EVALUATING IMPLICATIONS OF CATCHMENT LAND USE AND LAND COVER CHANGES ON ABUNDANCE AND BREEDING OF GREATER FLAMINGO (*Phoenicopterus ruber roseus*) AT FUENTE DE PIEDRA LAGOON, SPAIN

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By

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Abstract

Temporal and spatial changes in land use in an area over time have been associated with detrimental environmental impacts. Such effects include impacting on water resources eventually on biodiversity present as catchment irrigated lands dramatically increase against limited water reserves. In this study, the intensification of irrigated olive farming for the period 1984 to 2009 was presumed to impact on available groundwater resources, eventually impacting on the Greater Flamingo presence and breeding patterns in one of the major breeding grounds, Fuente de Piedra lagoon. Principal component analysis as a method of change detection indicated significant land use transitions in this catchment over the study period characterised by a drastic change from natural ecosystems of natural forests, shrub lands and heath lands to extensive monocultures of olive and increased urbanization. Single crop coefficient approach and up-scaling of sap flow methods integrated with remote sensing used to quantify temporal olive evapotranspiration potential indicate an increasing trend from 1.1 Hm^3 in 1984 from an olive extent of $30km^2$ to $3.8Hm^3$ in 2009 from an olive extent of $70km^2$. This against annual precipitation was observed to have a negative relationship, therefore then inferred to impact on lake water levels; being a closed basin that heavily depend on precipitation among other factors for surface water retention. Statistical analyses indicate a positive correlation between high lake water levels and presence and successful breeding of the Greater Flamingo in this lake. Increased olive evapotranspiration was found to heavily impact on available groundwater resources resulting to drastic decline in monthly lake water levels. This results to constrained food availability and declining habitat suitability for the breeding flamingos eventually causing sporadic presence and/or complete abstinence from breeding of the Greater flamingo over time. This eventually impacts on the recruitment potential of this population that over time could lead to its disappearance from this lake. Understanding the drivers and implications of land use and land cover changes in an area may provide the only solution to better land management strategies. This study recommends further research on reliability of irrigation systems in optimizing water application to enhance equity in allocation of a limited resource, water.

Keywords: Land-use, land-cover, principal component analysis, olive evapotranspiration, sap flow, Greater flamingo.

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List of Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CO2	Carbon dioxide
DBH	Diameter at Breast Height
EC	European Community
ECW	Enhanced Compressed Wavelet
EEC	European Economic Community
ET	Evapotranspiration
ET_o	Reference Evapotranspiration
ET_c	Crop Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization
ISODATA	Self-Organizing Data Analysis Technique
K_c	Crop coefficient
LAI	Leaf Area Index
LWF	Lake Water fluctuations
MSS	Multi Spectral Scanner
PCA	Principal Component Analysis
PC	Principal Components
PET	Potential Evapotranspiration
PM	Penman Monteith
RA	Extra-terrestrial radiation
ROI	Regions of Interest
RMSE	Root Mean Square Error
SPOT	Satellite Probatoire d'observation de la Terre
TM	Thematic Mapper
UNEP	United Nations Environmental Programme
UNESCO	United Nations Education, Scientific and Cultural Organization
UTM	Universal Traverse Mercator
VNIR	Very Near Infra Red
WGS	World Geodetic System
WLF	Water level fluctuation
WWF	World Wildlife Fund

1.0 Introduction

1.1. Background

Wetlands are dynamic wildlife systems both in time and space that are increasingly under threat due to climate change as well as human- induced changes to their hydrology (Gilvear & Bradley, 2000), with amounts of water available determining salinity levels, sedimentation and the temporal presence of water of variable depths (Bechet & Johnson, 2008). As global biodiversity hotspots, wetlands around the Mediterranean serve as important habitats for over 100 species of water birds of the Palaearctic –North African-Middle Eastern regions (Childress *et al.*, 2008).They serve as important feeding grounds, breeding, and stop-over points for both resident and migrating birds among a host of other ecosystem services. Among the birds that utilize these wetlands is the Greater Flamingo (*Phoenicopterus ruber roseus*), which uses them as feeding as well as breeding grounds.

The Greater Flamingo as described by Childress et al. (2008) is one of the most beautiful and enigmatic bird in the entire African –Eurasian region. It is listed in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II that stipulates the need for protection of the species and is considered to be threatened and likely to become endangered if factors affecting its survival are not controlled. As specialists, their diet mainly constitutes algae and tiny animals such as shrimps, molluscs and insect larvae which live in mud at the bottom of shallow pools. They are highly gregarious and their successful breeding is pegged on favourable conditions such as suitable water levels and food availability within or in the vicinity of their breeding sites and especially during the breeding season (Cezilly *et al.*, 1996; Martos & Johnson, 1996). They breed at large saline lakes, but can feed in a large variety of shallow lakes and lagoons either inland or coastal. Flamingos are generally non-migratory birds. However, due to changes in climate and water levels in their breeding areas, the establishment of their breeding colonies becomes sporadic (Rendón *et al.*, 2001). Drought conditions may thus force some flamingo populations to relocate. The Greater Flamingo only breeds at a few wetlands within its Mediterranean distribution range. The Camargue (France) and the Fuente de Piedra Lake in Spain are the main Greater Flamingo breeding sites within the western Mediterranean (Cezilly *et al.*, 1996; Rendón *et al.*, 2001).

Fuente de Piedra (Malaga Province , Spain; 37°06"N 4°45"W) is a shallow temporary saline lake located in an endorheic basin in the south of Spain that depicts frequent seasonal drought and a high degree of unpredictability (Garcia & Niell, 1993) and whose seasonal behaviour is strongly dependent on the annual hydrological budget (Garcia *et al.*, 1997). It is the only interior, seasonal lagoon in Europe where Greater Flamingos breed regularly (Rendón *et al.*, 2001). In some years it hosts the largest colony in the western Mediterranean (mean 1996-1997= 16,700 pairs, 13,260 chicks) (Rendón *et al.*, 2001). Fuente de Piedra salt lake as described by Childress *et al.*(2008) exhibits a number of characteristics which make it one of the most important breeding sites in the Mediterranean range. First, the lake has a great extension of 1,350 ha and isolated islets that provide very suitable nesting areas for flamingos. Further, most of the breeding colonies location coupled with suitable water levels are at large distances from the shoreline making it difficult for terrestrial predators to arrive which may affect adult and chick survival. Finally, the proximity of the lake to a chain of other wetlands in the centre of Andalusia enables flamingos to exploit resources available at different wetlands when raising the chicks.

Like other wetlands elsewhere in the world, Fuente de Piedra Salt Lake is also facing challenges of land use[1] and land cover[2] changes within its catchments. Olive *(Olea europaea L)* grove plantations which heavily rely on irrigation are expanding rapidly at the expense of conservation of protected areas and the biodiversity therein. Since joining the European Economic Community (EEC) in 1986, Spain's olive grove production intensified with a significant expansion of the area dedicated to olive growing. Irrigated olive and orchards plantation extents have increased significantly since 1980's from 80,000 to more than 323,000 hectares (Martinez Sanchez *et al.*, 2008) at present. This is attributed to the implementation of the Common Agricultural Policy (CAP) budget, which introduced strong productive incentives, characterized by high-density plantations, systematic irrigation and mechanized harvesting. Spain is by far the largest contributor to the olive oil market followed by Italy, Greece and Tunisia.

Olive production occupies 30% of the agricultural area in Andalusia; with major concerns on environmental impacts of severe erosion, water contamination and deficit and biodiversity loss (Martinez Sanchez *et al.*, 2008).This has subjected ecosystems such as wetlands to stresses through drainage and conversion to arable lands that has ultimately led to their degradation. Unending conflicts have thus arisen over time between pumping-based human developments and the awakening of an environmental awareness in society (Ngigi *et al.*, 2007)with the need to protect existing biodiversity. The way forward then for sustainable use of water resources, wetlands, and their biodiversity thus requires management approaches that incorporate explicitly the spatial and temporal interconnectedness among different ecosystems (Amezaga & Santamaria, 2000; UNESCO, 2005).

Change detection is one of the major applications of remotely sensed data that provides a useful management tool due to the repetitive coverage at short intervals and consistent image quality from Earth-orbiting satellites (Singh, 1989). Timely and accurate change detection of land cover is extremely important for understanding relationships and interactions between human and natural phenomenon and provides useful information for environmental protection, land planning, and decision-making at local, regional, national and global levels(Deng *et al.*, 2008).

1.2 Relevance of the research

Various land uses have negatively impacted on biodiversity causing their decline through the loss, modification and fragmentation of habitats, degradation of soil and water and the overexploitation of native species (Chapin Iii *et al.*, 2000; Hooper *et al.*, 2005). These land use changes as characterised by associated land covers are known to affect regional climates through changes in surface energy balance, affecting the partitioning of precipitation into evapotranspiration, runoff and groundwater flows as depicted by humans transforming the

[1] Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (Gregorio & Jansen, 2000).
[2] *Land Cover is the observed (bio) physical cover on the earth's surface* (Gregorio & Jansen, 2000).

hydrological cycle to provide freshwater for irrigation, industry and domestic use (Foley *et al.*, 2005).

Water scarcity, as portrayed in the Fuente de Piedra catchment, especially in the lower reaches of its major rivers has thus increased over the years resulting to conflicts between upstream and downstream water users. The dynamics in catchment land uses and their resultant water crisis is attributed to increasing farming activities; especially intensified olive farming, in this water deficit area where rain-fed agriculture is not sustainable. Water abstractions for irrigation thus have become a common phenomenon consequently reducing river and groundwater flows especially during dry periods. Ultimately then, the natural environment, in this case the Fuente de Piedra lake and the biodiversity it contains, have thus been threatened by both water withdrawals and water pollution (UNESCO, 2005). Water management in the olive orchards has thus become one of the issues where farmers, agronomists, and environmentalists demand more information. This is so taking into account the need for water saving in the areas where the olive is usually grown, as well as for the significant improvement in crop performance when the trees are irrigated (Fernandez & Moreno, 2000).

Conservation of biodiversity critically depends on sufficient knowledge of the spatial and temporal distribution and abundance of species. To effectively manage species it is often necessary to improve current understanding of factors influencing their abundance and distribution, thus providing a baseline for long-term monitoring for changes in status and trends. Large –scale processes, such as climate, land –use and land cover change, are believed to be drivers of species population dynamics at landscape to regional scales (Schrag *et al.*, 2009).Further, examples from ecosystems that have incurred similar changes suggest that these processes can be detrimental to indicator species such as birds (Schrag *et al.*, 2009). It is thus imperative then to establish a baseline relationship between these drivers and bird populations against which future changes may be compared.

Fuente de Piedra hosts an important flamingo colony whose establishment and success largely depend on conditions within the lake as well as other Andalusian Wetlands (Martos & Johnson, 1996; Rendon-Martos *et al.*, 2000).

This research study hence intended to establish the link between temporal and spatial changes in the catchment land use and its implications on population dynamics of the greater flamingo in this salt lake.

1.3 Research Objectives

The main objective of this research was to evaluate whether temporal and spatial catchment land use and land cover changes have any effect on the abundance and breeding success of the greater flamingo at Fuente de Piedra Salt Lake.

1.3.1. Specific objectives

To fulfil the main objective, the following specific objectives were formulated:

- To map actual land use and land cover in the lake's catchment.
- To establish temporal and spatial land cover changes around the lake catchment for the period 1984 to 2009.
- To establish relationship between land cover changes and lakes' water level fluctuations.
- To establish the relationship between lake water levels and flamingo population dynamics
- Evaluate the relationship between land cover change and Greater flamingo population abundance and breeding success.

1.3.2 Research questions

The following summarizes formulated research question for this research study.

- How has land use in this study area changed over the period 1984 to 2009 and what are its trends?
- What is the relationship between land cover changes and water fluctuations of the lake?
- What is the relationship between lake water levels and flamingo populations and its breeding patterns over time?
- What is the effect of catchment land cover changes on population and breeding success of the greater flamingo in this lake?

1.3.3 Hypothesis

In order to answer each research questions, the following hypothesise were formulated:

1. **H_0:** There is no significant change in land cover in the lakes' catchment area over the period 1984 to 2009.

   H_1: There is significant change in land cover in the lakes' catchment area over the period 1984 to 2009.
2. **H_0**: There is no relationship between temporal and spatial catchment land cover changes and temporal lakes' water fluctuations.

   H_1: There is relationship between temporal and spatial catchment land cover changes and temporal lakes' water fluctuations.
3. **H_0**: There is no relationship between lake water levels, breeding success and population of greater flamingo in this lake over time.

   H_1: There is a relationship between lake water levels, breeding success and population of greater flamingo in this lake over time.
4. **H_0**: There is no relationship between catchment land cover change and population and breeding success of the greater flamingo in this lake.

   H_1: There is a relationship between catchment land cover changes and population and breeding success of the greater flamingo in this lake.

1.3.3 Report structure

The following summarizes the organization of this thesis:
Chapter one is a brief overview of the scientific background for this study; the relevance of this research based on a wide scientific perspective, formulated objectives, hypothesis and associated research questions.

Chapter two details the background based on literature review of land use and land cover changes and its implications on water resources and biodiversity. It further gives a highlight on the dynamics of olive farming in Spain.

Chapter three describes the study area in terms of its location, geomorphology and hydrological systems and its flora and fauna diversity.

Chapter four describes the research methodology describing the materials and methods used in image analysis, crop water requirements estimations and secondary datasets used in further analysis.

Chapter five presents results of analysis carried out. It describes catchment land use and land cover changes for the period 1984 to 2009, with corresponding thematic maps and change detection statistics. It further describes results of two comparative methods of quantifying catchment olive evapotranspiration potential and its impacts on lakes' water level fluctuations and subsequently its relationship with the greater flamingo dynamics in this lake. Results on statistical analysis depicting predictor variables for two models on lake water levels and flamingo numbers are also presented.

Chapter six discusses the results obtained on catchment land use and land cover changes and its relationship with the monthly and inter-annual lakes' water fluctuations and how it impacts on the dynamics of the greater flamingo breeding in this lake.

Chapter seven summarizes the conclusions drawn from the discussions and puts forward some recommendations on mitigating implications associated with the catchment land use and land cover changes. This details the answers to the research questions, tested hypothesis and to what degree the objectives were achieved.

2.0 Literature review

2.1 Land use and land cover: An overview

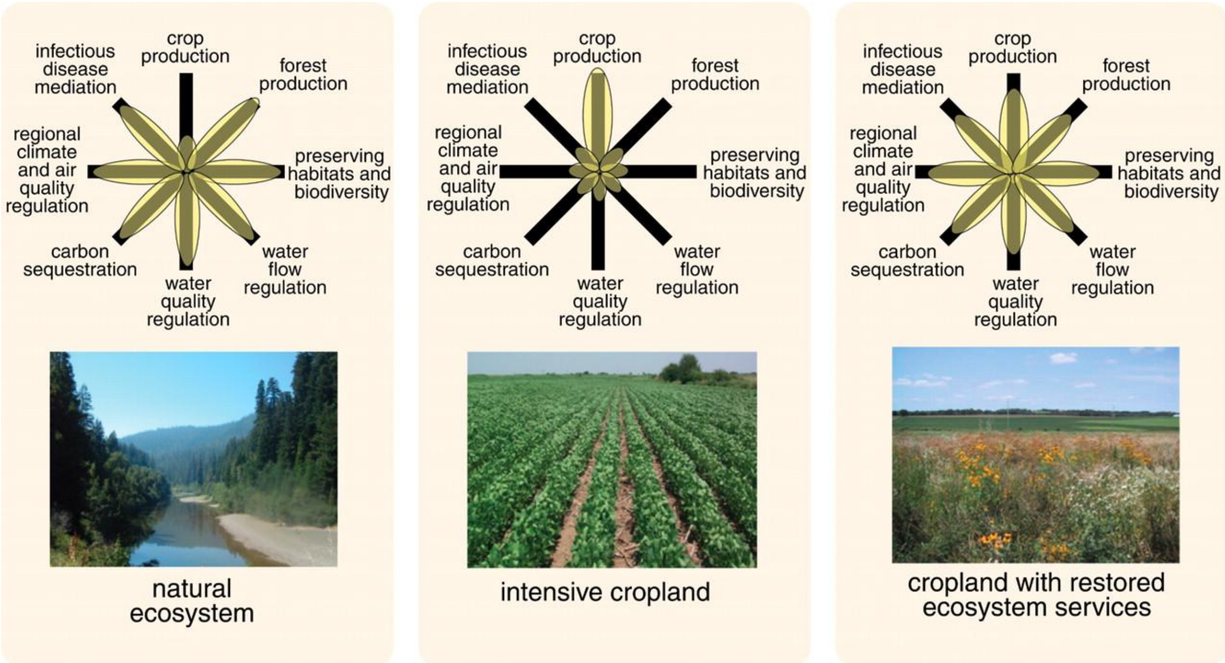
As described by Foley *et al.*(2005), land use activities; whether converting natural landscapes for human use or changing management practises on human-dominated lands, have transformed a large proportion of the planets land surface. This has been characterised by the clearing of tropical forests, intensified agriculture and farmland production, expanding urban centres, resulting to transformed landscapes over time. Lambin *et al*. (2001), further notes that land use and land cover changes are so encompassing that, they significantly affect key aspects of the Earth systems. These include directly impacting on global biotic diversity (Sala *et al.*, 2000a), contributing to both local and regional climate change (Foley *et al.*, 2005)as well as causing global climate warming (Chapin *et al.*, 1992; Turner *et al.*, 1994). This is because land cover is a fundamental variable that impacts on and links many parts of the human and physical environment. Its temporal and spatial change has been regarded as the single most important variable of global change affecting ecological systems (Vitousek, 1994) with an impact on the environment that is as large as that associated with climate change (Foley *et al.*, 2005). Despite its form, whether clearing of tropical forests, practicing subsistence agriculture, intensifying farmland production or expanding urban centres; all these are geared towards one main goal; the acquisition of natural resources for immediate human needs remains primarily the sole driver of land use changes , that is often at the expense of degrading environmental conditions (Foley *et al.*, 2005).

Intensive research over time has revealed the possible global environmental impacts of land use ranging from changes in atmospheric composition to the extensive modification of Earth's ecosystems[3] (Vitousek, 1994). For instance, land –use practises have played a role in changing the global carbon cycle with an estimated 35% of anthropogenic CO2 emissions resulting from direct land use and consequently impacting on the global climate (Foley *et al.*, 2005). Land cover changes are known to affect regional climates through changes in surface energy and water balance, with humans transforming the hydrological cycle to provide freshwater for irrigation, industry and domestic use. Anthropogenic nutrient inputs to the biosphere from fertilizers and atmospheric pollutants have widespread effects on water quality of coastal and freshwater ecosystems (Hooper *et al.*, 2005). Various land use have negatively impacted on biodiversity causing their decline through the loss, modification and fragmentation of habitats, degradation of soil and water and the overexploitation of native species (Chapin Iii *et al.*, 2000; Hooper *et al.*, 2005).

Despite the significance of land cover as an environmental variable, our knowledge of land cover and its dynamics is poor. Understanding the significance of land cover and predicting the effects of land cover change is particularly limited by the paucity of accurate land cover data (Foley *et al.*, 2005). Quantitative assessment will lead to a deeper and more robust understanding of land-use and land-cover change and to help put forward more appropriate policy interventions. Improved understanding is also required to assess and project the future

[3] An ecosystem is a dynamic complex of plant, animal and micro-organism communities and the non –living environment interacting as a functional unit (WorldBank, 2006).

role of land-use and land-cover change in the functioning of the Earth system (Lambin *et al.*, 2001; Veldkamp & Lambin, 2001). Confronting the global environment challenges of land use will require assessing and managing inherent trade-offs between meeting immediate human needs and maintaining the capacity of ecosystems to provide goods and services in the future (Foley *et al.*, 2005; Lambin *et al.*, 2001). Foley *et al*.(2005), developed a conceptual framework for comparing land use and trade-offs of ecosystem services; with the provisioning of multiple ecosystem services under different land-use regimes. Figure 2-1 below depicts a comparison of three hypothetical landscapes and promotions of supported ecosystems.



Adapted from (Foley *et al.*, 2005)

Figure 2-1: Conceptual framework for comparing land use and trade-offs of ecosystem services

He illustrates the provisioning of multiple ecosystem services under different land-use regimes with simple “flower” diagrams in which the condition of each ecosystem service is indicated along the axis (in this qualitative illustration, the axes are not labelled or normalized with common units). Three hypothetical landscapes; a natural ecosystem, an intensively managed cropland and a cropland with restored ecosystem services are compared. The natural ecosystems are able to support many ecosystem services at high levels but no food production. The intensively managed cropland, however, is able to produce food in abundance (at least in the short run), at the cost of diminishing other ecosystem services. However, a compromise, a cropland that is explicitly managed to maintain other ecosystem services-may be able to support a broader portfolio of ecosystem services.

Based on the above depicted illustrations land-use planners can model future landscapes and derive associated policies that support a win-win situation for all. Land use change modelling, especially if done in a spatially-explicit, integrated and multi-scale manner, is an important technique for the projection of alternative pathways into the future, which better our understanding of the interaction of key processes in land use changes (Veldkamp & Lambin, 2001).

2.1.1 Impacts of intensified food production

Croplands and pastures have been noted as together comprising one of the largest terrestrial biomes on the planet, rivalling forest cover in extent and occupying ~40% of the land surface (Foley *et al.*, 2005). Population pressure, disparities in access to the more productive lands, and civil strife have all pushed farmers into cultivating ever-steeper slopes for small-scale food production (WorldBank, 2006). An estimated ~12% increase in world cropland mostly driven by the "Green Revolution technologies" characterised by high-yielding cultivars, chemical fertilizers and pesticides, mechanization and irrigation are widely to blame for subsequent land degradation (Lambin *et al.*, 2001). Although modern agriculture has been successful in increasing food production, it has also caused extensive environmental damage. For instance, increasing fertilizer use has led to the degradation of water quality in many regions (Lambin *et al.*, 2001; WorldBank, 2006). Some irrigated lands have become heavily salinized causing the worldwide loss of an estimated 1.5million hectares of arable land per year corresponding to an estimated $ 11 billion on lost production (Foley *et al.*, 2005). Soil erosion, reduced fertility or losses of native habitats by degrading the services of pollinators have also been blamed on intensified[4] agricultural production. In conclusion, it has been observed that the current modern agricultural land-use practises may be trading short-term in increases in food production for long-term losses in ecosystem services, including many that are important to agriculture.

