An important role in the conservation and monitoring of wetlands in Andalusia, has the Plan Andaluz de Humedales[10].

Despite of the above-mentioned protection policies, increasing pressures over wetland ecosystems is still taking place in Andalucian region.

Fuente de Piedra lagoon has undergone continues pressures as result of diverse management and implementation policies that have not been properly coordinated and implemented creating a set of gaps in the sustainable management of the wetland functionality. In the framework of SWOS project as part of Copernicus program this study tends to give appropriate solution to the policy makers and wetland managers to reduce main impacts over the wetland area through new observation and monitoring tools and technics.

3. STUDY AREA

The Natural Reserve of Fuente de Piedra lagoon is located in the northwest of the province of Malaga in the region of Andalusia in Southern Spain (37 6'N 4th 46 'W). The Natural Reserve and its Peripheral Protection Zone have a total area of approximately 8.912 ha, of which about 1.475 ha belong to the water perimeter of the lagoon, located next to the village of Fuente de Piedra and Humilladero.

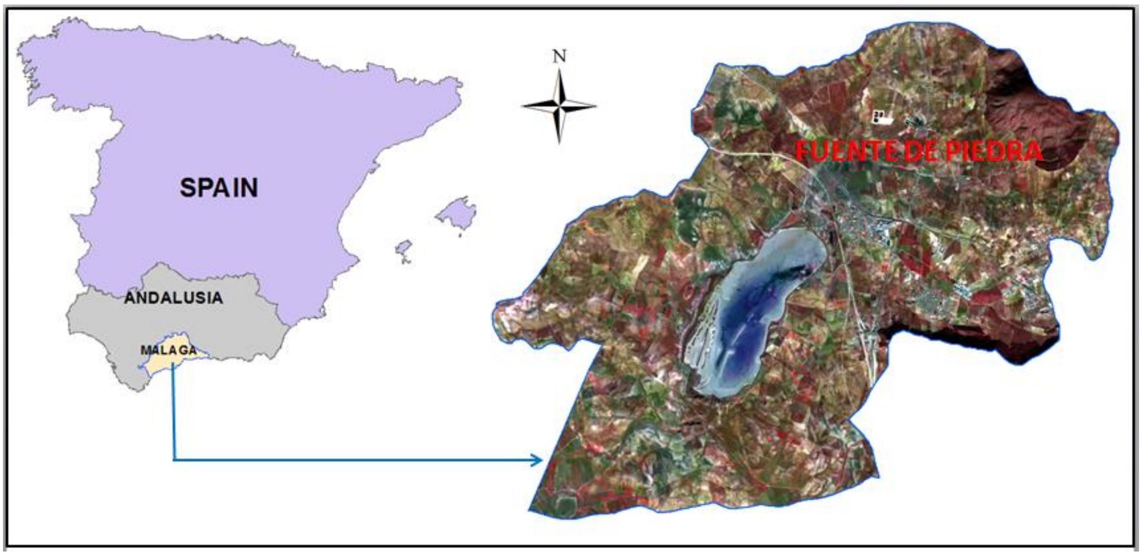


Figure 1: Geographical location of Fuente de Piedra wetland and define study area.

This small inland wetland is considered as one of the most important and special ecosystems and habitats in Spain due to the particular semiarid conditions in a hyper saline environment and her colorful biodiversity. Together with the wetland of Gallocanta (Zaragoza) present one of the two biggest wetlands extended in the Iberian Peninsula and the second most important breeding site for Flamingos (Phoenicopterus roseus) (12,000 pairs) along with the one in the Camargue (France).

Located in an altitude of about 410 m above sea level, the lake has an elliptical shape with length axes between 6.8 and 2.5 km, in a perimeter of 18 km and a volume approximately 5 million m^3. With very flat and smooth slopes, the water level usually does not exceed 1.7-2 m deep, surpassing this figure only in exceptional condition [32].

In this research we use the boundaries of the study areas, the wetland ecosystem delimitation guidelines as set by the SWOS[2] project that consider the *Hydro-ecological cycle and the Protected area limits(Fig2)*.

The Hydro-ecological cycle includes the hydro-geological basin, the vegetative structure, and the aquatic barriers, wetness, flow volume and flow regime**.** While the *Protected area boundaries,* support environmental conservation including the Ramsar Convention, designation of nature reserves (Natura 2000 sites, natural parks), surface and groundwater water policies, applied in the administrative context.

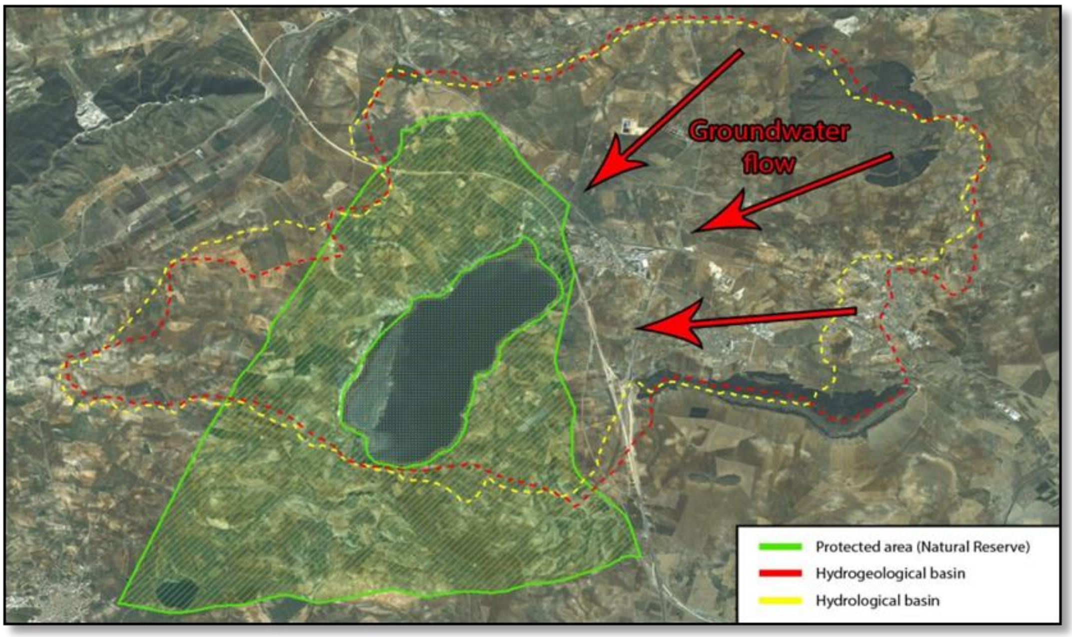


Figure 2: Borders of the natural reserve vs the area of hydric influence.

Wetland management it is rather influenced by administrative boundaries related to the peripheral protected area, infrastructure and economic activities, so on administrative responsible site managers, stands out the importance of the hydro-geological basin as it consist with the management limits.

Figure 3: Definitive study area border.

In this context the definitive study area limits is a combination of the three overlapped layers, hydrological, hydrogeological and protected area layer (Fig3).

3.1. Geology-Geomorphology-Soil Types

The lagoon is located in the geomorphological complex structure so-called *Trias* de *Antequera*. It has a chaotic internal structure, produced by an intensive process of tectonic displacement dated in the Middle Miocene, is slipped and includes sediments that are part of the Guadalquivir depression.
The genesis of the lagoon is related to the dissolution and karstification phenomena affecting the gypsiferous-saline materials of Trias -Antequera in this area. The depression in which the wetland is located, has originated from collapse and subsidence processes associated with the evolution of karst[33].
Associated with the semiarid Mediterranean conditions in a high salinity concentration, the soil properties and soil textures are defined from the rock formation, the lithological and geomorphological karstification processes. Soil properties form the recent Quaternar formation in a reddish-brown color, reach in carbonates and grew rich in salts, are represented mainly by Cambisol in the largest part. In the outside of the lagoon soils are calcareous and gypsiferous which cover 60% of the total surface with very low concentration of organic matter content. Going toward the borders of the lagoon, soils are more saline, which make difficult the crop production as few species are adapted in this high concentration. Carbonate formations are permeable, which origin the aquifers that are connected to each other, having Trias as an impermeable substrate.

Soil units composed by Eutric Fluvisols and Calcareous Regosols, formed up to the alluvial formations in flat and deep soils over 75cm, are mainly located in the streams plains, and south part near to Campillos wetlands. Mostly in the north part, units composed by Regosol Vertisol and Calcaleous Cambisol, formed on marl, clays, sandstones and conglomerates usually in slopes higher than 7% are quite deep soils up to 75 cm but with low drainage capacity. Calcareous associations composed by Regesol, Eutric Vertisol and Calcisol are present in smooth slopes less than 7% in the entire area, with some limitation in soil deepness less than 75cm [34].

3.2. Hydrology and Climate

The lagoon of Fuente de Piedra is known for the high water salinity content being around 100g/l, 5 to 6 times the seawater. The water mass corresponds to a complex hydrogeological system where the surface runoff and groundwater runoff interact. Called as endorheic basin has a surface of approximately 150 km^2, the water discharge into the lagoon of Fuente de Piedra.
The hydrological basin is constructed buy five aquifers: Quaternary, Miocene, Paleogene aquifer, Jurassic carbonate aquifer and Trias aquifer which is the substrate of the basin and its evaporating materials are responsible for the high water mineralization. The wetland has well defined affluent where the most important are the streams of Santillan, Charcón, Maria Fernandez and ¨de las Tinajas¨ either their waters are not permanent (Fig4).

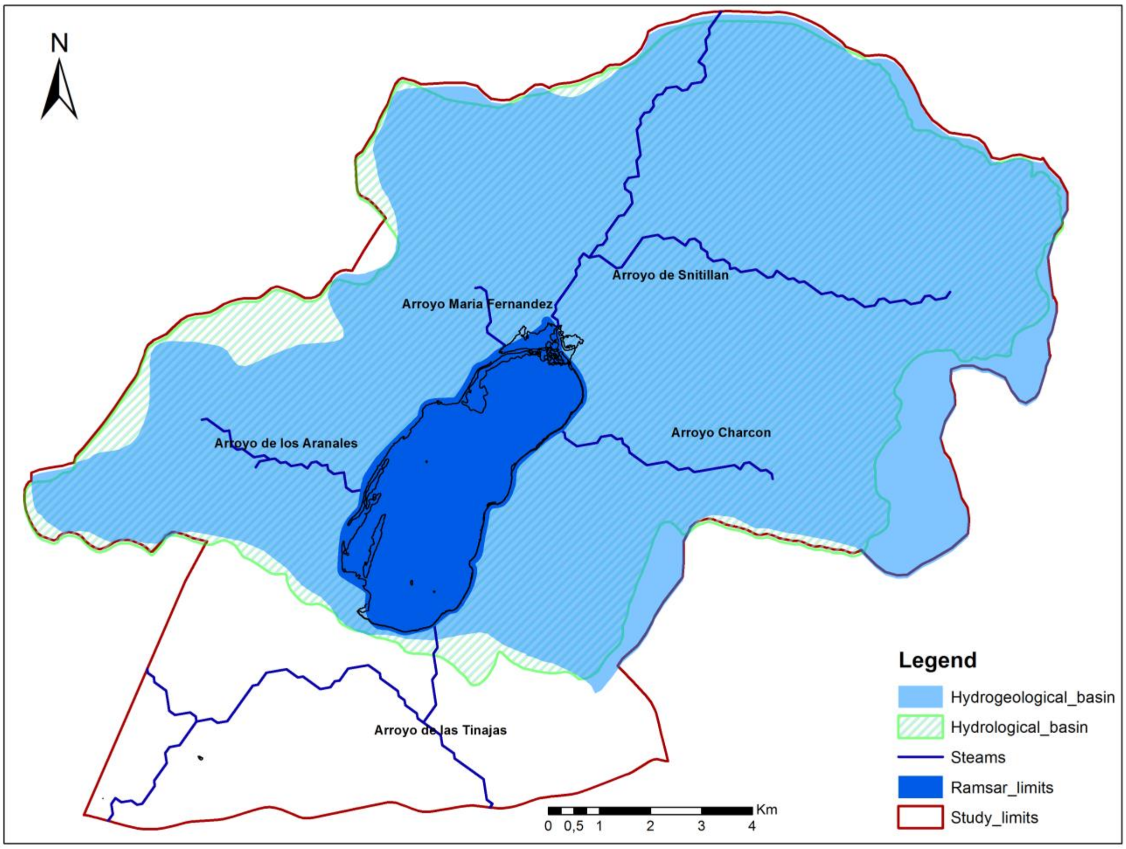


Figure 4: Hydrological, hydrogeological units and main streams.

The high salt content and high mineralization degree of the waters along flooding cycle are closely related to the fact that salinity evolves following a typical concentration pattern by evaporation. The water level of the lake is largely determined by the prevailing weather conditions, in a registered minimum of 20cm in a dry year and 1.70cm in a very wet year [33].

The available water resources in the water body of Fuente de Piedra, in terms of rainfall, have been estimated at 21 to 25 hm^3/year, of which 6 to 7.5hm^3/year are from direct precipitation on the lagoon, 5.6 to 7 hm^3/year are from surface runoff and 8.3 to 11 hm^3/year are due to the underground runoff (Fig5).

As results of high temperatures during summer period, the evaporation values are estimated near 25.3 hm^3/year which create negative water balance as a consequence the aquifer level diminish in critical quotes and the wetland stands dry for long periods[35].

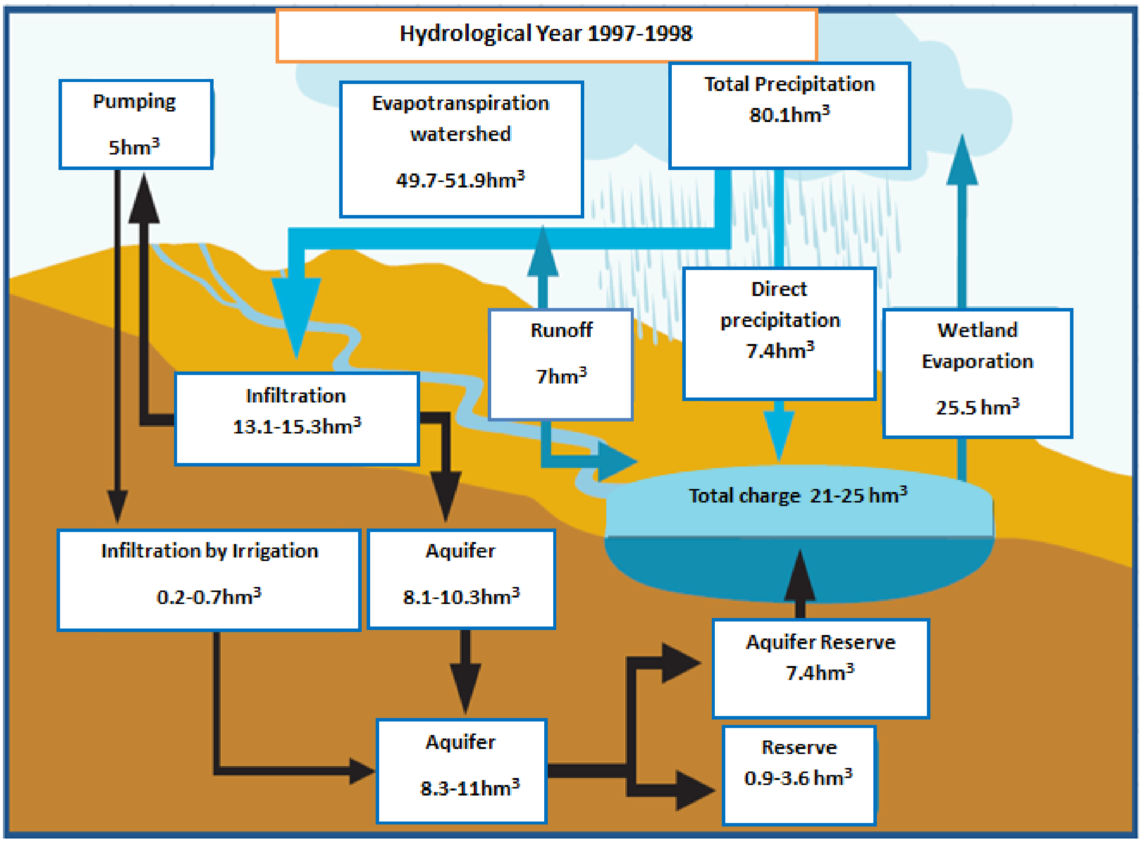


Figure 5: Water balance in Fuente de Piedra (source CIHEUMA).

Two urbanization cities of Fuente de Piedra and Mollina Humilladero are supplied by 0.75 hm^3/year groundwater comes from the carbonate aquifers. In recent years, there has been an increase in extractions for human supply as a result of the continued urban growth.

- **Water Quality**

It is difficult to define the water quality status of the Fuente de Piedra wetland, regarding to the high salinity and the variation of climatic conditions, the water present a wide range in water parameters. The higher salinities (96 g/l registered in dry condition 20cm) are registered in the water surface and especially in the northeast extension, coinciding with the most extensive outcrops of Triassic Basin. The lowest salinities have been found east of the lagoon extension, in the depression between the Sierra de Mollina and Humilladero, occupied by a large outcropping of Miocene materials.

The water basin of the lagoon is generally quite mineralized, presenting high vales of conductivity, relates to the soil texture and flood water dynamics. The waters contain sulfated calcium-sodium-chlorine with conductivity values between 20 and 100 mS/cm. The water temperature varies in an average of 20°C, in a pH mainly basic about 8.5pH and alkalinity 2-3 ÁM/mg CaCO3/l.
Present, the water quality in the lagoon is strict controlled based on the Water Framework Directive, Water Quality and Nitrates Directive. Two water treatment purification systems control and maintain the water quality effluent discharge in the lagoon from the sewerage effluent coming from near urbanizations of Fuente de Piedra and Humilladero village, while

new restoration measurements and implementation actions aim in reaching better water quality conditions [35][36].

- **Climate**

As Mediterranean climate is characterized by seasonality of rainfall which is not very abundant, the annual average rainfall is about 450 mm. The minimum precipitations have been registered near 200mm per year where the lagoon suffers shorter or longer drying periods. In addition, there is a wide variation in the year distribution of precipitation where the maximum precipitation registered exceeds 700mm per year.
The annual average temperature is 17 °C, the coldest months are January (9.6 °C) and December (9.9 °C) and the warmest August (26.2 °C) and July (25.7 °C), while the mean potential evapotranspiration is 830 mm, very high during the months of July and August[37].

Wind speed has influence on the study area as the prevailing winds generally have east direction, so-called east winds, that determine the movement of the watershed when the lagoon is completely or partially flooded, sometimes accelerating the evaporation and therefore drying the lagoon.
The intensity of the wind throughout the year ranges between 0.5 and 2m/s. In exceptional cases wind intensity can overpass 90km/h in winter months; in a general overview, wind intensity and frequency doesn’t impose any limitation for the agricultural development of the area [34].

3.3. Flora and Fauna

- **Flora**

Related to the location and its environmental characteristics the wetland of Fuente de Piedra presents a very heterogeneous and reach habitat with different plant and birds communities. Among them we can distinguish two types of ecosystems:

The first type depends on the rain water and occupies the external land perimeter of the lagoon. In this area the monocultures (olive trees) and intensive crops (girasol, sunflower, oats, and barley) are a potential vegetation of the surrounding environment. In addition, in very specific small areas it is represented the Mediterranean scrub, evergreen hard-leaf plants, very adapted to the dry summer period (holm oak, wild olive, mastic, grassland).
The second type of ecosystem is dependent on the length of water flood, salinity and soil texture. This corresponds to the native vegetation of this wetland, where have been found communities and species of great botanic values, related to special needs and characteristics of species and communities. On the border channels where a horizontal zonation of plant communities occurs and where the fresh water from runoff and precipitation accumulates, new dense formations communities as characteristic timberline (tree vegetation or wood land) of the lagoon, formed by shrubs, constituting great places of refuge for a diverse fauna (Fig6)[38].

The halophyte vegetation is the most characteristic of the wetland, constituting the main part of the border of the lagoon. They thrive in the clay soils of the inner area of the lagoon (dikes and islets), and they are able to resist the extreme conditions of drought and salinity. Some of the species that can be identified are: *Sarcocornia perennis, Suaeda vera, Arthrocnemum* [35].

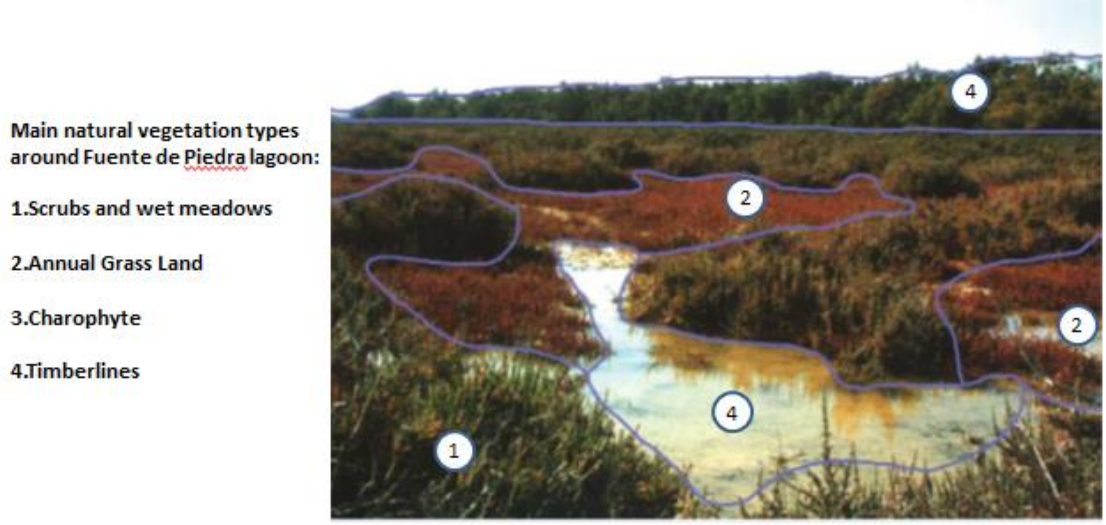


Figure 6: Natural vegetation in the water border zonification of Fuente de Piedra Lagoon.

A number of endemic species of special interest have been catalogued as rare or threatened species[38], including some rare aquatic halophyte plant such as the *Althenia orientalis*, some small water bryophyte plant such as *Riella Helicophylla*, *Althenia orientalisa* rare aquatic halophyte plant, *Riella Helicophylla* a small water bryophyte plant, *Ranunculus trichophyllu, Ruppia drepanenis* and *Zannichellia palustris other perennial plants.*

- **Fauna**

The fauna of Fuente de Piedra is closely related to the plant communities and watershed of the lagoon. The mammals have a distribution directly related to the different plant communities and the level of transformation of the environment by agriculture which in the area is quite high. It has found the presence of dormouse and water vole, besides the rabbit and hare that are abundant around the perimeter of the lagoon. The fox and badger are the most characteristic mammal's predators in the area.

The most diverse fauna in the lagoon are the birds, with over one hundred and seventy species cataloged, among them distinguish aquatic birds, red beds birds the halophile habitats birds and the terrestrial habitats (countryside) bird, some of them are cataloged in table 1.

	Sheet bad	Halophile	Red beds	Countryside
1	*Larus michahellis*	*Vanellus vanellus*	*Ciconia ciconia*	*Northen Harrier*
2	*Netta rufina*	*Motacilla alba*	*Podiceps criststus*	*Tyto alba*
3	*Tringa totanus*	*Gallinago gallinaga*	*Circus aerugionus*	*Aqthona noctua*
4	*Anas crecca*	*Himotopus himoptopus*	*Lanus ssenotor*	*Upupa epops*
5	*Recurvirosa avosetta*	*Asio otus*	*Grus grus*	*Saxicola torquatus*

Table 1: High interest birds in four main habitats of Fuente de Piedra (Birding map Fuente de Piedra).

Known as one of the most important Flamingo colonies, the habitat and ecosystem of the lagoon is the great paradise of this special bird. Flamingo is a bird of great size, between 1.30 and 1.50 m tall. Their feet are webbed like ducks; their legs (tarsus) are long and their neck long and flexible. They are pink, with yellow eyes, red legs, pink beak and intense black-tipped wings [35].

Their flight is very characteristic, with necks and legs stretched, while during migration the group takes the form of V. These species are feeding by microorganisms that live in the water, like crustaceans, larvae, mollusks, etc.; reason why they prefer the shallow and saline water of Fuente de Piedra lagoon.

Figure 7: Pink flamingo (Phoenicopterus roseus) colony in Fuente de Piedra.

3.4 Pressures on the Fuente de Piedra wetland

The actual situation of Fuente de Piedra reflects the various actions that inhabitants have done throughout history to utilize its salt and trying to dry it. The remains of ancient salt mining have modified the original territory creating dams, depressions and freshwater canals. These artificial structures have created new environments in which plants and animals have settled.
In the past decades there were several attempts to dry the lagoon converting it in an agricultural land, or to facilitate the salt works and salt extraction[33].

Recent years the exploitation of groundwater by agriculture, urban water supply and industries has been producing different impacts on the system creating gaps in the sustainable use and management of the lagoon Some transport infrastructures limit the lagoon, the national road N-334 (Sevilla-Antequera), the local road of Fuente de Piedra –Sierra de Yeguas and the train way Sevilla-Bobadilla in the north part.