2.1.2 Impacts on water resources

As noted by Foley *et al*.(2005), land use can disrupt the surface water balance and the partitioning of precipitation into evapotranspiration, runoff and groundwater flow. He further notes that surface runoff and river discharge generally increase when natural vegetation; especially forest is cleared. Water demands associated with land use practises, such as irrigation, directly affects freshwater supplies through water withdrawal and diversions. In the global context, water withdrawals now total ~ $3900km^3yr^{-1}$ equivalent to approximately 10% of the total global renewable resources with the consumptive proportion of water; that is not returned to the watershed, being estimated at approximately 1800 to $2300km^3yr^{-1}$ (Foley *et al.*, 2005).He further states that agriculture alone is estimated to account for approximately 85% of global consumptive water use resulting to reduced flows in major rivers, some drying up completely. This is particularly so in areas where crop, livestock and forestry productivity is constrained by drought and recurring water deficits, necessitating irrigation from groundwater extraction for increased productivity (WorldBank, 2006). Nevertheless he acknowledges that extraction of groundwater reserves is almost universally unsustainable and has resulted in declining water tables in many regions.

2.1.3 Impacts on biodiversity

The abundant diversity of life forms that have evolved on Earth is beginning to disappear as a consequence of anthropogenic climate change and more directly as a response to anthropogenic modifications of natural habitats (Dobson, 2005; Vitousek, 1994). Identifying the drivers of change in biodiversity is paramount in monitoring its changes over time in a given area. (Sala *et al.*, 2000b) identified five most important determinants of changes in

[4] Intensification is defined as higher levels of inputs and increased output ; in quantity or value; of cultivated or reared products per unit area and time(Lambin *et al.*, 2001).

biodiversity at the global scale as changes in land use; atmospheric CO_2 concentrations, nitrogen deposition and acid rain, climate and biotic exchanges (deliberate or accidental introduction of plants and animals to an ecosystem). The conversion of approximately 50% of total global land to agricultural land by the year 2100 ranks land use as the major driver of change in biodiversity (Sala *et al.*, 2000b). The Convention on Biological Diversity (CBD) 2010 Biodiversity Targets set a major challenge to the ecological and conservation community by requesting a detailed understanding of rates of biological change by 2010 (UNEP, 2003). As biodiversity declines through habitat modification and other anthropogenic disturbances, the need to quantify the changes in goods and services that impact on human health and economic gains as a result of the losses should be considered (Dobson, 2005). Dobson, (2005) further cites recommendations in CBD that in quantifying biodiversity loss as described through its CBD 2010 Biodiversity indicators it seeks to measure changes at a hierarchy of levels; from species population sizes, through to the distribution and condition of habitats to changes in rates of delivery of goods and services to the human economy.

2.2 Olive grove farming in Spain

2.2.1 Olive grove characteristics

As stated by Beaufoy (1998a),olive production is a significant land use in the southern member states of the EU with important environmental, social and economic considerations. Spain leads with an approximate 2.4 million hectares of olive production, followed by Italy (1.4 million ha), Greece (1 million ha), and Portugal (0.5million ha). Olive farm sizes range from the very small (0.5ha) to the very large (>500ha) and from the traditional, low-intensity groves to the intensive, highly mechanized plantations. Beaufoy (1998a), further categorized them into the following three broad types:

- Low-input traditional plantations and scattered trees, often with ancient trees and typically planted on terraces, which are managed with few or no chemical inputs, but with a high labour input.
- Intensifies traditional plantations which to some extent follow traditional patterns but under more intensive management making systematic use of artificial fertilisers and pesticides and with more intensive weed control and soil management. There is a tendency to intensify further by means of irrigation, increased tree density and mechanized harvesting.
- Intensive modern plantations of smaller tree varieties planted at high densities and managed under an intensive and highly mechanized system, usually with irrigation.

He states that as a result of their particular plantation characteristics and farming practises, the low-input traditional plantations have potentially the highest natural value (biodiversity and landscape value) and most positive effects (such as water management in upland areas) as well as the least negative effects on the environment. These plantations are also the least viable in economic terms and hence most vulnerable to abandonment.

The intensified traditional and modern intensive systems are inherently of least natural value and have potentially, and in practise, the greatest negative environmental impacts, particularly in the form of soil erosion, run-off to water bodies, degradation of habitats and landscapes and exploitation of scarce water resources. The broad picture for the olive sector is of intensified production leading to certain negative effects on the environment (EC, 1999).

2.2.2. Economics of olive production

Beaufoy (1998a), acknowledges that despite the negative environmental impacts associated with the sector, olive production is an important economic sector in many rural areas in the Mediterranean. The olive sector has developed rapidly in recent years in the main producing regions of Andalucía, with notable increases in both productivity and quality of production. Olive farming provides an important source of employment in many rural areas of the Mediterranean, including many marginal areas. It is also an important part of local rural culture and heritage in many areas. Tree densities and planting patterns depend partly on local traditions but water availability is also a determining factor: under rain-fed cultivation, the lower the rainfall, the lower the tree density should be, by necessity (Martinez Sanchez *et al.*, 2008).

Traditionally, olive plantations characterized dry land farming and were not irrigated, except in certain situations where water was readily available. However, irrigation with relatively small amounts of water enables plantations to produce much higher and more consistent yields (Beaufoy, 1998a; EC, 1999; Orgaz & Fereres, 1997). Many factors determine the variability in water use such as the irrigation system used, climatic and soil conditions, tree density etc. The amounts are estimated to range from under 1500m3 to over 5,000m3 per ha per year (Beaufoy, 1998a). Drip irrigation has been popularized on a large scale in some areas especially in new plantations and in traditional plantations which are being intensified and 'densified' (new trees planted in the lines between existing trees). Water sources for irrigation vary from different sources, including bore-holes, surface water courses and private and public reservoirs.

Average yields range from 200-500kg/ha/year in traditional plantations in marginal areas to as high as 8,000- 10,000kg/ha/year in the most modern, intensive plantations on good soils and with irrigation (Beaufoy, 1998a; Martinez Sanchez *et al.*, 2008). Consistency in yield is a very important factor in olive farming as it has been noted that olive trees have a natural tendency to produce the main harvest once every two years (Fernandez & Moreno, 2000). Management practises such as traditional pruning and harvesting practises tend to accentuate this tendency, so that harvests may be reduced to almost zero in the non-harvest year. Modern techniques such as mechanized harvesting combined with irrigation can reduce this fluctuating tendency greatly; modern intensive plantations with irrigation produce consistently high yields, even though there may be fluctuations from one year to another (Fernandez & Moreno, 2000; Martinez Sanchez *et al.*, 2008; Orgaz *et al.*, 2006; Ramos & Santos, 2009).

With the intensification in olive production the status of water resources (ground and surface) in the farmed areas becomes an important issues for consideration, both in terms of quantity (extraction and recharge rates) and quality (present contaminated status and vulnerability to contamination ,e.g. from leaching and run-off) notes Beaufoy (1998a) and Fernandez & Moreno (2000) . Average rainfall, evapo-transpiration and temperatures, as well as soil types and other factors, all have an influence on the benefits produced by irrigation and on the quantity of water consumed (Fernandez *et al.*, 1991; Fernandez *et al.*, 1997; Moreno *et al.*, 1996b; Pastor & Orgaz, 1994).

2.2.3: Olive farming and biodiversity

Beaufoy,(1998b) states that an analysis on the effects of a farming system on biodiversity should take account of the land-use pattern of the area in that the land-uses and habitat types adjacent to the olive plantations and the presence in the area of species of conservation importance. He notes that in common with many farming systems, olive plantations have a more potential to make a positive contribution to biodiversity when they exist in a mosaic with other land uses, such as arable cropping, other tree crops or forest. Similarly olive plantations may add landscape diversity when they are present in areas dominated by other land-uses, such as forest or arable land. On the other hand, where olive monocultures themselves dominate the landscape, the result tends to be a monotonous landscape with very limited visual diversity.

2.2.4 Policies on olive production

Spain joined the European Economic Community in 1986 and as Common Agricultural Policy (CAP) support for olive production in Spain came into force, it appears to have provided an incentive to increased production and new plantations have increased steadily while grubbing-out schemes ceased in the 1980s. New plantations have been created over large area of land previously under arable crops, grasslands, scrub and forest, particularly in provinces with a high concentration of commercially oriented producers (Martinez Sanchez *et al.*, 2008). In some cases, natural vegetation is cleared illegally to make way for new plantations. Overall, these figures indicate an average planting rate during the 1990s of about 50,000ha per year (Martinez Sanchez *et al.*, 2008). He further states that new plantations are being established even though under the 1998 interim reform of the support regime subsequent plantations cannot receive CAP aid. WWF (2004) raises concern that if the current production aid continues, it will be very difficult for the authorities to prevent these plantations from receiving production support as there is no system for knowing which trees a particular delivery of olives has come from. Intensification has been widespread in Spain since the 1980s. Irrigation is becoming increasingly widespread in lowland areas and is standard in new plantations.

2.3 Use of Remote Sensing in change detection

As described by Singh (1989) and Lu *et al.*(2004), change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. It encompasses the application of multi-temporal datasets to quantitatively analyse the temporal effects of a phenomenon. Because of the advantages of repetitive data acquisition, its synoptic view, and digital format suitable for computer processing, remotely sensed data, such as Thematic Mapper (TM), Satellite Probatoire d'Observation de la Terre (SPOT), radar and Advanced Very High Resolution Radiometer (AVHRR) , have become the major data sources for different change detection applications during the past decades (Lu *et al.*, 2004). Timely and accurate change detection of the Earth's surface features is extremely important for understanding relationships and interactions between human and natural phenomena in order to promote better decision making in management and use of natural resources (Deng *et al.*, 2008; Lu *et al.*, 2008; Lu *et al.*, 2004). Remote sensing data are primary sources extremely used for change detection in recent decades. A variety of change detection techniques have been developed and many have been summarized and reviewed (Green *et al.*, 1994; Lu *et al.*, 2004; Singh, 1989).Previous studies have shown that image differencing, principal component analysis and post- classification comparison are the most common methods used in change detection (Lu *et al.*, 2004)..Different change detection algorithms have their own merits and no single approach is optimal and applicable to all cases.

Remote sensing is considered an attractive source of thematic maps such as those depicting land cover as it provides a map-like representation of the Earth's surface that is spatially continuous and highly consistent, as well as available at a range of spatial and temporal scales. Modelling, especially if done in a spatially explicit, integrated and multi-scale manner, is an important technique for the projection of alternative pathways into the future, for conducting experiments that test out understanding of key processes and for describing the latter in quantitative terms (Lambin *et al.*, 2001; Veldkamp & Lambin, 2001). They offer the possibility to test the sensitivity of land-use patterns to changes in selected variable though by definition, any model falls short of incorporating all aspects of reality, it provides valuable information on the system's behaviour under a range of conditions (Veldkamp & Lambin, 2001).

2.4 Research flowchart

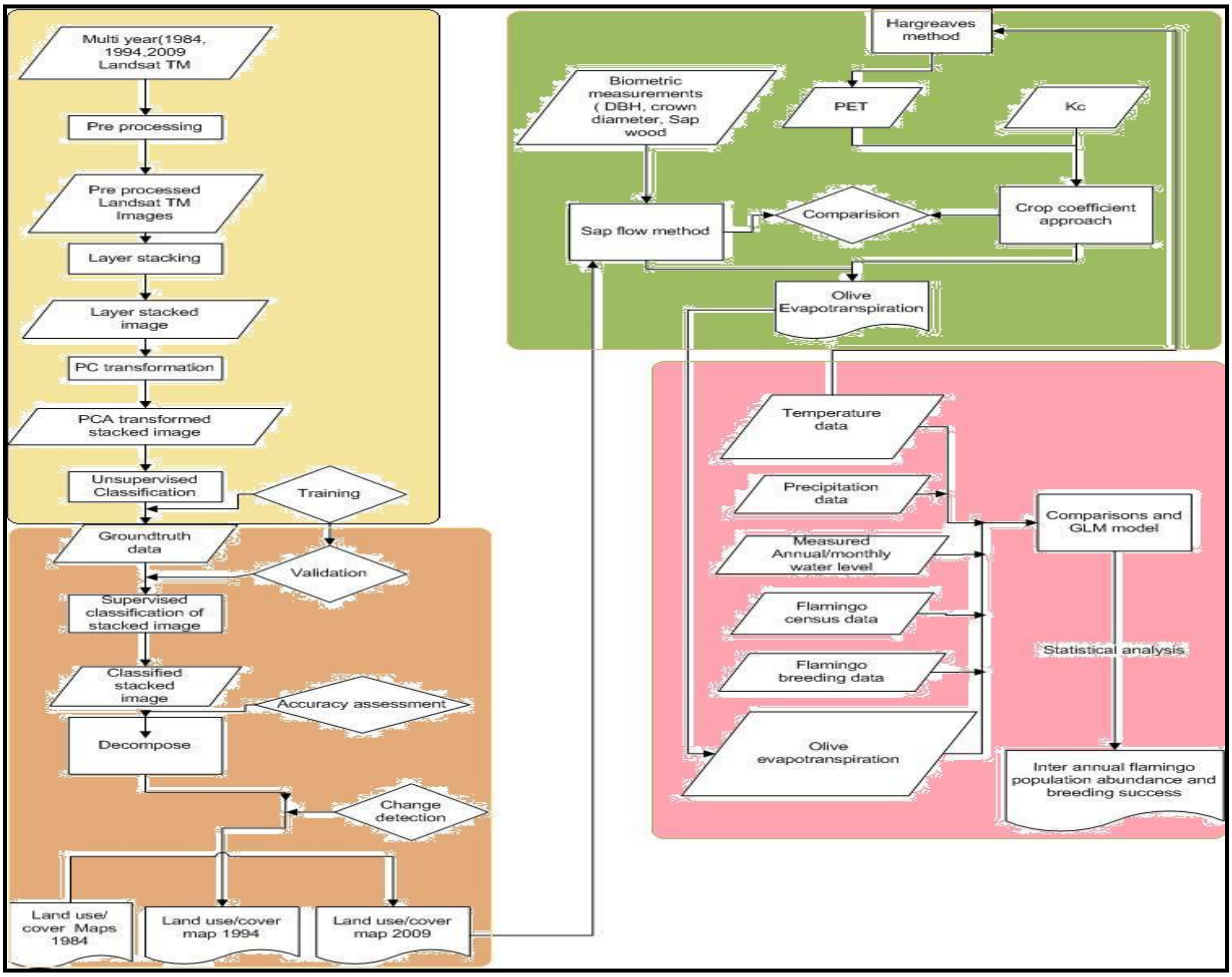
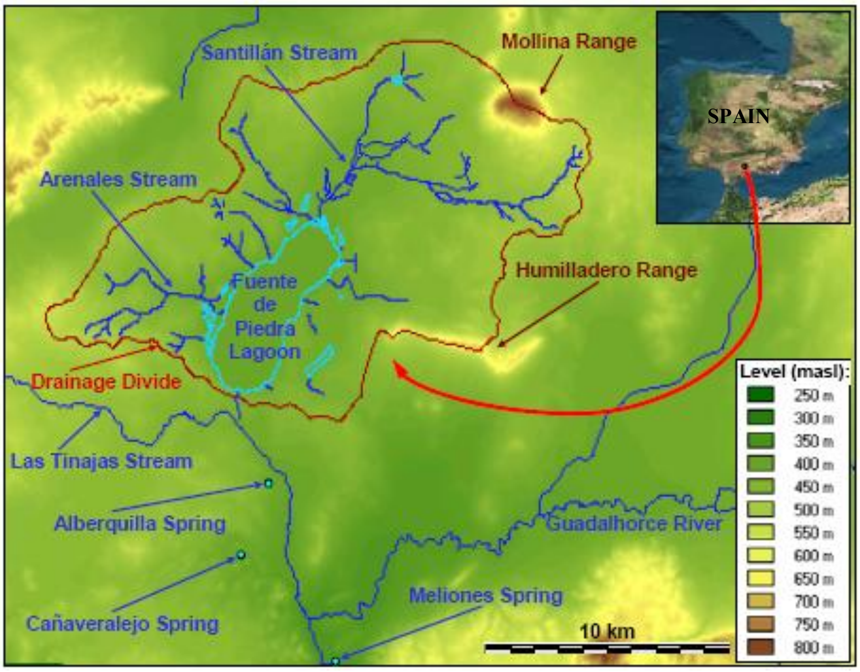


Figure 2-2: Research methodology flowchart

3.0 Study area

3.1 Location

Fuente de Piedra lagoon is a very shallow lake situated in an endorheic basin in the southern part of the Iberian Peninsula (37°06''N and 4°45''W) in the province of Malaga, Spain. It is a temporary playa lake with a mean depth of 2.4m and lies at an altitude of 400m above sea level with a surface area of 13.5km^2 and catchment coverage of 150km^2. It is highly dependent upon rains for flooding; and thus characterized by irregular cycles, with frequent seasonal drought and a high degree of unpredictability (Garcia & Niell, 1993). Figure 3-1 depicts the hydrological and catchment extent of Fuente de Piedra lagoon.



Source: (Heredia *et al.*, 2004)

Figure 3-1: Location and geographic features of the Fuente de Piedra lagoon basin

3.2 Climate

The study area being located in Western Mediterranean depicts a semi-arid climatic condition characterized by mean precipitation of 450mm, with December and February being the months with the highest rainfall averaging 60mm and 70mm respectively. The driest months are July with average values invariably below 5mm followed by August with 5mm to 6mm. Mean annual average temperatures varies between 15° to 17°C with the coolest months being December (9.3°C), January (9°C) and February (10.1°C). The warmest month is August (26.1°C), followed by July (25.7°C) and September (22.6°C). The potential mean annual evapotranspiration value (according to Thornthwaite) is 820mm, July and August having the highest PET values. Mean evaporation rates range between 1200mm/year to 1450mm/year.

3.3 Hydrogeology

Fuente de Piedra lagoon combines the morphological and limnological characteristics of the very shallow lakes; having some infrequent episodes of permanence but usually becoming dry in the summer. The Santillan and the Arenales streams are the main feeder streams in the hydrological network, with 55km2 and 20km2 basins respectively. Its aquifer is made up of primarily of Upper Miocene calcareous sands and of Quaternary alluvial materials. Kasrtified Jurassic carbonate materials also outcrop over the basin and are also integrated in the hydrological system (Heredia *et al.*, 2004; ITGE, 1998). The basin is characterised by two aquifers; an upper one and a lower one depicting different flows systems in each (Heredia *et al.*, 2004). The lagoon is the system's natural point of discharge, replenished by rainfall, surface runoff from the basin and the subterranean flow from the aquifer, while evaporation remains its only form of discharge. The lagoon normally dries up during summer and the probability of retaining water in the lagoon in the low-water period depends on the surplus in the wet season (Heredia *et al.*, 2004).

3.4 Legal Status

In 1982 the lake was designated as a RAMSAR site, a wetland of international importance especially for waterfowl protection. The site is an important breeding ground for the Greater flamingo population among a host of other waterfowls. In 1984, it was declared "an Integral reserve" by the Andalusian parliament and later as a natural reserve in 1989. Under the Birds Directive of the European Environment Commission (EEC), it was designated as a Special Protection Area for birds with an area of 8,543ha (Beaufoy, 1998b).

3.5 Topography

The lake was previously used for production of salt dating back to the Roman times (Martos & Johnson, 1996). Previously there were no islands in the main part of the lagoon until the 18th Century when modifications were made after elevated areas to the South of the lake were found to impact on the flamingo's breeding success especially when the water levels are low. Major modifications included the building of canals and dykes to enhance salt mining until when it ceased in 1951. This later favoured the flamingo breeding in this lake as islets of earth were created when the canals were dredged providing suitable breeding grounds.

3.6 Vegetation

Although vegetation is absent from the playa surface during desiccation period, submerged angiosperms such as *Druppia drepanensis* colonize the flooded playa floor in some of these systems (Guerrero *et al.*, 2006; Rodríguez-Rodríguez *et al.*, 2006). The lake is dominated by a diversity in planktonic assemblages with high halotolerant phytoplankton species (*Dunaliella salina* and *D.viridis*) (Garcia *et al.*, 1997). Terrestrial vegetation in form of shrubs (*Tamarix Africana, Nerium oleander*) and reeds (*Juncus sp., Phragmites sp. and Typha sp*.) surrounds the maximum flooded area and other species from the *Quenopodiaceae* family ; *Salicarnia sp*.,*Sarconornia sp*., and *Arthocnemum sp*. (Rodríguez-Rodríguez *et al.*, 2006). The catchment is dominated by intensive monocultures and small proportions of mixed cropping. Oaks and Mediterranean shrubs also appear in limited areas.

3.7 Fauna

The lagoon is host to one of the largest Greater Flamingo breeding colonies in Europe; with almost 20,000 nesting in 1998, and an immense concentration of 50,000 adults and chicks in 2000. It is the second largest Flamingo breeding site in Europe after the Camargue in France. An approximate 170 bird species have been recorded here such as the cranes, grey herons, black-necked grebes, great crested grebes, teals, mallards, avocets, shovelers, red-crested pochards, white –headed ducks, marbled ducks, and wigeons.

4.0 Research Methodology

4.1 Land Use and Land Cover assessment

4.1.1. Data selection and Pre-processing

Primarily, remote sensing land-cover change detection requires the availability of two or more dates of imagery upon which the same area of land can be observed (Deng *et al.*, 2008; Fung, 1990; Green *et al.*, 1994). Mostly, the commonly used remote sensed data for change detection are MSS, TM, SPOT, AVHRR, radar and aerial photographs. In this study three, medium resolution, same sensor imageries; Landsat 5 TMs of September 1984; June 1994 and July 2009 were chosen for subsequent processing of catchment temporal and spatial land use and land cover change detection. The Landsat 5 TM has a repeat cycle of 16 days with 3 bands in the visible spectrum (Blue, 0.45~0.52; Green, 0.52~0.60; Red, 0.63~0.69) NIR (0.76~0.90), SWIR (1.55~1.75; 2.09~2.35) and Thermal band (10.40-12.50) with a spatial resolution of 30m. These temporal imageries were considered due to their relatively high spatial resolution, their easy availability, and the essence that they were having almost near anniversary acquisition dates. The data were geometrically corrected through geo-refencing them to the WGS_1984_UTM_ZONE_30N Projection Coordinate System and each image was further rectified using ground control points taken from a topographic map at 1:35000 scale. The images were also atmospherically corrected to minimize any atmospheric discrepancies between image acquisition dates. The three images were then resampled into the same 15-m spatial resolution using the nearest-neighbour method. An RMS error of 0.2 was achieved against the recommended less than 0.5 (Deng *et al.*, 2008; Green *et al.*, 1994; Lu *et al.*, 2004).Further image –to- image co-registration was undertaken to ensure that all images represented similar objects on the ground. Band 6, the thermal bands were not included in this study. All data were radiometrically normalized through sensor specific calibration in ENVI 4.6.1 software in order to reduce the radiometric discrepancies between the three data.

4.1.2 Principal Component Analysis (PCA) enhancement

PCA-based change detection has been used in change detection for many years and has become one of the most popular techniques because of its simplicity and capacity of enhancing the information on change and works on the premise of maximum variance in a finite number of orthogonal components based on eigenvectors analysis of the data correlation matrix. PCA attempts to reduce the dimensionality of a data set that often consists of large numbers of interrelated bands, whilst retaining as much as possible of the variation present in the data set (Deng *et al.*, 2008; Dewan & Yamaguchi, 2009; Im *et al.*, 2008; Li & Yeh, 1998; Lu *et al.*, 2004).This is achieved through transformation of existing data to a new set of bands, principal components (PCs), which are uncorrelated, and ordered so that the first few components retain most of the variation present in all the original bands (Deng *et al.*, 2008; Richards, 2005)

All three image bands were layer stacked together and transformed using forward principal component rotation in order to produce uncorrelated bands, to segregate noisy bands and to reduce the dimensionality of data sets. Forward PC rotation uses a liner transformation to maximize the variance of the data and uses correlation matrix when calculating the principal components.(Richards, 2005). High correlation was observed between images for the unchanged areas, and relatively low correlation between the significantly changed areas. The first four principal components were found to contain at least 99.9% of the variance and therefore were subset based on percentage Eigen values. The principal components were then standardized using the correlation matrix as studies have indicated that standardized PCA has a better alignment along the object of interest and appears more effective than unstandardized PCA for change detection (Deng *et al.*, 2008; Eastman & Fulk, 1993; Lu *et al.*, 2004).

4.1.3 Image classification for change –information extraction

4.1.3.1 Unsupervised classification

As described by Li & Yeh,(1998) and Lu et al,(2004) image classification applies to both post-classification and pre-classification change-detection approaches and can be performed using either supervised or unsupervised approaches. Although pre-classification spectral change-detection methods, such as PCA, actually enhance and concentrate the change information from original images, they have difficulty in labelling and obtaining “from-to” change class information, thus the appropriate selection of classification is crucial (Deng *et al.*, 2008; Lu *et al.*, 2004). Unsupervised classification using the Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm was used to determine classes by spectral distinctions inherent from the transformed components as the basis for further supervised classification of the images. The ISODATA has the potential to produce class signatures that are numerically separable in feature space, portrayed as unlabelled cluster map and therefore provide as a basic set classes that assist in further supervised classification for accurate change detection (Deng *et al.*, 2008; Lu *et al.*, 2005; Lu *et al.*, 2004). A total of 26 classes were derived based on a 50% pixel change threshold. The number of classes generated is crucial as it affects the capability of an ISODATA classifier for capturing most of the land-use variability from the image analysed (Li & Yeh, 1998; Yang *et al.*, 2003). Orthophotos from 2004, with a spatial resolution of 1 x 1m and agricultural statistics were used to assign probable land cover classes to the classified maps and whether changed or unchanged as described in the field procedures topic.

4.1.3.2 Land use and Land Cover field procedures

Sampling for vegetation species composition and percentage coverage for dominant vegetation species in the lagoon and its catchment area was conducted in the month of September 2009. This was done using stratified random sampling method on user-defined square quadrants or plots (Deng *et al.*, 2008; Lu *et al.*, 2008) whose size varied according to the vegetation life form being sampled. For trees a 20 x 20 meter quadrant was used, for shrubs a 10 x 10 metres, while for herbs a 1 x1 meter was used (Stehman, 1999). Random points were generated in ArcGIS 9.3 software based on the land use and land cover spectral changes as strata. The unsupervised map cluster and sampling points were loaded into an IPAQ for field data validation. Orthophotos of 2004 with a spatial resolution of 1 x 1 meter were compressed into Enhanced Compressed Wavelet (ECW) format and input into an IPAQ to guide in field land use and cover sampling. Raw data was entered both into the IPAQ and into derived data sheets. Appendix 4 depicts a sample of the field data sheets. Land use and land-cover percentages were analysed using MS EXCEL software for further use in image supervised classification.

4.1.3.3 Supervised Image classification

A total of 341 reference points were obtained during fieldwork depicting land use, land cover percentages and dominant land cover for supervised classification image validation (100points) and subsequent accuracy assessment (241points). The supervised classification of the multi-temporal stacked principal component image was undertaken using Maximum Likelihood Classification. Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. No probability threshold was chosen to ensure that all pixels were classified (Richards, 2005). Regions of interest (ROIs) were derived from the layer stacked PC transformed image as spectral signatures used for image classification. The ROIs were evaluated for separability, first using the n-D Visualizer where the distribution of the points within the ROIs and between ROIs was visually assessed. Further, statistical separability of the ROIs was assessed using the ROI separability option. It computes the Jeffries-Matusita and Transformed Divergence separability measures, which range between 0 and 2. Values greater than 1.9 indicate good separability, while values less than 1 indicate same cover components. The cover types with less than 1 separability were merged together as they indicate same cover type. The separability statistics were thus enhanced to between 1.5 and 2.0 indicating good cover type statistical separability (ENVI4.6.1Help). A total of 13 land cover types were thus derived as the final classes used in image classification. The statistics are shown in appendix.1.

The stacked classified image was later decomposed into the three time steps images; 1984, 1994 and 2009 using the interactive ROI tool in ENVI 4.6.1 software to generate the temporal land cover maps. The FAO Land Cover Classification System was used in deriving the final land cover classes for the temporal maps (Gregorio & Jansen, 2000). This classification is based on a string of classifiers, aimed at achieving a logical and functional hierarchical arrangement of land cover classes given their heterogeneity. The Modular-Hierarchical phase, in which land cover classes are created by the combination of sets of pre-defined classifiers based on the eight major land cover types as described by Gregorio & Jasen (2000), was used.

4.1.3.4 Change detection

The accuracy of change detection results depends on a number of factors among which are precise geometric registration between multi-temporal images, calibration or normalization between multi-temporal images, availability of quality ground truth data, complexity of landscape and environments of the study, change detection methods or algorithms used, analyst's skills and experience ,time and cost restrictions to name just a few (Lu *et al.*, 2004). In this study, change detection statistics were derived as a detailed tabulation of changes between two classification images using the computing change detection statistics function in ENVI 4.6.1. software.

4.1.3.5 Accuracy Assessment

Accuracy assessment forms a major component of thematic mapping from remotely sensed data (Foody, 2009; Stehman, 2009).As discussed in many remote sensing literatures (Foody, 2002; Kalkhan *et al.*, 1998; Koukoulas & Blackburn, 2001; Morisette & Khorram, 2000), there are many methods of accuracy assessment, the most widely promoted and used being that derived from a confusion or error matrix. Map accuracy comprises bias and precision and the distinction between the two is important as one may be traded for the other, as such it has been recommended that in the assessment and reporting of accuracy for products of remote sensed data, the error or confusion matrix and an additional, at least one quantitative metric of classification accuracy should be provided (Foody, 2002; Foody, 2009).In calculating the percentage of classes correctly classified, the values are calculated by dividing the pixel counts in each ground truth column by the total number of pixels in a given ground truth class as in equation 1.

(Equation 1)

$$Percentage\ correct = \frac{\sum_{k=1}^{q} n_{kk}}{n}\ x\ 100$$

User's accuracy is a measure indicating the probability that a pixel is in a class A given that the classifier has labelled the pixel into class A as in equation 2.

(Equation 2)

$$User's\ accuracy = \frac{n_{ii}}{n_{i+}}$$

The producer accuracy is a measure indicating the probability that the classifier has labelled an image pixel into class A given that the ground truth is class A as in equation 3.

(Equation 3)

$$Producer's\ accuracy = \frac{n_{ii}}{n_{+i}}$$

The kappa coefficient (k) is a metric measure of accuracy calculated by multiplying the total number of pixels in all the ground truth classes (N) y the sum of the confusion matrix diagonals (X_{kk}), subtracting the sum of the ground truth pixels in a class times the sum of the classified pixels in that class summed over all classes ($x_{k\Sigma}x_{\Sigma k}$) as in equation 4.

(Equation 4)

$$k = \frac{N\sum_K x_{kk} - \sum_k X_{k\Sigma} X^{\Sigma k}}{N^2 - \sum_k x_{k\Sigma} x^{\Sigma k}}$$

4.2Quantifying Olive actual evapotranspiration

The climatic variation in the Mediterranean regions as characterised by high temperatures and small precipitation has necessitated the correct evaluation of water losses by the crops as evapotranspiration (ET) to be of paramount importance (Allen *et al.*, 1998; Fernandez & Moreno, 2000; Rana & Katerji, 2000). As reviewed by Rana and Karerji (2000), there are various methods available for ET measurements and classified according to the used approach such as hydrological, micrometeorological and plant physiological methods. These include: soil water balance, weighting lysimeter, energy balance/Bowen ratio, aerodynamic method, eddy covariance, sap flow method, chambers system, Penman-Monteith model, crop coefficient approach and soil water balance modelling approach among others. As indicated by Rana and Karerji (2000), actual crop ET can be measured[5] (directly or indirectly) or estimated and a great variety of methods are available. The suitability of a method varies with its accuracy or cost or its suitability for given space and time scales. In directly or indirectly measuring ET, the following factors are considered; the soil water content and the physical characteristics of the evaporative surface (height, plant density, canopy roughness, albedo) and climatic variables; solar radiation, wind speed and thermodynamic characteristics of the atmosphere above the canopy (Allen *et al.*, 1998; Rana & Katerji, 2000). In addition, actual ET can be estimated by means of more or less complex models: whose accuracy is defined by the degree of empiricism in the used model or sub-model (Rana & Katerji, 2000).

While using the ET empirical models, the water consumption of crops is estimated as a fraction of the reference evapotranspiration (ETo) (Allen *et al.*, 1998; Doorenbos & Pruitt, 1977) where Kc is the experimentally derived crop coefficient and ETo is the maximum evapotranspiration that can either be evaluated on a reference crop or on a free water in a pan. The accuracy of as estimation method depends on (Rana & Katerji, 2000):

- the reference chosen (grass meadow or free water in a standard pan);
- the method used to evaluate reference ET (measurement or modelling)
- the method used to evaluate the crop coefficient Kc.

The most common approach to calculate crop evapotranspiration (ET) has been as the product of reference evapotranspiration by the crop coefficient (Kc) which depends on ground cover and crop characteristics (Allen *et al.*, 1998). In this study we compare two of the methods; the crop coefficient approach and the sap flow method in trying to quantify olive evapotranspiration capacity within the Fuente de Piedra catchment.

4.2.1 Estimating Olive ET using Crop Coefficient Approach

Efficient irrigation management of olive orchards; which is the dominant crop in vast areas of Southern Europe, require a good quantification of evapotranspiration (Fernandez & Moreno, 2000; Testi *et al.*, 2006; Villalobos *et al.*, 2000). Traditional olive orchards in Spain have typically around 100 trees per ha with ground cover rarely exceeding 25% while modern orchards are usually drip-irrigated, with 200-300 trees per ha and ground cover of 40-60%.Drip irrigation has also extended to numerous traditional orchards using groundwater with uncertain supply (Villalobos *et al.*, 2000). More intensive olive farming requires greater economical inputs, in plantations of higher densities thus a lack of knowledge about the water

[5] Measurement of a physical parameter is a quantification of an attribute of the material under investigation, directed to the answering of a specific question in an experiment (Kempthorne & Allmaras, 1986).

requirements of olive posses a great challenge (Testi *et al.*, 2004). The expansion of permanent irrigation systems in orchard crops has changed the focus of irrigation scheduling, from determining irrigation timing to quantifying irrigation amounts. Because olive is an evergreen tree crop grown in areas with scarce rainfall, the estimation of crop evapotranspiration (ET) of orchards that vary widely in canopy cover should be preferably partitioned into its evaporation and transpiration components (Orgaz *et al.*, 2006). Crop water requirements; evapotranspiration are thus the essential information for scheduling irrigation in orchards.

As the most commonly used approach to calculate crop evapotranspiration (ET), the FAO crop coefficient approach was used to estimate olive evapotranspiration within the catchment. The FAO crop coefficient approach uses standard conditions[6] where no limitations are placed on crop characteristics such as crop growth or evapotranspiration from soil water and salinity stress, crop density, pests and diseases, weed infestation or low fertility(Allen *et al.*, 1998) It has been extremely successful worldwide because it has a good level of precision combined with ease of use and transferability. The water consumption of crops is estimated as a fraction of the reference Evapotranspiration (ETo)(Allen *et al.*, 1998; Doorenbos & Pruitt, 1977). The ETc was calculated using the single crop coefficient formulae in equation (5):

(Equation 5)

$$ETc = Kc.ETo$$

Where:

ETc Crop evapotranspiration of reference grass (mmd^{-1})

Kc Crop coefficient (dimensionless)

ETo Reference evapotranspiration (mm)

The single crop coefficient approach incorporates effects of the various weather conditions into the ET_o estimate and the crop characteristics into the K_c coefficient as described by Allen et al.,(1998) and Testi et al.,(2004). It also integrates differences in the soil evaporation and crop transpiration rate between the crop and the grass reference surface. Changes in vegetation and ground cover means that the crop coefficient Kc varies during the growing period. Even in mature , intensive orchards, full ground cover is never reached due to horticultural reasons, so that Kc is always influenced by soil wetness to some extent (Orgaz *et al.*, 2006). As ET_o represents an index of climatic demand, Kc varies predominantly with the specific crop characteristics and only to a limited extent with climate. This enables the transfer of standard values for Kc between locations and between climates. This has been the primary reason for the global acceptance and usefulness of the crop coefficient approach and K_c factors developed in past studies (Allen *et al.*, 1998). A major constrain of using this method in olive crop is the unavailability of information on Kc values and only values obtained mainly from ET measurements using soil water balance are currently available;(Allen *et al.*, 1998; Moreno *et al.*, 1996a; Orgaz *et al.*, 2006). Orgaz *et al* (2006) calculated monthly variations of Kc as the sum of four components; tree transpiration (K_p), direct evaporation of the water intercepted by the canopy (K_{pd}), evaporation from the soil (K_{sl}) and evaporation from areas

[6] Standard conditions refer to crops grown in large fields under excellent agronomic and soil water conditions (Testi *et al.*, 2004).

wetted by the emitters (K_{s2}). Pastor and Orgaz (1994) determined Kc for the conditions of Cordoba, assuming negligible soil evaporation. Orgaz and Fereres (1997) took evaporation into account which explains their higher Kc values. Table 4 -1 below indicates olive Kc values derived from previous studies and used in this study.

Reference evapotranspiration values (ETo) were downloaded from the modelled Global Aridity and Global-PET database that uses data available from the WorldClim Global Climate Data (Hijmans *et al.*, 2005; Trabucco & Zomer, 2009) as input parameters. The monthly average data of the following climatic parameters; mean, minimum,and maximum temperature modelled using the Hargreaves method were spatially characterized. The above climatic parameters are insufficient to fully parameterize physical radiation-based ETo equations (i.e. FAO-PM) but sufficient to parameterize simpler temperature-based PET equations (Allen *et al.*, 1998; Hijmans *et al.*, 2005)

Table 4-1: Crop coefficients (Kc) obtained for olive orchards in South Spain (Adapted from Fernandez & Moreno (2000).

Month	Pastor and Orgaz (1994)	Orgaz and Fereres (1997)
Jan	0.5	0.65
Feb	0.5	0.65
Mar	0.65	0.65
Apr	0.6	0.6
May	0.55	0.55
Jun	0.5	0.55
Jul	0.45	0.5
Aug	0.45	0.5
Sep	0.55	0.55
Oct	0.6	0.6
Nov	0.65	0.65
Dec	0.5	0.65

.

The Hargreaves method is used as an alternative when solar radiation data, relative humidity data and /or wind speed reference data are missing among other climatological parameters used in computationally extensive equations such as FAO-PM (Allen *et al.*, 1998). Reference evapotranspiration (ET_o) was calculated using mean monthly temperature (T_{mean}), mean monthly temperature range (TD) and mean monthly extra-terrestrial radiation (RA, radiation on top of atmosphere) for the period 1950-2000 estimated using the Hargreaves equation 6 (Allen *et al.*, 1998; Hargreaves & Allen, 2003; Rahimi Khoob, 2008).

$$ETo\_HG = a + b.\frac{1}{\lambda}.0.0023.\left(\frac{Tmax+Tmin}{2} + 17.8\right).\sqrt{Tmax - Tmin}\ .Ra \qquad \text{(Equation 6)}$$

Where:

ET_o_HG (mm day^{-1}) is computed reference evapotranspiration using Hargreaves Method
Tmax (°C) is maximum daily air temperature,
Tmin (°C) is minimum daily temperature,
R_a (mm day^{-1}) is the water equivalent of extra-terrestrial solar radiation computed according to Allen *et al.*(1998),

As recommended by Allen *et al*. (1998) the above equation is calibrated using the PM method on a monthly basis by determining empirical coefficients (*a, b*) by regression analysis or visual fitting (Hargreaves & Allen, 2003; Rahimi Khoob, 2008).

4.2.2. Estimating olive evapotranspiration through Sap flow method

Sap flow measurements can be used to estimate olive water consumption and the dynamics of transpiration through measurement of water uptake by roots and tree trunk (Cermak *et al.*, 1973; Fernandez *et al.*, 2006; Ortuno *et al.*, 2006; Sakuratani, 1981; Santos *et al.*, 2007; Steinberg *et al.*, 1990). Various studies have been conducted to test the robustness of this technique; through testing of the two basic methods used in sap flow measurements; the heat pulse and the heat balance method. In heat pulse method, sap flow is estimated by measuring heat velocity, stem area and xylem conductive area, though it has been deemed inaccurate at a low transpiration rates(Cohen *et al.*, 1988).It thus has been deemed suitable for estimation of the short-time dynamics of transpiration, or changes in the hydraulic behaviour of the trees (Cohen *et al.*, 1988; Fernandez *et al.*, 2001).The transpiration potential of any crop depends on the energy supply, vapour pressure gradient and wind as well as crop characteristics such as canopy size, environmental aspects and cultivation practices (Allen *et al.*, 1998; Fernandez *et al.*, 2006; Fernandez *et al.*, 2008; Fernandez & Moreno, 2000; Moreno *et al.*, 1996a; Ramos & Santos, 2009). The estimation of the transpiration of orchards and their water use on the basis of sap flow measurements in individual trees require the scaling up of data(Cermak *et al.*, 2004; Goodrich *et al.*, 2000; Rana & Katerji, 2000),. This is achieved through development of a relationship between sap flow and selected stand characteristics measured as biometric parameters such as DBH, tree height and LAI that can be directly measured on trees in the field. A major drawback of using this method in crop evapotranspiration estimation is that it estimates only transpiration measurements, neglecting soil evaporation, and studies have shown that, under the Mediterranean climate evaporation from soil can be a very important fraction (up to 20% of total evapotranspiration) of the soil-plant-atmosphere water budget (Brutsaert, 1982; Klocke *et al.*, 1985b; Klocke *et al.*, 1985a).

In this study, the transpiration rates of each olive stand was evaluated from measurements made in individual –independent trees and scaled up using the method proposed by Gazal *et al.*,(2006). Each olive stand transpiration (T) was calculated based on estimated individual tree sap flow derived from previous studies conducted within close proximity of the study area and total canopy area of the particular stand plots extent. Total canopy area of each particular population of trees in each age stand was estimated through averaging values derived from measurements taken from a sample of 64 randomly chosen trees and then multiplied by the number of trees estimated from the extents derived from the land cover classified images and a 2004 1 x 1m orthophotos given the density in tree stands. Table 4-2 depicts categories of olive stands as used in this study.

From previous studies; the estimated sap flow estimates for each tree in a stand were 1.7 lm^{-2} d^{-1} (Fernandez & Moreno, 2000) values for 'Manzanilla' olive trees of 25-30 years of age; and 4.56 lm^{-2} d^{-1} for an 80 year-old mature olive trees (Ramos & Santos, 2009). The value (1.7lm^{-2} d^{-1}) was assumed to be the lower limits for the new and young stands that are between 0 to 35 years and later value (4.56lm^{-2} d^{-1}) for the medium and old stands that are > 35 years respectively. Further, the sap flux was assumed to be linearly related to the biometric measurements; DBH and canopy diameter.

Table 4-2: Categories of olive stands, their estimated age ranges and productivity states

Category	Age (years)	Productivity state
New	0 to 7	Not productive
Young	7 to 30	Constant increase in productivity
Medium	30 to 150	Tree maturity and full productivity
Old	> 150 years	Age with productivity for years

4.2.3 Olive grove field sampling procedures

In order to quantify the evapotranspiration of the catchment olive crop, the approximate age groups of olive stands as described above were identified from a 2004 mosaic of 1m by 1m Orthophotos of the study area and a randomly chosen number of trees representative of each of the olive stand categories were measured for biometric characteristics of canopy size and diameter at breast height (DBH). Appendix 2 depicts the different crown sizes as observed in the orthophoto image representing the different age categories as used in this study. The DBH was sampled at 0.5m height using a 30m- measuring tape as most olive trees were observed to branch out mostly above this height. The crown diameter for each tree was measured on each direction; North-South and East-West.

The biometric measurements were used to compute their relationships with estimated sap flow evapotranspiration potential of the olive trees within this catchment over the study period; 1984-2009.

4.3 Lake water level fluctuations

As described by Hofmann *et al*.(2008), water-level fluctuations (WLF) of lakes have temporal scales ranging from seconds to hundreds of years, generated by an unbalanced water budget resulting from meteorological and hydrological processes such a precipitation, evaporation and inflow and outflow conditions. The overall impacts of such water level fluctuations on abiotic and biotic conditions primarily depend on the temporal scale under consideration. For instance, long term water level fluctuations induce a slow shoreline receding that could be of several metres to kilometres, but immediate physical stress due to currents is not immediately quantifiable (Brauns *et al.*, 2008; Hofmann *et al.*, 2008).

These displacements if occurring at a large scale eventually change the habitat availability for organisms adapted to terrestrial and aquatic conditions. On the other hand, short time water level fluctuations do not significantly displace the boundary between the aquatic and the terrestrial habitat, but impose short-term physical stress on organism living in the littoral zone and on organic and inorganic particles deposited in the top sediment layers. The interaction of WLF acting on different timescales amplifies their overall impact on the ecosystem (Hofmann *et al.*, 2008). There are various reasons and causes of water level fluctuations; hydrologically induced are as a result of climate change or seasonal variations in meteorological conditions or can be of anthropogenic use of water resources. Hydrologically induced WLF result from a change in the water budget and therefore, depends on the amount of precipitation, evaporation, catchment size and characteristics and on the discharge conditions (inflow versus outflow) of the basin. In evaluating the ecological consequences of long-term WLF on aquatic organism living in the littoral zone, the short-term WLF form an important basis (Hofmann *et al.*, 2008; Wantzen *et al.*, 2008).