The agricultural use has transformed all the land surrounding the lakes, while livestock is not developed (just some small sheep and goats farms). Pollution from urban sewage and agricultural origin is one of the biggest impacts noted, although the last years due to agricultural policies and financial support have been attempts to control phytosanitary products (Figure 8).

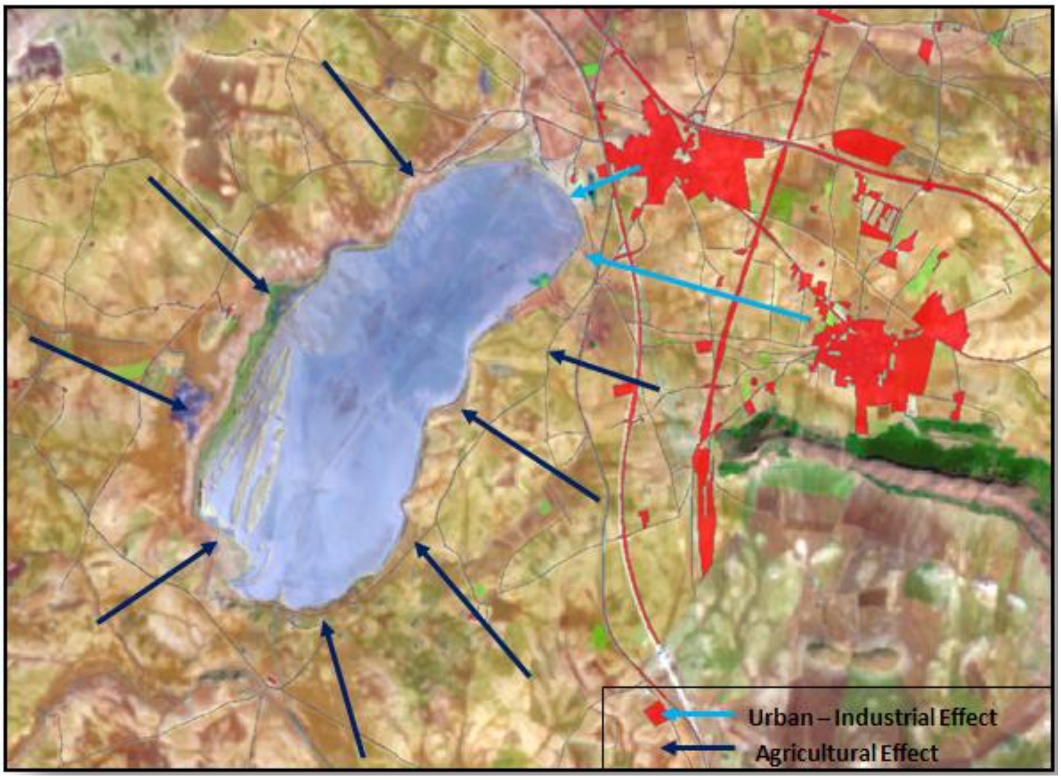


Figure 8: Agricultural and Urban Pressures over Fuente de Piedra wetland area

In the largest part, the lagoon has lost the originality and natural landscape, where changes in agriculture and infrastructures have led in a large fragmentation of the area, restrict the naturality just in the water surface and the peripheral channel.

Figure 9: Extend of urban areas (left) extent of intensive agriculture in the lagoon limits (right).

Soil erosion and soil loss due to physic-climatological conditions and, land use change, stands a serious risk for the water quality and sediments loading which increase the pressures on the biological habitats. Like an important part of the actual situation and management from the local administration is the purchase of land and convert it in public space to ensure the proper management of uses around the lagoon[35][39].

3.5. Legal context and protection

In 1962, at the First International Conference on Wetlands, at the request of the IUCN the Fuente de Piedra wetland was included in the list of wetland protected areas. In 1983 it was included in the (Ramsar Convention) Wetlands of International Importance.

In 1984 was declared Integral Reserve by the Andalusian Parliament (Law 1/1984), renamed Nature Reserve after its inclusion in the inventory of natural protected areas in Andalusia (Act 2/1989, of July 18) and in 1987 it was declared a Special Areas of Conservation (SAC).

Actual Protection Categories	
Restrict Protected Area	8.662,78 ha
Natural Reserve:	1475, 67 ha.
Peripheral Protected Area	7.187,11 ha.

Table 2: Protection Categories of Fuente de Piedra wetland.

Closely related to the habitats conservation and with the approval of the European Commission they name it in 2006 as a Sites of Community Importance (SCI). The last years as part of the Life-Wetland Project the lagoon was included in several restorations founded by several European and Regional projects.

4. METHODOLOGY

This thesis uses GIS and RS as main tools to assess the condition of the Fuente de Piedra wetland ecosystem and the major pressures (LULC change, erosion risk, water regime and water dynamic) this wetland is subjected to as well as the changes in these pressures in time. It assesses pressures individually, and then analyses the factors that are most influencing the wetland. From the remote sensing side, the thesis identifies some tools that could support management and monitoring of the wetland, tests them and proposes them as reliable tools for use for management purposes (Figure 10).

The general procedure for this study can be divided into three main parts. The first part focuses on data selection to assess the ecosystem condition and pressures and preprocessing of the dataset. The second one addresses land use identification distribution and classification, vegetation and water indicators based on Remote Sensing. The third part involves the implementation of statistical regression analysis on specific natural condition namely the physical-climatic variables and the erosion risks effecting the wetland ecosystems and functionality.

The first approaches based in the data selection and preprocessing intent to harmonize data availability in a spatial and temporal acquisition.

The second approach uses LULC layer and Landsat images as basis for the calculation of different NDVI, NDWI attributes, as well new Sentinel 2 images from the EC Copernicus program to differentiate LULC. The seasonality and productivity response of the vegetation index shows the different thresholds within land use classes. NDWI indicator delimitate the water flooded areas identifying wetland water extend and changes over them.

The third approach assess the effects of specific factors namely LULC, slope altitude, lithology precipitation, temperatures and time factor on soil erosion in the study area based on a correlation and regression analysis to estimate the hierarchical relationships between them. The main variables used for this analysis are the potential soil loss layers, land use layers, land cover layers, and additional environmental layers which describe the landscape properties.

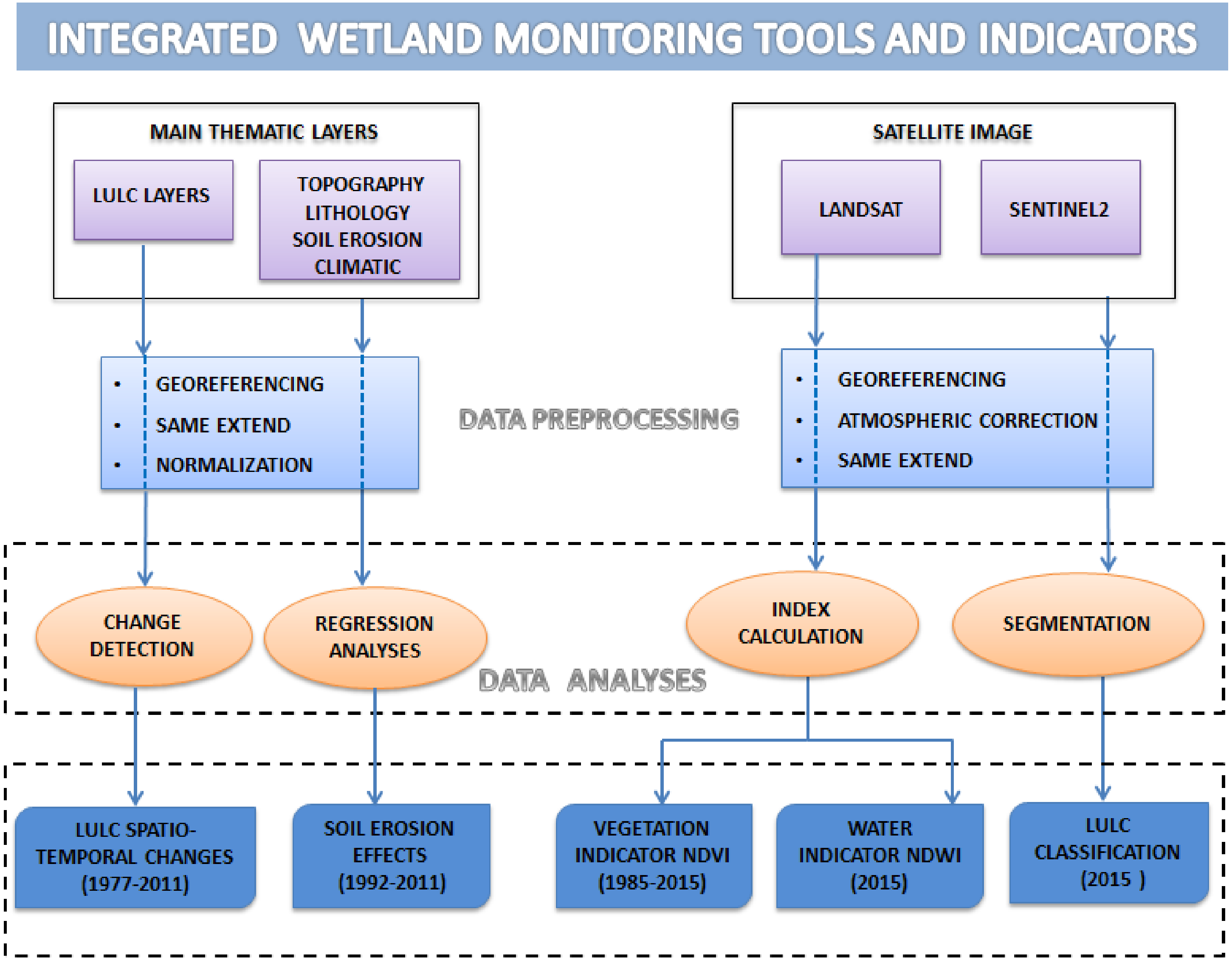


Figure 10: Methodology process of integrated wetland monitoring tools and indicators used.

4.1. SOURCE OF INFORMATION

Different sources of information are used in the analysis. The collected data from different sources are listed and their technical specifications are described in this section.

Four classes were identified to categorize the different type of datasets depending on their nature, scale and specific characteristics. These classes are listed below and the details are given in this section:

1. Thematic layers,
2. Ground Data,
3. Satellite Image Data,
4. Ancillary Data.

<u>Class 1 -Thematic layers:</u>

A series of specific spatial datasets were collected in order to describe the natural conditions of the land surface as fundamental in the potential distribution of rural and urban areas. They include landscape and thematic layers representing the biophysical, geomorphological and administrative characteristics. These layers are:

- Protected Areas layer (Wetlands of Andalusia Included in the Ramsar List),
- Hydrological and hydrogeological layers,
- Land use-land cover layers,
- Topographical variables (digital elevation model (DEM) and DEM derived layers (aspect, slope, elevation),
- Lithology layers,
- Soil Erosion layers.

The details and technical specifications of these layers are described in the following paragraphs and Table1.

- **Protected Areas Layer – Wetlands of Andalusia Included in the Ramsar List**

The protected area layers delimitated the most important wetland sites as areas with high ecological interest and the conservation of biodiversity. These layers have been used in the delimitation process for the study area.

Along with RENPA (Red de Espacios Naturales Protegidos de Andalucia), provided from Junta de Andalusia representing the last updated protected areas limits for 2015.

➢ Hydrological and hydrogeological layers

A series of related hydrogeological layers are considered important for the definition of the study area limits. Taking it from an ecosystemic perspective, the Fuente de Piedra wetland ecosystem delimitation is determined by the water body and the hydro-geological basin boundaries.

The superficial and underground hydrographic water-system layers are used as a source coming from the Hydrogeology department of the University of Málaga (CEHIUMA). The hydrogeological boundaries are completed with the superficial and underground water layers, as a complementary source coming from REDIAM (Red de Información Ambiental de Andalucía). This layer provides an important information related to spatial location of hydrogeological units, springs, drilling, watershed, groundwater flows, aquifers points, quality networks etc., in a vector format and reference system "ETRS89¨(UTM, 30N projection).

	Theme/category	Dataset/indicator	Format	Resolution/Scale	Temporal coverage Years	Spatial coverage	Source	Data availability	Details
Thematic Layers	Protected Areas	**Wetlands Inventory of Andalusia**	Shape File	1:10.000	2012	Andalucía	REDIAM	Public access	Includes the most important wetlands of a huge ecological and biological interest.
	Protected Areas	**Andalusia Wetlands included in RAMSAR list**	Shape File	1:10.000	2013	Andalucía	REDIAM	Public access	Wetlands inculded in the list of the Wetland of Internacional Importance, RAMSAR List;
	Hydrogeology	**Hydrogeology environment surrounding Andalusia wetlands**	Shape File	1:5.000	2006	Andalucía	REDIAM	Public access	Hydrogeological limits, hidrologycal basin in
	Land use/land cover	**SIOSE Andalucía Land Use and Land Cover Information System of Spain (SIOSE)**	Shape File	1:10.000	2005-2009-2011	Andalucía	REDIAM	Public access	As part of the national information system project of land use in Spain (SIOSE), this dataset is the most detailed information on land use for Andalusia.It presents an intensive characterization of each one of the approximately 2 million polygons which have been defined in terms of land use land-cover and vegetation-flora. 2013 data are under process.
	Land use/land cover	**MUCVA**	Shape File	1:25.000	1977-1984-1991-1999	Andalucía	REDIAM	Public access	Cartografía de los usos y las coberturas vegetales del suelo de Andalucía http://www.juntadeandalucia.es/medioambiente/site/rediam/informacionambiental
	Lithology	Geology and Lithology map	Shape File	1:50.000		Andalucía	IGME	Public access	
	DTM	**Digital Elevation Model 5 m**	Raster	5 meter	2012	Spain	IGME	Public access	Sistema geodesico de referencia ETRS89 (en Canarias REGCAN95, compatible con ETRS89) y proyección UTM en el huso correspondiente a cada hoja y también en el huso 30 extendido (para hojas situadas en los husos 29 y 31). El MDT25 se ha obtenido por interpolación de modelos digitales del terreno de 5 m de paso de malla procedentes del Plan Nacional de Ortofotografía Aérea
	Soil Erosion	Natural Risks - Erosion	Raster	75x75m	1992-2012	Andalucía	REDIAM	Public access	Annual monitoring of the evolution and impact of soil erosion in Andalusia
Ground Data	Water quality	**Surface Water Data set for Andalusia**	Shape File Tabular	1:10.000	2012	Andalucía	REDIAM	Public access	Superficial Water parameters for Andalucía region. Location control points, reservoir, wetland and river controles. The water quality data are actualized in 2013.
	Water quality	**Red de Control de la calidad de las Aguas Superficiales de Andalucía, 2013**	Tabular	-	2013	Andalucía	REDIAM	Public access	Control of Surface Waters established in compliance with the provisions of the Water Framework Directive (Directive 2000/60 / EC). Results include both biological and physico-chemical sampling. http://www.juntadeandalucia.es/medioambiente/site/rediam/informacionambiental
Satellite Imagery	Satellite imagery	**Landsat images**	Raster	30 m	1970-2015	Global	GLOVIS Earth Explorer	Public access	The Landsat satellite images cover the entire Earth every 16 days in 8-day offset from Landsat 7. Data collected by the instruments onboard the satellite are available to download at no charge from GloVis, EarthExplorer, or via the LandsatLook Viewer within 24 hours of reception. http://earthexplorer.usgs.gov/
	Satellite imagery	**Sentinel Image**	Raster	20m	2015-2016	Global	ESA	ESA Access	

Table 3: General description of the dataset.

- **Land use –land cover Layers**

Two different set of land use-land cover dataset based on different time reference are provided from the Environmental Ministry and Junta de Andalucía (REDIAM). These layers, which give accurate and detailed information about the land use land cover classes, are SIOSE and MUCVA land use land cover layers. They were used for supporting the analysis of land use change and for understanding the wetland dynamics changing in time. They are mainly built in three levels of information; and include from 25 to 72 classes (present in our study area), with a detailed and semi-detailed scale, that has simplify their use and interpretation.

- **SIOSE(time series: 2005, 2009, 2011)**

The Land Use and Land Cover Information System of Spain (SIOSE) for2005, 2009, 2011 is the most detailed information on land use for Andalusia in 1: 10,000 scale. The project which was part of the national information system of land use in Spain (SIOSE), presents an intensive characterization of each one of the approximately 2 million polygons which have been defined in terms of land use (182 occupation classes are identified covering entire region in its most detailed level), land-cover and vegetation. Series from 2005, 2009 and 2011 where available, meanwhile for 2013 are still under process.

- **MUCVA (time series: 1956, 1977, 1984, 1991,1995, 1999)**

Another important cartographic series taken from the same source in the comprehensive time tracking of land use -land cover layers at a scale 1: 25.000 (MUCVA25),that is updated every four years from 1999 to 2007. The maps are continued into the past layers of 1956, 1977 and 1984, throughout the photo interpretation and use performed on historical ortho-photos for corresponding years. The layers of 1991 and 1995 have more detailed scale 1:50.000.

- **Lithology Layer**

Geological, geomorphological and lithological properties of land surface are related to geological forms, rock formation, the soil structure and soil formation. This type of information is important to include in the research as a parameter that is closely related to the distribution of land cover patterns, land use and vegetation distribution, as well as soil formation. The lithological and geomorphological layers are produced by the Instituto Geografico Nacional (IGM) and are freely accessible. For this study, the following lithological sheets, Hoja 1023, 1006, 1002, were respectively downloaded as they cover the study area in 1:50.000 scale.

- **DEM-Digital Elevation Layer**

The ground elevation is an important element that allows the identification of the relationship between terrain patterns like topography, morphology, orientation, identification of hydrological system and the vegetation spatial distribution[40][41].
The Digital Elevation model of the area obtained from the Instituto Geografico Nacional, builds from the Plan Nacional de Ortofotografía Aérea (PNOA) in 2012, was available in a raster format and in a reference Geographic coordinate system ETRS89, UTM projection. It has a 5 m spatial resolution, which might provide appropriate precision for a small scale study area such as Fuente de Piedra.

- **Soil Erosion and Soil Degradation Layer**

The environmental impacts of soil loss caused by erosion are diverse and extremely serious: loss of fertile soil, desertification of large areas, siltation of reservoirs, increase the danger of floods and loss of biodiversity, among others. As well the degradation of soil by erosion is of particular concern because soil reformation is extremely slow and difficult process and consider as non-renewable resource[42]. Accumulation of sediments in wetlands from upland erosion may decrease wetland volume, decrease the duration wetlands retain water, and change plant community structure. At a European scale, soil erosion was assessed as one of the major threats effecting natural ecosystems [43]. Named study, defines the Andalusia region as one of the hotspots where soil erosion rates are extremely high.

Fuente de Piedra wetland being a shallow lagoon with high temporal fluctuation in climatological and hydrological conditions might suffer from a potential pressure deriving from soil erosion, which might affect the natural functionality and disturb the life of her habitats and communities.

Annual monitoring of the evolution and impact of soil erosion in Andalusia provided from Junta de Andalucía and Ministry of Environment for the period between 1992 and 2011 were used to assess the evaluation of soil loss and its negative effects on biodiversity and natural resources conservation.

The Ministry of Environment within the framework of the Environmental Information Network of Andalusia, conducts annual monitoring of the evolution and impact of Soil Erosion phenomenon in the region in order to make territorial and multi-temporal comparisons on environmental risks.

As the most of the layers are in a free online access, soil erosion layers were downloaded in a raster format within a pixel resolution of 75m and re-projected in the same coordinate system (ETRS_1989_UTM_Zone_30N).

<u>Class 2- Ground Data:</u>

Analytical ground data, related to specific ground conditions of the area. Climatology data as temperature, precipitation, water level and water quality coming from different regional and national sources(Natural Reserve of Fuentye de Piedra, Junta de Andalucía and University of Malaga, Instituto Geologico y Minierio de España). These data are analyzed due to indication they give on the environmental condition in the study area. They include data and measurements on soil properties, land use -land cover variables; bio-physical conditions on the water parameters as well the bio-ecological ecosystem distribution.

- Precipitation and temperature data

These data were obtained from three different sources: The Andalusia Meteorological Organism- Red HidroSur, REDIAM and data-series from the Natural Park authorities of Fuente de Piedra. Monthly records of three different meteorological stations were collected:
1. Fuente de Piedra station I
2. Cerro del Palo station
3.Herriza station

Figure 11: Meteorological station positioning

The time series of precipitation and temperature data cover different time-series, as was not reliable to obtain the same time series. We used the temporal series of almost 40 years for the precipitation data covering the hydrological years between 1974 and 2015; from 1982 to 2015 for temperature data.

- **Water Level data**

The water level data were obtained from the Natural Park authorities, Fuente de Piedra, responsible for the monitoring and management of the lagoon.
The time series covered begin with the hydrological year of October 1983 and end with the hydrological year of October 2015. The information is obtained by a limnograph, located in an old well of the lagoon, which records the fluctuations of the water level, on the well depth. The data were provided in 32 excel tables (for the corresponded hydrological years) representing the daily water level measured in centimeters.

- **Water Quality**

The water quality data was obtained from the online portal of Junta de Andalusia and the Network of Surface Water Quality of Andalusia, 2013. The data mainly concentrated in two different data sources; surface water properties and underground water properties.
In a wild extend of elements we select main control points and physio-chemical water parameters in a dbf format including in 22 measured points from1997 to 2011. After 2009 the water quality parameters have been monitored just in three control points; in the centric zone of Fuente de Piedra lagoon, the second one in the Laguna Dulce and the third one in the Arroyo de Charcón. Moreover this data, related to the complexity to obtain them, presents some small gaps and missing values in different parameters on the time series. (More details are available in Annex I).

Class 3 -Satellite Image Data:

Multi-Temporal Image from the time series of Landsat data archive from 1985 to 2015 of the National Aeronautics and Space Administration (NASA/USGS Global Visualization Viewer) and European Space Agency (ESA) have been used as spatially explicit information to assess some of the remote sensing processes. A huge dataset table has been downloaded and prepared for all Landsat image respectively: Landsat5(TM), consist of seven spectral bands with a spatial resolution of 30 m, Landsat 7 (ETM+) consist of eight spectral bands with a spatial resolution of 30m and Landsat 8(OLI), consist of nine spectral bands with a spatial resolution of 30 m, in a Geotiff format.

Sentinel 1, 2 images, with a higher spatial resolution of 20m, have been provided from the ESA (European Space Agency), restricted in a short series of couple of months as Sentinel was launched lately. Considering them as the best imagery data available, have been sufficiently utilized in different steps of the analyses.

In the long time archive of 40 years of Landsat, satellite images were selected and downloaded for the considered period (Table1). The data selection was related to the year of interest, free of clouds and noise disturbance image for each of the target years, to cover various phonological and seasonal stage of the vegetation cycle. All selected Landsat image have been reprocessed in an atmospheric correction, calibration and ortho-rectification done by ENVI image processing. As well they had to be re-projected to the same projection as our thematic maps. (More details are available in Annex I)

Class 4- Ancillary Data:

To identify our study territory we used complementary data related to socio-economic components, demographic distribution and related economic activities extracted from Andalusia Institute of Statistics. The statistical data includes population assessment of Fuente de Piedra village and the nearest village Humilladero from 1990 to 2015. Statistical data related to the establishment of economic activities and agro-industrial activities (crop production per year, new agro-food industries) covering a short period are used as well. The source of ancillary data are previews official institutional reports and studies such as Plan de Ordenacion del Territorio, Plan Estratégico Español para la Conservación y el Uso Racional de los Humedales, PORN etc. This statistical data was used in order to check the relevance of the calculated data and to give some answers on the past change of the area.

4.2. DATA PREPRPCESSING

In order to harmonize the data which comes from different sources, a series of transformations are prepared and conducted in varied levels, with the aim of having a well-organized and complete dataset as the base source in the further spatial-temporal analytical analyses. In this section, the preprocessing part with short descriptions for the three main data classes is described.

4.2.1. Ground data preprocessing

Assessing the importance of climatic variables such as temperature, precipitation, evaporation, evapotranspiration and water parameters, allowed understanding better the past and present conditions of the study area. As the fundamental climatic factors precipitation, temperature, water level and water quality data were preprocessed as explained in the coming paragraphs.

- **Precipitation**

The long time-series of precipitation data are essential to understand the variation in precipitation and their possible effects on the biodiversity and natural resources in the study area. Daily and monthly precipitation data was collected from three meteorological stations. We decide to take into analyses a period of 32 years starting with the hydrological year 1983/84 and ending with hydrological year 2014/15. As well was important to have precipitation data temperature and water level data compatible and cover same time series, thus have been determine the climatic series taken into analyses.

A long data table including years 1983 to 2015 time series was build, showing the monthly average of the two main stations (Sero del Palo, Herriza); Precipitation data from Fuente de Piedra station I was not taken into account as they present a shorter time period between 1990-2015, but for more in a comparison with the Cerro del Palo data they present same monthly precipitation values. In order to have a better understanding on the weather conditions and precipitation values, a comparison was made conform the precipitation data from the nearest meteorological station of Bombadilla, showing not significant difference in the monthly precipitation values.

The monthly average from both stations between October 1983 and October 2015 has been calculated from the monthly precipitation data. For more over the monthly average has been calculated the total annual precipitation and annual average for the corresponded years.

➢ Temperature

Same procedure of the precipitation data has been followed for the temperature data, from same meteorological station (Cero del Palo, Hierrza) and for the same time-period. In order to have a valuation in the temperature variation over this period, monthly registered temperatures from 1983 have been used to calculate the annual average temperatures. Small data gaps in the dataset, like the year 1998, could not be completed.

➢ Water level

The water level data from Fuente de Piedra local Monitoring center which represents the daily water level registrations as continues measurements taken by the limnograph in the lagoon was used in this study. The daily water level data in centimeters was used to calculate the monthly mean water level per year. Negative values were replaced with a 0 value, as they represent the dry days where the lagoon is totally dry (no water present).

Data on water level in the region were not complete; they present gaps in two months (January –February 1998). In question months were completed as simulated values comparing the precipitation values for these two months, as well comparing trends in past years.

In addition to have an overall valuation of the climatic data and searching for the relation and trends between them (water quality are explain in the next paragraph), a summary table was build.

➢ Water Quality

More than 30 water parameters and water quality indicators were analyzed from samples extracted from 3 different points (in the big lagoon and in two others smaller lagoons located in the south part of study area (Figure 12) for the time period 1997-2011.

The sample points have the corresponded coordinates in a UTM projection:

Fuente de Piedra big lagoon
(X: 343387, 34; Y: 4109293, 97)
Laguna de Labon
(X: 337918,38; Y: 4103329,07)
Laguna Dulce
(X: 336782,99; Y: 4102176,23)

Figure 12: Water quality control points.

The availability of water parameters was not complete for all years (1997-2011), we have approximately 5-6 monthly measurements for the first two years, then they were reduce in two measurement per year, besides the data gaps in few indicators. So far a mean average for each year has been taken, and only indicators that have been considered important/relevant have been analyzed. For the selection of the relevant indicators, mostly it's been focused on the main water parameters that are more significant in detecting water quality contamination. The studied indicators which are related to the physicochemical and hydrological conditions of the lagoon are as the following: water temperature, conductivity, pH, sulfate, nitrate and phosphorus concentrations, chloride and salinity (More details are available in Annex I).

4.2.2. Vector Layer Preprocessing

➢ **LULC Layers**

Coming from different sources the thematic vector layers have been pre-processed, in different path. Land use-land cover layers in a vector form, soil erosion layers in a raster format, topographic layers in raster format have passed through a trimming process according to the defined limits and boundaries, extracting just the study area Same time they have been adjusted in same coordinate system, projection and same extend. (Transverse Mercator ETRS_1989_UTM_Zone_30N)

The land use land cover maps of SIOSE from the years 2005, 2009 and 2011 are the vector maps at 1: 10.000 scale, and include 70 different sub-classes in level 3 Similarly, the MUCVA land use-land cover layers from the years 1977, 1984, 1991, 1995 and 1999 have approximately 30-45 different sub-classes in level 3.Those classes have been aggregated into fewer classes on analytical process over the attribute tables. The re-classified LULC classes in mainly in 5 general classes: as:

- Urban
- Forest
- Wetlands
- Scrubs and Grassland
- Agriculture

As a last step of the analytical process, all layers were converted to raster format with 75 meters of pixel resolution, in order to incorporate them in further analyses which will be explain in the next steps.

➢ **Topographic thematic layers**

Digital Elevation Model (DEM) sheets (H1006, H1022 and H 1023) in 5m resolution were merged to cover all study area. The 5 m resolution DEM was used to generate altitude, slope, aspect and other hydro geological variables such as water flow and water accumulation, in order to have the relationship between the topographic variables and the land cover distribution.

4.2.3. Preprocessing of the satellite images

The Landsat satellite series from NASA- USGS are freely available to be download and used for scientific purposes. Seen 1972 when Landsat1 was lunched, a new age for the remote sensing imagery and an important change in the land observation from space was generated. Advancing with the Landsat 5(TM) Thematic Mapper in 1984 and Landsat 7 (ETM+) Enhanced Thematic Mapper in 1999, the capacity perform in a high spatial resolution of 30m and a temporal resolution with a 16- day frequency[44] (2). Landsat 8 become available from May 2013, in a 30m spatial resolution and 195 km of swath caring out two improved instruments, the "Observational Land Image (OLI)" and the "Thermal Infrared Sensor (TIRS)", covering a wild range of electromagnetic spectrum in 11 Bands; band8 has improves panchromatic resolution in 15 m and the thermal bands 10 and 11 are now useful in providing more accurate surface temperatures data (Table 2).

Landsat7 Enhanced Thematic Mapper Plus (ETM+)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.77-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	60 * (30)
	Band 7	2.09-2.35	30
	Band 8	0.52-.90	15

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Launched February 11, 2013	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Coastal aerosol	0.43 - 0.45	30
	Band 2 - Blue	0.45 - 0.51	30
	Band 3 - Green	0.53 - 0.59	30
	Band 4 - Red	0.64 - 0.67	30
	Band 5 - NearInfrared (NIR)	0.85 - 0.88	30
	Band 6 - SWIR 1	1.57 - 1.65	30
	Band 7 - SWIR 2	2.11 - 2.29	30
	Band 8 - Panchromatic	0.50 - 0.68	15
	Band 9 - Cirrus	1.36 - 1.38	30
	Band 10 - ThermalInfrared (TIRS) 1	10.60 - 11.19	100 * (30)
	Band 11 - ThermalInfrared (TIRS) 2	11.50 - 12.51	100 * (30)

Table 4: Band designations Landsat 7and Landsat 8 (USGS source).

The combination of different bands using ratios and RGB compositions (Red, Green, Blue) can highlight and detect elements of the surface, distinguish water surface from vegetation and urban areas, but also small and linear features can be better recognized with the high resolution of Sentinel image in 20m spatial resolution.

From the large series of 40 years of Landsat archive, 8 different years starting from 1985 till 2015 have been selected. Several criteria was taken into account in the selection of the corresponded years; the availability of the images, the quality of the images (as some of the ETM+ have errors, data gaps), but also to have an equal distribution of the years taken into analyses over 30 years (More details are available in Annex I).
The satellite image pre-processing part includes mainly three steps:
1. Downloading,
2. Change projection to UTM,
3. Atmospheric correction.

Over the selected years, all images (in total 45 images) starting from March to September have been trimmed over the study area as the image extension covers almost all Andalusia. The atmospheric correction is processed using ENVI Radiometric correction tools.

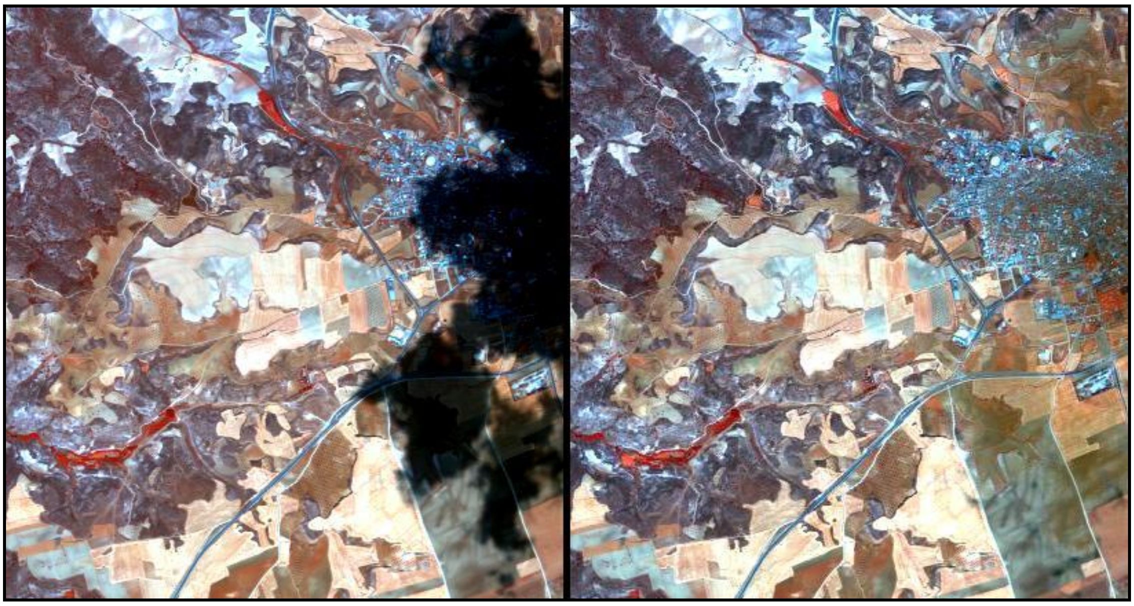


Figure 13: Landsat 5 TM April 1992, (left) before atmospheric correction (right) after atmospheric correction.

Atmospheric correction procedure is important due to the effects and the accuracy of the results obtains from the image. In the calculation of different indicators, differences in the illumination conditions are directly affecting the results, as we discern in the NDVI values.

4.3. DATA ANALYSES

4.3.1. Calculation of LULC and LULC change

LULC are the main driver of change in the study area from 1977 to 2015. We identify and assess LULC changes over last 50 years. The total areas of each 5 main classes were calculated starting with LULC from 1977, 1984, 1991, 1994, 1999, 2005, 2009 and 2011:

- Urban,
- Forest,
- Wetlands,
- Scrubs and grassland
- Agriculture.

The reclassification results represent the occupation of each class in the study total area. The values are calculated in hectares and percentage to assess the changes. In order to reduce possible errors of reclassification process, a special attention was dedicated to the total surface of the LULC coming from each. Figure 13 presents the steps that have been followed in the LULC cover change detection process.

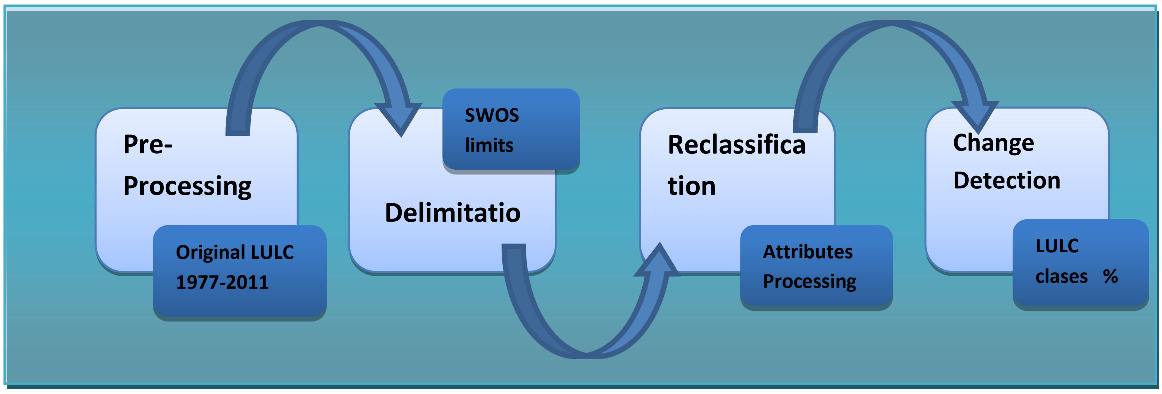


Figure 14: LULC analytical process.

After the preprocessing part (explained in 5.2.2) and the delimitation part (define by the SWOS project), the work on reclassification and calculation for different LULC classes for the studied years was based on using ArcGIS processing tools. Through processing the attribute information, statistical data for each layer have been extracted to calculate the general surface of dissolves shape-classes in square meters and after convert in percentage for each LULC class (Figure 14).

The study area is dominated by agriculture land use that has been experienced changes in crop cultivations and different management practices used by farmers over the time. Looking on the importance and the robust changes over this time period we decide to focus more in the agriculture changes. We used the same reclassification procedure for the calculation of different LULC classes and for the same time series using ArcGIS tools.

We took the third level or semi-detail SIOSE LULC layers for the years 1956, 1977, 1984, 1991, 1995, and 1999 and third detail level for the years 2005, 2009, and 2001 as base layers. The agricultural classes in level 3 for the different LULC layers do not specify the same classes in the same way. For example, LULC layers from 1956 to 1999 classified in agricultural third level much more agricultural classes than SIOSE 2005-2011 as shown in Table 5.

Level 3_LULC classes 1977-1999	Level 3 SIOSE classes 2005-2011
Arable crops in dry land	Herbaceous crops different to rice
Herbaceous and wood trees in dry lands	Olives
Woody crops in dry lands: Olives	Other wood trees
Woody crops in dry lands: vineyards	Fruit trees - Nuts
Mosaic with dry and irrigated arable crops	Vineyard
Mosaic non irrigated herbaceous and woody crops	
Other irrigated arable croplands	
Other woody tress in dry lands	
Other irrigated woody tress	

Table 5: Agricultural classes included in third level in LULC 1977 to 1999 and third level LULC 2005 to 2011.

Olive groves, vineyards and other fruit trees are distinguished to identify within the wood trees croplands, instead in the herbaceous croplands we classify in dominant categories of irrigates cereal croplands and nor irrigated cereal croplands. In the SIOSE LULC layers from 2005, 2009, and 2011 non-irrigated crops classes does not appear, as after 2005 regarded to specific conditions the croplands (both herbaceous and wood trees) have been converted in irrigated fields, reasoning we assume and consider them as irrigated croplands.

We extract only the total agricultural areas from where we calculated the total areas occupied from each of sub classes in this reclassified classes:

- Arable crops in dry land (mainly cereals)
- Irrigated arable crop-land (mainly cereals)
- Vineyards
- Olive groves
- Dry wood crops(fruit trees)

We calculate the total occupation area for each sub-classes in hectares and percentage in order to have the annual occupation for each class, therefore we build a temporal comparative analyses to identify and quantify change over this time period.

4.3.2. Detection of LULC changes using NDVI

A big number of vegetation indices have been developed over the last years in order to quantify and qualify the vegetation cover using satellite image. There are different vegetation indexes that have been developed such as NDVI, EVI, SAVI, LAI, etc. NDVI (Normalized Difference Vegetation Index) is one of the most popular vegetation indicator used in the discrimination of different types of land use land cover at global and local scales[45]. At regional scale, the ecosystem functioning can be characterized by a difference state of the vegetation structure, important in to assess ecological responses and environmental changes [46]. Different studies have proved that NDVI indicator is one of the best indicators in vegetation discrimination especially in the Mediterranean region due to the climatic and vegetation conditions that this region present [45][47].
Vegetation indices are mainly derived from the plant phenology information and the reflectance data in the red and near-infrared part of the spectrum. They operate by contrasting intense chlorophyll pigment absorption in the red against the high reflectance of plant materials in the NIR.

NDVI formula is expressed:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \qquad (1)$$

Where “NIR” is Near Infrared spectral band and “RED” is Red spectral band.

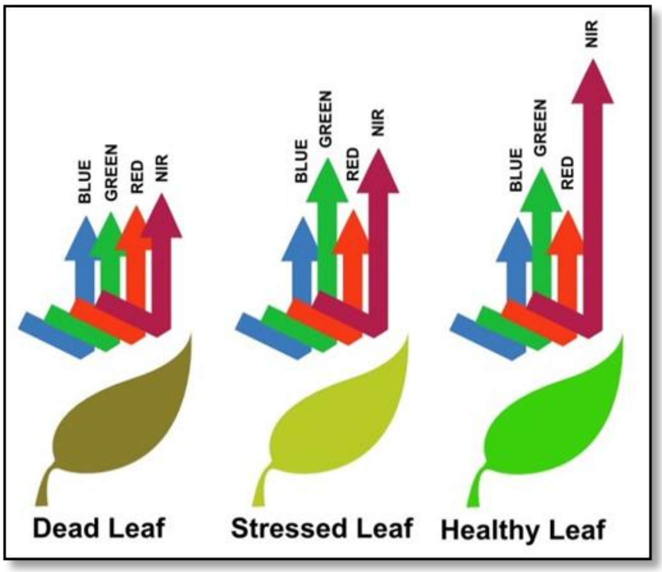


Figure 15: NDVI reflectance in different leaf greenness**.**

The calculation of NDVI derived from remote sensing technics is a very good tool for monitoring vegetation status and their temporally dynamics. Despite the high ability that NDVI indicator gives in discrimination vegetation attributes, can serve and provide accurate information to distinguish within LULC classes, as water surfaces, grassland, natural vegetation areas, urban and infrastructures features, and in particularity agricultural crop lands. Seasonal and yearly NDVI changes can be calculated by showing the annual maximum NDVI, and annual ranges of NDVI; but also the dates of the beginning or end of the growing season, length of the green season and timing of the annual maximum NDVI[48].

The principal objective was to distinguish into the agricultural class, main croplands as herbaceous and olive groves fields, as they cover the mayor part of our study area. In the time series of the Landsat Image (1985, 1989, 1994, 2000, 2007and 2015) we selected 5-6 image per year (depending on the availability of the cloud-free images); starting from March, as the cereal peak of greenness is in spring, and ending with September, as the harvest month of the herbaceous and cereal crops. In a total of 35 Landsat images, we calculated the NDVI values in each 30x30m pixel size, extracting for each image the mean, maximum and minimum NDVI value and the corresponds standard deviation. The NDVI values show significant and robust results differentiate LULC classes, but especially high magnitude into agricultural class in order to detect change between herbaceous and olive groves crops.

4.3.3. Surface Water Dynamic Mapping

Indicators derived from satellite images can be calculated to map and monitor surface water dynamics. In Fuente de Piedra wetland flooded area can also be discriminated to support the delimitation of surface water temporality. Normalizes Difference Water Index is a widely used indicator to enhance and extract water surface information [49][50].

NDWI formula is expressed:

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}} \qquad (2)$$

Where “Green” is the green spectral band and “NIR” is the Near Infrared spectral band.

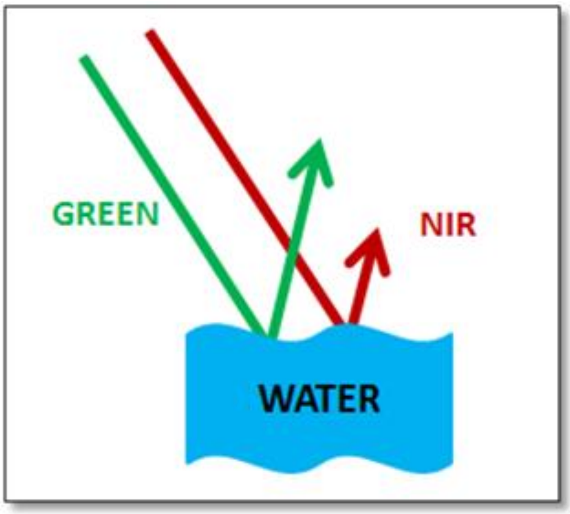


Figure 16: NDWI reflectance in different leaf greenness.

We use two different water indicators as TWI (Topographic Wetness Index) combined with NDWI (Normalized Difference Water Index) in order to define the potential water areas.

The TWI is a climate-topographic index that is able to predict the structure and general extent area of wetlands[51]. Based on the DTM we create the slope layer in a raster size of 30x30m. From slope layer using spatial hydrological toolbox we calculate the drainage network, flow accumulation, flow direction and the compound topographic index layers. Formulas used are:

- Fd = flow direction (DEM 30)
- Sac = flow accumulation (Fd)
- Slope = (slope (DEM) * 1.570769) / 90
- Tan_slope = con (slope>0, tan(slope), 0.001
- Sac_scaled = (sca + 1) *30
- CTI = ln (sca_scaled / tan_slp)

These elements are important topographic features that show the small streams and river cumulative account in a pixel parch. As the values for the TWI are not normalizes a threshold with the minimum elevation model value (420m) was created in order to define areas with the highest water potential accumulation.

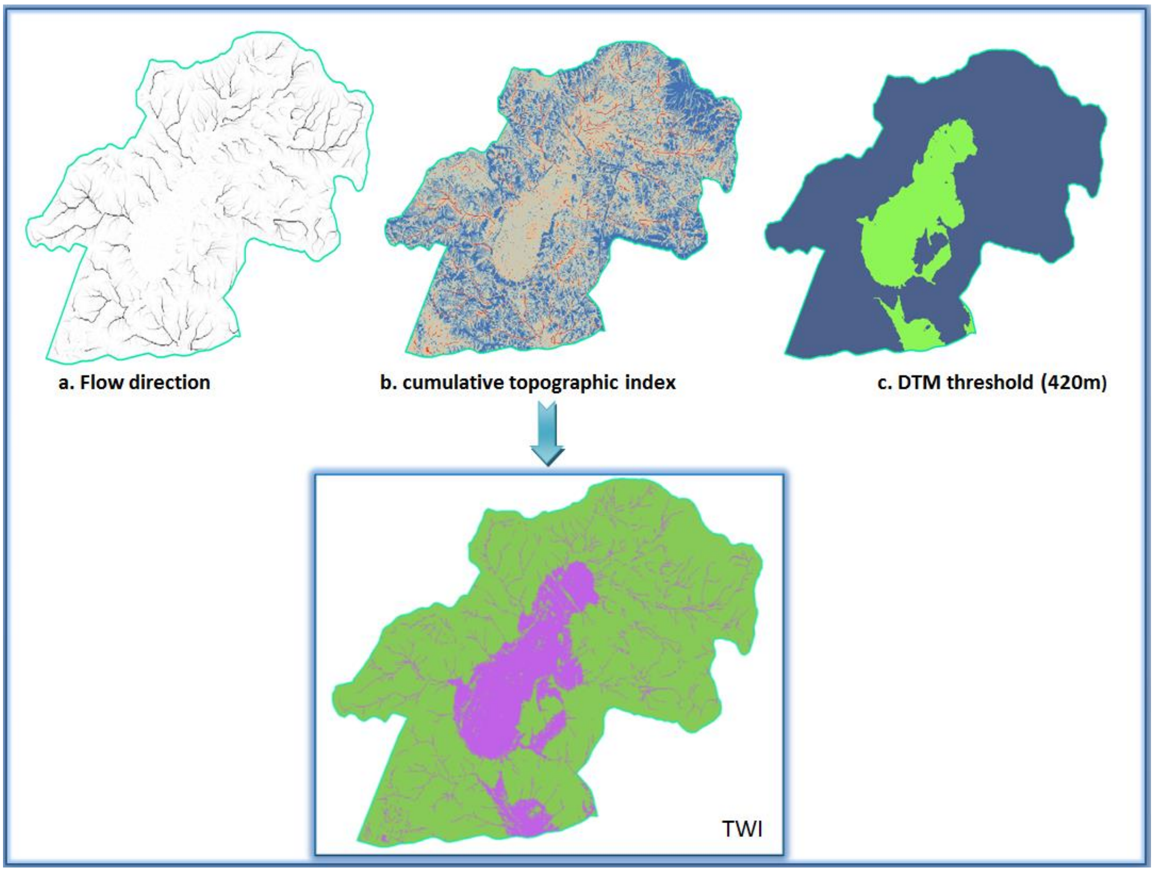


Figure 17: TWI creation as a sum of (a) Flow direction, (b) Cumulative topographic index, (c) DTM threshold layer.

As a second step, NDWI Indicator was created from Landsat time series for 2015 where 9 images between January and September were selected for 2015 (depending on the image that were free of clouds and noise disturbances); Having more than one image per month could be better for identifying and checking water dynamics and flooding processes in a shorter time period (within a month).

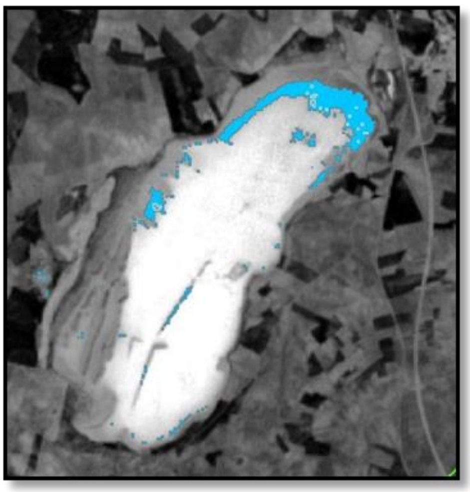


Figure 18: Water extends change February –March 2015

NDWI indicators were calculated by using Band 3 (green) and Band 5(NIR) for Landsat8; and Band 2 (green) and Band 5(NIR) for Landsat 7 to extract the information on inundated areas. Values range from were -1 to 1, where positive values 0 to 1 represent inundate pixels and 0 to -1 others. All NDWI images have been harmonized in raster with two values:

- 1 for inundated pixels
- 0 for non-inundated pixels.

In order to account for the temporal or seasonality of water dynamics the raster calculator was used to sum the NDWI binary layers (0-1) into one single raster layer. The sum of the values coming from the 9 images for 2015 is added to get a final layer accounting (Figure 19).

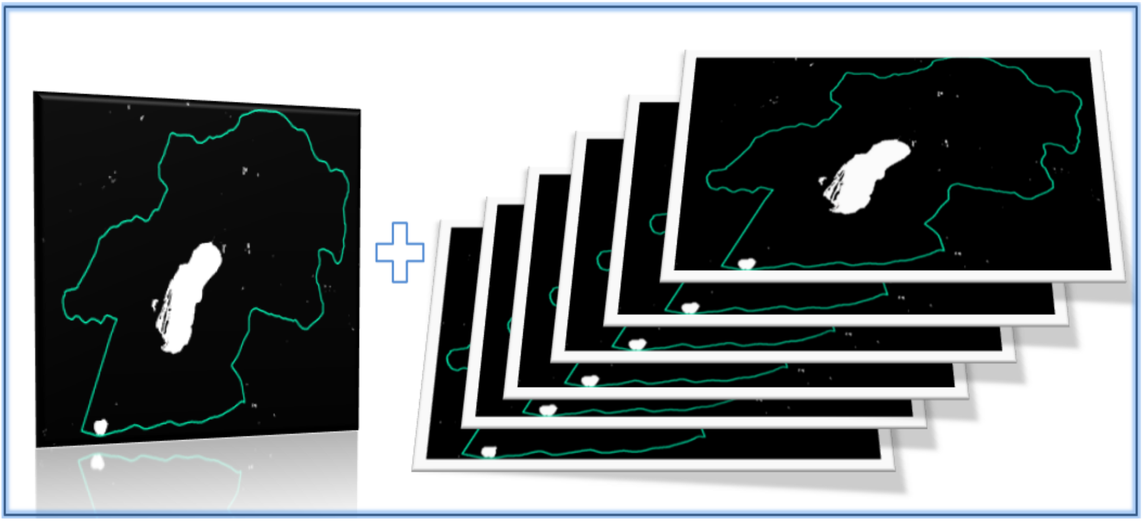


Figure 19: Extraction of inundated area by NDWI binary layers; sum of layer union process to obtain surface water dynamic map for 2015

The final NDWI layer has accumulative value 9 as maximum (depends on the number of months analyzed. Maximum number obtain was 6, which corresponds to (pixels) those areas that are inundated six times in the year2015.