In this study, auxiliary data on long term daily readings on lake water levels (1984-2009) were obtained from the Reserve Management for analysis on lakes' water level fluctuation trends. The data is derived from a piezometer (SGOP-2) located in the lake from where daily measurements of both surface and ground water are measured throughout the year. From previous hydrological studies; the lake water levels have been found to be influenced by other climatic variables such as rainfall, and evaporation (Kohfahl *et al.*, 2008; Leira & Cantonati, 2008; Martos & Johnson, 1996; Wantzen *et al.*, 2008). Additional data on piezometers located elsewhere within the catchment was obtained from the Institute of Meteorology, Spain for further analysis and comparative assessment on groundwater trends.

4.4 Flamingo population numbers and breeding patterns

Auxiliary long term data (1984-2009) on Greater Flamingo population counts conducted at least one to seven times per week during the breeding period and once to twice fortnightly during the rest of the year was obtained from the Park Management offices for comparative analysis on impacts of land use and land cover implications on abundance and breeding patterns of the flamingo at Fuente de Piedra.

The flamingo breeding data is derived from the colony observations conducted throughout the breeding season from observation towers at 200m distance from the breeding areas and from a mobile hide. The number of young fledged is derived from annual ringing activities conducted at the colony and in the crèche after every breeding season (Bechet *et al.*, 2009).

Further analysis using general linear models to compute predictor variables that may be considered useful for further monitoring of the species and the environmental variables affecting their survival were evaluated.

5.0 Results

5.1 Land use and Land cover

Land use with associated land cover changes have been found to affect regional climates through changes in surface energy balance, impacting on hydrological cycles as water resources are continuously extracted for irrigation (Foley *et al.*, 2005). As noted by Belward et al.(1999), few parameters depicted on maps change as rapidly as land cover and so it is fundamentally important to accurately monitor it.

From the analysis of the satellite images, the Fuente de Piedra catchment was found to be particularly dominated by three major land uses; built-up areas, natural vegetation and cropland; with the latter being predominant. Transitions in land use and cover within this catchment over a period of 25 years were evaluated in this study as indicated below.

5.1.1 Land use and cover 1984

In 1984, catchment land cover was dominated by five major land cover classes; olive (20%), natural forest (18%), grapevines (13%), maize (12%) and heath land (11%). The other land cover classes covered approximately the following percentages in extent; water (8%), shrub land (5%), groundnuts (3%) grassland (4%), built-up-areas (2%), pine forest (2%), sunflower (1%), and wheat (1%) respectively. The land use in this year was predominantly that of cropland and natural ecosystems such as natural forests and heath land coupled with frontier clearings for cropland expansion. Figure 5-1 shows the spatial distribution of the land use and land covers in 1984.

5.1.2 Land use and cover 1994

In 1994, there was a significant shift in land cover dominance with the olive (37%) being the single most dominant land cover. Wheat (11%), water (9%), natural forest (8%), and built-up areas (8%), followed in dominance; while the rest of the land covers; grassland (3%), pine forest (3%), shrub land (3%), grapevines (2%), sunflower (3%), groundnuts (3%) and maize (3%) occupying almost equal extents were the least land covers in dominance. Figure 5-2 depicts the spatial distribution of these land uses and land cover classes in 1994.

5.1.3 Land use and cover 2009

Land use was predominantly that of cropland dominated by olive monocultures (49%) as the sole dominant cover in 2009. A considerable increase in built-up areas was noted (10%) ,while the other land covers occupied the following percentage extents; wheat (9%), water (8%), natural forest (7%), maize (5%) heath land (4%), grassland (3%), shrub land (2%), pine forest (1%), grapevines (1%), sunflower (1%), and groundnuts (1%), respectively. A decline in extents occupied by natural ecosystems was observed to decrease and a corresponding dominance in monocultures on the rise. Figure 5-3 shows the 2009 land use and land cover spatial distribution.

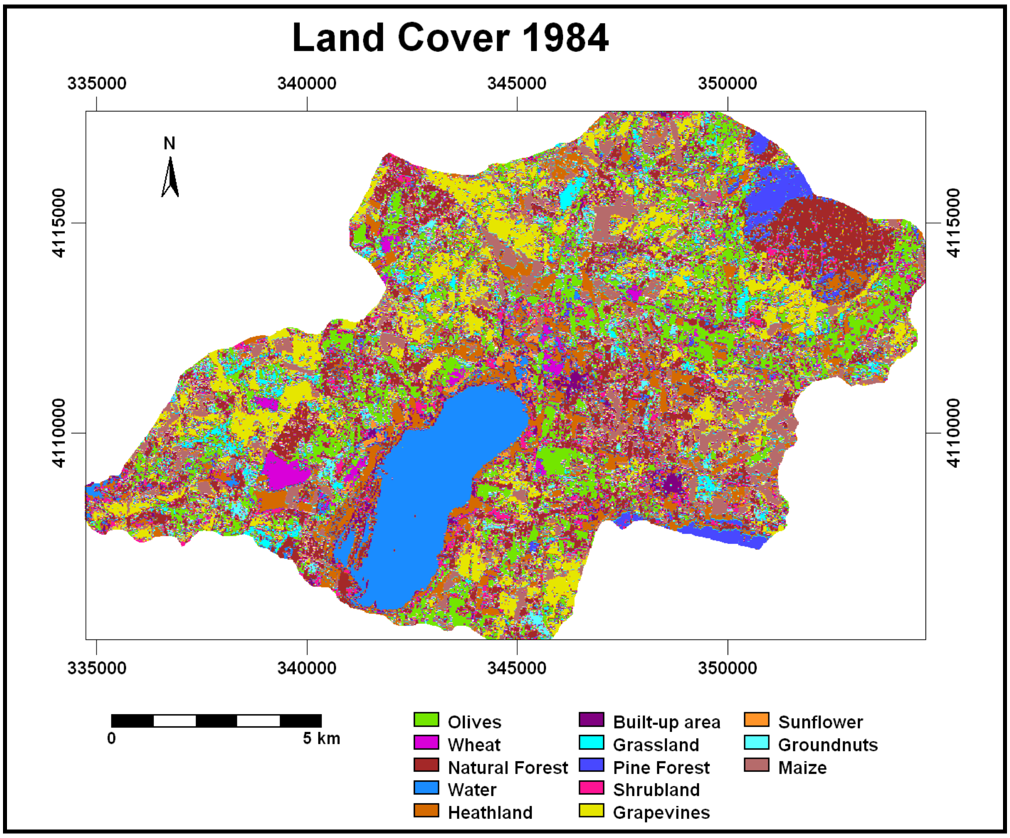


Figure 5-1: Map of catchment land use and land cover 1984

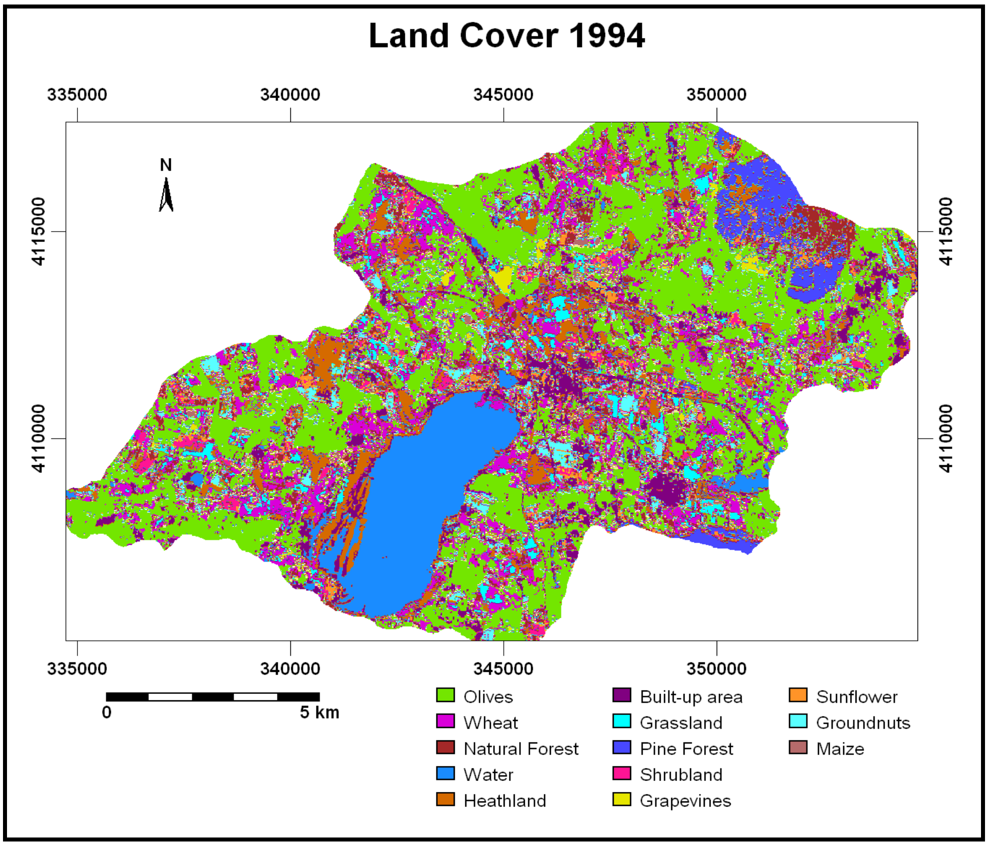


Figure 5-2: Map of catchment land use and land cover map 1994

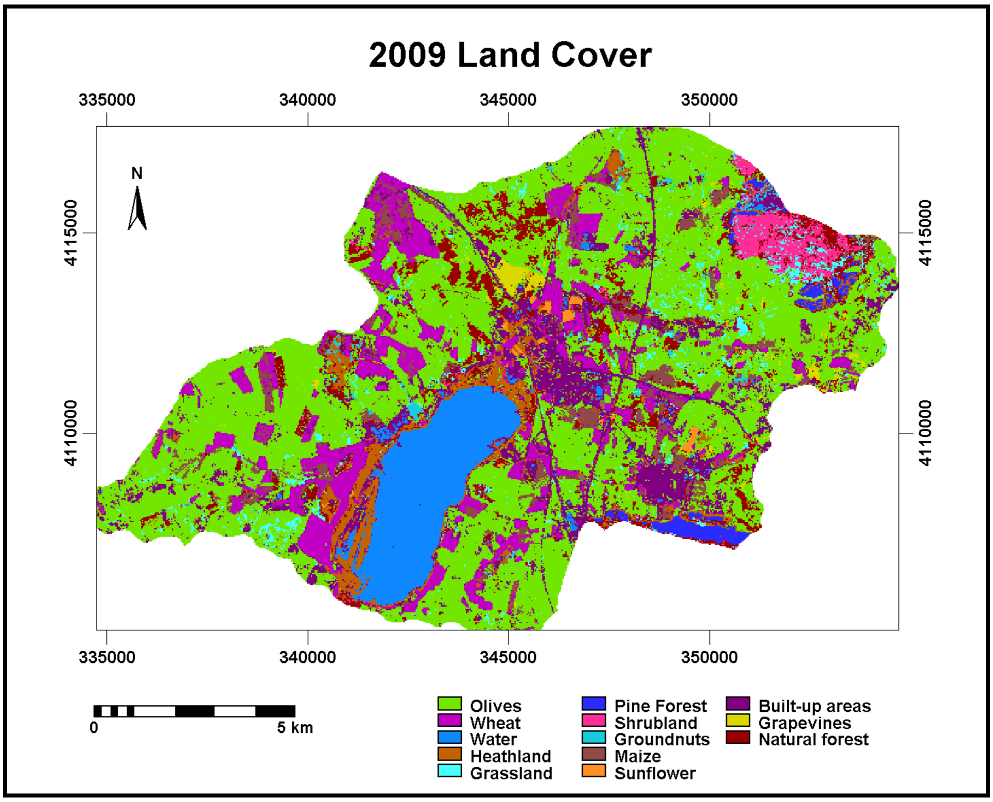


Figure 5-3: Map of catchment land use and land cover 2009

5.2 Change Detection

In this study, change detection statistics were generated as post classification products for the three temporal classified images. The change statistics depicted land use and land cover percentage change within the three temporal images as well as the land cover conversion statistics.

5.2.1 Change percentages

From the classified images, the 1984 land cover was largely dominated by natural ecosystems characterised by a sizeable extent of natural forests and heath lands. Food crops mainly cereals such as maize, also formed a great proportion of land cover types. Traditionally grown olives formed a sizeable proportion of land cover types as has been the grapevines that all have some economic and cultural attachments. In 1994 and 2009 there is a significant shift in land use with a dominance of olive land cover monocultures as the single most dominant class occupying approximately 34% of the catchment area and a noticeable reduction in natural ecosystems especially natural forests and heath lands due to clearing for olive plantation as has been noted even from previous studies(Beaufoy, 1998a; Beaufoy, 1998b). Cereals on occupy marginal extents of the landscape while a steady increase in the built-up areas is observed. Figure 5-4 below depicts the variation in percentage coverage of each land cover class over the period under study.

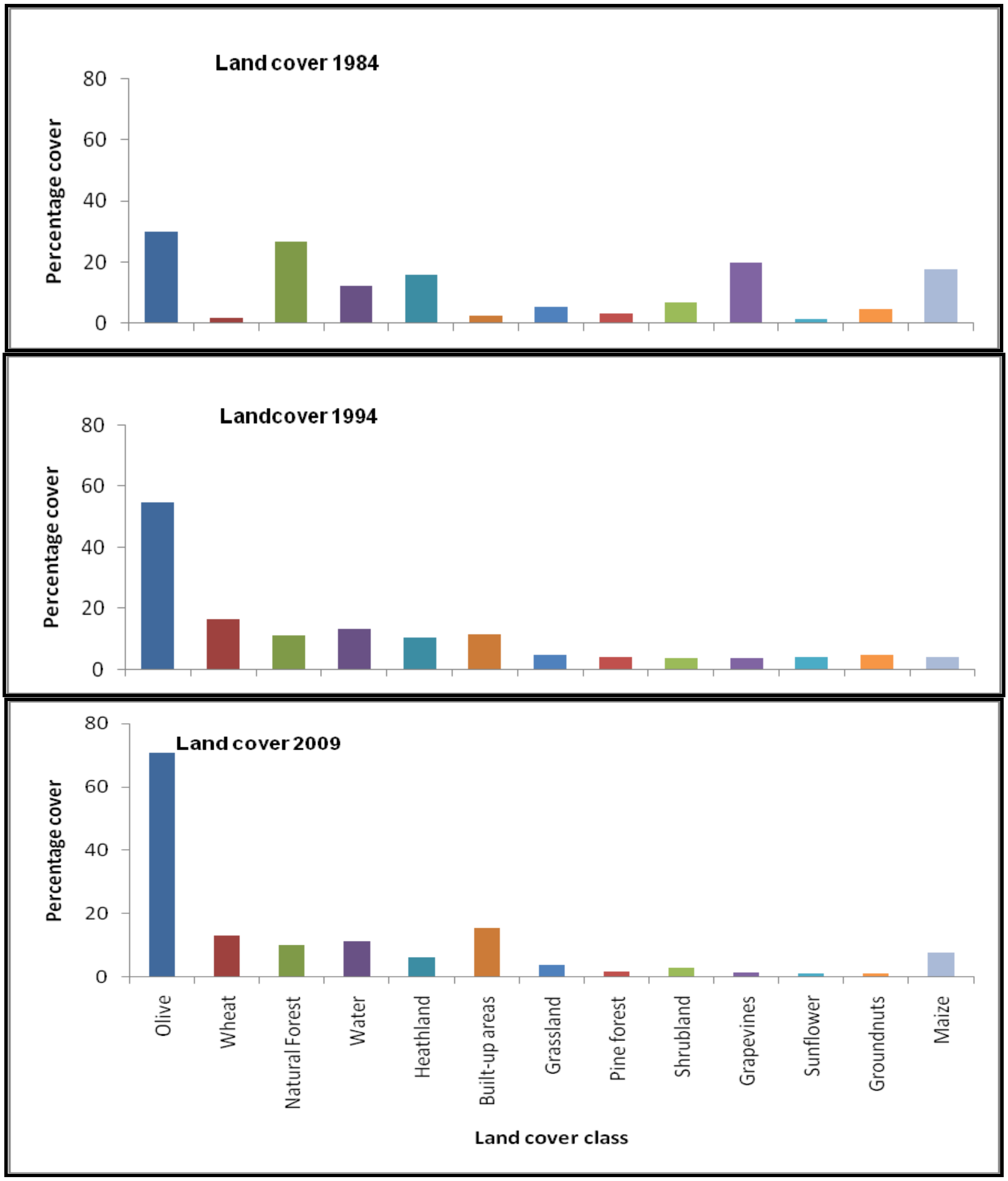


Figure 5-4 : Percentage land cover changes in extents in square kilometres for the period 1984, 1994 and 2009

5.2.2. Change trajectories

Between 1984 and 2009 various magnitudes of land use and land covers changes of took place where either a certain class increased or decreased in total coverage over time or one class changed to another class. Noticeable changes include the shift from arable crops especially the cereals such wheat, and maize to economically driven monocultures such as of olives and grapevines. Of importance also is the transition from natural ecosystems such as natural forests and heath lands to monocultures of olive plantations. Notable too is the steady increase in the built up area throughout the study period. Figures 5-5 and 5-6 below show bar graphs summarizing the within and between land cover classes changes within the 25-year time span. In the bar graphs, 100% change represents the total percentage land cover extent in final state year while the individual segmentation per each land cover indicate transformations of one land cover class to the other; for instance 100% of olive land cover in 1984-1994 graph indicate a 54.62sq.km coverage of olive in 1994, while the segmentations depict corresponding land cover transformations to olive land cover.

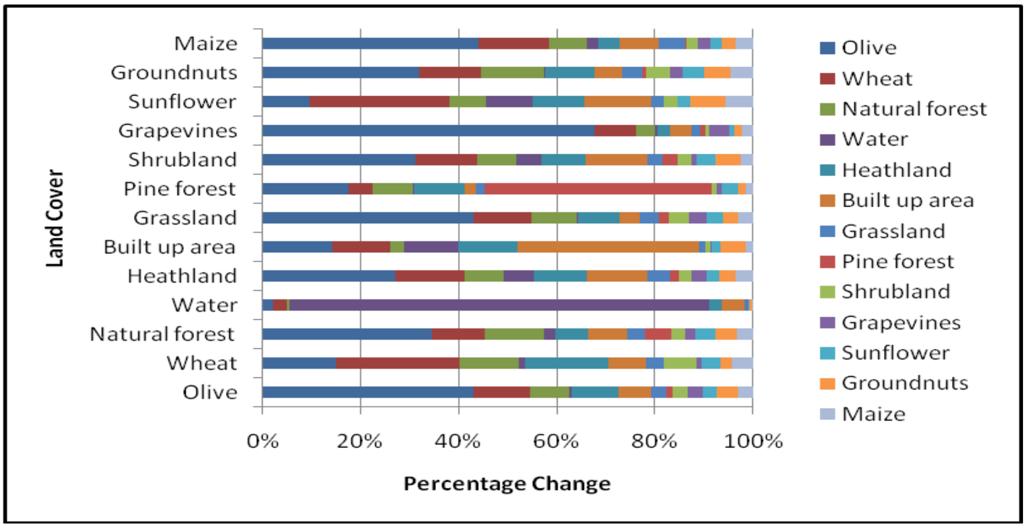


Figure 5-5: Graph of between and within land cover class changes between 1984 and 1994

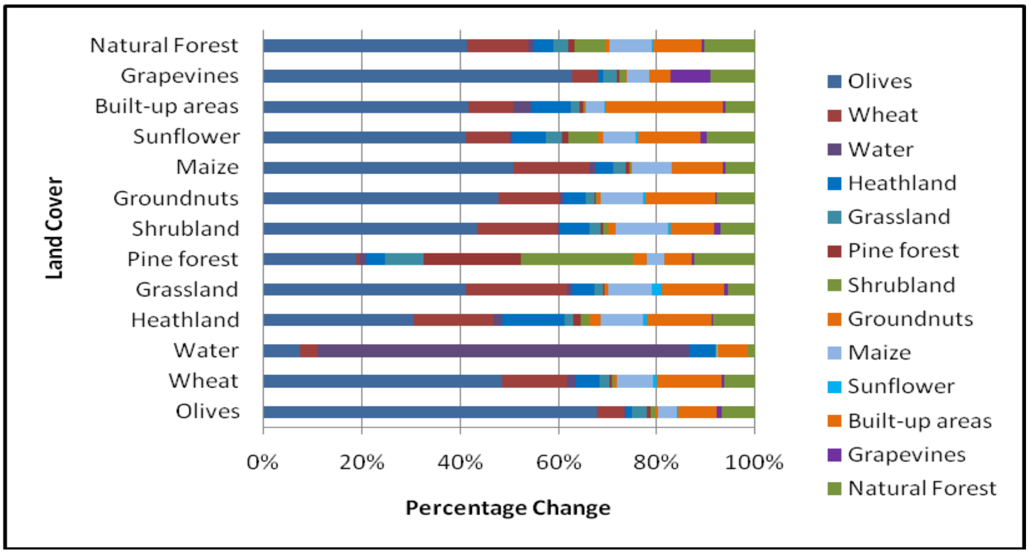


Figure 5-6: Graph of between and within land cover class changes between 1994 and 2009

5.2.3. Change rates and extents

Various land cover classes changed in extent over the 25 year period, noticeable of which are the increased extents of olive plantations and wheat as the major cover crops. Conversely, are declining extents in natural ecosystems such as natural forests, shrub lands and heath lands and other food crops as maize and groundnuts. Further a steady increase in the built up areas is also observed throughout the study period. Table 5-1 summarizes the overall change in extent and rate of change for each land cover type during the period of study. Both decreases and increases in individual land cover extents were observed.

T able 5-1: Catchment land cover changes from1984 to 2009 in square kilometres

Class	From	To

	1984	1994	2009	% change rate (84-94)	% change rate (94-09)	% change rate(1984-2009)
Olive	29.89	54.62	70.83	82.74	29.68	136.97
Water	12.03	13.28	11.4	10.39	-14.16	-5.24
Grassland	5.15	4.78	3.71	-7.18	-22.38	-27.96
Shrub land	6.9	3.61	2.94	-47.68	-18.56	-57.39
Grapevines	19.67	3.5	1.29	-82.21	-63.14	-93.44
Sunflower	1.19	3.83	1	221.85	-73.89	-15.97
Groundnuts	4.54	4.86	1	7.05	-79.42	-77.97
Wheat	1.73	16.32	13.19	843.35	-19.18	662.43
Maize	17.66	4.14	7.73	-76.56	86.71	-56.23
Pine Forest	3.15	4.19	1.78	33.02	-57.52	-43.49
Heath land	15.63	10.39	6.09	-33.53	-41.39	-61.04
Natural Forest	26.47	11.02	9.98	-58.37	-9.44	-62.3
Built-up area	2.31	11.48	15.35	396.97	33.71	564.5

5.3. Accuracy assessment

In assessing the accuracy of the classified multi-temporal images, both the confusion matrix and the Kappa coefficient were derived as the measures of accuracy. Tables 5-2, 5-3, and 5-4 show summaries of the confusion matrices and Kappa coefficient values for each classified temporal image.