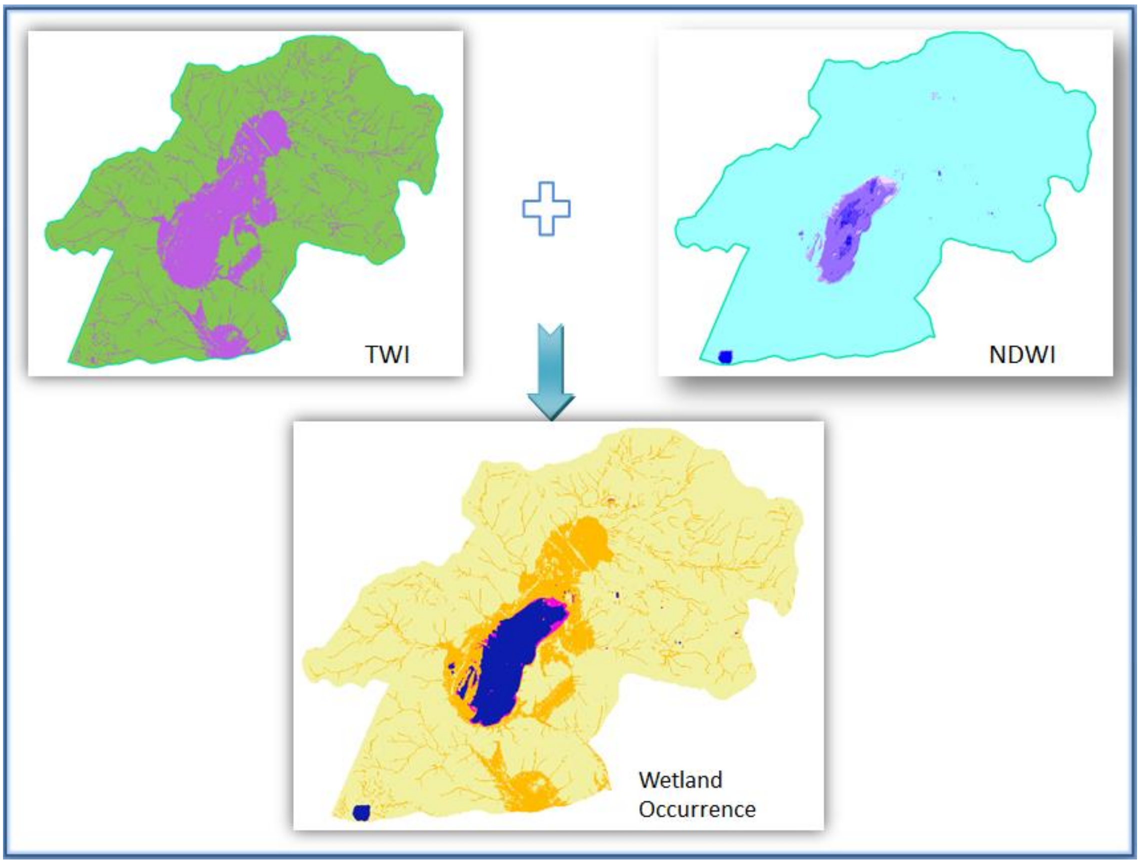


Figure 20: Wetland occurrence map in percentage, expressing low and high occurrence probability

In continuation, topographic water index map (TWI) has been overlapped with the water dynamic map. The result map represents the probability of the wetland occurance depending on the water holding potentiality and inundated variation, as areas temporaly or permanently inundated.

4.3.4. Detection of LULC through SRS (segmentation)

Monitoring spatial-temporal changes in LULC by remote sensing (RS) tools has been more precise and reliable. The availability of open Earth Observation source data, are an effective approach to support land surface change detection, and help to solve unexpected present and future threats and disasters. In the context of SWOS objectives to provide support tools on valuating ecosystem services capacities on specific wetland sites, challenging future concerns for a better sustainable monitoring on wetland catchment, a number of specific reliable methods have been tested.

Geo-classifier toolbox provides accurate results on land use classifications and LULC mapping, through satellite image. It's an accurate technique that can provide successful results especially in cases where wetland and LULC inventories area a big gap. One of our main objectives is to check how new data coming from Sentinel improve the classification accuracy.

Segmentation and supervised classification techniques were applied on the Landsat 8 images and Sentinel 2 new series (Table 6) in order to classify and distinguish vegetation cover classes within agriculture crops lands and natural vegetation areas. The resulting map is a rough habitat and/or LULC classification which allows the identification of the main wetland ecosystems founded in the studied area.

	Sentinel_2	Landsat_8
Swath	290 km	195 km
Bands Number	13	11
Spatial Resolution	20m	30m
Temporal Resolution	5days	15 days
Launched	June_2015	May_2013

Table 6: Landsat 8 and Sentinel 2 resolution details.

Processing methodology for the classification is based on features definition, so called segmentation. For Landsat-8 and Sentinel-2 for the year 2015 annual series have been processed by using following steps:

Segmentation: This process creates a segmentation of the satellite image depending on the pixel similarities and aggregates close pixel in same spectral characteristics in same segmentation group. We define the tolerance and minimum mapping unit that we give to the segmentation process as it defines the segment size. The study area limits have been used as a mask layer to concentrate the procedure just in the study.

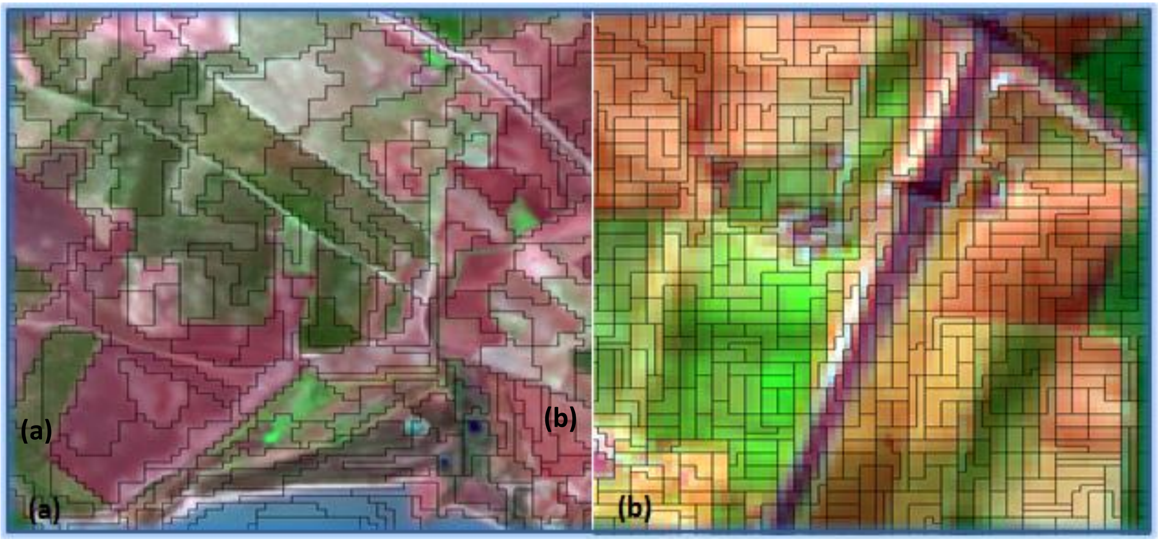


Figure 21: Segmentation tolerance.

(a) High segmentation tolerance; (b) low segmentation tolerance; (c) total segmentation in tolerance, with minimum mapping units of 4pixel (400m^2) for Sentinel 2 and 4pixel (3600m2) Landsat8).

Training Areas: In the training process, we give to the segments allocation to indicate corresponding classes. We create the training areas regarding the spectral and visual perception that we take from the image, as well from ground information that we have from the study area. We define main training areas based on specific nomenclature as the CLC classes incorporating Ramsar wetland classification nomenclature. Training classes are defined as:

- Urban
- Sclerophyllous Vegetation
- Wetlands and Water courses
- Non-irrigated arable lands
- Vineyards
- Fruit trees
- Olive groves
- Coniferous forest (T.C.D. > 80%)
- Coniferous forest (T.C.D. 30 –
- Pastures and bare lands

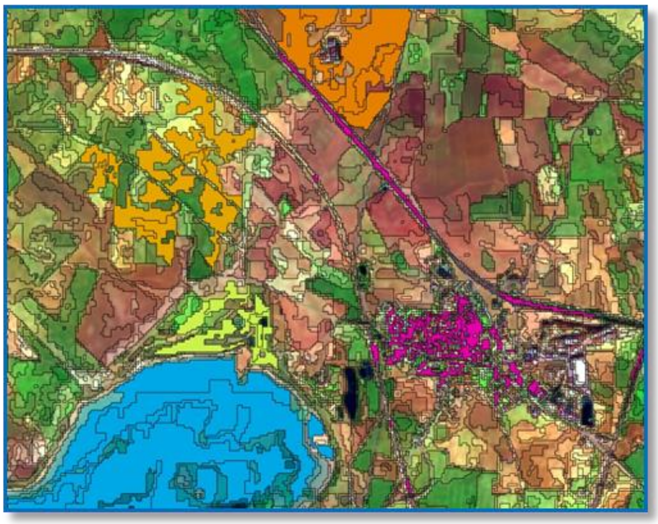


Figure 22: Training classes assignation.

Depending on the resolution limitations and pure knowledge over the study area, it was better to take certain uses and support data as local / regional land use maps. There are classes that can be defined in a simply view of the image and other classes that needs support data

Classification: This is the third step of the classification procedure. The tools classify all pixels of the images in the corresponded training classes depending in each pixel spectral value. In order to increase the accuracy on the obtain results, we proceed a final cleaning process were small error classification was corrected, by defying manually in corresponded classes.

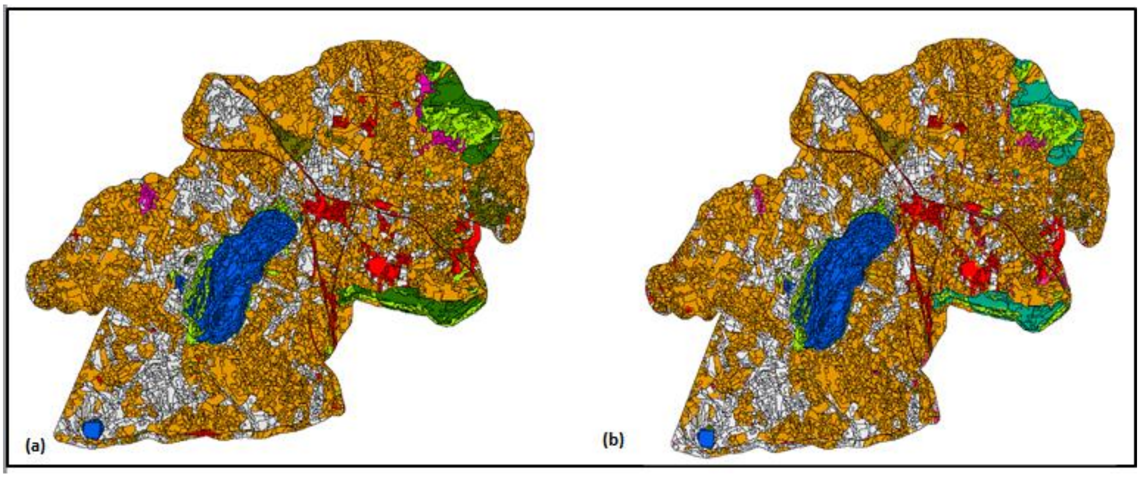


Figure 23: (a) Landsat 8 classified image; (b) Sentinel 2 classified image.

Over the classified images, we extract the identification number of classes in order to continue with the calculation and validation procedure and extract classification results.

We calculated the accuracy or precision of the classification, which shows the part of the image that we classified correctly and part that we classified wrongly. We used SIOSE LULC layer for the year 2011 as reference since there is no recent update layer for 2015.

It was necessary to adjust the CLC-Ramsar nomenclature with the SIOSE nomenclature which is more simplified and detailed for wetland habitats. The “tabulate area geo-classifier tool” creates a matrix by comparing surfaces of the different type of land uses which overlap in inventory and the classified images. The result is a tabular data with the calculated number of pixel that corresponds to each class and identification number, which in the next step we convert them in total surface in Km^2 or percentage in such way to be comparable and measured.

In the validation process we calculated two possible types of errors:

1. **Error A (commission error):** is the percentage of land that is wrongly classify in another class (area that is wrongly classified as wetlands, or urban)
2. **Error B (omission error):** is the percentage of real land that is not detected by our classification (the area of wetland that is not classified as such).

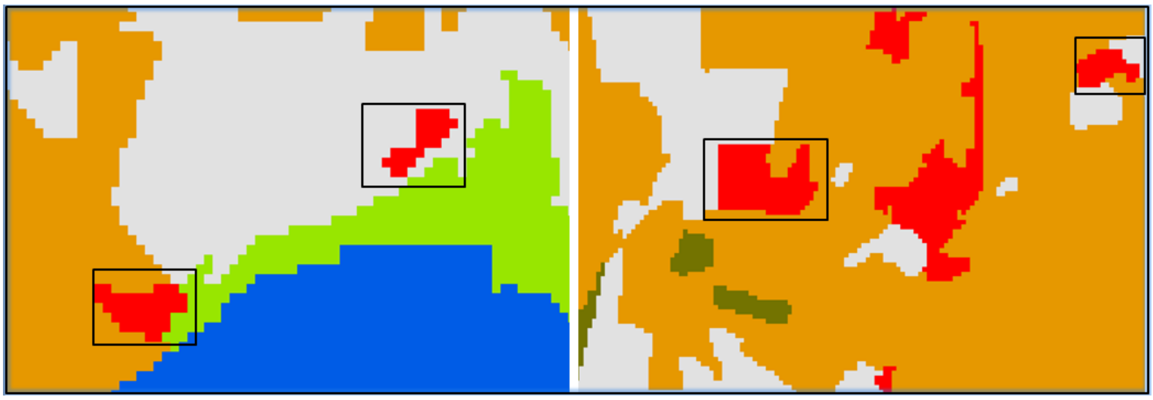


Figure 24: Commission error, bare land and olive groves wrongly classified as urban.

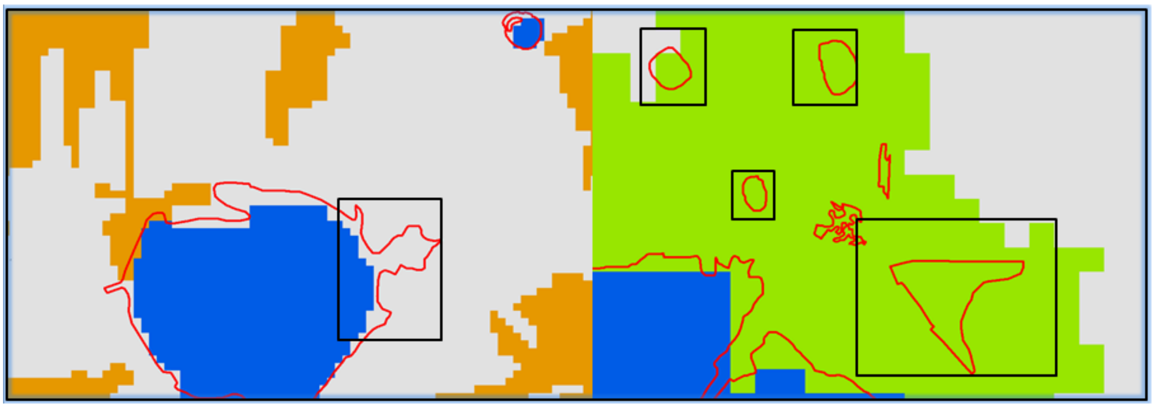


Figure 25: Omission error, Wetland areas that have not been detected.

Examining the error matrix derived from both images classified (Landsat8 and Sentinel2) we calculated the total commission and omission error, and the total correctness of our classification.

4.3.5. Finding Environmental Drivers on Soil Erosion by Statistical Analyses

Based on the literature survey on erosion models the one of the most used parametric model for evaluation of erosion is known as the Universal Soil Loss Equation (USLE), related to six variables; soil loss(K), slope length (L), the slope (S), rain power (R), soil protection that provides land use cover –vegetation (C) and different conservation soils practices (P) estimates the value in tons per hectare per year and the amount of soil removed by water erosion sheet. This quantitative value is an environmental indicator without full quantitative expression, while for a full absolute valuation an experimental calibration would be necessary to adapt field local conditions[52].

The soil erosion data has some limitation as expressed below:

1. Results were the application of an empirical model in an area which has not been calibrated or tested.

2. The model was designed to predict average losses in long series of data so the annual quantitative analysis may be not full representative.

3. Being a regional analysis using LULC layer which are generated every 4 years and always refers to average factor C and therefore does not reflect the exact annual evolution of vegetation.

However it can be still used as an effective tool for spatial comparisons and to follow the temporal evolution of these processes.

We performed Regression statistical analysis to assess the relationship between the potential soil loss by potential erosion and spatial-temporal variables that might affect soil loss.

Regression, correlation and ANCOVA analyses were performed taking as dependent variable soil erosion evaluation rates, from soil erosion layers (1992-2012) selected spatial-temporal data were:

- Physical characteristic: Lithology
- Topographic components: Elevation model, slope , aspect
- Climatic Components: Precipitation, temperature
- Vegetation Components: Land use land cover classes, vegetation indicators (NDVI)

The study years were selected based on data availability; erosion layers start from 1992 to 2012 but the LULC layers are not annually (we used same LULC layers available MUCVA 1991-SIOSE 2011). Rest of the layers as lithology and topographic variables are constant variable as they don't change temporally. Selected years were: 1992, 1995, 2000, 2007 and 2011, also including erosion layers for one year before and after.

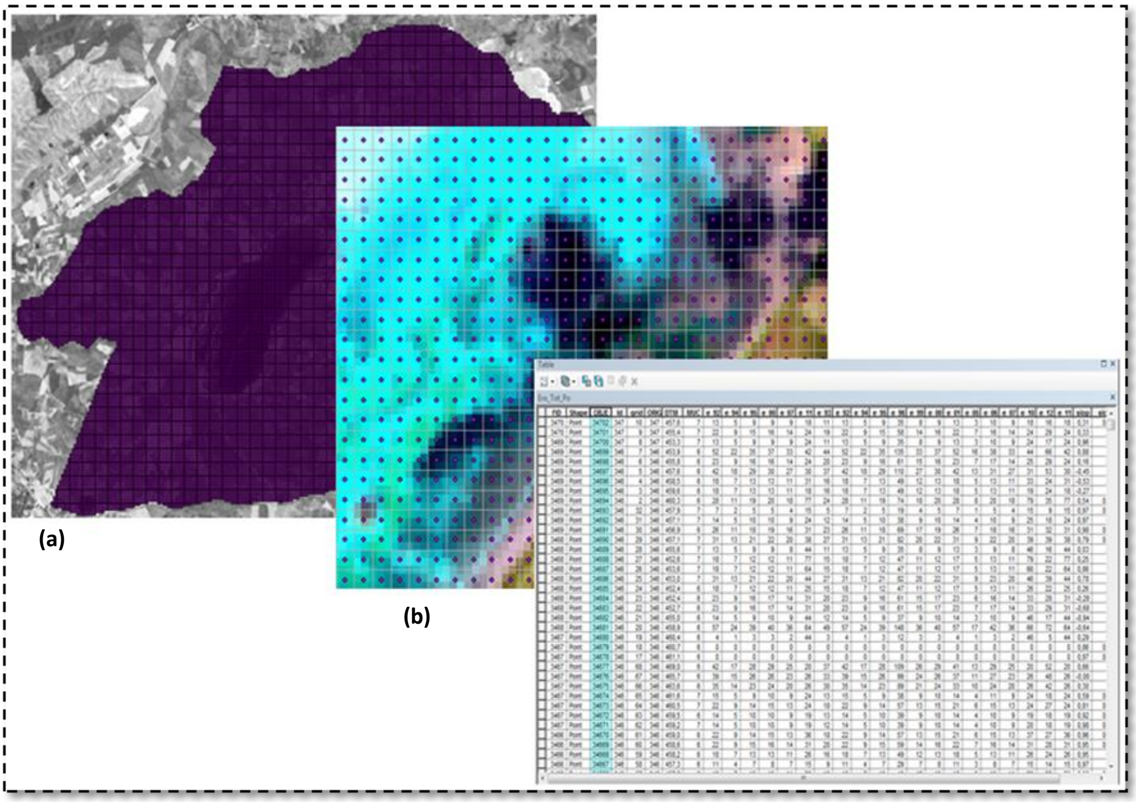
Mention variables were transformed in raster format, in pixel units 75x75m taking as base soil erosion pixel size. Moreover, it was necessary to convert them into the same projection and same extension in order to extract all information. Also, the normalization of the dataset is needed to make all the data comparable in regression analysis. Therefore, all layer values were normalized by either reclassifying into the binary layers (0-1) for categorical classes (LULC classes and Lithology classes) or calculating sinuses of the values for aspect and slope(-1 to 1).

Layer	Name	Binary layer values
LULC_1	Urban/Infra	0-1
LULC_2	Forest	0-1
LULC_3	Wetland	0-1
LULC_4	Scrub/grassland	0-1
LULC_5	Cereal	0-1
LULC_6	Olive	0-1
Lithology_1	Water	0-1
Lithology_2	Alluvial	0-1
Lithology_3	Calcarenitic	0-1
Lithology_4	Limestones dolomites	0-1
Lithology_5	Colluvial glacis	0-1
Lithology_6	Subbetic dolomite	0-1
Lithology_7	Subbetic marl	0-1
Lithology_8	Subbetic limestones	0-1
Lithology_9	Tr¡as	0-1
Erosion	-	0-922 tm/hm3/year
Aspect	-	(-1/1) grade
Slope	-	(-1/1) grade
DEM	-	401-795 m
NDVI	-	(-1/1)

Table 7: Binary and standardized variable values.

The final number of binary layers that represents all variables was 63. Over these layers was performed a fishnet and central point conversion, creating 34702 points for all study area in pixel value 75x75m. We performed multiple values extraction to overlap all raster layers and extract the information for each point.

The result procedure gives cell values at specified central point for all raster, and records the values to the attribute table. This final attribute table is used as a base for the regression analysis.



(c)

Figure 26: (Fishnet); (b) central point values (c) table attributes.

The next step was to check and harmonize extracted tabular data and make them ready to include in the statistical SPSS toolbox.

4.4. RESULTS

4.4.1. Quantitative description of the study area

Based on the used delimitation of the wetland ecosystem of Fuente de Piedra, it´s area covering a total area of 19,518.5 ha The analyses of DEM shows a complex topography with low elevation gradients ranging between 400 and 796m where the permanent and temporary wet areas are located, increasing to the highest point of Mollina mountain in the north part of the study area.

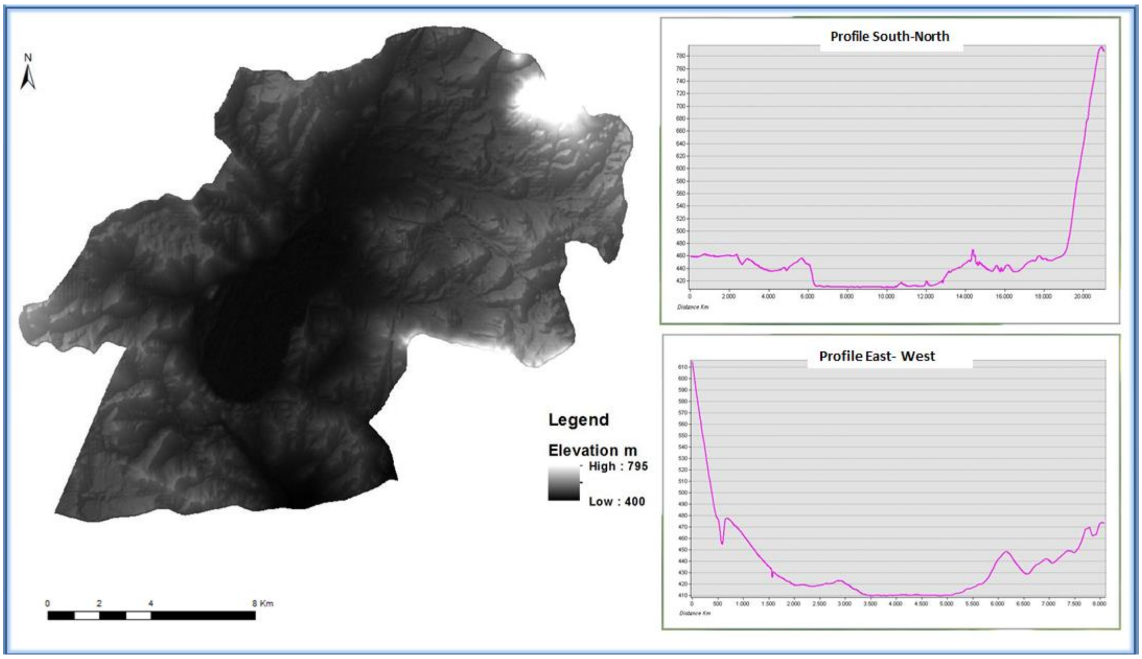


Figure 27: (a) Elevation range between 400-795m, elevation profile south-north/ east-west; (b) land surface orientation (aspect).

Almost 90% of the total area is considered as shallow with slope values less than 0-5 degree of inclination and being dominated by agriculture production, as they present smooth and low slopes for the herbaceous and cereal crops. Higher inclinations 5-10 and 10-15 degree cover 7.7% were mostly olives are cultivated. Just a 2.2 % of the total surface presents inclination value between 15 and 30 degree, located in maximum altitudes (up to 800m) where forest and grassland areas are the dominant land cover type.

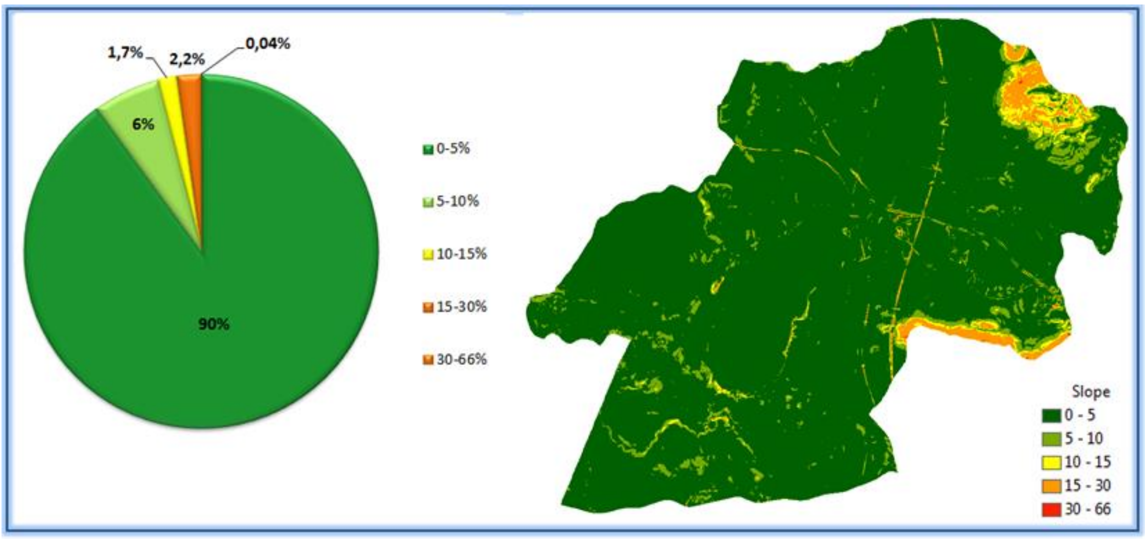


Figure 28: Inclination (slope) percentage distribution in Fuente de Piedra, values in degree.

The study area is mainly dominated by 3 main formations: calcareous (28%), alluvial (15%) and colluvial (31%) (Figure29). The rest of the area is cover by marl, limestones and trias formations. The main soil types are Cambisol and Fluvisol, the detailed information were given in Section 4.1. However, there is no local scale detailed soil map for the study area. The only maps were found are coming from the broader scale which doesn't reflect the different soil types of the area.

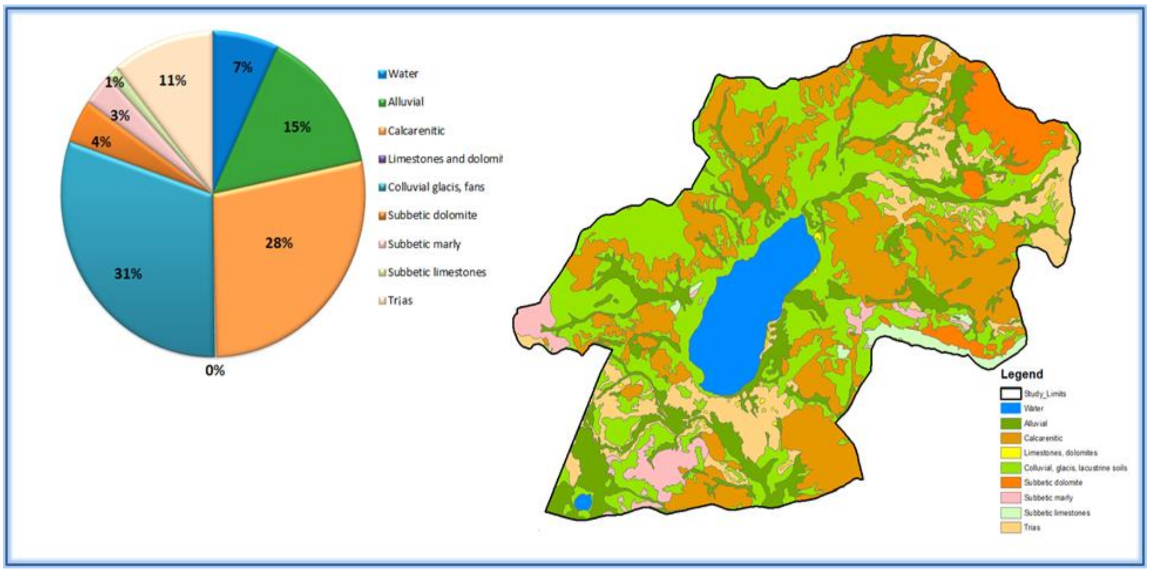
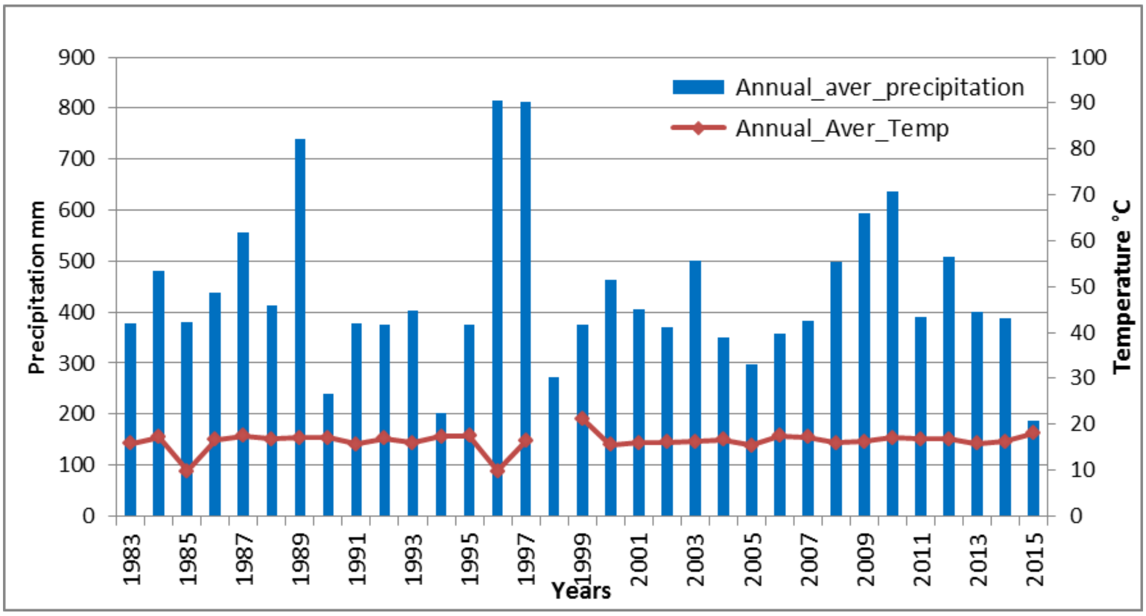


Figure 29: Geological units in Fuente de Piedra (source IGM).

The annual average precipitation calculated between 1983 and 2015 is around 450mm per year with variation between very dry years (200mm, year 1994) and very wet years (820mm, year 1996) (Graph 1).

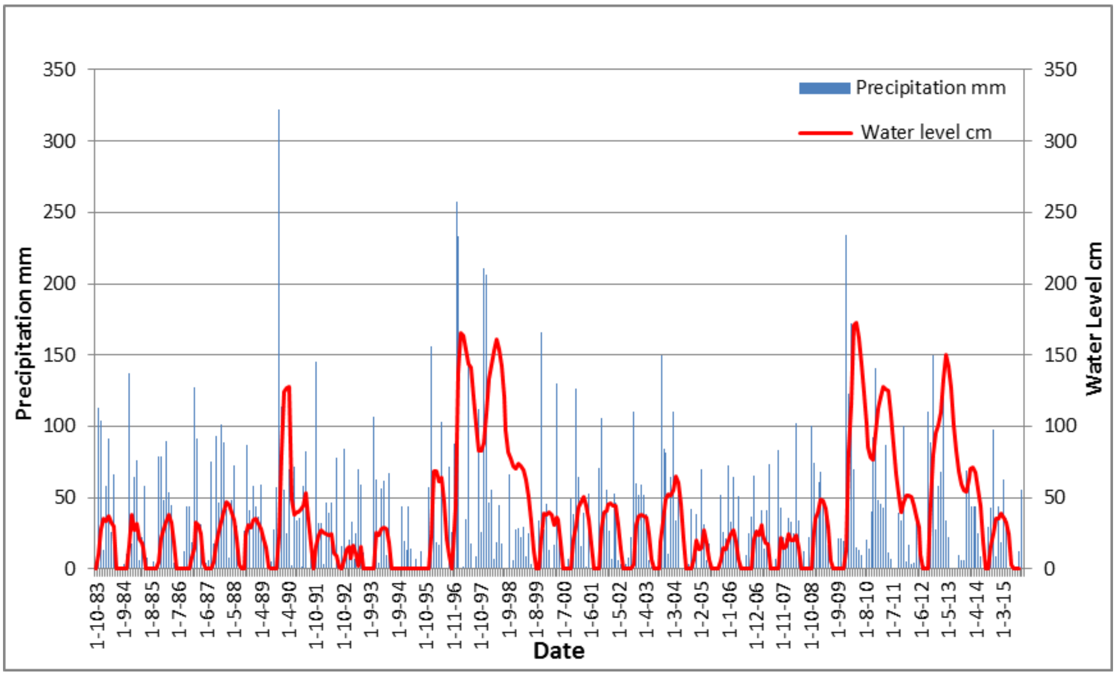


Graph 1: Annual mean precipitation (blue bars) and mean temperature (red line) calculated from two climatic stations for the time-period between 1983-2015; data absent in temperature for the year 1998.

During this period, wet years namely the years 1989, 1996, and 1997 show levels above 700 mm/ year, overpassing significantly the annual average (Graph 1). On the other hands we have the extremely dry years where precipitation values are around, 200mm/year namely the years 1990, 1994 and 2015.

The mean temperature based on the 2 stations registers of the study area is around 16.3^{o} C. The lowest mean annual temperature registered in the years 1985 and 1996 being around 10 ^{o} C and the highest average temperatures reached during the study period registered in1999 being around 21^{o} C (Graph 1). Looking on the monthly and annual temperature variability, trend line over the time series shows and increase in the temperature values within 1O^{o} C.

As an endorheic basin, rainfall and precipitation are the source of recharging for the wetland aquifer, which is directly reflected in the water level and watershed of the lagoon. The highest level reached presents the months with the highest precipitation values, being the winter and spring period as the wetness and water surface expansion draw near to the lagoons borders. These high amounts in precipitations are directly reflected in the water level, reaching the highest values in the lagoon, around 1.5-1.8 cm (January-February 2010, Graph2). While in dry summer period where the precipitations are scare, the water level reaches 0, due to the high temperatures and high evaporation.



Graph 2: Monthly precipitation (blue line) and water level (red line) between 1983-2015.

The wetland highest water level was reaches in the years 1996, 1997, 2009 and 2013, while the low precipitation in the year 1994 and 1955 implicate a total dryness with water levels into 0.

Figure 30: Fuente de Piedra water table.

4.4.2. LULC changes

The analysis of the land use land cover (LULC) map of the year 2011 shows that the dominant land use in Fuente de Piedra is agriculture, which covers an overall area of 15,600ha, or around 80% of the overall study area. Wetlands and grasslands cover a much lesser extent of the total area being 6.63 % and 6.36 % respectively; followed by urban coverage of around 5% and forest less than 2 %(LULC 2011) (Table 8).

From the analyses of the LULC change for the last 34 years (1977 - 2011) the results show some changes in the LULC of the study area, where the most important changes are related to agriculture and urban uses. A decrease of around 6% of the overall agricultural area was detected whereas urban cover shows a significant increase of more than 4 % (from 0.37% coverage to 4.71%) with the major increase detected between 1999(1.78%) and 2005(4.11%) for urban and for the agriculture 1999 (85.2%) to 2005(81.8%).

The changing areal distribution of the land use classes over the study period are represented in Table 8.

LULC Classes in %		1977	1984	1991	1995	1999	2005	2009	2011
1	Urban	0.76	1.12	0.81	0.84	1.78	4.11	4.67	4.71
2	Forest	0.50	0.52	0.55	0.55	1.38	1.60	1.56	1.56
3	Wetland	6.47	6.55	7.53	6.75	6.6	6.49	6.45	6.63
4	Scrub/Grassland	6.15	5.92	4.91	5.46	4.55	5.90	6.14	6.36
5	Agriculture	86.10	86.78	86.18	86.40	85.20	81.80	81.16	80.70

Table 8: Results of LULC occupation in percentage for corresponded years; (source, REDIAM).

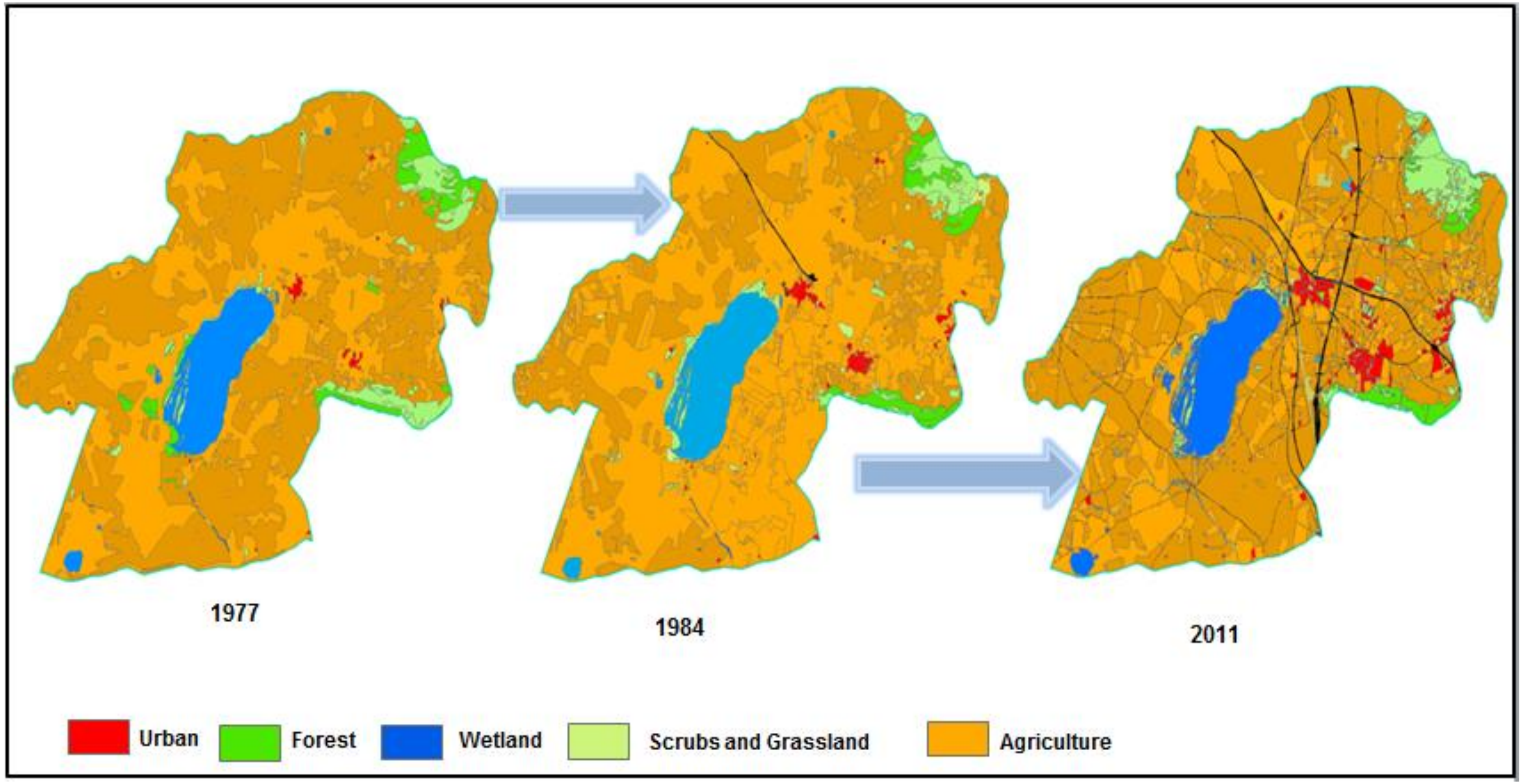


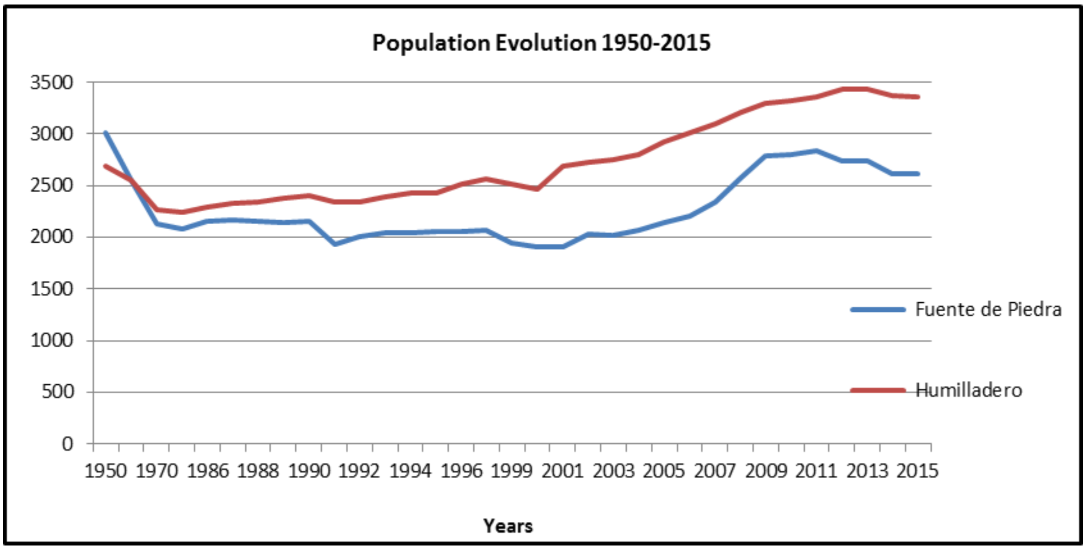
Figure 31: **La**nd Use –Land Cover change between 1977-1984-2011.

Figure 31 shows the spatial changes in the LULC during the study period, where urban extension is clearly shown as an increase in the transport network in the region including the high speed railway train that crosses the North Eastern side of the study area, in addition to the increase in the rural settlements during this period (the red polygons in Figure 31).

The most important changes take place between the years 1999 and 2005 as result of new industries, factories and construction sectors, as part of the regional and national rural development plans in the region.

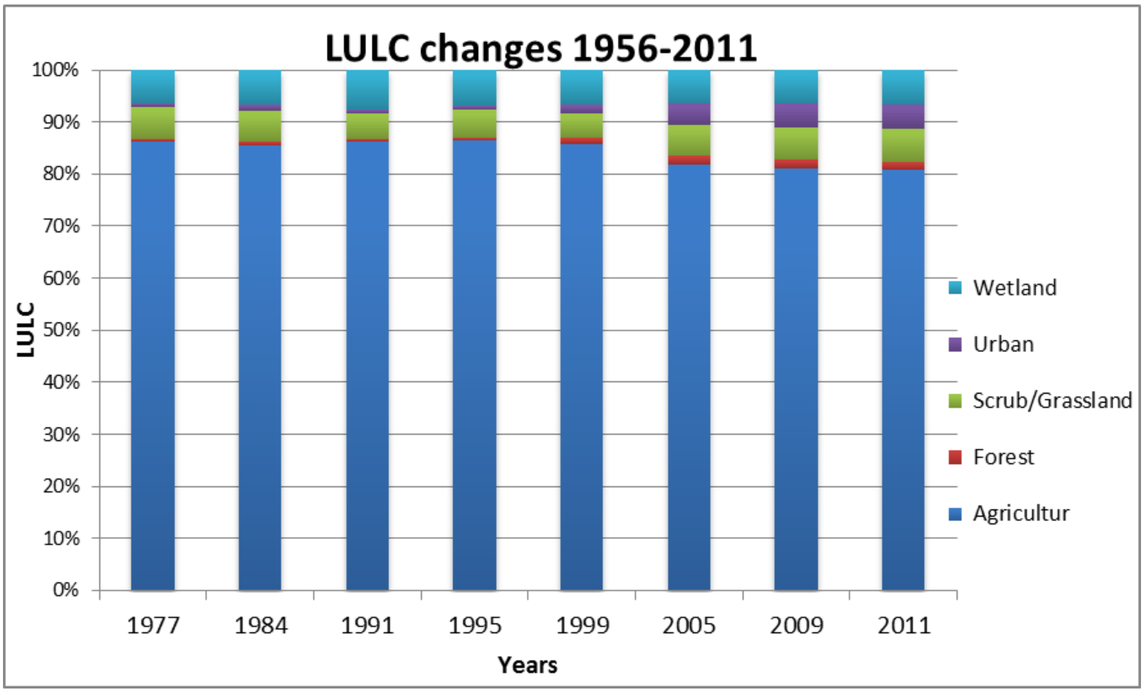
Agriculture mainly after 1999 shows a small decrease due to urban expansion, as new industries and communication infrastructures take place in agriculture lands, extending more in the agricultural exterior borders of the two small villages which increase the number of population over this period[53].

As a consequence of the new industries, of which a large part food industries related to the agricultural sector of the area; as well new improved communication infrastructures with rest of Andalusian region, shows a positive correlation with the population increment after 1999(R^2=0.84).



Graph 3: Population Evolution in the last 65 years (1950-2015) in Fuente de Piedra and Humilladero villages.

Year 1991 shows an increase of 1%in the wetland area compared to the rest of the years taken into study This increase is related to the wet year and the increase in the water level data; 1989, 1990 stands as highly wet years (precipitation over 300mm for October 1989 and water level reaching 1.3m), a reason that might have been reflected to the in the increase in the wet surface of the area.



Graph 4: LULC percentage distribution between1977 and 2011.

Scrubs, and grasslands located in the borders of the watershed cover a small part of 6.4 % in 2011 and forest are mainly present in the north and north-west part of the study area covering 1.6% in 2011. They include mixed forest of coniferous, oaks, other broadleaved forest, dense and disperse scrub.

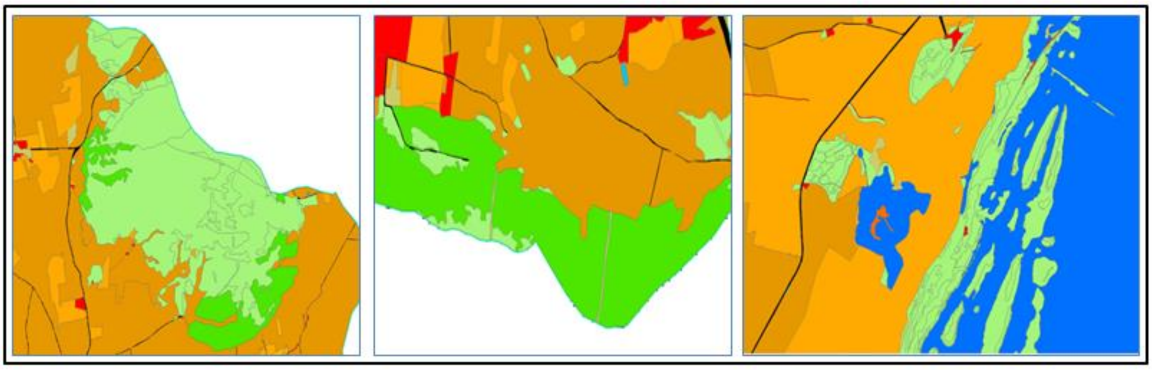


Figure 32: Coniferous and mixed forest and scrub in north part (left); coniferous, scrub and grassland in the north-west (middle); wetland halophyte vegetation in the wetland east borders (right).

Throughout the study period land use does not show significant changes, where agriculture is the dominant occupation over past and present years, highlighting the dependency of a main socio-economic activity in the region. In recent years the lagoon area is becoming an important attraction point for nature tourism, which can provide better benefits to local community, as diversification of the economy.