Table 5-2: Confusion matrix for accuracy assessment of 1984 land cover

Class	OL	WT	NF	WA	HL	BA	GL	PF	SL	GV	SF	GN	MZ	Prod. Acc. (%)	User Acc (%)
OL	**575**	9	8	0	8	2	1	8	4	0	2	11	0	89.98	91.56
WT	0	**729**	0	0	0	0	0	0	0	0	0	0	0	98.51	100.00
NF	6	0	**290**	0	6	0	1	7	6	0	0	0	0	64.59	91.77
WA	0	2	0	**1202**	0	0	0	0	0	0	0	0	0	99.92	99.83
HL	14	0	17	0	**525**	17	0	7	10	0	0	0	0	89.29	88.98
BA	0	0	2	0	25	**354**	0	0	9	0	0	0	0	88.94	90.77
GL	0	0	0	0	0	0	**114**	0	0	0	0	36	0	86.36	76.00
PF	1	0	21	0	0	0	0	**925**	0	0	0	0	0	97.27	97.68
SL	14	0	111	0	20	13	0	4	**89**	0	0	0	0	75.42	35.18
GV	0	0	0	0	0	0	0	0	0	**324**	0	0	2	100.00	100.00
SF	0	0	0	1	0	12	0	0	0	0	**99**	0	0	98.02	88.39
GN	29	0	0	0	0	0	16	0	0	0	0	**153**	0	76.50	77.27
MZ	0	0	0	0	4	0	0	0	0	0	0	0	**54**	96.43	93.10
Total	**639**	**740**	**449**	**1203**	**588**	**398**	**132**	**951**	**118**	**324**	**101**	**200**	**56**		
Overall Accuracy = 92.1%															
Kappa Coefficient = 0.910															

OL=Olive; WT=Wheat; NF=Natural Forest; WA=Water; HL=Heath land; BA=Built-up areas; GL=Grassland; PF=Pine Forest; SL=Shrub land; GV=Grapevines; SF=sunflower; GN=Groundnuts; MZ=Maize

Table 5-3 : Confusion matrix for accuracy assessment of 1994 land cover map

Class	OL	WT	NF	WA	HL	BA	GL	PF	SL	GV	SF	GN	MZ	Prod. Acc. (%)	User Acc. (%)
OL	**860**	7	7	0	0	31	0	0	0	0	0	0	2	94.09	94.82
WT	11	**208**	6	0	7	10	1	0	0	0	0	0	0	66.03	85.6
NF	5	20	**170**	0	7	0	0	0	16	0	3	4	6	77.63	73.59
WA	0	0	0	**743**	0	9	0	0	0	0	0	0	0	100	98.8
HL	0	27	4	0	**412**	8	3	0	0	0	0	0	0	87.66	90.75
BA	13	7	0	0	9	**796**	0	0	0	0	0	0	2	90.56	96.25
GL	0	23	0	0	18	0	**49**	0	0	0	0	0	0	92.45	54.44
PF	0	0	0	0	0	0	0	**1029**	0	0	0	0	0	100	100
SL	0	0	19	0	7	0	0	0	**164**	0	9	0	0	89.13	82.41
GV	8	0	0	0	0	0	0	0	0	**186**	0	0	0	100	95.88
SF	0	0	6	0	3	21	0	0	4	0	**68**	0	0	81.93	66.67
GN	13	0	0	0	7	4	0	0	0	0	0	**145**	0	97.32	85.8
MZ	4	23	7	0	0	0	0	0	0	0	3	0	**64**	86.49	63.37
Total	**914**	**315**	**219**	**743**	**470**	**879**	**53**	**1029**	**184**	**186**	**83**	**149**	**74**		
Overall Accuracy = 92.3%															
Kappa Coefficient = 0.9124															

OL=Olive; WT=Wheat; NF=Natural Forest; WA=Water; HL=Heathland; BA=Built-up areas; GL=Grassland; PF=Pine Forest; SL=Shrub land; GV=Grapevines; SF=sunflower; GN=Groundnuts; MZ=Maize

Table 5-4 : Confusion matrix for accuracy assessment of 2009 land cover map

Class	OL	WT	WA	HL	GL	PF	SL	SF	GN	MZ	BA	GV	NF	Prod. Acc. (%)	User Acc. (%)
OL	**1703**	0	2	0	4	0	0	1	0	0	18	3	5	77.8	98.1
WT	0	**169**	0	3	0	0	0	0	2	0	0	0	0	96.02	97.13
WA	0	0	**605**	0	0	0	0	0	0	0	3	0	0	97.9	99.51
HL	4	7	0	**364**	0	3	0	0	0	0	6	0	0	96.81	94.55
GL	49	0	0	0	**70**	0	11	0	2	1	0	0	0	89.74	52.24
PF	0	0	0	0	0	**325**	0	0	0	0	0	0	2	98.78	100
SL	1	0	0	0	1	0	**275**	1	0	0	0	0	0	92.59	97.86
GN	28	0	0	1	0	0	4	**77**	0	0	0	0	3	93.22	85.94
MZ	3	0	0	0	1	0	0	0	**55**	0	0	0	0	98.18	98.18
SF	0	0	0	1	0	0	0	0	0	**54**	0	0	5	96.25	70
BA	101	0	11	3	0	0	0	0	0	0	**416**	0	0	93.48	78.34
GV	6	0	0	0	0	0	0	0	0	0	0	**229**	0	97.66	97.21
NF	294	0	0	4	2	1	7	1	0	0	2	2	**93**	86.11	77.09
Total	**2189**	**176**	**618**	**376**	**78**	**329**	**297**	**80**	**59**	**55**	**445**	**214**	**108**		
Overall Accuracy = 87.87%															
Kappa Coefficient = 0.8496															

OL=Olive; WT=Wheat; NF=Natural Forest; WA=Water; HL=Heath land; BA=Built-up areas; GL=Grassland; PF=Pine Forest; SL=Shrub land; GV=Grapevines; SF=sunflower; GN=Groundnuts; MZ=Maize

Given the extensive change in extent of the olive grove land cover; this research intended to further evaluate its impacts on lake water levels through evaluation of its actual evapotranspiration potential.

5.4 Quantifying actual olive evapotranspiration

5.4.1. Estimated ETc using single crop coefficient approach

The FAO crop coefficient approach is an empirical method primarily based on estimation of crop evapotranspiration using climatological data. ETc was calculated using the single crop coefficient formulae as in equation (5).

Crop coefficients estimated at different growth stages of the olive orchard from previous studies by (Pastor & Orgaz, 1994) were used as standard Kc (table. 4-1) in this study. Nevertheless it is worth noting that many studies have been carried out that ascertain that Kc vary among locations and even among years, depending on soil evaporation, vapour pressure deficit, solar radiation and reference evapotranspiration(Allen *et al.*, 1989; Doorenbos & Pruitt, 1977; Klocke *et al.*, 1985a). The modelled monthly ET_O spatial maps as depicted in figure 5-7 were used to derive the monthly ETo ranges for olives given its spatial distribution in the land cover classified map.

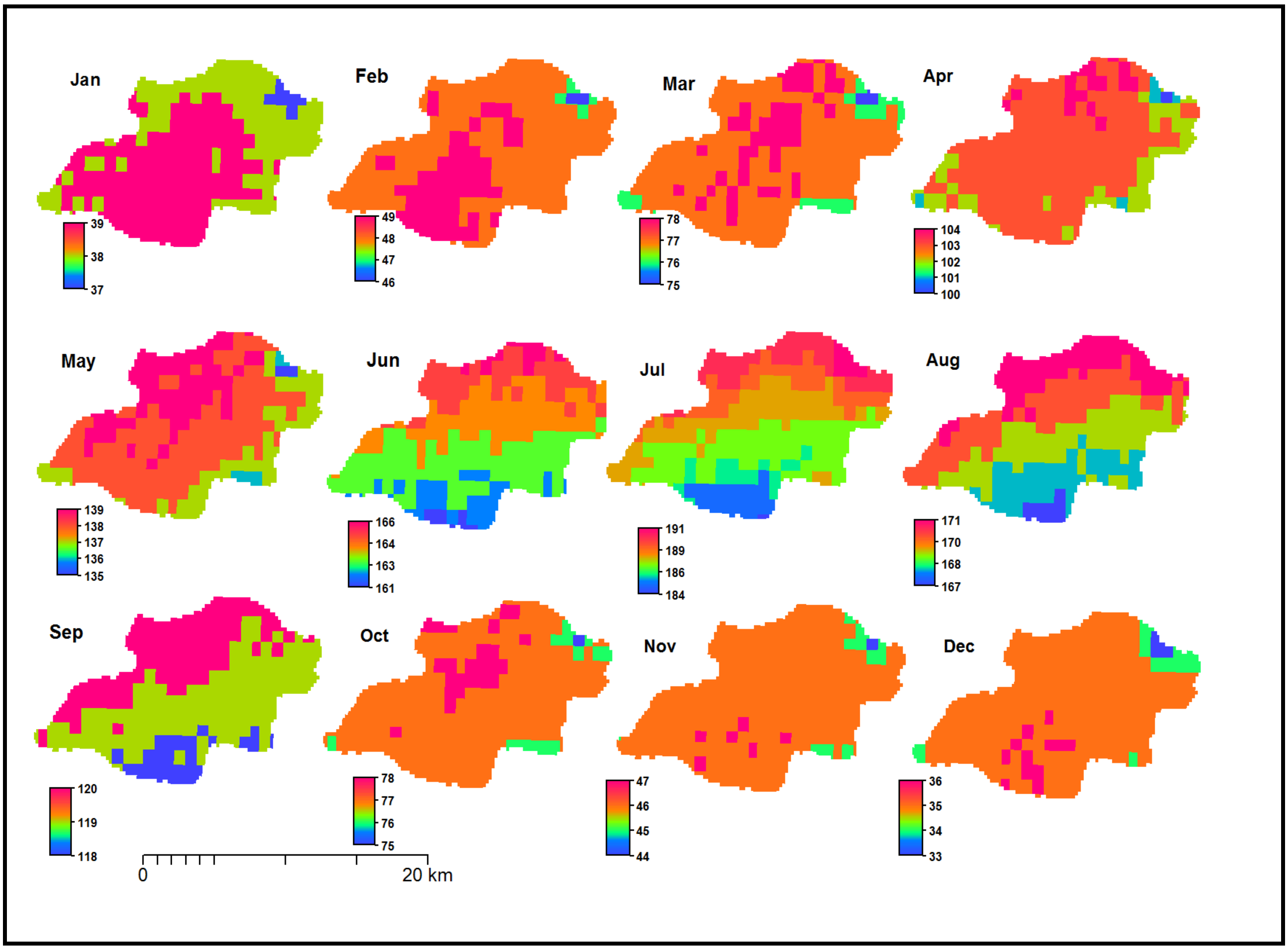


Figure 5-7: Catchment temporal and spatial maps of modelled ETo using Hargreaves method

Olive evapotranspiration was found to gradually increase as the crop developed through its annual cycle. As the vegetative growth progressed so did the ET of the crop. The highest ET values were observed to be between the months of April to September that denote the yield formation period with the following values; April (61mm), May (76mm), June (82mm), July (85mm), August (76mm) ,September (66mm) and October (46mm) respectively which characterise the period when irrigation of the crop is paramount for good yield formation. The ET declined gradually as the crop annual cycle progressed towards fruit ripening, harvesting and the dominant stages of the crop; November (30mm), December (17mm) January (19mm),and February (24mm) respectively that are further characterised by reduced need for irrigation except in stabilizing the soil moisture content in preparation of next year's crop depending on the precipitation amounts. A gradual increase in ET values was observed as the crop progressed into the next year's annual cycle with budding period; March (50mm) depicting the onset of vegetative growth. Figure 5-8 below depicts the trend in ET calculated using the single crop coefficient approach. The crop coefficient approach resulted in a total of 630mm as the annual olive ET.

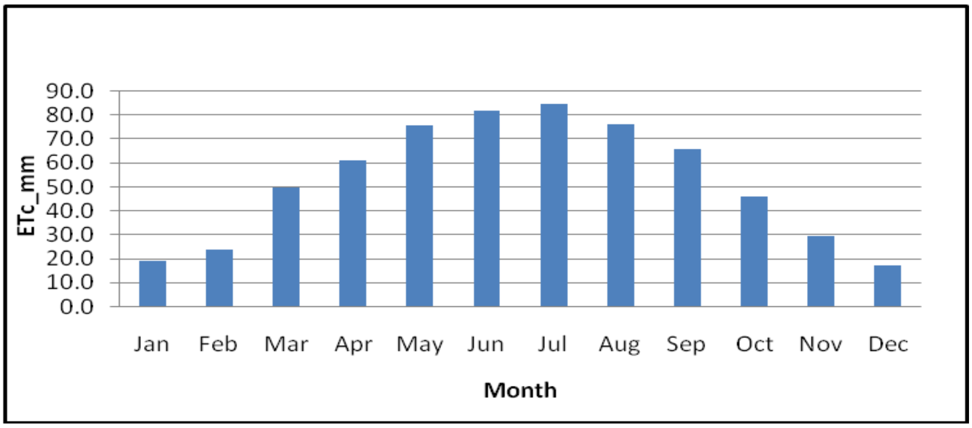


Figure 5-8 : Monthly variation in estimated olive evapotranspiration using single crop coefficient approach

From the observed ET, this research further intended to evaluate its implications on Lake water levels through impacting on groundwater resources that form a major contributor towards the lake water budget. The calculated monthly variation in ET was thus converted to volumetric measurements to evaluate the estimated quantities of water extracted from the ground water resources by the olive crop and lost through evapotranspiration. This was further evaluated against monthly precipitation volumetric contribution. Annual rainfall contribution was of the order of 6Hm^3 towards the annual lake water budget. On the other hand, annual potential evapotranspiration was estimated at 71.Hm^3 while the actual olive evapotranspiration for the year 2009 was estimated to be in the order of 45.6Hm^3.Additionally, it was observed that the highest volumes of estimated water loss through evapotranspiration were during the periods when the lake water levels have declined often below zero; that is the lake has dried up. Table 5-5 below indicates the calculated estimated monthly volumetric values of water extracted from the groundwater and lost through transpiration given the 49% (~70sq.kms) coverage by olive as a land cover within this catchment in 2009. When analysed against lake water levels, a negative relationship was observed with highest olive ET being observed when the lake is usually dry as indicated in the figures 5-9, and 5-10 below. As the demand for irrigation declined, the volumetric values in olive ET were observed to decrease too. Irrigation of the olives mainly takes place from February to September each year.

Table 5--5: Comparison of monthly precipitation amounts versus estimated monthly volumetric ET_olive values computed using crop coefficient approach

Month	Aver. Precipitation (mm/month)	Precipitation (m3)/70sq.km	Aver. ETo (mm/month)	ET_Olive (m3)/70sq.km
Jan	51.1	7661667	38	1332977
Feb	48.2	7229583	48	1666222
Mar	39.6	5933750	71	3488542
Apr	43.1	6457917	102	4293590
May	30.2	4535833	137.5	5305600
Jun	10.4	1555417	163.5	5735310
Jul	2.4	367083	188	5935257
Aug	6.6	987083	169.5	5351202
Sep	21.5	3219429	119.5	4611049
Oct	54.6	8195000	79.5	3220193
Nov	60.0	8994583	45.5	2074884
Dec	62.8	9420000	34.5	1210203

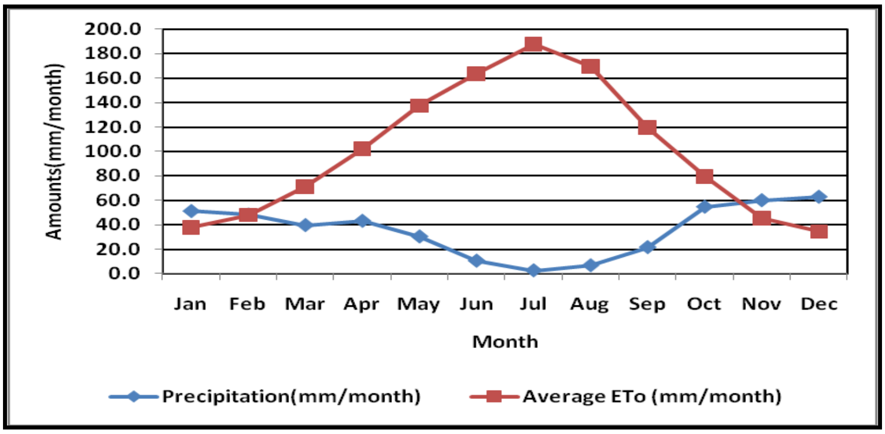


Figure 5-9: Graph of estimated olive potential evapotranspiration versus average monthly precipitation for the period 1984 to 2009

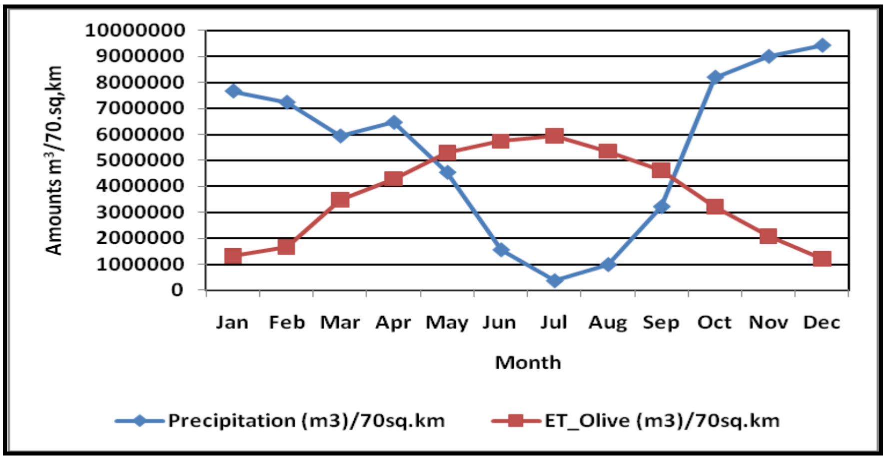
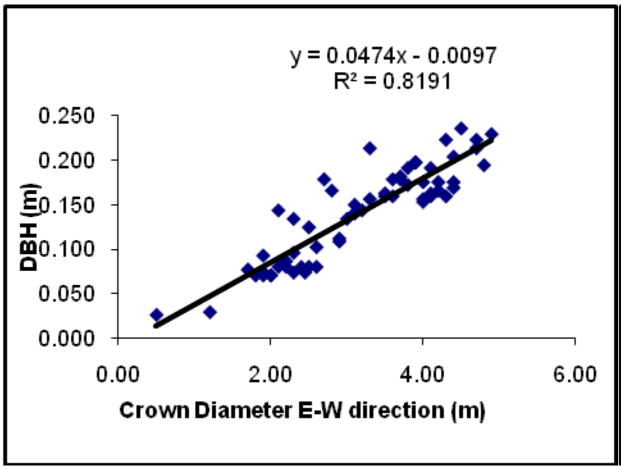


Figure 5-10: Graph of monthly average catchment volumetric precipitation versus estimated actual olive evapotranspiration for the year 2009

5.4.2 Up-scaling of the sap flow in estimation of olive orchard evapotranspiration

Olive orchard water uptake can be expressed as crop evapotranspiration , accounting for total water consumption by transpiration and soil evaporation, or solely as transpiration (Ramos & Santos, 2009). From the measured biometric characteristics of the different olive stands; that is DBH and canopy size in each direction, a linear relationship was developed to evaluate how they vary. Figures 5-11a and 5-11b below show the plotted relationship between DBH and crown diameter in each direction.



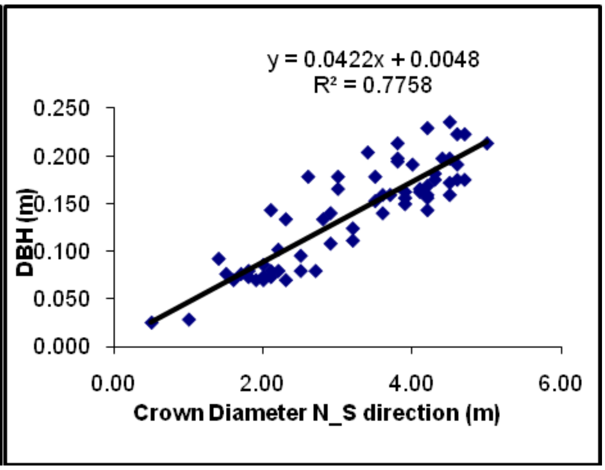


Figure 5-11a, b: The relationship between different olive trunk diameters with canopy size in East-West and North-South directions

Significantly positive relationship between DBH and crown diameter in each direction was observed; r^2 =0.82 and r^2=0.76 in East-west and North south directions respectively. From each olive stand category, the tree crown diameters were used to derive the estimated crown area for each sample trees. Given the sap flow rates derived from previous studies as 1.7l m^{-2} day^{-1} (Fernandez & Moreno, 2000) for a 'Manzanilla' stand of 25 to 30 years old and 4.56l m^{-2} d^{-1}(Ramos & Santos, 2009) for a 80-year old olive stand , the sap flow rates were up-scaled to estimate total transpiration of the olive crop in the catchment. The number of trees per category of olive stands was derived from the land cover classified image given a 7m by 5m spacing distance.

The estimated transpiration rates of each category were; 3521m^3/day for the new stands category, 6915m^3/day for the young stands, 53571m^3/day for the medium stands and 47916m^3/day for the old stands respectively. An estimated monthly evapotranspiration of 210mm was arrived at using the sap flow method. The daily estimated transpiration was then averaged and converted to estimated volumetric transpiration for the olive crop within the catchment which was estimated to 3.8 Hm^3 per month. This is equivalent to an estimated annual actual evapotranspiration of 45.6 Hm^3. This indicates the volume of water extracted from both surface and ground water resources by and for the olive crop through irrigation and lost as transpiration each month within the catchment. Figure 5-12 and 5-13 below depicts linear relationship between daily sap flow estimates and plant structural characteristics; the DBH and crown diameter indicating good positive correlations of r^2 =0.73 and r^2= 0.91 respectively.

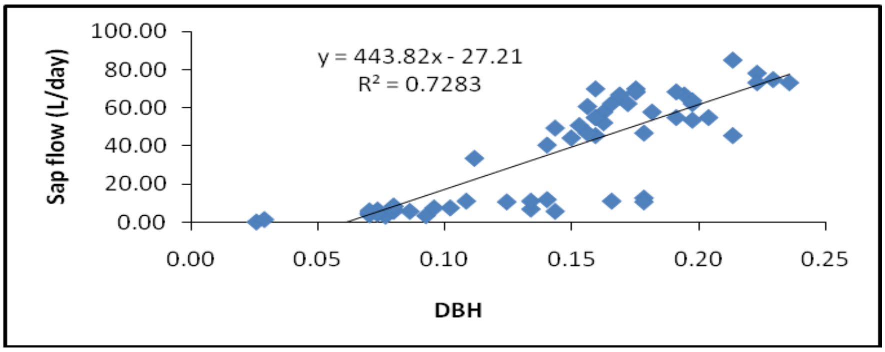


Figure 5-12: Linear relationship between estimated daily sap flow rates and DBH

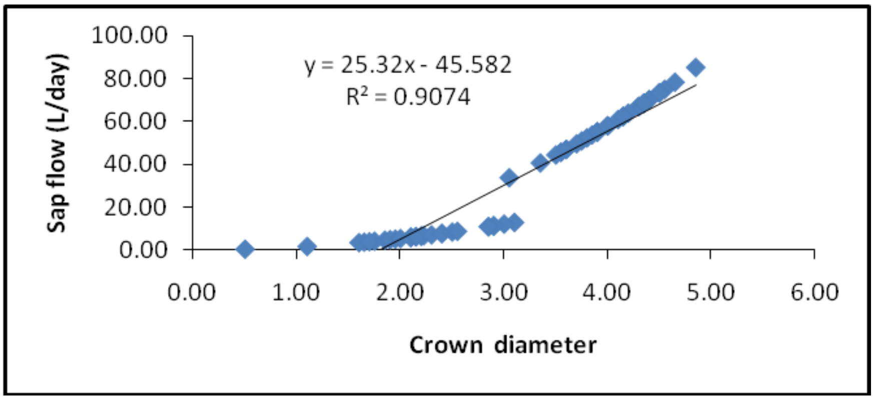


Figure 5-13: Linear relationship between estimated daily sap flow rates and crown diameter

A positive relationship was also observed between sap flux rates and canopy area for the different olive stands. Figure 5-14 below depicts this relationship with an r^2 = 0.96 indicating that transpiration is highly determined by the crown diameter of each tree.

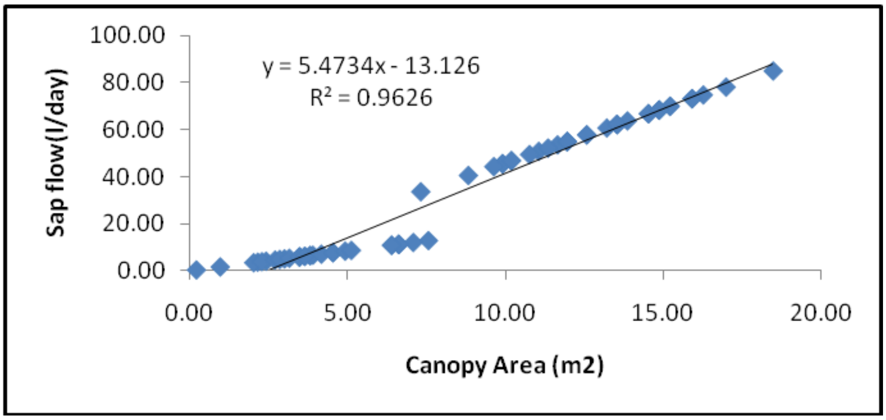


Figure 5-14: Relationship between total canopy area for the olive categories and estimated daily sap flow rates

5.4.3 Comparison of estimated olive evapotranspiration using crop coefficient and sap flow methods

The average monthly olive crop evapotranspiration estimated using the crop coefficient approach and that estimated using up-scaling of sap flow method were compared and a similar trend in these estimates was observed. The olive evapotranspiration is observed to increase as the extent of the olive within the catchment increases over the twenty five years of study (1984-2009).Between 1984 and 1994 when the olive extent increased by an estimated 83%; the corresponding monthly estimated evapotranspiration is observed also to double with an estimated 129% increase; 1.1Hm^3 in 1984 to 2.6Hm^3 in 1994, while between 1994 and 2009 the evapotranspiration also increases by 44%; from 2.6Hm^3 in 1994 to 3.8Hm^3 in 2009. These values corresponded to olive evapotranspiration within the catchment estimated using both the crop coefficient approach and sap flow method. This indicates that both methods relatively follow similar trends in estimating evapotranspiration potential.

Based on the estimated volumetric olive evapotranspiration derived using the single crop coefficient approach and up-scaling of sap flow method, the two methods indicate a significant implication of olive plantations on water resources given that they most heavily rely on irrigation for optimized productivity. Table 5-6 below depicts the effects on growth and productivity of the olive crop given a water stress situation.

Table 5-6: Effects on the growth and production of the olive tree of water stress in different periods of the annual cycle (adapted from (Beede & Goldhamer, 1994; Goldhamer *et al.*, 1994)

Phenological event	Period of the year	Effects of water stress
Shoot growth	Mainly from late winter to the beginning of summer and autumn	Reduced shoot growth
Flower bud development	February to April	Reduced flower formation
Bloom	April to May	Incomplete flower
Fruit set	May to June	Poor fruit set, increased alternate bearing
Fruit growth due to cell division	June to July	Reduced fruit size due to the decreased cell division
Fruit growth due to cell enlargement	August to harvest	Reduced fruit size due to the decreased cell expansion
Oil accumulation	September to harvest	Reduced fruit oil content

From the table above, it is apparent then that in a bid to optimize productivity from each orchard stand, and to minimize the alternative bearing experienced by an olive crop for viable economic returns, irrigation is considered paramount (Beaufoy, 1998a; Fernandez & Moreno, 2000). In this regard then, various methods are used for olive irrigation such as drip irrigation, furrow, sprinkler, and subsurface in a bind to optimize olive productivity given the limited water resource availability. In this study, we sought to evaluate the implications of intensified water resources exploitation through olive plantation irrigation on lake water levels. This has been further evaluated below.

5.5 Lake water level fluctuations

Studies examining the seasonal variations in most playa lakes and lake's water budget indicated that groundwater discharge plays a key role in the hydrological dynamics and the maintenance of the playa ecosystems and that evapotranspiration in most wetlands could account for over 50% of the water loss and thus require an accurate quantification to determine the wetland water balance (Gilvear & Bradley, 2000). Seasonally to perennially filled playa lakes tend to occur in depressions whose floor intersects the water table (Duffy & Al-Hassan, 1988). At Fuente de Piedra lagoon water levels have been identified to be heavily dependent on rainfall for surface flooding as well as the groundwater elevation for water budgets (Garcia & Niell, 1993; Rodríguez-Rodríguez *et al.*, 2006) .

In this study, long-term lake piezometer readings were analysed for variations of both surface and groundwater levels that is reflected as fluctuations in the lake. Figure 5-15 below depicts the inter-annual lake surface water monthly mean levels for the period under study, which is 1984 to 2009. The monthly water levels fluctuations were observed to follow a general trend with considerably raising levels after the onset of the rainy season in September to early October through to January - February when the levels are at their highest followed by a gradual decline as summer period sets in. The lake dries out during summer period with an exception of years with considerably high rainfall amounts (666mm) as observed during the years; 1990, 1996 and 1997. The length of the dry out period varies considerably depending on the total rainfall amounts experienced during hydrological year, mostly observed from May to September.

Based on these inter-annual variations in lake water levels, three categories of hydrological years can be identified: normal years with approximately 200 – 500mm total annual rainfall amounts (1984 to 1989, 1991, 1996, 1999 to 2004, 2006, 2008 and 2009) ; wet years when there was exceptionally high rainfall amounts thus total annual rainfall amounts being greater than 500mm (1990, 1997 and 1998) and exceptionally dry years when total rainfall amounts were well below normally expected, < 150mm (1993 to 1995, 2005 and 2007). Figure 5-16 below depicts a sample of trends of both surface and groundwater fluctuations as depicted by categorized hydrological years. Further analyses are presented in appendix 3.

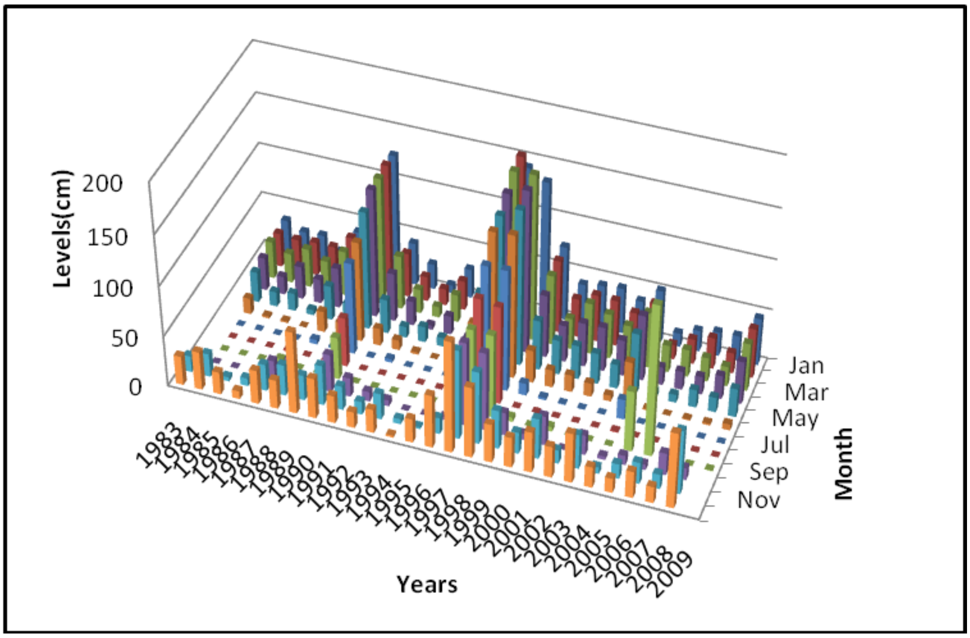


Figure 5-15:Inter-annual average surface water levels variations for the period January 1984 to September 2009

The graphs indicate that during the normal years, the lake water levels starts rising from the mid to end of October depending on the rainfall amounts. Early November through to mid June is characterised by surface flooding of variable depths (mean level: 10.0cm to 40.0cm) followed by a complete dry out from July through to end of September. A relatively dry year is characterised by much longer dry period with its onset being as early as April through to October when the normal rainy season starts. The mean water depth is approximately 19.0cm to 0.00cm. Conversely, a wet year is characterised by no drying out of the lake and retention of surface water from the previous hydrological year (mean level: 74.0cm to 160.0cm).

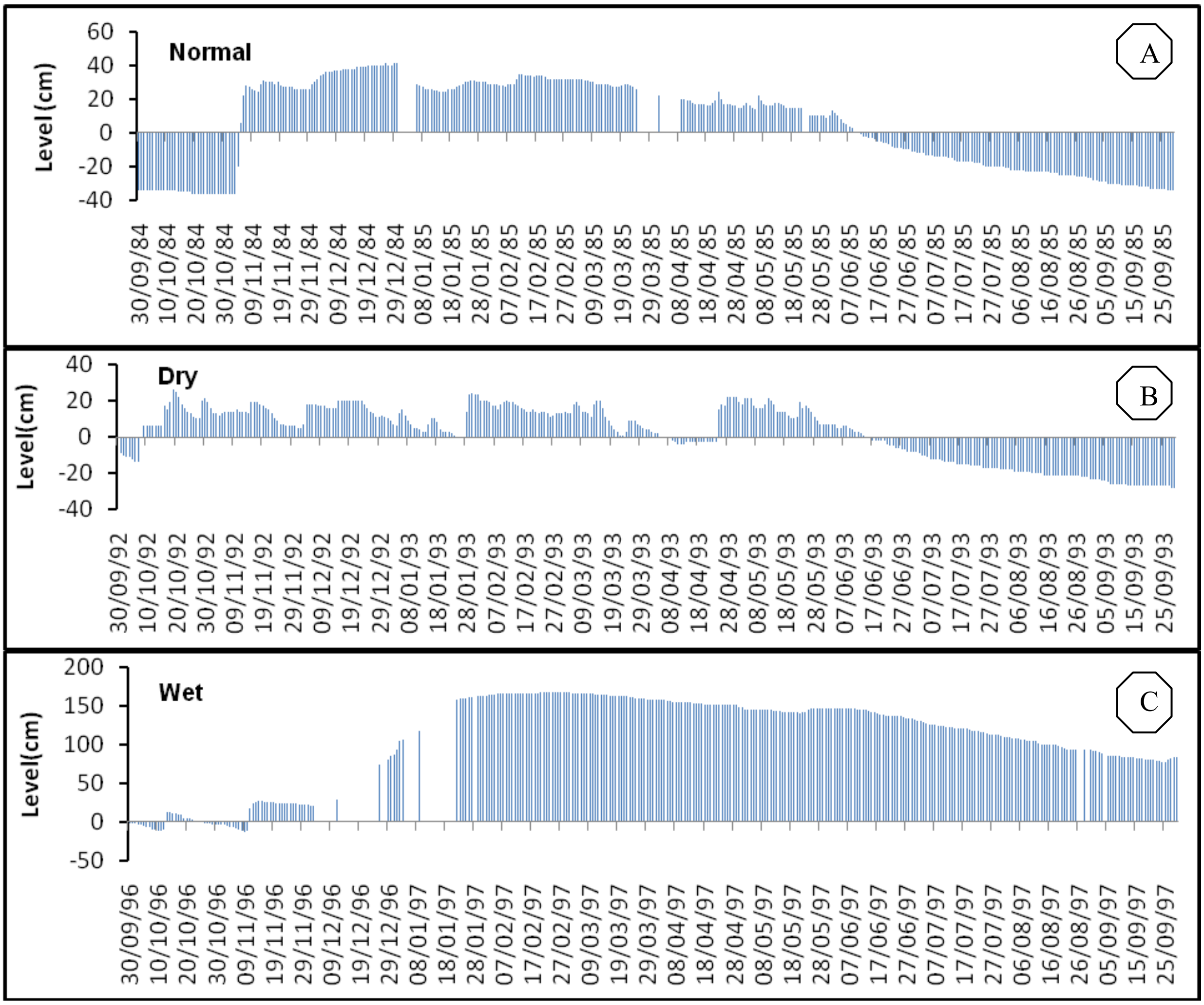


Figure 5-16: Daily variations in lake surface and groundwater for different categories of hydrological years*(A: Normal, B: Dry, C: Wet.)*

Other hydrological manipulations such as over pumping out of ground water in the watershed of a playa lake have been known to further degrade these ecosystems (Rodríguez-Rodríguez *et al.*, 2006).In the Fuente de Piedra catchment, the irrigated crops especially the olive extents have intensified greatly and heavily depend on both surface and groundwater resources as sources of water for irrigation purposes. The implications of the over exploitation of these water resources on lake water levels was evaluated by analysing the lake water levels as indicated above and further comparing these to other measured ground water flows in other parts of the catchment such as the Santillan inflow in the northern part of the catchment and Humilladero Town stream areas that forms part of the hydrological network of Fuente de Piedra lake. The piezometer readings analysis for the period 1985 to 2009 indicate varying trends in groundwater flows with considerably low annual levels below 20m being registered for the Santillan area and characterised by great fluctuations especially during the months of April through to September, that can be attributed to coincide with olive irrigation period. The flows are observed to increase as soon as the annual rainfall sets in, that account for the infiltration amounts that recharge the aquifer and increased irrigation returns during the irrigation period.

On the other hand, the Humilladero Town piezometer analysis indicate a steady decline in groundwater flows throughout the period of study (1984-2009) that could be attributed to increased extraction not only for olive irrigation but also for domestic use as this coincides with an increase in built-up area depicted in the classified images. The Fuente lagoon piezometer depicts great fluctuations with considerably high ground water flows observed during years with relatively higher rainfall amounts than normal and very low levels being registered for years with considerably low amounts herewith referred to as dry years. These fluctuations are characterised by low water levels below lagoon surface levels during periods of no rainfall and intensified extraction of aquifer waters for olive irrigation and resumption to natural state on the onset of annual rainfall and reduced aquifer extraction activities. Figure 5-17 below indicates these ground water flows as analysed.

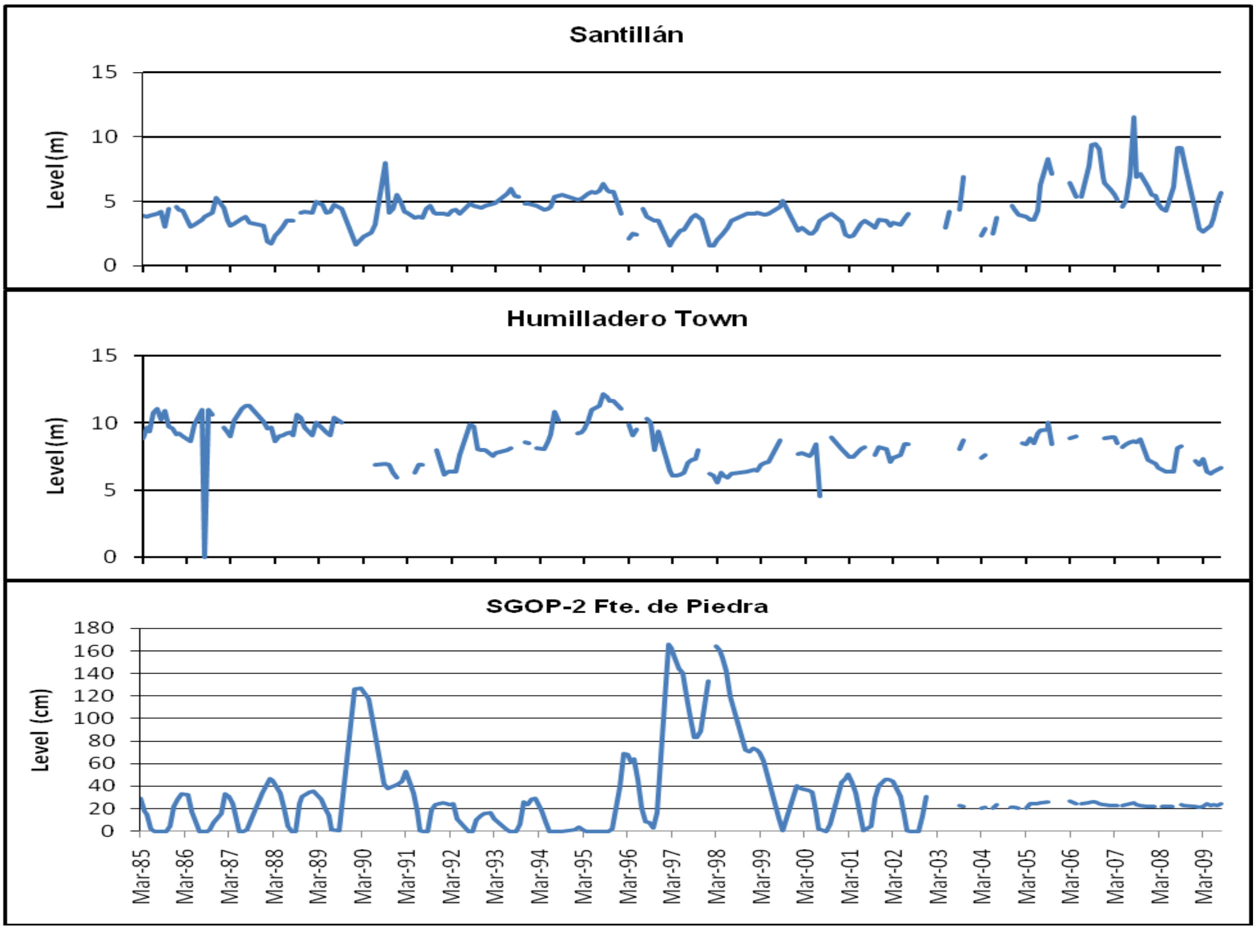
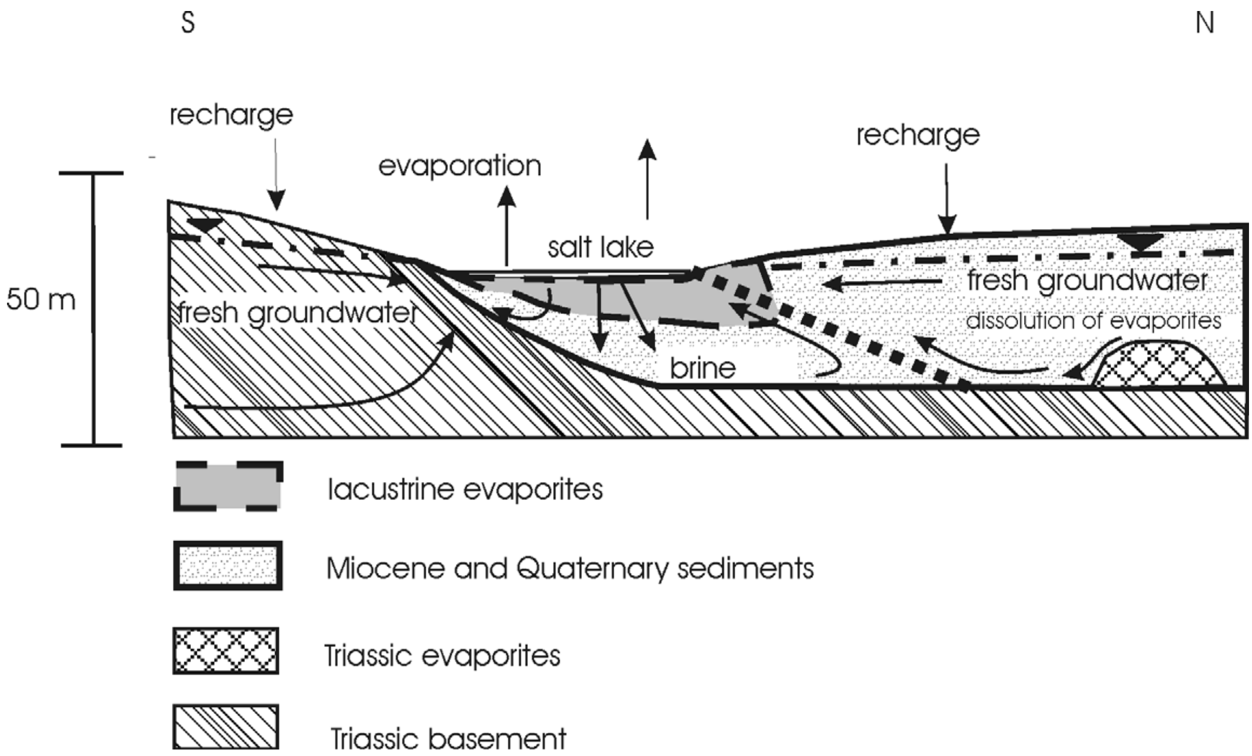


Figure 5-17: A comparison of groundwater piezometer readings at the lake and two other stations within the catchment; Santillan and Humilladero Town

According to previous hydrogeological studies conducted in this lake (Kohfahl *et al.*, 2008; Rodríguez-Rodríguez *et al.*, 2006), as illustrated in figure 5-18 below, a horizontal ground-water flow trend, where recharge flows from outer recharge areas towards the salt lake, forms the bases of categorizing the lake as centripetal, that means its floor constitutes the base level of the aquifer. Further, these studies indicate that the catchment area; in terms of surface inflows and surface runoff, and groundwater limits are similar and thus contribute a 50-50 amount towards the lake water budget. Consequently then, with ground water flows into the lake being highly conditioned by evaporation in the lake basin for most of the year (Rodríguez-Rodríguez *et al.*, 2006), intensified extraction of ground water for olive irrigation that coincides with the summer period is bound to heavily impact on the lakes' ground water recharge amounts significantly decreasing lake water levels.