Intensification of agricultural practices

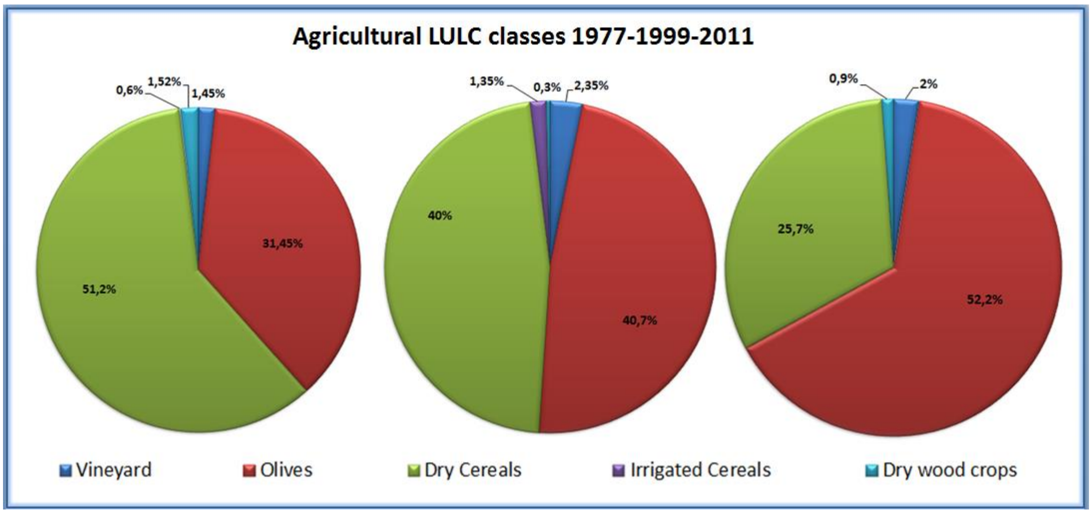
During the study period, the agricultural practices have shifted from more extensive traditional type of agriculture relying mainly on the cultivation of cereals, towards more intensive type of agricultural system with a change in the crop types as well as an increase in the irrigated areas. The main agricultural classes identified are: Arable crops in dry lands (mainly cereals), irrigated arable crop-lands (mainly cereals), vineyards, olive groves and dry wood crops other fruit trees.

Detailed analyses of the agricultural classes and their changes during the study period shows the changes over agriculture crop cultivation, where dry cereal cultivation cover more than 51% of total area in 1977 decreasing in 40% in 1999 and reach a minimum around 26% in 2011 (Table 9). Important to be mentioned, that after 2005 dry cereal have been converted mainly in irrigated cereals croplands where now days just a small part of the area is not irrigated.

Years	Total %	Vineyard	Olives	DryCereals	Irrigated Cereals	Dry Wood crops
1977	86.10	1.45	31.45	51.22	0.12	1.52
1984	86.78	1.46	30.63	52.00	0.12	2.59
1991	86.20	0.84	30.06	52.18	0.78	3.6
1995	86.40	0.84	31.28	49.75	1.22	3.2
1999	85.20	2.70	40.73	39.97	1.35	0.30
Years	**Total %**	**Irrigated Vineyard**	**Irrigated Olives**	**Irrigated Cereals**		**Dry Wood crops**
2005	81.80	2.35	49.51	29.08		0.94
2009	81.60	2.24	51.87	26.15		0.89
2011	80.70	1.98	52.15	25.69		0.90

Table 9: Agriculture occupation sub-classes in percentage over the total agriculture percentage; year 2005, 2009, 2011 cereal values belong into irrigated cereals.

Total agriculture percentage is extracted by total LULC occupation, where the difference presents the rest of the land covers classes (see table 8).



Graph 5: Agricultural changes between 1997-1999-2011.

On the contrary, the olive groves cultivations which present 31.5% in 1977 increase in 41% in 1999 and reaching a maximum over 52% in 2011, being the majority in irrigable lands. Classes like vineyard and wood trees (fruit trees) cover a small area, less than 4 % of overall agricultural arable land. Meanwhile after 1999 all arable lands were converted in irrigated arable lands increasing productivity but also pressures on the ecosystem.

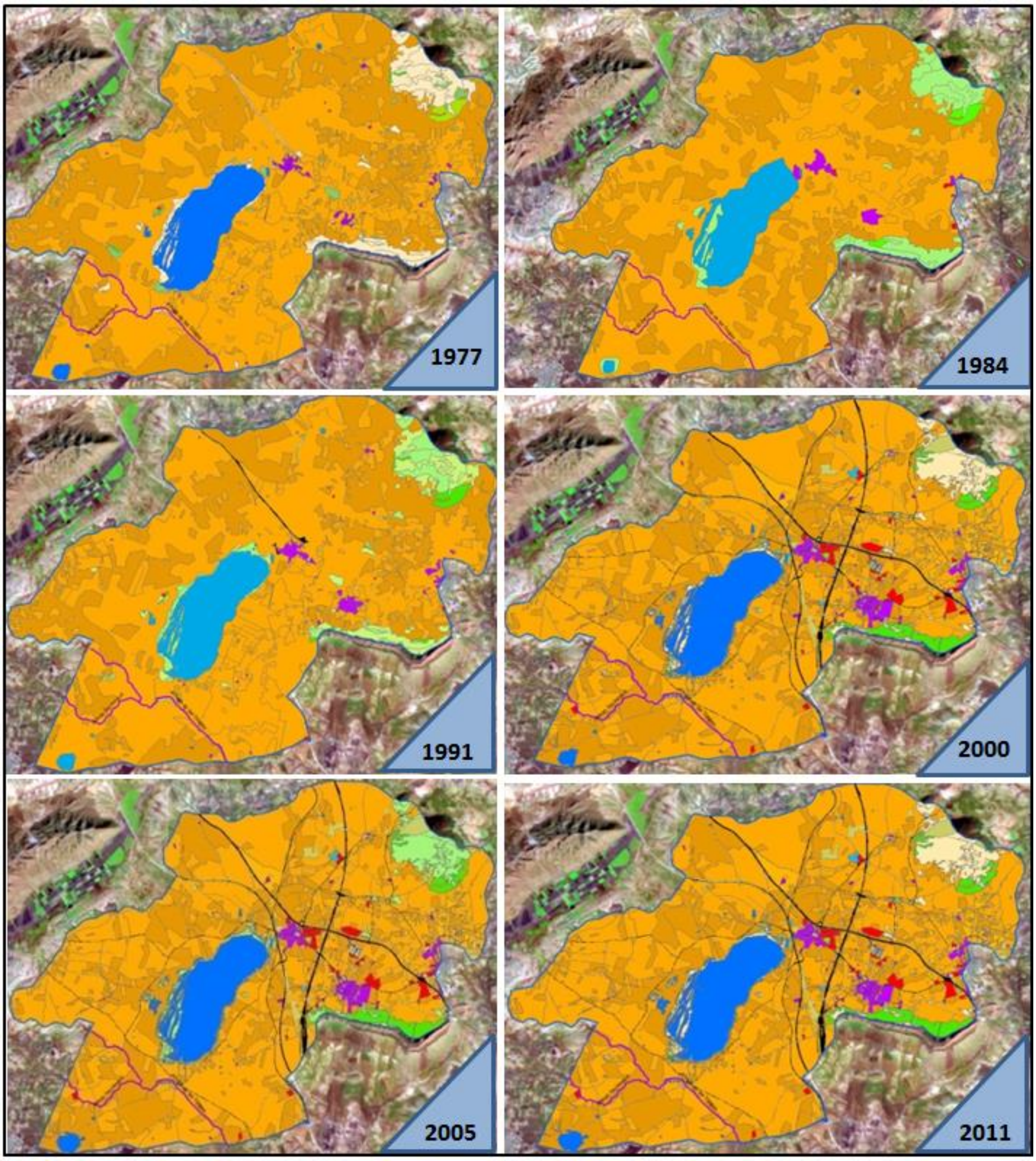
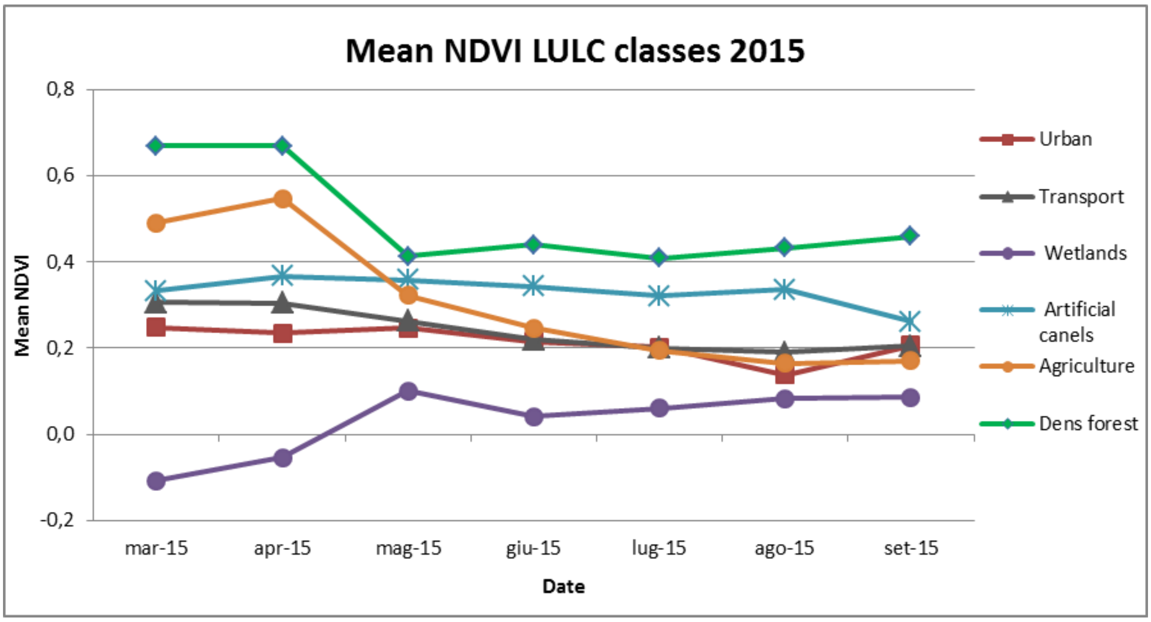


Figure 33: LULC changes between 1977 and 2011.

4.4.3. Detection of LULC changes using remote sensing

We applied the NDVI index to the study area to show the difference response of this index to different LULC types as explained in the data analysis section (Section 5.3.4). Graph 6 shows the different values of NDVI per LULC type. In contrast with the biological parameters, behavior of non-biological parameters presents low values in mean NDVI range. Wetland and water surfaces give negative values or near to 0, make this class easy to identify. On the other hand urban and infrastructure classes give stable NDVI values, that shows very little seasonal variability. Scattered distribution of urban houses, mixing with small vegetated parches, small parks, bare vegetated lands or either small olive fields within the urban core makes difficult the identification of unique spectral behavior of this class.



Graph 6: Mean NDVI seasonality trends for olive groves.

As a semiarid region, the natural vegetation in the area is sparse. The small forest and grassland surfaces in the north and north-west show high mean NDVI values above 0.5 and the maximum NDVI values around 1 in the area where the dense forests are present. In parallel, other vegetation, namely crop cultivations, shows lower mean NDVI values ranging between 0.4-0.6. An example of the discrimination of LULC in the study areas is shown in figure 34 where a clear discrimination between certain land uses such as the water surfaces (shown in red), cereals (shown in green), and olives groves (shown in yellow) is obvious.

This first general segregation using remote sensing and vegetation index showed to be effective to differentiate between broad land use types and water covered areas from vegetated areas; and its application could support monitoring of specific uses trough time.

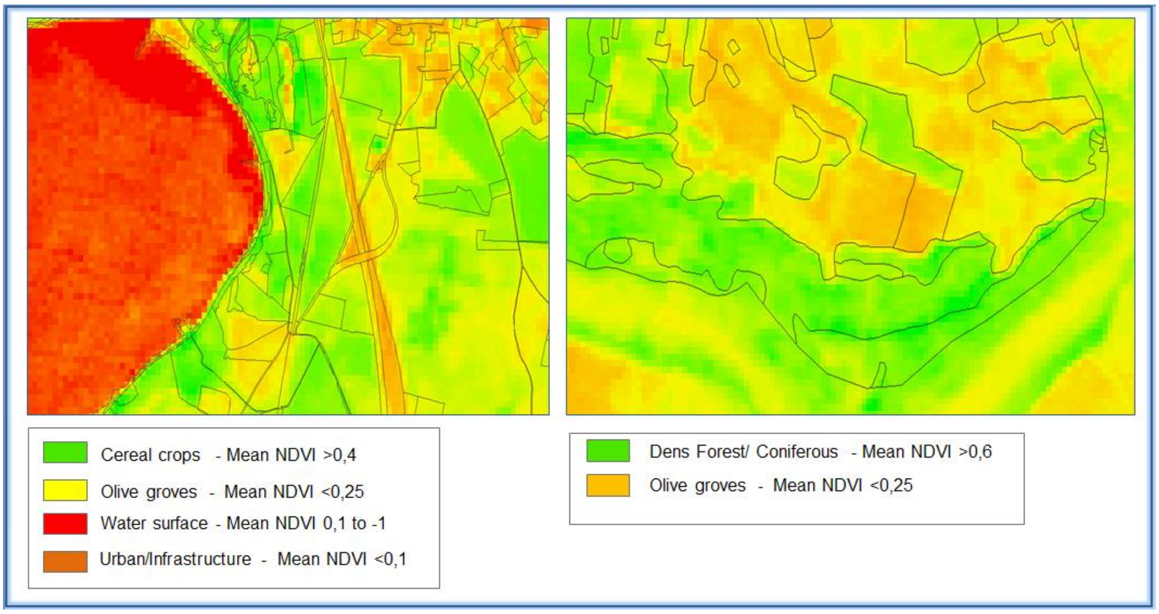
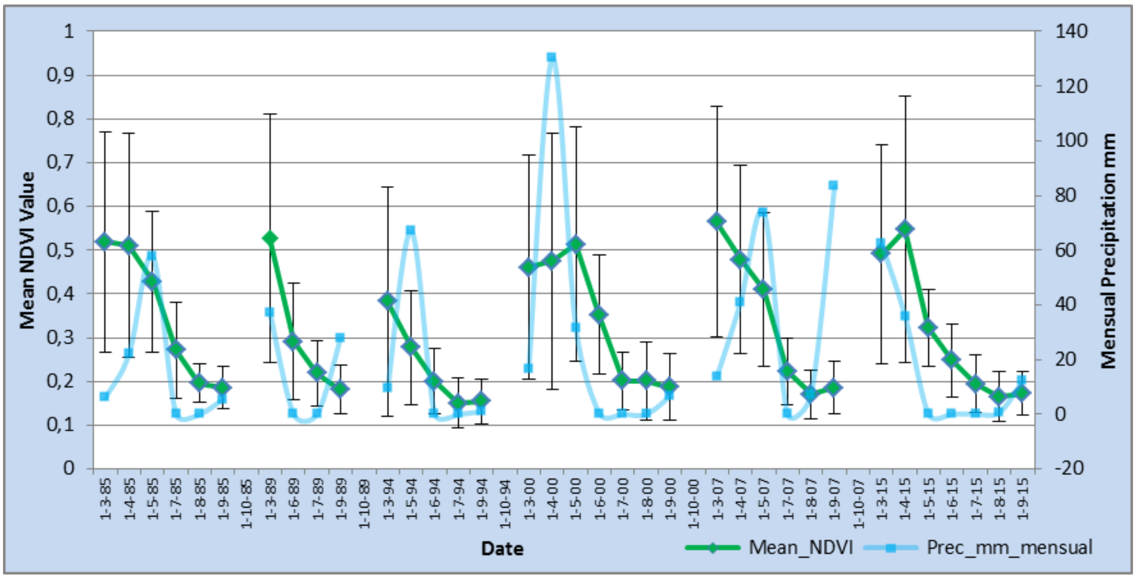


Figure 34: Discrimination between LULC types, on the left side the image shows the clear difference between water surface (NDVI<0), infrastructure (NDVI<0.1), olive (NDVI<0.25) and cereal (NDVI>0.4); in the right side shows the difference between olive and natural vegetation/coniferous (NDVI>0.6). Segments are taken by NDVI image Landsat7 on March 2011.

- **Cereal**

Seasonal and short time monitoring was tested to differentiate agricultural uses; mainly for olives groves and cereals we test the NDVI as a tool in the study area. The result of the test is shown in Figure 6 for cereals the ¨seasonality¨ of the crops cycle is very visible peaking between March and May (growth period for the cereals crops) for each year with mean NDVI values ranging between 0.5 and 0.6 except for the year 1994 where the mean NDVI is around 0.4. This is explained by this dry year, where the precipitation values were very low (March 9.5mm, April 0mm, May 67mm) (grsph7). The correlation of the NDVI seasonal development with cereal is very high (R^2 =0.96) showing the strong relation between the mean NDVI ¨greenness¨ and the level of precipitation.

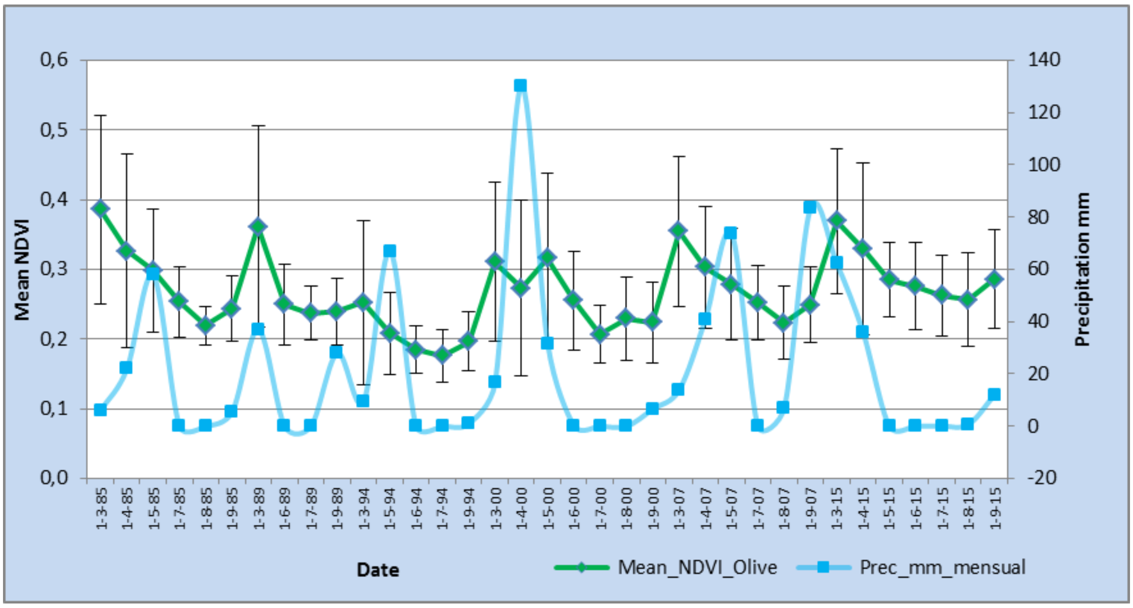


Graph 7: Green line presents mean NDVI monthly trends for cereals and standard deviations between March-September 1985, 1989, 1994, 2000, 2007 and 2015); each peak represents a seasonal cereal cycle (seedtime to harvest); blue line presents mean monthly precipitation.

- **Olive groves**

On the other hand, in the case of olives groves (graph 8), the mean NDVI seasonal change range between 0.2 and 0.4 in all the studied years expect 1994, the extremely dry year where mean NDVI values drop below 0.2.

Unlike the relationship between seasonal crops(like cereals) and precipitation is strongly reflecting the mean NDVI of olive groves seem to be less dependent on the precipitation variability where the correlation (R2 =0.26) shows to be less significant.



Graph 8: Green line presents mean NDVI monthly trends for olive groves and standard deviations between March-September 1985, 1989, 1994, 2000, 2007 and 2015) ; blue line presents mean monthly precipitation.

In Iberian Peninsula, crop production has big variation in timing of ploughing, sowing and harvesting; as well the cultivation cycle in Andalusia varies between the regions. In Fuente de Piedra, herbaceous seeding time starts late February and harvest time ends by middle September. Mean NDVI values show highest values between March-April around 0.6 and Max NDVI near to 1, where the vegetation growth reach the maximum and starts to decrease after May when herbaceous and especially cereals reach the maturity, having a minimum of greenness or total dryness stage (Figure 35)

Figure 35: Cereal growing cycle in a specific year in a Mediterranean environment.

Compared to the analysis of NDVI in the case of olive groves that are dominant in the study area shows that the seasonality is not reflected in the NDVI as the olive groves are permanent trees that last for long seasons. As shown (Graph 8) the mean NDVI values range between 0.19 and 0.4 with peak values in March of each year, being lower than the values shown in cereals.

Figure 36: Olive plantation in Fuente de Piedra

Our results shows for the both cases that NDVI monitoring seems to be adequate in seasonality crop discrimination and they temporally change.

From the other hand LULC detection through vegetation indicators as NDVI shows the changes over the same time series. Mean NDVI values characterized different LULC classes, where for the vegetation patterns having NDVI values which are high positive and close to one; meanwhile urban, infrastructures and water patterns shows negative or near to 0 values.

Using the NDVI indicator we could also evaluate the total changes from 1985 to 2015. Based on pixel values, we can see which pixels have been changed. Significant changes depend on the threshold value that we give to the change detection process; the sensitivity of vegetation crop identification (cereal vs olives) in NDVI value is around 0.2 (setting of threshold may lead to different results).

Result map (Figure 37) shows the polygons (thus from pixel grouping) have been changed (increased or decreased).

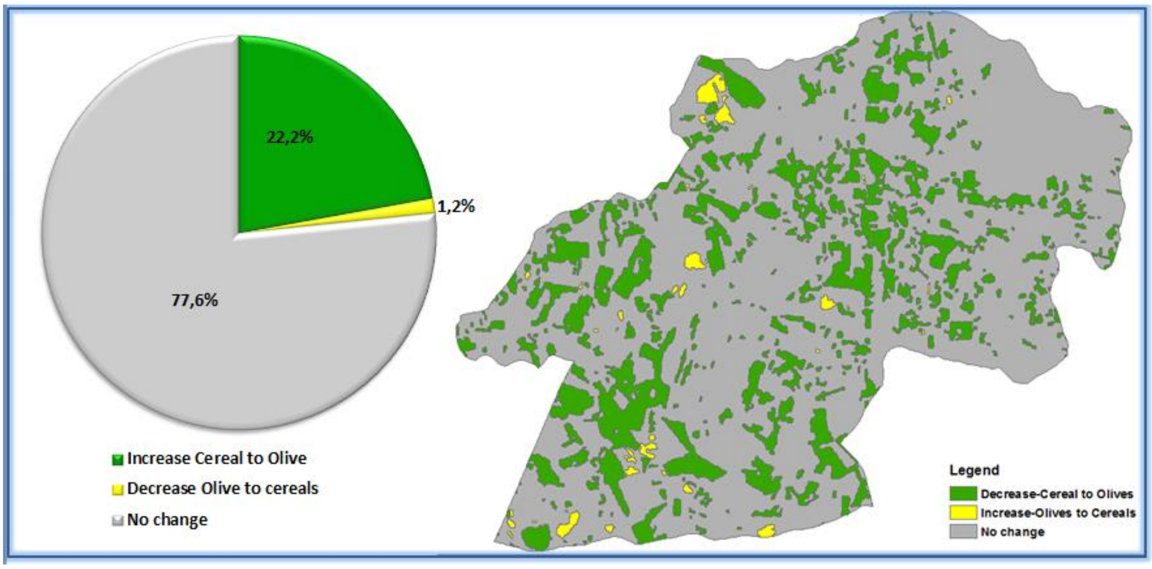


Figure 37: Changes 1985 to 2015 through NDVI values; In gray areas with no change, in green areas that have decreased (mainly herbaceous to olive) in yellow areas that have increased (olive or other fruit trees to herbaceous).

Results shows a total of 23.4% of the area has undergone a change, where 22.2 % (4330.75 ha) of the change shows to have decrease. Comparing to the LULC calculation, herbaceous crops have decreased with almost 26% (5074.7 ha) from 1984 to 2011, proving that our differences in NDVI change gives a quite accurate result in identification vegetation change in time.

4.4.4. Detection of Water Dynamic

Water dynamic analyses and NDWI results show that 62% of the total wetland area (quantified as 5.4 ha by NDWI index) was at least inundated 3 times in the year 2015, while just 1% of the wetland area was inundated 5 times during the study year(2015).Results depends on the numbers of images taken into analyses.