Source: (Kohfahl *et al.*, 2008)

Figure 5-18: Sketch illustrating the cross-section of the flow system in the Fuente de Piedra playa

Nevertheless, according to other studies it is known that the lake water levels are not only determined by rainfall amounts and patterns over the years but also by other climatological factors such as temperature and evaporation rates (Crapper *et al.*, 1996; IGME, 1984; Rodríguez-Rodríguez *et al.*, 2006). These climatological variables were further analysed and trends compared to lake water levels. Evaporation and olive evapotranspiration were observed to have a negative relationship with water levels with the highest evaporation and evapotranspiration rates being experienced during the driest months when the lake levels are considerably low. On the other hand, rainfall was observed to have a positive relationship with lake water levels and to negatively relate with temperatures. Statistical analysis conducted to evaluate the significance of these variables as predictor valuables are shown in the statistical analysis part in this report. Figure 5-19 below depicts these comparative analyses.

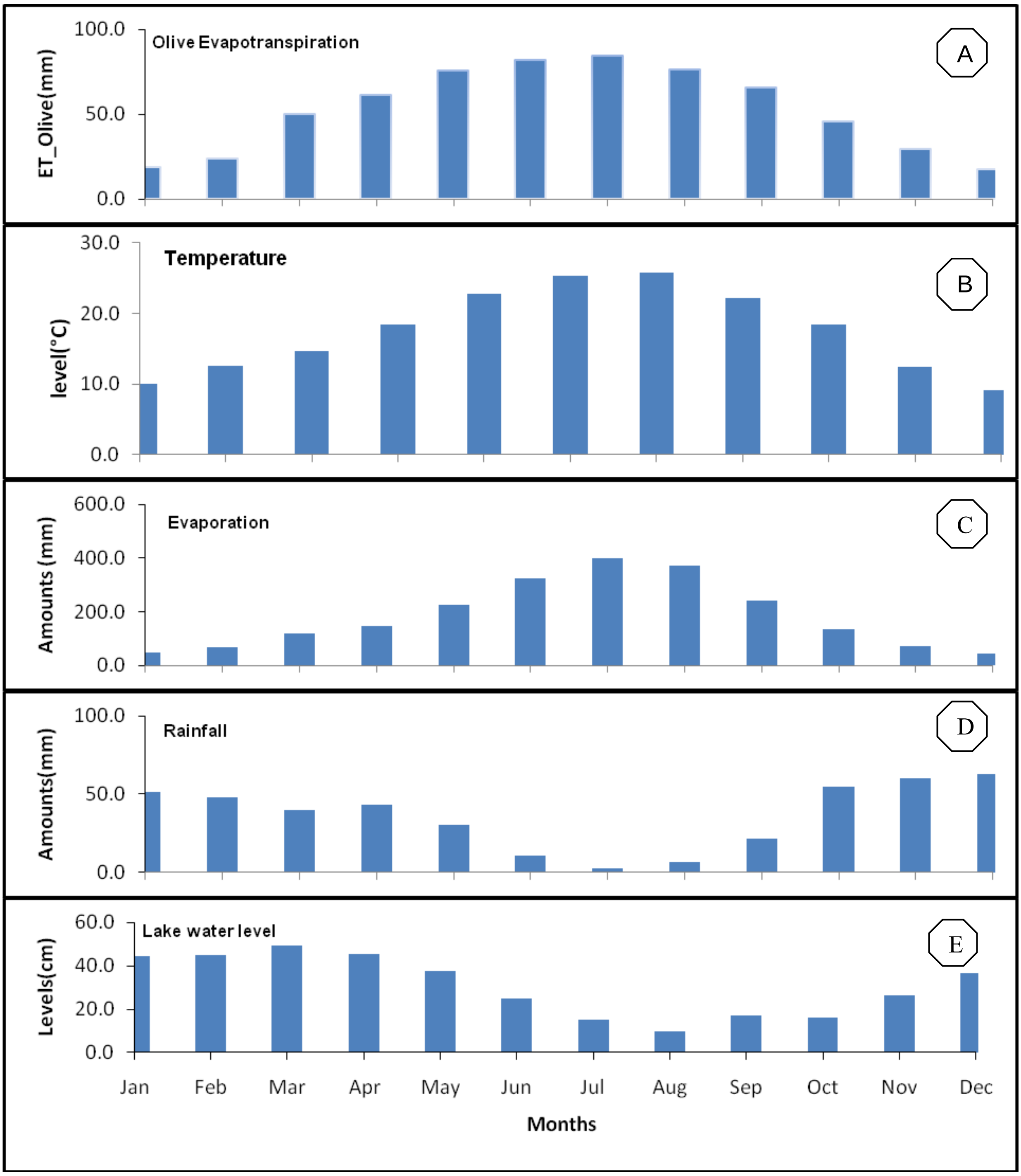


Figure 5-19: A comparison of monthly average variation in lake water levels, olive evapotranspiration and other climatological variables from 1984 to 2009 (A. Olive Evapotranspiration; B: Temperature; C: Evaporation; D: Rainfall, E: Lake water levels).

This noticeable inter-annual variation in the water levels in the lake was observed to influence the number of flamingos present in the lake at any time and has in turn also dictated the breeding patterns of the Greater flamingos present in this lake (Bechet *et al.*, 2009; Cezilly *et al.*, 1995). In this regard, further analysis on trends in lake water levels and how they vary and influence the presence or not of the Greater flamingo and corresponding breeding patterns were further analysed.

5.6 Flamingo abundance and breeding patterns

From previous studies (Bechet & Johnson, 2008; Bechet *et al.*, 2009; Cezilly *et al.*, 1995; Rendon-Martos *et al.*, 2000), it has been noted that in most wetlands, fluctuations in water depth appear to influence breeding success of waterbirds by strongly influencing food availability thereby increasing competition among foragers. Reduced breeding, or even abstinence from breeding , and low reproductive success during periods of drought have been reported for a number of bird species and explained by the effect of fluctuating water levels on the birds' food supply (Erwin & Custer, 1982; Johnson *et al.*, 1991)

In many colonial waterbirds, reproductive success is highly affected by water levels around the colonies (Cezilly *et al.*, 1995; Newton, 1998). Using long term data on flamingo population numbers and breeding colonies based on the annual census and ringing of the chicks hatched each year, the evolution in the number of individuals, breeding pairs and young fledged from the crèche in relation to the lake water levels where breeding takes place for period of 25 years (1984-2009) was analysed.

From the analysis, as indicated in figure 5-20 the number of Greater flamingos each year was observed to be highly variable and to positively correlate with high water levels over the years. Years denoted by high water levels approximately above 40cm monthly averages were observed to have more numbers of flamingos, an establishment of a breeding colony and subsequently a high number of young fledged. These include the following exceptionally wet years; 1990; 1996 and 1997.

On the other hand; years categorised as dry; denoted by low monthly average water levels of approximately <20cm were characterised by low number of individual flamingos, no establishment of a breeding colony and subsequently no young fledged from the crèche. The following are categorized as the dry years; 1984 to 1989, 1992, 1993, 1995 and 2005.

The normal years depicted by variable water levels normally above 20cm monthly averages were characterised by varying number of individuals, varying number of breeding pairs establishing a breeding colony and subsequently a varying number in young fledged from the crèche. These included the following years; 1991, 1994, 1998, 1999, 2000 to 2004, and 2006 to 2009.

A positive correlation was observed between the breeding pairs, numbers of young fledged and high lake water levels. It was further observed that the establishment or not of a breeding colony further depended heavily on the lake water levels, with years of low lake water levels being characterised by no breeding colony establishment and subsequently no fledging of the young flamingos. Nevertheless, it is worth noting that 2008-09 breeding data was not provided so not considered in this analysis.

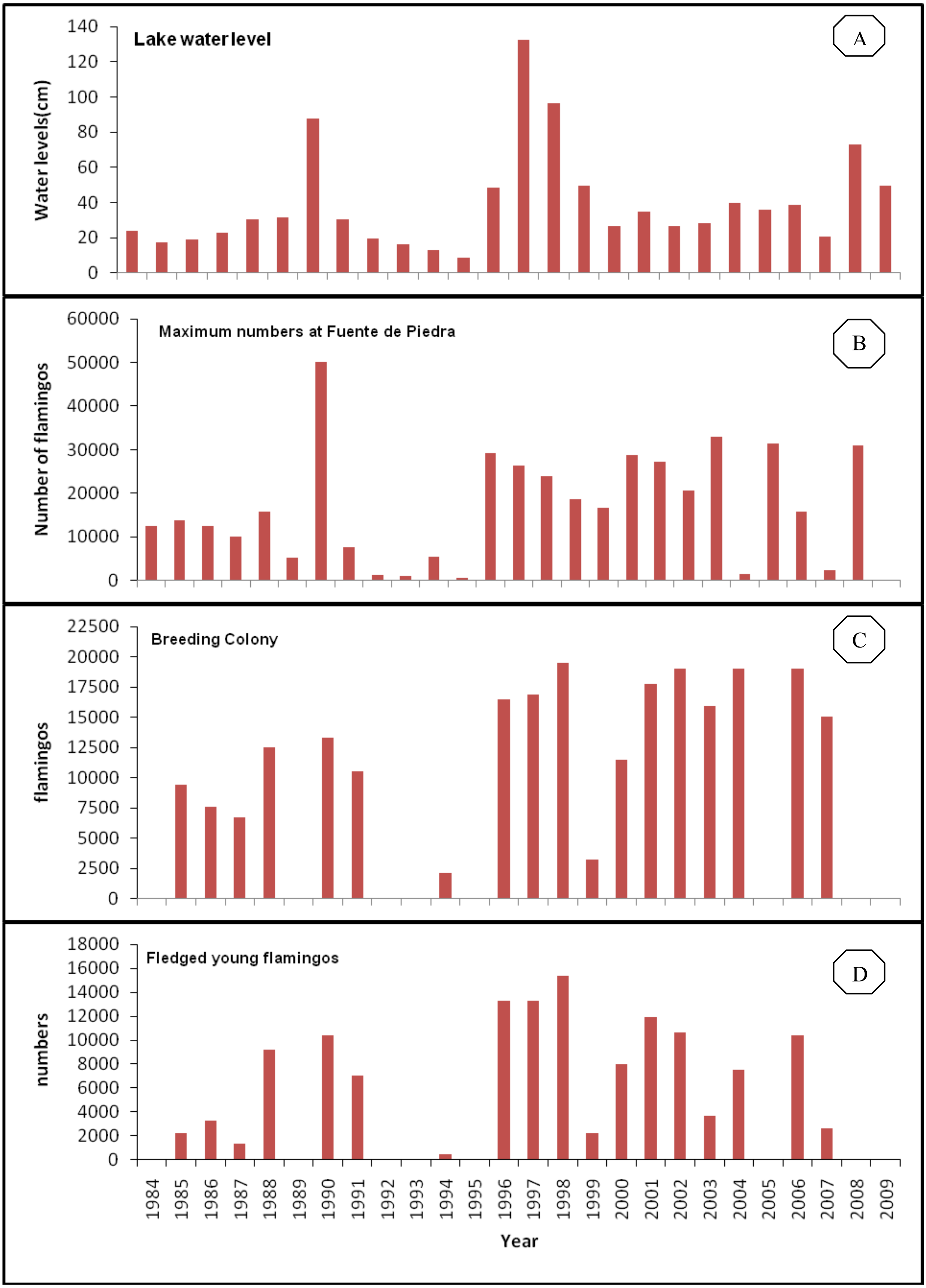


Figure 5-20: A comparison between inter-annual variation in lake water levels and number of Greater Flamingo at Fuente de Piedra lake from 1984 to 2009 (A. Lake water levels; B: Flamingos at the lake; C: Flamingos at breeding colony; D: Flamingos young fledged)

Further analysis was conducted on how the numbers of flamingos related with estimated monthly variations in olive evapotranspiration within the catchment. It was observed that the olive evapotranspiration is negatively related to lake water levels. High evapotranspiration rates are experienced during the period when the lake goes completely dry. This further corresponds to the irrigation period of the olive annual cycle as well as during the flamingo breeding season that culminates in the chick fledging stage. The flamingo breeding period in this lake starts from February through to July when the last of the fledglings leave the crèche. In this regard then, one can infer that olive evapotranspiration impacts on lake water levels eventually implicating on the Greater flamingo breeding and fledging success over the years.

Figure 5-21 below depicts the comparison between estimated monthly olive evapotranspiration, monthly lake water levels fluctuations and Greater flamingo numbers.

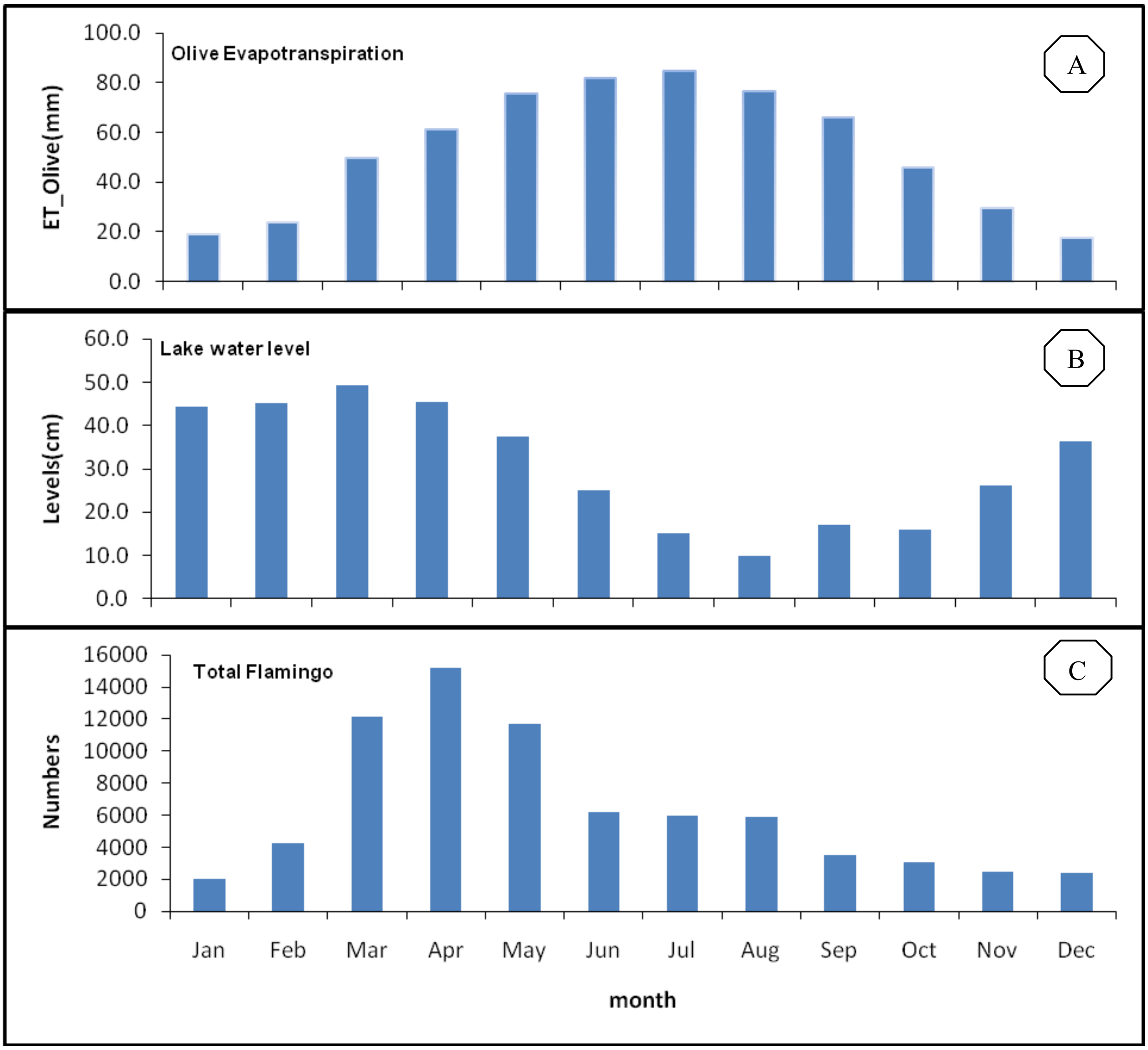


Figure 5-21: A comparison between monthly average variations in Greater Flamingo numbers, lake levels and olive evapotranspiration from 1984 to 2009 (*A: Olive evapotranspiration; B: Lake water levels; C:Greater flamingo numbers*)

5.7 Statistical analysis

From previous studies it has been noted that other climatological factors such as temperature and evaporation rates influence lake water levels as well as the evapotranspiration rates of crops such as the olive. The analysis of trends of these climatological variables against lake water levels and olive evapotranspiration as depicted in figure 5-21 above illustrates the interdependency of these factors in influencing the breeding patterns and fledging success of the greater flamingo in this particular lagoon over the period of study (1984-2009). The statistical analyses were conducted using SPSS 17.0 Software to establish their significance.

5.7.1 Evaluating relationship between predictor variables

To evaluate their relationship and significance in predicting lake water levels and flamingo breeding and fledging success, a general linear model using multiple linear regression method was used. Table 5-7 below depicts the Pearson's multi-collinearity test of the predictor variables indicating that precipitation was highly negatively correlated to evaporation (r=-0.96) and olive actual evapotranspiration (r=-0.96) while evaporation is positively correlated to olive evapotranspiration (r=0.98) and temperature (r=0.96). Additionally, temperature was also found to be highly negatively correlated with water levels (r=-0.80) and positively correlated to olive Evapotranspiration(r=0.92). Other variables showed less multi-collinearity indicating less correlation between them as predictor variables.

Table 5-7: Multi-collinearity test results

	Precipitation	*Evaporation*	*Temperature*	*water level*	*ET_crop*	*Flamingo Nos.*
Precipitation	1.00					
Evaporation	**-0.96**	1.00				
Temperature	-0.89	**0.96**	1.00			
water level	0.54	-0.68	-0.80	1.00		
ET_crop	**-0.96**	**0.98**	**0.92**	-0.56	1.00	
Flamingo Nos.	-0.23	0.21	0.14	0.39	0.36	1

5.7.2 Evaluating significance of predictor variables in explaining water levels and flamingo breeding

From previous studies, the hydrological regime of this lake has been noted to be greatly influenced by the rainfall intensity (Bechet *et al.*, 2009; Cezilly *et al.*, 1995; Rendon-Martos *et al.*, 2000). Nevertheless, it is worth noting that rainfall alone cannot account for the inter-annual variations in water levels in this lake and its catchment. Additionally, other factors besides water level fluctuations are known to influence the dynamics of Greater flamingo species population. Therefore then, statistical analysis of other climatological factors; based on their monthly means for the period 1984 to 2009 was conducted and their input into a GLM based on ecological baselines as deduced from previous studies (Amat *et al.*, 2005; Bechet & Johnson, 2008; Bechet *et al.*, 2009; Cezilly *et al.*, 1996; Gilvear & Bradley, 2000; Guerrero *et al.*, 2006; ITGE, 1998)in a bid to evaluate their statistical significance as predictor variables. Multi-linear regressions using backward stepwise method in two statistical models as shown in equations 8 and 10 below were used to evaluate how well the predictor variables can explain the outcome variable; in this case lake water levels and flamingo numbers and breeding success.

5.7.2.1. Lake water levels

(Equation 8)

$$\boldsymbol{water\ levels = 92.78 - 0.493 precipitation - 0.236\ evaporation - 2.569 temperature + 0.552 ET\_Olive}$$

The model on water levels as the dependent variable and with ET_olive, precipitation, temperature and evaporation as predictor variable was found to be highly significant with $r^2 = 0.924$ ($p<0.05$) and adjusted $r^2 = 0.881$($p<0.05$), an F statistics of 21.419 with significance levels of 0.001($p<0.005$) indicating that using these predictors in the model can predict the outcome variable explaining 92% of its variation. Precipitation and evaporation were previously excluded from the model due to their high multi-collinearity as predictor variable of water levels, nevertheless based on the value of r^2 that depicts the ability of a model to explain the variation of a population, the model including all predictors was found also to be significant. The model was also found to be significant based on Durbin –Watson test statistics which tests the assumption of independent errors with a value of 1.183 against the recommended 2 (Field, 2005). Precipitation and evaporation though were found not to be significant based on t-statistics. The adjusted full model based on t-test significance values was adopted as equation 9:

(Equation 9)

$$\boldsymbol{Water\ levels = 74.96 - 4.287 Temperature + 0.36 ET\_olive}$$

Where:

ET_olive	(Beta = 0.36; t= -3.919; t.sig =0.004)
Temperature	(Beta = -4.287; t= -6.166; t.sig= 0.000)

($R^2 = 0.869$, df=11, F= 29.816.125, F.sig. =0.000)

From the above t-test significances; it can be concluded that temperature and olive evapotranspiration are better predictors of lake water levels.

5.7.2.2 Greater flamingo

(Equation 10)

$$\boldsymbol{Flamingo\ nos. = -44431.90 + 1.764 water\ levels + 1.667 precipitation + 0.629 evaporation + 1.872 temperature + 0.601 ET\_crop}$$

Equation 10 above was evaluated for significance of predictor variables; lake water levels, precipitation, temperature and ET_crop in explaining the outcome variable which is the flamingo numbers and breeding success. The model encompassing all mentioned predictor variables was found to be highly significant with an r^2= 0.916 ($p<0.05$) and an adjusted r^2 value of 0. 846. The model has a significant F statistics value of 13.056 with a significance of 0.004 ($p<0.05$) indicating better predictability of outcome variable using the model than guessing through mean. Evaporation and ET_crop were excluded from this model as a predictors as they were found to have high level of collinearity; r=0.956 and r=0.938 respectively and were also not statistically significant based on t-test. The model was also found to be significant based on Durban Watson test statistics with a value of 2.278 against the recommended 2(Field, 2005). Thus the overall predictors in the model that were found to be statistically significant based on t-test and their corresponding b values are as in equation 11 below with an r^2=0.880 and adjusted r^2= 0.835 and F statistics 19.493 with F.sig.0.000($p<0.05$). This indicates that these predictors can explain 88% of the variation in Greater flamingo population.