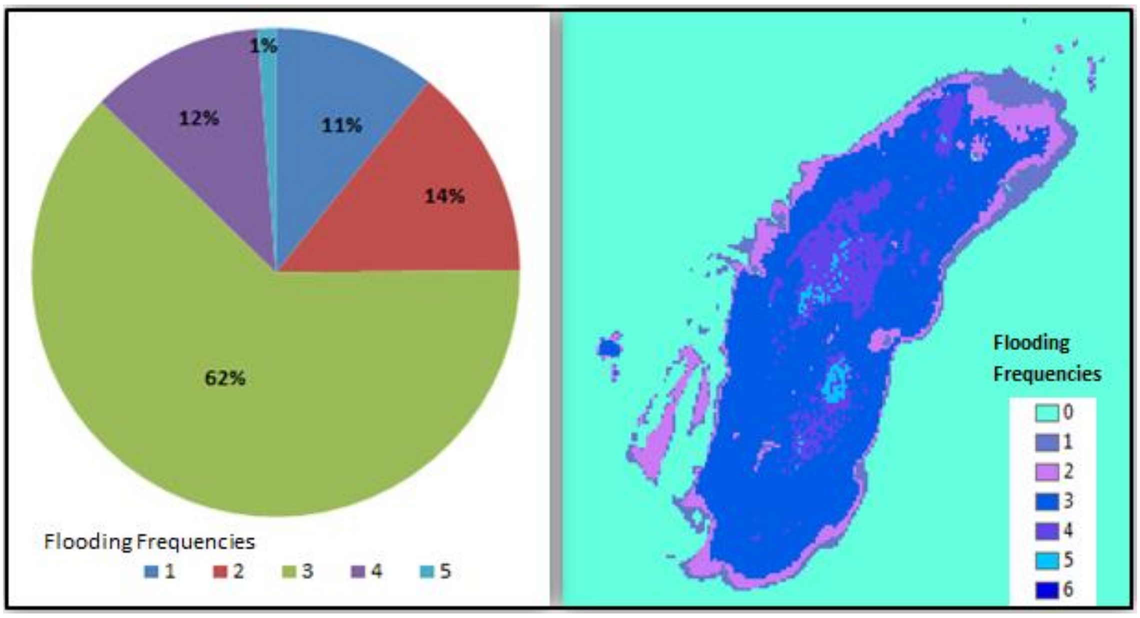


Figure 38: Result water dynamic map 2015, with seasonal flooding frequencies for year 2015; inundation frequency of 6 times detected in artificial wetlands.

The combination of water frequency map calculated by NDWI whith the topographic weteness index give as result the wetness accuracy map. Results show the areas were there is high wetland occuracy (100% of probability) and areas with less probability (0 %). As well wetland occurrence map shows the areas with the major flooding risk that might be inundated during exteme events (Figure 39).

Combining TWI index with NDWI or other water index seems to be a good and accurate method to define the areas with the higher potentiality of holding water and the areas with the higher flooding probability. For more indicator can provide information on water fluctuations during long and short periods, while gives accurate information retrieved to better understand and prevent flooding hazards and extreme events that can result very risky.

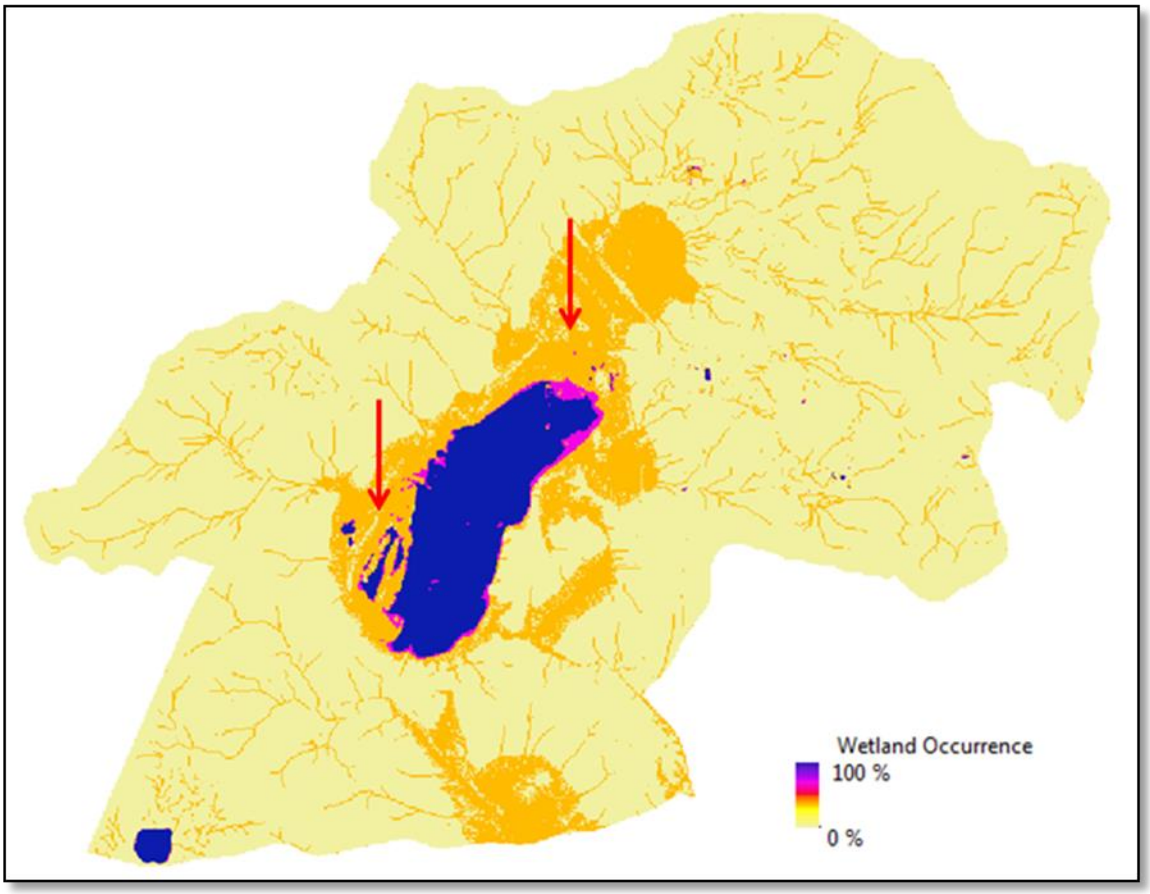


Figure 39: Wetland occurrence map for the year 2015; red arrows show the areas with highest inundation risk.

4.4.5. Segmentation Accuracy Calculation

The segmentation of Landsat8 image (April 2015) and Sentinel2 image (April 2015), shows that the overall error (calculated from the commission and omission error) is lower when using Sentinel2 image (89%) then using Landsat8 image (84.2 %).
Error A (commission error) is the percentage of land that is wrongly classify in another class;
Error B (omission error) is the percentage of real land that is not detected by our classification.
The overall accuracy shows the total area of our classification that coincides with the reference land use layer (SIOSE 2011).

Accuracy results for Landsat image classification show an overall correctness around 84.2% being the error A (commission error) 17% and error B (omission error 15.8%.
Results show that there were classes better classified showing high accuracy and other classes not well classified showing low accuracy values. Namely coniferous dense forest shows high percentage of accuracy near 95% as they are easy to be distinguished and classify up to the high tree density and overall greenness reflected. In a total correctness over 90% were wetland areas, olive groves and in a lower accuracy almost 85% were correctly classified non-irrigated arable lands (Table 10).

Some confusion exist also between urban areas and olive groves, as urban areas contain small areas of vegetation and olive fields, reasoning the low accuracy 64.5% on urban area classification. Next to the urban, calculations shows that fruit trees had a high degree of confusion (error A = 57.1%; error B= 53.4%) mainly with olives.

		Landsat8			Sentinel2		
	Inventory area	Error A	Error B	Correctness	Error A	Error B	Correctness
Urban	10455599	19,76	63,49	36,51	16,01	40,80	59,20
Sclerophyllous vegetation	7775000	37,82	52,86	47,14	23,67	23,27	76,73
Wetlands	12822214	1,83	7,73	92,27	2,65	7,07	92,93
Non-irrig. arable land	50169581	8,99	22,06	77,94	8,77	17,23	82,77
Vineyards	3905178	44,42	17,90	82,10	24,36	33,30	66,70
Fruit trees	1748628	74,70	50,34	49,66	53,62	38,72	61,28
Olive groves	101345499	15,06	5,76	94,24	11,77	3,16	96,84
Coniferous forest (T.C.D. > 80%)	3921132	39,13	4,50	95,50	15,44	5,43	94,57
Coniferous forest (T.C.D. 30 - 50%)	681146	88,60	72,56	27,44	51,89	43,36	56,64
Average		36,70	33,02	66,98	23,13	23,59	76,41
Total inventory	195170594	17,00	15,83	84,17	12,10	10,92	89,08

Table 10: Overall classification accuracy for Landsat8 and Sentinel 2.

Sentinel 2 classification shows higher correctness values of the segmentation in terms of LULC type being round 89%, where omission error round 11% and commission error round 12% (Table 10).

The classes that show highest level of correctness are the olive groves (97%correctness), coniferous dense forest (almost 95%), wetland areas (93%) and non-irrigated arable lands (almost 83%) (purple square Figure 40). It stands a better identification in sclerophyllous vegetation (almost 77%), improving in more than 20% this class comparing to Landsat8 classification (red square Figure40).

Results also show improvements in urban areas identification, where classification from sentinel2 is more sensible in linear features. However the overall correctness in urban class detection is still below the level of confidence (52%) (Table 10).

Fruit trees classification as well improved in 61% correctness, al contrary vineyards classification correctness show to decrease (almost 67%) mostly confused with the olive groves and other fruit trees (green square Figure40).

As explained in the previous paragraphs, we can conclude that classification and segmentation tool by using Sentinel 2 image improve results due to its high spatial resolution.

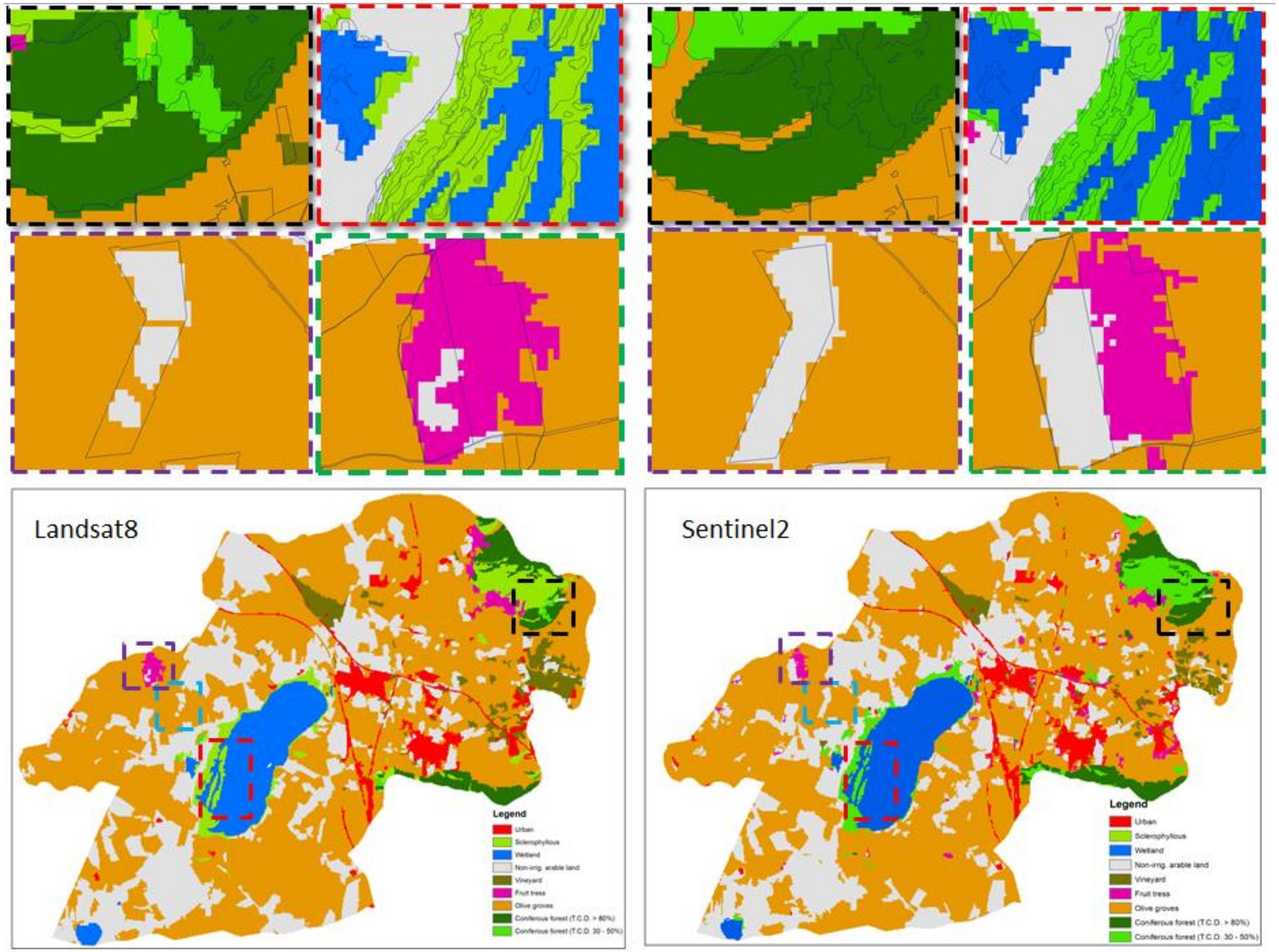


Figure 40: Landsat 8 verse Sentinel2 accuracy classification.

4.4.6. Spatial changes affecting erosion

As the soil lose rates in international, national and regional scale present high concern, recent policy developments in European level call for quantitative assessments of soil loss rates, through the Soil Thematic Strategy, the Common Agricultural Policy, Europe 2020, and the 7th Environmental Action Programme, assessing soil lose rats from water erosion and soil degradation[43].

The Mediterranean region because of the fragile environmental conditions, is subjected to long dry periods followed by heavy and burst rainfall, in high slope areas with fragile soils is subject considerable amounts of erosion [54]. Particular in Spain and in Andalusia region because of the sleeps slopes, drought followed by intense rainfall, soil characteristics and spares vegetation, have been measured soil erosion values up to 50 tons per hectare, in specific regions soil lose up to 100 tons/ha/year[55].

Seeing as a threat in Andalusia, as well in our study area we consider important to have an assessment and evaluation in the soil lose rates deriving from water erosion. How past changes in wetland area has been affected from soil erosion, specific conditions and main properties increasing or not the risk from soil erosion.

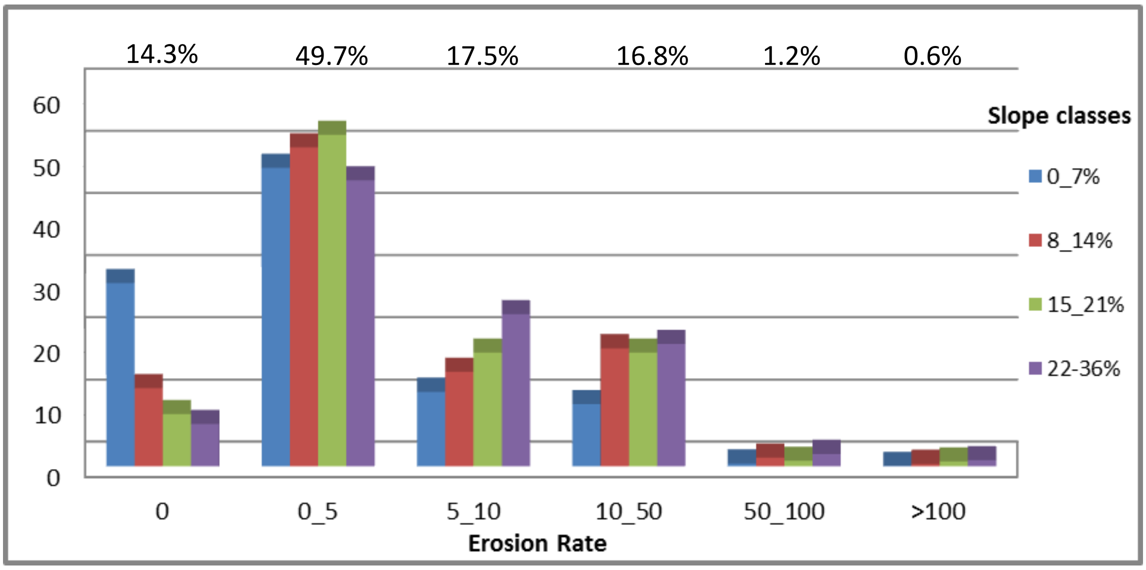
Our hypothesis and approach was to analyze the potential relationship between soil erosion lose and vegetation cover, and to check whether these changes in combination with other topo-climatic variables are significantly different between. Through this analysis, we emphasize on answering the following questions:

- Does the level and potential risk of erosion depend on LULC type?
- Is there significantly difference between spatial and temporal variables?

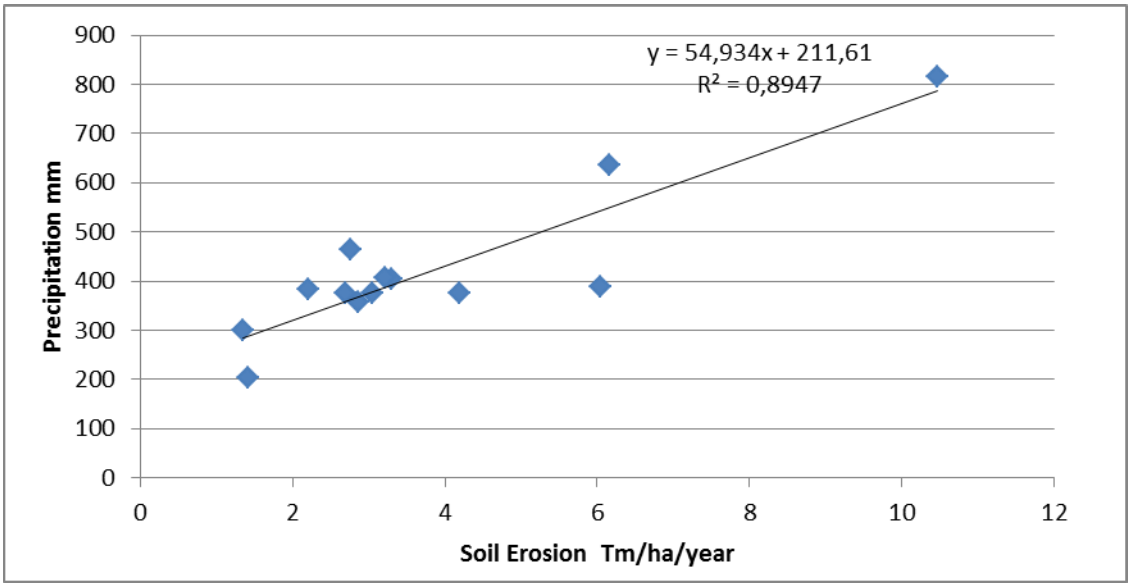
We performed statistical analysis to assess the relationship between the degree of erosion as a dependent variable and independent variables such Lithology, LULC, slope, elevation, and temporal changes like precipitation and time change factors.

Correlation and regression analyses show very strong and moderate correlations between the different variables. In order to test the strength of the relationship among the studied variables, we used the regression analyses, showing Pearson correlation coefficient. Linear regression and ANOVA shows a total of 41% (R^2) of prediction ($P<0.05$); of the variability in the dependent variable that is explained by the independent variable.

Analyses show that 14.3% of the total area is not affected by soil erosion, while almost 50% of the areas show rates 0 to 5 Tm/ha/year of soil loss. In a higher risk 17.5% of the area shows rates between 5 to 10 Tm/ha/year that are located mostly in steep slopes (higher than 15%). Erosion rates up to 10 Tm/ha/year are considered areas with high erosion risk. They cover almost 18.5% of the study area and are mostly concentrated in hilly, steep surfaces and bare vegetated. Under these conditions and high precipitation regime the erosion rates present a high risk in those areas.



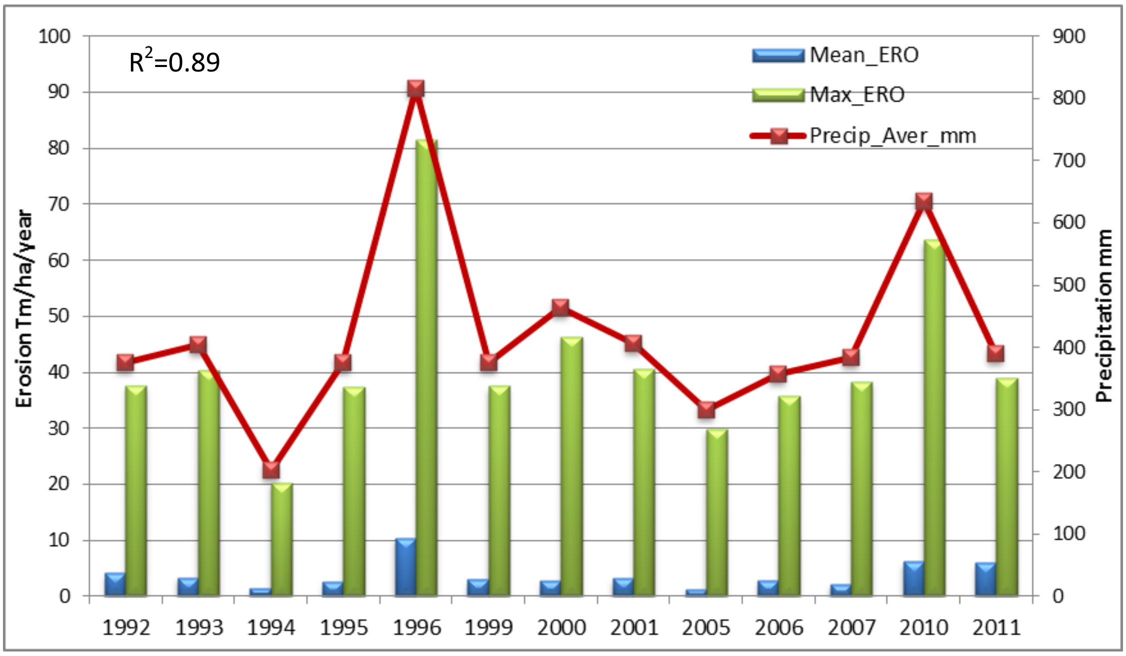
Graph 9: Distribution of different erosion rates in the different slope classes; (above) percentage occupation of each erosion rate in the total area.



Graph 10: Exponential relationship between annual soil erosion and annual precipitation values between the years 1992-2011.

We found very strong and positive correlation between precipitation variable and erosion (R^2 =0.89). Trends over the precipitation annual precipitation and erosion annual average shows to be high correlated (Graph 10), indicating the strong relation between this two variables.

This may be related to the high variation and intensity of rainfall characteristics in the study years ranging between 200 and 800mm. Erosion rates during humid years is twice or even more comparing to dry periods (Graph 11); humid year 1996 vs dry year 1994). In 1994 mean erosion shows values around 1.4 Tm/ha/year in a maximum of 78.1 Tm/ha/year in mean precipitation values near 200m while in 1996 the mean erosion rate rise to 10.4 Tm/ha/year (max 464 Tm/ha/year) as a consequence of precipitation values up to 800mm per year. Our findings are also in parallel with a number of studies specify the role of rainfall variation and intensity in the soil erosion rates and soil erosion effects.



Graph 11: Minimum and mean erosion rates (Tm/ha/year) show a high correlation with changes in precipitation (mean annual 450mm).

		Aspect	Slope	Altitude
Pearson Correlation	ER_1992	0,004ns	0,180***	0,164***
	ER_1994	0,0045*	0,159***	0,139***
	ER_2000	0,0007*	0,183***	0,169***
	ER_2007	0,0024*	0,188***	0,167***
	ER_2011	-0,007*	0,28***	0,29**

*** p≤0,001; **p≤0,01; *p≤0,05; ns(not significant).

Table 11: Correlation among topographic variables (aspect, slope, altitude) and annual erosion for the studied years.

Furthermore, we observed that the spatial distribution of erosion shows to be largely influenced by topographic variables. Results show significant and positive correlation (P≤0.001) between slope and altitude (P≤0.001), and negative not significant relationship with aspect variable (Table 11).

Independent from the temporal erosion variability, slope shows same tendencies in all study years, as being the second most important variable (P<0.001). Erosion shows to be positively affected by altitude as well, combining with high steep slopes, in specific areas in north part of the study area and in southwest side of the lagoon presents higher erosion values during entire temporal variability (maximum soil erosion loss are reached in these locations).

Lithological variables represented by 9 different lithological classes(Figure 25) present different correlation trends with the level of erosion in the study area. Most of the classes show non signifficant correlation with erosion, except class 7 (Subbetic marl) and class 8 (Subettic limestones) that presents significant correlation with erosion variability during the studied years.

		lithol_1	lithol_2	lithol_3	lithol_4	lithol_5	lithol_6	lithol_7	lithol_8	lithol_9
Pearson Correlation	ER_1992	-0,133***	-0,072***	-0,000***	0,012*	0,029***	0,056***	0,117***	0,055***	0,024***
	ER_1994	-0,132***	-0,070***	0,009*	0,011*	0,033***	0,033***	0,127***	0,048***	0,013**
	ER_2000	-0,131***	-0,074***	-0,003*	0,013**	0,033***	0,045***	0,128***	0,052***	0,023***
	ER_2007	-0,125***	-0,07***	-0,009*	0,012**	0,03***	0,016***	0,124***	0,124***	0,02***
	ER_2011	-0,099***	-0,066***	-0,028***	0,002ns	-0,010*	0,202***	0,068***	0,105***	0,004ns

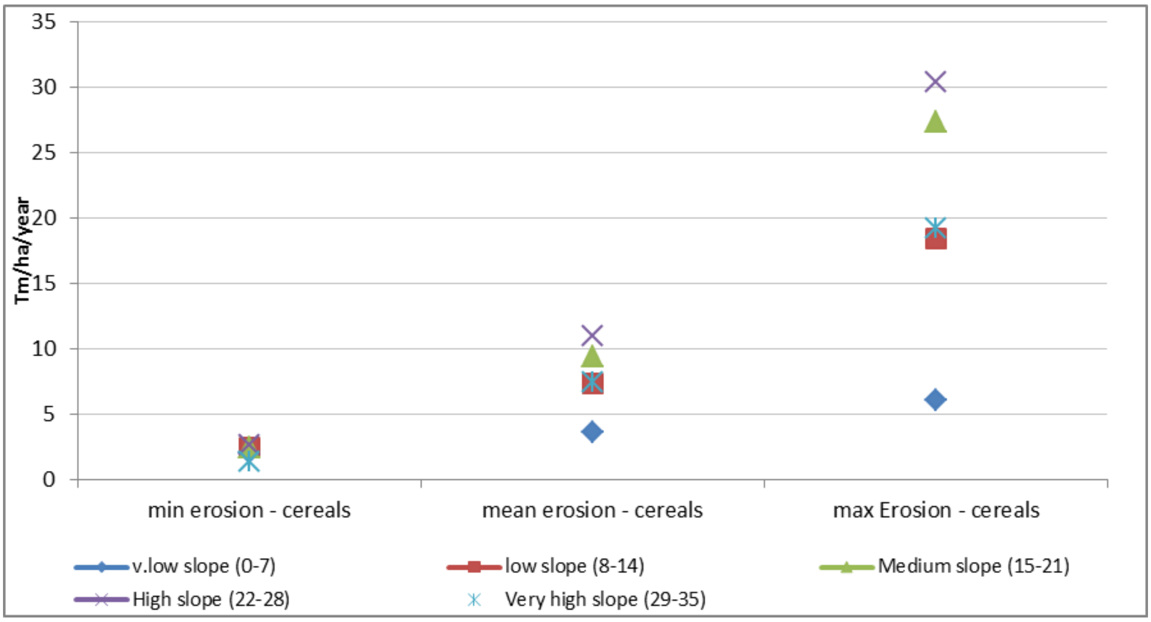
*** p≤0,001; **p≤0,01; *p≤0,05; ns(not significant).

Table 12: Correlation among geo-lithological classes, highlight correlated class 7 and class8

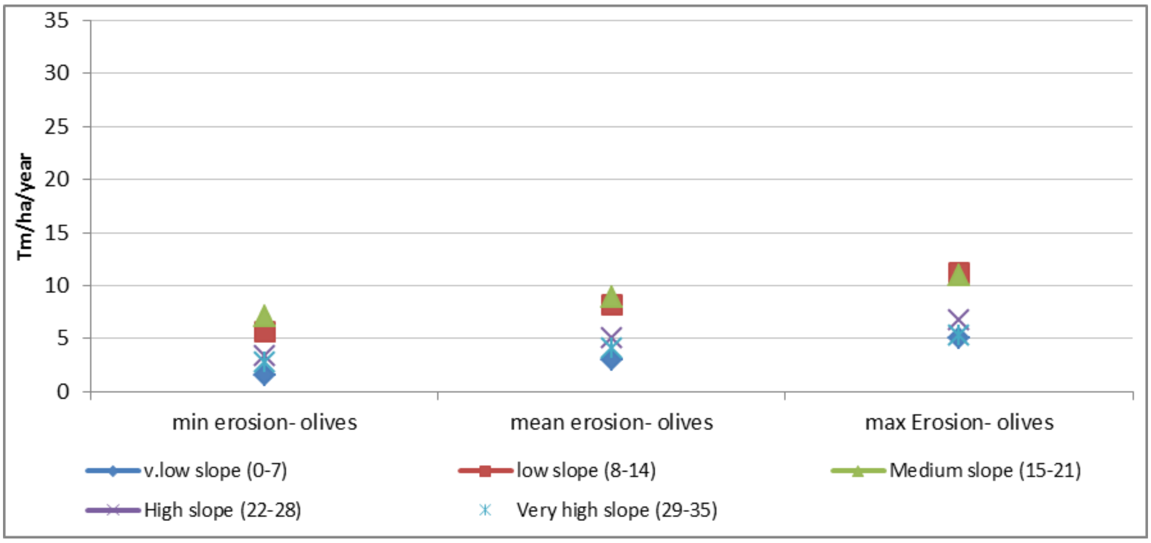
The classes subettic marley and subbetic limestones cover very little area in Fuente de Piedra, around 4.5% of the study area. But combined with the high steep slopes values provied evidence why the erosion rates are higher in this geological formation types.

A more detaied analyses was done for the major land uses in the study area being the agriculture class, differentiating between olive groves and cereals cultivations in order to take the relation they have with soil erosion in the study area. In order to disminuish the extend number of pixel taken in the analyses(34702 pixel values, which create difficulties to run the analyses), we stand out the negative correlation between LULC class 1, classe 3, class 4 (urban, wetland and scrublands). We decsided to limit our analyses to agricultural land, namely cereals and olives(agricultural class 5 and class 6) that cover the majority of the study area (LULC change analyses).

Our results show that the rate of soil erosion is greatly affected by the (agricultural practice) type of land cover. The highest rates of soil loss were detected in hilly areas under cereals with maximum erosion above 34 Tm/ha/year (graphs below) where the maximum erosion rates were up to five times higher than erosion rates shown under olive groves (6,72 Tm/ha/year).



Graph 12: Shows the range of erosion in cereal crops, in the different slopes distribution



Graph 13: Shows the range of erosion in olive groves, in the different slopes range.

The spatial distribution of cereals and olives in the study area is influenced by the slope, where cereals are mainly distributed over very low slopes 0-7 % and while the olive cultivations are distributed over medium to higher slopes being mainly located in the south-western part of the lagoon. Though olive groves are normally distributed on higher slopes, the erosion rates over this land cover are reduced when compared to the soil erosion rates in land covered by cereals.

When related to soil erosion, the results show that both slope and land cover types influence the soil erosion in the study area. At lower slopes, the erosion rates over cereals (graph 12) and olives groves (graph 13) show low rates. With higher slope ranges, the difference between the erosion rates over the 2 land uses changes significantly where soil erosion over cereals shows to increase significantly (up to 7 times) over high and very high slope range (graph 12), while erosion over olive groves seems to be less affected by the slope gradient.

4.4.7. Spatio – temporal model

We assess the influence of spatial (slope, LULC) and temporal (mean annual precipitation, Maximum NDVI) trends in effecting the level of erosion in the study area. The ANOVA results show the studied parameters explain 41% of the variability of soil erosion influenced mainly by precipitation variability between years, by the vegetation cover calculated as maximum NDVI levels and the slope where interaction between precipitation and slope shows to be positively related to the soil erosion.

Results show that precipitation variable, which is temporally effecting erosion in the different years, is the most significant factor. As well maximum NDVI and slope are in relevant importance (P<0.0001) showing strong gradient.

Source of variance	Df	F	P	R^2
For the time period between 1992 and 2011				0,41
Slope	272	23,64	<0.0001****	
Precipitation	4	180,13	<0.0001****	
Max.NDVI	1	99,24	<0.0001****	
LULC	5	3,45	0.004*	
Slope * precipitation	1016	14,62	<0.0001****	
Slope* prec.* ndvi mean	272	13,52	<0.0001****	
Slope*prec.*ndvi max	1021	11,71	<0.0001****	
Residuals	77227			

Table 13: ANOVA results shows the variables influencing soil erosion loss in the study years.

Despite the large variability and uncertainty in data, (LULC layers, and erosion layers) there is a tendency of increasing soil loss rates in the last years. This is attributed to the insufficient land cover mainly in cereal, were soil surface remains bare for some period mainly in autumn which consist with the humid months, in intense and frequent rainfall.

5. DISCUSSION

This research uses an ecosystem based delimitation as defined by the Horizon 2020 SWOS project to define the hydro-ecological boundaries of the wetland ecosystem of Fuente de Piedra, being the study area of this research, and covering a total area of around 19518ha. In the study area agriculture is the major share of the land use of the study area. Based on the 2011 land use land cover map (SIOSE, 2011), the results show that the total study area is covered mainly by agriculture (81%), followed by wetland habitats covering 6.6% of the total area, then by urban settlements and infrastructures (4.7%), and very small share covered by forests (1.6%).

Historically, land management practices have shaped and modified the landscape heavily at this saline wetland, the historical assessment developed during the study period of this research between the years 1977-2011, shows shifting trends in the crop types cultivated in the study area and intensification in the management practices employed. More precisely, the analysis shows that herbaceous and cereal dominant crops that used to cover 51% of the total agricultural land in 1977 were significantly reduced (by around 50%) and cover around 26% of the total agricultural land in 2011. On the other hand, olive groves cultivation that used to cover 31 % of the total agricultural land 1977 has increased to cover 52 % of the agricultural area.

The statistics extracted from SIOSE and MUCVA between 1977-2011 show obvious intensification signs related to shift from traditional management practices into modern technologies where olive and cereal cultivations are increasingly irrigated in the study area, where the major shift happened after the year 1999. These obvious signs of intensification of irrigated land in the study area have been influenced by local, regional, and European policies including "La Agenda del Regadío Andaluz H-2015"[57], the reforms of the Common Agricultural Policy (CAP) and its reduction in the level of support for cereals by 29% for Europe in the last decades, as well as the changes in the global market [58].

These increasing pressures mainly coming from agricultural intensification in the study area increase the environmental pressures in the region such as using the limited water resources for irrigation, affecting water quality through the increase in the use of fertilizers, among others. This situation stresses the need of developing adequate environmental monitoring tools to support managers in their local and regional decisions in the region.

Our results show that the water quality of Fuente de Piedra lagoon shows high concentrations of nitrates and phosphates during the years 1997-2003. The increase in nitrates in superficial waters is directly related to the increasing use of fertilizers for agriculture and farming industries and closely linked to the shifts towards more intensified management [59]. After 2003 the water quality seems to improve, influenced by the new policies and regulations [60].

Soil erosion was analyzed in the region during the study period 1992-2011 (as soils erosion data were available for this period) and our results show that erosion is positively related with the precipitation regimes in the study area, where years with high mean annual precipitation (over 500mm) show the highest levels of erosion (R^2=89) over 50 Tm/ha/year, namely the years 1996 and 2010. On the other hand, the type of land use shows to affect erosion as well the level of erosion seems to be significantly dependent on the land use type, though to a lesser extent, where area covered by cereals shows higher rates of soil erosion than areas covered by olive groves, in addition to the slope of the area. Our results show that the precipitation is the main variable effecting erosion rates (R^2=0.89) where the mean annual soil erosion is around 50Tm/ha/year in mean precipitation more than 500mm. These results are in line with a number of studies that prove the positive relation between the climatic factors, namely precipitation variation with the intensity in the soil erosion [61][62].

Furthermore, topographic variables, such as slope and elevation affect significantly the soil erosion in the region. The results show a significant positive correlation between slope range and soil erosion ($P \leq 0.001$) where almost 17.5% of the area presents erosion rates between 5 to 10 Tm/ha/year that are mostly located in steep slopes with more than 15% of inclination and 18.5 % of the study area present high erosion risk (up to 10 Tm/ha/year) concentrated in hilly surfaces (over 600m of altitude and slopes over 20% of inclination).

Whenever the lithology of the region was analyzed, the results show strong correlation between two geological classes (subettic marl and subettic limestone) and erosion rates. These classes cover 4.5% of the study area, located in the south and south eastern part of the study area, where high slopes present erosion values up to 10 Tm/ha/year. These results were also in line with other studies that prove the sensitivity of marl and limestone formations to soil erosion loss [63].

Our research shows that the land use also has an effect on soil erosion in Fuente de Piedra, where the highest soil erosion rates (more than 100 Tm/ha/year) were registered in hilly areas under cereals. Areas cultivated with wheat and corn are sensitive to erosion, especially during winter, increasing runoff and sedimentation loss (30.43 T/hm3/year) especially during humid years with mean yearly rainfall averages 450 mm per year. While olive groves under same climatic conditions provide to restrict soil loss to low values (10.95 T/hm3/year) when compared with erosion rates registered over cereals, result also shown in other studies in Mediterranean environments [64].

The results of the spatio-temporal assessment show precipitation regime is the main fact, followed by slope that also shows positive effect on erosion and interaction among them leads in a higher erosion risks. This factor is important to consider in Fuente de Piedra as it is located in a Mediterranean climate with high influence of torrential rains in specific seasons normally occurring where the soil is in preparation for the cultivation of cereals (bare soils) increasing the risk of erosion in these areas, during specific seasons.

Regular field analyses and the validation techniques would improve the analyses, as the complexity of interaction between overall spatio-temporal variables and the erosion risk is very high, which will need further research and more field work and time.

Vegetation indicator such as NDVI and water dynamic indicator NDWI show high accuracy to differentiate between broad land use classes as water bodies, natural vegetated areas agricultural areas in the study area. The NDVI indicator shows high effectiveness in the seasonality discrimination between agricultural crops as the olive and cereal croplands during the study period between 1985 and 2015.

The mean NDVI values calculated for cereal crops show to be valid tools for the monitoring for seasonality cycle of cereals during the studied years, with the highest NDVI values captured during the spring months (March - April) where mean NDVI values show ranges 0.5 to 0.6. NDVI shows high positive correlation (R^2=0.96) with precipitation level during these months. The minimum mean NDVI values (<0.2) was capture in September, being the harvest period for the cereal crops. Whereas the seasonal mean NDVI values in olive groves shows lower range (between 0.4 to 0.2) during spring period (March-April) when the olive groves reach the maximum greenness, showing less variation between the mean and high values as olive groves are permanent crops and are less depended on the precipitation variability (R^2=0.26), unlike cereals.

Moreover changes in mean NDVI values between the years 1985 and 2015 show that 23% of the study area has lower mean NDVI values, showing mainly the changes from cereals to olive groves during this period. This technique proves to be valid for small scale agricultural observation and monitoring, providing support and accurate information in crop discrimination for agricultural purposes over time.

On the other hand, water dynamics and water flooding indicators (NDWI, TWI) show high capacity on long and short term monitoring of surface water dynamic. Results show the temporality of the water table variation during the year 2015. Almost 33 % of the wetland area was inundated at least three times during that year and just 1% of the area was inundated 5 times in the same year. The limitation of this indicator lies on the number of input images used for the analyses (we took 9), which will improve with Sentinel2 images. The Copernicus programme and the Sentinel2 images that are available on a five days basis will give the opportunity to increase accuracy on water dynamic monitoring.

NDWI indicator show to be a valid tool to monitor and support relevant applications in wetland inventories, delimitation, water dynamics as support of the Ramsar Convention and implementation of important directives as the Water Frame Directive, Flood Directive, and the Habitat Directive of the EC.

Furthermore, we found new segmentation mapping techniques very useful to identify LULC classes in the region with an overall accuracy of 89% for Sentinel2 and 84% for Landsat8. Sentinel 2 classifications seem to improve and enhance the classification of linear features and boundaries due to its higher spectral resolution. This might give support to wetland water monitoring, delimitation, agricultural crop identification and habitat delineation, especially in areas and regions where inventories are not available.

6. CONCLUSIONS AND RECOMMENDATIONS

From this study we can conclude that the wetland of Fuente de Piedra has been subjected important changes during the last 40 years, due mainly to agricultural practices and urban expansion. Our results show that Remote Sensing and new Earth observation techniques are very useful for land management and are effective tools that can facilitate the monitoring and conservation of complex wetland ecosystem such as Fuente de Piedra ecosystem.

Our results show that the use of vegetation indices (NDVI) provide accurate results in the identification of short and longer term land cover transformations. NDVI indicator provides a great support for main practices in rural areas such as agricultural purposes and the discrimination of spatial and temporal crop production. Land managers can rely in such techniques, as they are precise, less time consuming and easy to use. Besides, water dynamic indicator shows to be an appropriate method for predicting and monitoring water surfaces, the wetland water dynamics and possible flooding areas. High resolution satellite image from Landsat and Sentinel2 can give a great support to local managers for a continuous monitoring of water extension, improving the temporal resolution in 5 days in the case of Sentinel 2 versus Landsat 15 days which can help managers to identify flooding risk areas and plan appropriate measures should be applied.

In order to reduce soil erosion in high risky areas, integrated management efforts are crucial of agricultural practices. The implementation of agri-environmental commitment of the Common Agricultural policy can play a key role to reduce these risks in the region, as it calls for crop diversification. Integrated measures such as biodiversity and landscape conservation in agricultural farming, and the need to increase support to traditional, low-intensity farming practices need to be implemented by farmers. Though the CAP sets clear measures to be implemented with incentives, so far, the region of Andalusia did not effectively implement these measures at a significant scale[65].

Because of the high salinity concentration of the soil and the watershed itself, we might expect soil salinization problem in the future due to the climate change reality. Therefore, the changes of soil properties should be monitor regularly by measuring the soil samples taken from the field to mitigate region-specific problems such as soil degradation, soil organic carbon, soil erosion, etc. Moreover, preparation of detailed soil map for study area might be very useful for this aim.

Measures over reduce high levels of soil erosion and run-off in the region, specially agriculture uses, it´s necessary to promote changes in management practices or change in land use maintaining vegetation under olive trees.

The need to improve tools for controlling wetland management should be considered by wetland managers and decision makers as they provide accurate and precise data for a continuous monitor of their territory in order to improve planning, to balance the socio-economic demands of the population and the natural capacities provided by land. In this study, developing integrated wetland monitoring indicators with the help of latest monitoring techniques and tools allowed us to understand the importance of their usage in mapping and monitoring pressures as well as changes over the wetland area.

Thought agricultural practices are the main economic activity in the area; diversification of the local economy by giving higher importance to other sectors like eco-tourism could be an alternative solution for the development of the area and the natural resources conversion. The designation of the lagoon as a Ramsar site and the presence of Nature 2000 site are already attracting ecotourists to visit and use the Fuente de Piedra wetland sustainability.

The ecological state should be a priority in the wetland conservation, as the large number of diverse species, habitats and vegetation communities depends on water availability and condition. Monitoring of water quality and quantity is important for this purpose.

Therefore, the local and national authorities of Fuente de Piedra wetland can have a strongly support application to promote a greater and consistent Sustainable Rural Planning Framework, thought the introduction of EO and GIS tools to support their management and land monitoring efforts.

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ANNEX I

Table 1 shows the list of satellite images from different sources that were checked for relevance to this research between the years 1985 and 2015.

1985	ESA	ESA	ESA	TM	TM		ESA	ESA x2	ESA	ESA x2	ESA	
1986	ESA					ESA x2	ESA	ESA x2	ESA	ESA		ESA
1987			ESA		TM	TM	TM/ESA	TM	TM x2	ESA	ESA	ESA
1988		TM	ESA				TMx2	TM			TM	TM
1989	ESA	ESA	ESA x2			ESA	ESA		TM	TM	ESA	
1990								TM x2	TM	ESA	TM	
1991	ESA						TM			ESA	ESA	ESA
1992				ESA	ESA	ESA	ESA		ESA			
1993	ESA	ESA	ESA x2	ESA		ESA		ESA	ESA			
1994	ESA		ESA x2		ESA	ESA x2	ESA	ESA	ESA	ESA	ESA	ESA
1995		ESA x2			TM	TM	TM	TM	ESA	ESA	ESA	
1996			ESA		ESA	ESA	ESA+	ESA		ESA x2	ESA	
1997	ESA	ESA x2	ESA x2		ESA	ESA x2	ESA x2	ESA	ESA x2			
1998		ESA	ESA x2						ESA	ESA x2		ESA
1999	ESA		ESA	ESA	ESA	ESA	ESA	ETM+	ESA	ESA	ETM+	ETM+/TM
2000	ETM+	ETM+	ESA	ESA	ETM+ x2	ESA	ETM+	ETM+	ETM+	ESA+	ESA	ETM+
2001	ETM+			ESA+	ESA	ETM+	ESA	ETM+	ETM+		ETM+	
2002		ETM+	ETM+	ETM+	ETM+	ETM+	ETM+		ETM+			
2003				ETM+	ETM+		TM x2	TM		TM	ETM+	
2004	ETM+			ETM+		ETM+			ETM+	ETM+		ETM+
2005	ETM+					ETM+	ETM+		ETM+		ETM+ x2	ETM+
2006	ETM+				ETM+	ETM+ x2					TM/ETM+	TM/ETM+
2007	TM	TM	TM	TM	TM x2	ETM+	TM	ETM+	ETM+		ETM+	ETM+
2008			ETM+	ETM+		ETM+	ETM+x2	ETM+		ETM+	ETM+	ESA
2009	ESA		ETM+/	ETM+x2	ETM+	TM	TM x2	TM x2	TM	TM	TM	ETM+
2010	TM		ETM+	TM/ETM+	TM	TM x2	TM		ESA	ETM+	ETM+	TM
2011		TM	ETM+	TM	TM	TM	TM		TM	TM	TM	ETM+
2012	ETM+	ETM+ x2		ETM+		ETM+	ETM+	ETM+ x2/TM	ETM+/TM			ETM+
2013	ETM+ x2	ETM+		OLI	OLI	OLI	OLI x2	OLI x2	OLI	ETM+	OLI	OLI
2014	OLI	ETM+	ETM+	ETM+	OLI x2	OLI x2	OLI	OLI x2	OLI	OLI x2		OLI x2
2015	OLI	OLI x2	ETM+ x2	OLI		OLI	OLI x2	ETM+	OLI			

Good	Area is free of clouds	OLI	Landsat 8
Useful	Small cloudy areas, most free	ETM+	Landsat 7
	Not available or too much clouds	TM	Landsat 4-5
		MSS	Landsat 1-3
		ESA	Landsat TM available on ESA
	Reference year	ESA+	Landsat ETM+ available on ESA
	Areas with errors		

Table 2: Water Quality parameters between 1997-2011, no values present gaps in the parameter value.

WQ indicators	units	1997	1998	1999	2000	2000	2003	2004	2007	2009	2010	2011
Temp. Water	°C	19,9	26,0	19,1	22,2	0,0	13,4	11,6		8,4	11,6	
Temp. Aire	°C	19,9	21,1	17,5	22,0	33,0	21,5	13,0				
pH (pH)		8,1	7,9	8,9	9,3	9,0	7,8	7,9		9,4	8,6	
Alcalinity	ÁM/mg CaCO3/L	2,8	3,3				1,9	4,2	2,5	61,7	87,0	
Conductivity	mS/cm	39,1	23,9	120,8	189,9	2,2	101,8	90,8		61,0	38,2	
Salinity	g/l	30,8	19,0				86,2	78,5	153,5	40,1	24,5	
Total Solids	mg/l	35354,8	16051,3	111942,0	265591,0		48348,8	92320,0	138920,0	24050,0	10000,0	
Solids in suspension	mg/l	627,8	207,8				96,3	244,0	96,5	204,0	48,8	
Dissolve Oxygen	mg/l	6,3	4,2	8,8	7,1		7,4	12,2		14,7	9,3	
Clorophile a	mg/m3	111,7	48,5				4,5	94,2	11,6	395,9	23,3	
Calcio	mg/l	845,9	511,9	1394,5	1249,6		1483,0	1372,5	1786,5	1136,8	952,0	841,0
Mg	mg/l	1493,9	671,1	3717,3	6941,4		3147,9	2909,1	6534,9	1838,3	1038,0	2159,0
Sodio	mg/l	8735,1	4421,3	23454,4	48126,0		27878,0	22846,0	36122,8	12389,0	6668,0	11761,0
Potasio	mg/l	48,5	70,6	55,3	95,3		111,7	136,5	272,6	122,8	85,0	128,0
Clorode (Cl-)	mg/l	17596,9	8423,5	59556,0	115942,8		49893,5	46385,0	63951,7	23159,5	14321,8	
Sulphate (SO4=)	mg/l	1881,6	1493,7	6011,0	8623,0		3572,5	4624,0	5119,9	3280,0	5462,0	
Carbonates	ÁM	0,0	0,0				6,0		21,0	2,0	15,0	
Bicarbonates	ÁM	2,8	3,2				100,7	256,3	107,1	61,7	106,0	
Nitrate (NO3-)	ÁM	76,1	161,6		55,7		0,1	0,0	0,1	0,0	0,2	5,4
Nitrits(NO2-)	ÁM	1,7	3,7				0,0	0,0	0,0	0,0	0,0	2,5
Ammonium (NH4+)	ÁM	50,2	140,6				3,3	15,0	1,2	0,2	0,5	4,3
Total nitrates	ÁM	720,7	990,0				7,0	14,6	7,7	2,1	3,4	7,8
Phosphat (PO4-)	ÁM	6,1	22,4	10,0	4,2		0,0	1,5	0,1	0,0	0,0	0,0
Total phosphat	ÁM	40,3	54,6				0,1	1,2	0,1	0,3	0,1	0,6
(Si)	ÁM	208,8	155,9	8,4	42,0		0,8	3,3	0,3	0,5	0,7	4,6
(Cu)	mg/l	51,7	457,5	11,3		11,7	0,2	0,2	0,2	0,0	0,0	

Cinc (Zn)	mg/l	3721,6	3531,6	14,4		19,6	0,0	0,1	0,0	0,0	0,0	0,0
Manganeso	mg/l	26750,1	38884,3			28,8	0,2	0,3	0,3	0,0	0,1	0,4

Figure 3: Water Quality parameters, showing high concentration of several water quality parameters during the years 1997 and 2010 / 2011. High values of Nitrate and Phosphate are shown for the years between 1997 and 2000 followed by decrease in the values for the following years.