(Equation 11)

$$\begin{aligned} \textit{flamingo numbers} &= -43490.05 + 1.954\,\textit{water level} + 1.104\,\textit{precipitation} \\ &\quad + 2.683\,\textit{temperature} \end{aligned}$$

Where:

Precipitation (Beta = 1.104; t = 3.237; t.sig = 0.012)
Temperature (Beta = 2.683; t = -5.552; t.sig= 0.001)
Water level (Beta = 1.954; t= 7.340; t.sig = 0.000)
(R^2= 0.880, df =11, F=19.493, f.sig= 0.000)

Water level as a variable explained 45% of the probability of the young flamingo to be successfully fledged in this lake.Based on the t-test significance levels it can be concluded that monthly variations in water levels, precipitation and temperatures significantly predict the presence or not of the Greater flamingo and their breeding success over the years in this breeding site; Fuente de Piedra lagoon. A considerable change in these predictors should raise alarm on the probability to have the flamingo in the lake and consequently their annual breeding success.

5.7.2.3. Models Cross validation

In assessing whether our models derived from our sample data is representative of the entire population; and whether the predictors chosen in these models accurately predict the outcome variables; cross validation of the model was conducted. Two main methods of cross-validation can be used; adjusted r^2 that indicate the loss of predictive power or shrinkage and data splitting that involves randomly splitting data set in half , computing a regression equation on both halves of data and then comparing the resulting models(Field, 2005).

Both models on Lake water level and flamingo numbers as dependent variables were validated using both methods of adjusted r^2 and data splitting. Data splitting was based on validating the model derived from data from 1995 to 2009 with model derived from data from 1984 to 1994. The 1984 lake water level model with precipitation, temperature, evaporation and olive evapotranspiration as predictor variables resulted in an adjusted r^2 = 0.914 while the 1995 model resulted into a adjusted r^2 = 0.952. The results are quite comparable as they depict similar percentages of above 90% predictive power.

The 1984 flamingo numbers model with lake water levels, precipitation, temperature, evaporation and olive evapotranspiration as predictor variables resulted in an adjusted r^2 = 0.67

compared to the 1995 model with an adjusted r^2 = 0.72. The results are also quite comparable with an increased predictive power in the later model.

6.0 Discussion

6.1 Catchment Land use and land cover

Lambin & Strahler (1994) listed five categories of causes that influences land use and cover-changes within a given area over time: long-term natural changes in climate conditions; geomorphological and ecological processes such as soil erosion and vegetation succession; human –induced alteration of vegetation cover and landscapes such as deforestation and land degradation; inter-annual climate variability; and the greenhouse effect caused by human activities. In the Fuente de Piedra catchment, the analysis of temporal and spatial changes in land use and land cover over the 25-years period (1984-2009) depicts a human induced alteration of land use and subsequent vegetation cover besides natural ecological process of vegetation succession. As noted by Foley *et al* (2005), societies appear to follow a sequence of different land-use regimes: from pre-settlement natural vegetation to frontier clearings, then to subsistence agriculture and small-scale farms, and finally to intensive agriculture , urban areas and protected recreational areas. This clearly denotes the land use and land cover transitions as experienced in Fuente de Piedra catchment over the period of study. In 1984, land use and land cover was primarily dominated by natural ecosystems of natural forests, heath lands, pine forest and shrub lands with few proportions of cropland and built-up areas indicating a land-use still in its pre-settlement state with a small proportion of frontier clearings for food crop growing.

Over the next span of 25 years, notable changes in land use and subsequent vegetation cover within the catchment were observed with increased settlements in terms of urban areas, a shift from mixed cropping systems of cereals such as wheat and maize, and commercially based crops such as grapevines and sunflower to monocultures of olive plantations. 2009 land use and land cover depicts a complete shift of landscape vegetation cover composition to olive monoculture dominance that corresponds to an estimated 49% coverage of overall catchment area associated with far-reaching environmental impacts. Previous studies (Beaufoy, 1998a; Beaufoy, 1998b; Martinez Sanchez *et al.*, 2008; WWF, 2004) have identified a number of drivers of these changes key among which is policies geared towards sectral development. The Common Agricultural Policy (CAP) was introduced in 1986 with strong productive incentives based on subsidies being paid to olive producers in direct proportion to their annual output of olive fruits and oil. The level of subsidy ranges from less than 100Euros per hectare for the most traditional, low-intensity farms to over 10,000Euros per hectare for the most modern , irrigated and mechanized plantation (Martinez Sanchez *et al.*, 2008; WWF, 2004). This means the less viable, traditional low density olive groves were abandoned or uprooted for the more economically profitable high-density plantations, that are intensive and systematically irrigated and highly mechanized. This explains the drastic change in catchment land use and land cover between 1984 and 2009 characterized by high-density olive monocultures as observed in the classified land cover maps. Spain is listed as the leading olive oil producer in the world with the area of Andalucía region on which the Fuente de Piedra catchment falls leading in productivity with an estimated 1.5million hectares of olive plantations (Martinez Sanchez *et al.*, 2008). Given the current global trends in olive oil demand, the olive grove intensification is expected to continue in this catchment.

Additional land use transition observed during this study period are the increased built-up areas especially the urban centres associated with increased emigration of persons who provide labour in the olive farms and other associated industries. An incredible growth in extent of 562% between 1984 and 2009 for the urban centres was observed. Wheat extent also had a significant increase of 662% during the same period depicting also the global demand on wheat products. The land use changes in this catchment are good indicators of habitat fragmentation that should be further researched on.

Principal component analysis in image analysis of catchment land use and land cover changes as used in this study depicts the use of remote sensing and GIS in temporal and spatial land use and land cover change detection thus emphasis their use as viable tools that can be used by the management in monitoring change over time and space positively contributing to decision making processes.

6.2 Intensified olive farming and its impacts on water resources of Fuente de Piedra Catchment

Agriculture is by far noted as the single most user of groundwater resources accounting for an estimated 85% of global consumptive use (Foley *et al.*, 2005) and as further noted by World Bank (2006), the contribution of increased irrigation water to agricultural production in selected countries is sizeable, but global supplies of irrigation water will be increasingly constrained. This is the case with Fuente de Piedra catchment that is characterised by increased extraction of ground water resources for olive grove irrigation. Previous hydrogeomorphological studies (Heredia *et al.*, 2004; Kohfahl *et al.*, 2008; Rodríguez-Rodríguez *et al.*, 2006) characterise Fuente de Piedra lagoon as a discharge playa whose basal level intersects the regional aquifer. This means that besides the lake being fed by surface runoff from periodical and ephemeral rivers (Arroyo Santillan and Charcon) and rainfall, ground water inflows form a major contributor to the hydrological budget in this lake. The salt lake desiccates in summer and/or only remains flooded throughout the year only when abnormally high rainfall has been received in the previous hydrological year while evaporation is the only discharge point (IGME, 1984; ITGE, 1998; Rodríguez-Rodríguez *et al.*, 2006). This is partially attributed to the Mediterranean climate characterised by hot and dry periods in summer and a mild temperature associated with annual rainfall in winter.

Intensified irrigation of the vast extents of olives in the catchment means that water is lost through crop evapotranspiration, the actual estimation of which is complex noting the influencing factors such as climate, crop type and characteristics that include the crop growth stages. Other factors such as the variation of the crop coefficient (Kc) over time and place also complicate the calculation of exact actual crop evapotranspiration capacity. Prevailing climatic conditions in this case hot and dry summers induce the need for increased irrigation given the phenological stage of the olive crop and the need to optimize productivity from each tree given that systematic and controlled irrigation is known to boost tree yields (Allen *et al.*, 1998; Doorenbos & Pruitt, 1977; Jensen *et al.*, 1990). The quantification of the crop water needs defined as the depth (or amount) of water needed to meet the water loss through Evapotranspiration (Allen *et al.*, 1998) has been done through a variety of methods as reviewed by Rana & Katerji (2000). In this study, the olive evapotranspiration requirement was estimated at average of 3.8Hm^3 per month using both crop coefficient approach and sap flow methods respectively. This depicts the amount of water needed by the crop to grow optimally upon which irrigation contributes. Further, the negative relationship between actual evapotranspiration and precipitation justifies the need for intensified irrigation for productivity optimization. The months of May to August which depicts the peak of irrigation given the olive crop phenological stages had an estimated 5.3Hm^3, 5.7Hm^3, 5.9Hm^3 and 5.7Hm^3 evapotranspiration requirement respectively. This against an estimated annual water resource in the catchment of 18Hm^3 to 22Hm^3 (Heredia *et al.*, 2004; IGME, 1984), two thirds of which are estimated to infiltrate to the aquifers, that's an approximately 12Hm^3 to 15Hm^3 ,that equates to the subterranean flows resources of the lake per year, means that the monthly irrigation requirements of the olive plantations are incredibly heavily impacting on the available water resources of the catchment . Volumetric conversions of the mean rainfall data for the period (1984 to 2009) indicate an estimated 6Hm^3 annual amount contributed by rainfall that compares well with those derived by IGME (1984); 6Hm^3. He further notes an approximate 3Hm^3 of water as extracted through pumping in 1983, though in this study, this was not quantified as there was no available data.

Though described as a parsimonious water user (Fernandez & Moreno, 2000; Pereira *et al.*, 1999), the olive tree stand characteristics such as orchard densities, canopy size, growth stage and phenological stage heavily determine the water use by the trees besides other climatological factors such as sunshine, temperature, humidity and wind speed during the irrigation periods. Further, under irrigation the root system develops in the wetted area and even beyond (Palease *et al.*, 2000) thus low water availability reduces canopy and root growth, and may alter the root-canopy ratio (Dichio *et al.*, 2002) affecting tree productivity. Newly planted shoots (0-7 years) require more water to ensure complete establishment while other stands; > 7 years to the end of tree productivity heavily depends on the individual tree water needs for optimal productivity. Critical phenological stages are the flowering and yield formation that encompasses fruit formation and oil accumulation that must be enhanced through adequate irrigation. Further, it is worth noting that naturally the olive tree has a biennial cycle that may impact negatively on the economic returns derived from this crop. So in a bid to mitigate this, sustained irrigation of the crop becomes indispensable. This thus determine the forms of irrigation used within the catchment such as drip, subsurface, furrow, sprinkler irrigation methods that are aimed at sustained deficit irrigation wherewith referring to the trees inability to get enough water to remove water stress during the year (Goldhamer *et al.*, 1994). The need for the olive trees to receive optimal water requirements throughout the year have been shown to yield greater productivity per tree than if it goes through the periods of water stress. The estimated monthly olive evapotranspiration corresponds to an estimated annual irrigation depth of 1476mm against the recommended annual irrigation depth of 950mm (Beede & Goldhamer, 1994; Fernandez & Moreno, 2000; Fernandez *et al.*, 1997; Goldhamer *et al.*, 1994; Hamdy & Lacirignola, 1999; Lavee & Wodner, 1991; Moriana *et al.*, 2003; Pastor & Orgaz, 1994; Tognetti *et al.*, 2005). This means that currently most of the farmers are over-irrigating their olives as it was observed not all who have adopted the systematic irrigation methods such as drip irrigation. Nevertheless, it is worth noting the contribution of the morphological characteristics of the olive tree such as stomatal closure that ensures that as water deficit increases the photosynthetic rate is maintained over a wide range of leaf water potential, though the stomatal response to vapour pressure deficit is attenuated in highly stressed plants (Fernandez *et al.*, 1997; Moriana *et al.*, 2003; Moriana *et al.*, 2007). This coupled with management activities such as pruning also assist in maintaining optimal productivity of a tree by reducing the unnecessary vegetative cover and optimizing water use by few branches resulting in better yields per tree.

Given then the olive stand characteristics and extents of the olive crop in the Fuente de Piedra catchment, their evapotranspiration estimates, and the hydrogeomorphological regime of the Fuente de Piedra lagoon, it is possible then to infer that intensified extraction of ground water for olive irrigation indeed have a huge implication on the lake water levels. This majorly may be concentrated during the phenological stages of flowering to the end of yield formation; that correspond to the months of February to August. The huge impacts on groundwater are reflected as both lake surface water and ground water flow fluctuations. Further quantification through previous studies (Rodríguez-Rodríguez *et al.*, 2006) of water budget in terms of both surface and groundwater inflows amounts indicate a half-half contribution towards the overall lake water budget. This mean that with no surface inflow during summer coupled with intensified extraction of ground water resources, the lake levels decline immensely contributing to its dry out. This is further confirmed by an analysis of two other piezometer data readings for the same period (1984-2009) for Santillan influent stream on the northern side of the catchment and Humilladero Town area to the west. The trends depict a considerable fluctuation in ground water flows especially during the intensive extraction periods corresponding to the irrigation period of the olive crop calendar and the resumption of the optimal state with the cessation of the period and onset on the annual rainfall season. Given the current trend in olive grove expansion within the catchment, ground water resources are severely threatened which would mean complete overexploitation in the long run. Declining ground water flows have been observed also for the Humilladero town point indicating that the extraction of water for olive irrigation might not be the only cause of the declining levels but this needs further investigation. This research thus affirms the concerns raised by the Director of Fuente de Piedra reserve; Dr. Manual Rendon and a number of other researchers on the implications of intensified olive farming on water resources in the Fuente de Piedra catchment. Based on these analysis, land cover changes especially the olive expansion have a negative impact on lake water levels thus the alternative hypothesis was thus accepted. This is also is confirmed by the predictors derived from the general linear models that determine water levels; temperature and olive Evapotranspiration with an $r^2 = 0.87$, in that they both explain at least 87% of the lake water level variation.

Further, from the modelled potential evapotranspiration spatial and temporal maps, it can be observed that in this catchment, irrigation may not be only for the olive crop but even for other food crops as wheat, groundnuts, and grapevines amongst other crops that could also be impacting on the available water resources of catchment. Additionally the evapotranspiration potential of other vegetation types within the catchment needs to be quantified. This research study did not cover this and thus further studies are recommended. The quantification also of the actual annual ground water extraction capacity of the catchment needs to be conducted putting in consideration also the illegal extractions from unregistered boreholes.

6.3 Intensified olive farming and their implications on the temporal breeding of the Greater Flamingo at the Fuente de Piedra Lake

The olive phenological stages of flowering to the end of yield formation that drives the need for increased sustained irrigation of the crop for optimized productivity coincidentally corresponds to the breeding period of the Greater flamingo in this particular lake ; February to July when the last fledglings leave the crèche. As indicated in this study, over the study period, the estimated monthly olive evapotranspiration has increased dramatically in response to the increased extents in olive monocultures. In 1984 the estimated monthly olive evapotranspiration was $1.1Hm^3$ corresponding to an estimated $13.2Hm^3$ annual evapotranspiration from an olive extent of $29.89km^2$. In 1994, the monthly olive evapotranspiration was estimated at $2.6Hm^3$ corresponding to an annual total of 31.2 Hm^3 from an olive extent of $54.62km^2$ while in 2009 an estimated $3.8Hm^3$ corresponding to an estimated annual total of $45.6Hm^3$ from an olive extent of $70.83km^2$. With the drastic increase in olive evapotranspiration and no corresponding increase in annual precipitation, that is estimated to contribute an approximate annual volume of $6Hm^3$, this undoubtly heavily impacts on available water reserves in the catchment. As indicated in the depicted categories of hydrological years, the probability of the lake maintaining adequate water levels in subsequent year heavily depends on the annual precipitation amounts from the previous hydrological year. Given the variation in annual precipitation and its contribution towards lake water levels as previously illustrated in the categories of hydrological years; wet, dry and normal, the intensity of impact of olive evapotranspiration thus varies considerably.

In a normal year, the lake water levels fluctuate gradually from an approximate level of >40cm in March to 0.00cm in June when the lake dries out until the end of September after the onset of the annual rainfall period. In a wet year characterised by almost double the amount of annual precipitation (>700mm), the lake maintains a surface level of fluctuating depths throughout the year, while in a dry year when the annual precipitation is < 150mm; the lake dries out for much longer period; from April through to October. Given then that the olive irrigation period commences from February through to September each year, the intensity of impact of the olive evapotranspiration on lake water levels varies relative to the precipitation amounts of the previous hydrological year. In this regard then, its impacts on the presence of flamingos, the establishment of a breeding colony and successful fledging of the young depends on its impact intensity on lake water levels. Years categorized as wet years, were characterised by presence of large numbers of flamingo, an establishment of a breeding colony and a successful fledging of the young, for instance, 1990, 1996 and 1997. Years categorised as normal; 1998, 1999, 2000 among others were characterized by reduced flamingo numbers, reduced number of flamingos that establish the breeding colony or sporadic breeding colony establishment and subsequently reduced number of young fledged. In dry years, 1989, 1992, 1993, 1995, and 2005 were characterized by very low flamingo numbers, and no establishment of a breeding colony therefore no young fledged. Low rates or no successful breeding eventually affects the recruitment potential of this population. Given then an increase in catchment olive extents, its intensity of impact on lake water levels is expected to further increase and subsequently its implication on the presence and breeding of the greater flamingo in this lake to further be quite detrimental and could eventually lead to the complete disappearance of this species in future.

Optimal water levels have been suggested at 0.5m with no breeding colony established when water levels are at less than 0.3m. Optimal water levels especially on the onset of breeding period play a major role in the consideration by the species as a breeding site. Constant decline in lake water levels; from monthly averages of greater than 40cm (Feb-April) to levels lower than 20cm (May-Sep) as a result of intensified extraction of ground water for olive irrigation, as the flamingo breeding period progresses, heavily impact on their successful breeding. This is in line with previous studies conducted that emphasize the dependency of the flamingo on suitable water levels for successful breeding (Bechet *et al.*, 2007; Bechet & Johnson, 2008; Cezilly *et al.*, 1995; Cezilly *et al.*, 1996; Garcia & Niell, 1993; Rendon-Martos *et al.*, 2000). As a result, declining breeding frequency or even complete abstinence from breeding and low breeding success during periods of drought was observed from the analysis conducted. This could be attributed to declining food supply as the Greater flamingo feeds on organisms dependent on presence of surface water; molluscs, shrimps, insect larva's and algae. Further, if the breeding pairs have to travel for long distances to get food, some never return to the crèche thus desert their young. As a result, as this lake dries out as the breeding season progresses, the dependency and availability of food for the adults and their chicks can only come from surrounding wetlands such as of the Guadalquivir basin, therefore the connectivity between these wetlands also determine the successful breeding of the flamingo in this lake. This was not quantified in this study. Further, suitable water levels are required for protection of both the adults and chicks during the breeding season from terrestrial predators which would negatively impact on their breeding success. The impact of these predators on the flamingo breeding success was not quantified in this study and thus requires further research.

In trying to mitigate against the effects of fluctuating water levels on the breeding colony in this lake, the management of the reserve has developed an initiative of managing the nesting site by pumping water to the area surrounding the breeding colony site in order to protect the crèche until the end of the breeding season that coincides with the onset of the annual rainfall season. This has over the years positively contributed to the successful breeding of the flamingo at this lake as detailed by Martos & Johnson (1996). This falls within the conservation management strategies for water birds within the Mediterranean region as described by Erwin (1996).

7.0 Conclusions and recommendations

Understanding the drivers and implications of land use and land-cover changes in an area may provide the only solution to better land management strategies. As observed in this study, peoples' response to economic opportunities can lead to drastic changes in land uses and associated land covers. This may in turn lead to unprecedented environmental impacts as observed in this catchment where intensified water uses for olive monoculture irrigation is resulting to overexploitation of the limited ground water resource. Continued increase in olive extents characterised by drastic increase in water loss through crop evapotranspiration that necessitate the continued intensified extraction of groundwater for irrigation to maximize crop productivity, ultimately negatively impact on lake water levels; being a closed basin that only rely on annual precipitation for replenishment. Based on this then, the alternative hypothesis on the relationship between catchment land cover changes and lake water levels was accepted.

To optimize water application to various crops given the diversity in soil types, irrigation systems and climatic conditions, further research certainly becomes paramount in providing adequate knowledge on soil-water-plant relationship. The evapotranspiration potential of other vegetation covers in this catchment and their ultimate implication on the available water resources should be investigated. Further, research on the reliability of irrigation systems versus crop water requirements should be encouraged in optimizing the allocation of a limited resource such as water in this catchment. Additionally, as noted by World Bank (2006) and Beaufoy (1998a) identifying perverse incentives and underlying economic forces that lead to resource degradation is critical for sustainable land management, a key element of which will be the implementation of the kinds of incentives that will lead to more efficient land management and optimal output levels. Equity in allocation of this limited resource and other management strategies as pricing water as a commodity may serve as a viable option for regulating the use of a limited resource The continued expansion of the olive plantations especially onto sensitive and natural habitats such as forests and wetlands should be stopped and restoration measures for degraded areas initiated.

The connectivity between various components of the environment means that a negative impact on one component results into an impact on the other and as such no strategy is comprehensive enough unless it is all inclusive. This means that the need to meet global demand for olive fruits and oil should also encompass addressing the environmental impacts associated with their production. This, if addressed will save a fraction of our biodiversity that also relies on similar resources for survival as the olive production systems. The Greater Flamingo is one amongst such in this catchment that relies on water resources for their survival.
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From the analysis, water has been identified as a key determinant for the survival of the Greater Flamingo species in this breeding site. As such to ensure its longevity, the provision of optimal water levels especially during its breeding season must be addressed. According to this study, lake water levels are highly determined by annual precipitation and olive evapotranspiration potential, thus unsuitable water levels in a given year deter the flamingos from breeding this lake. The relationship then between increased olive expansion and its implications on the population and breeding patterns of the flamingo as has been earlier outlined is quite evident. In this regard then, the alternative hypothesis on relationship between catchment land cover changes and population and breeding success of the greater flamingo in this lake was accepted. This underscores then the need to continuously monitor other environmental parameters such as climate change that could negatively impact on this species and derive appropriate mitigation measures.

The Management of Fuente de Piedra over the years have initiated a management strategy of pumping water around the crèche during the lake dry out periods during the flamingo breeding season , the continuity of which is pegged on available ground water flows adequate enough to raise lake surface water levels to optimal levels especially around the crèche. Further monitoring of other environmental factors that may negatively impact on this species need to be investigated. Further, research on how water level fluctuation impact on other water bird species breeding or resident in this lake should be conducted.

Education and awareness on the interrelationship and inter-dependency of various environmental components may serve to enlighten the community on the need to share limited resources. Further, the derivation of economic returns by the community from biodiversity conservation may cultivate the sense of ownership and responsibility from the community.

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Appendix 1: ROIs Separability statistics

Land cover map 2009

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
Olive	Wheat	1.99961025	1.99996075
	Water	1.99919861	2
	Heathland	1.92395825	1.98998247
	Grassland	1.82500687	1.99537782
	Pine Forest	1.99861303	2
	Shrubland	1.9559353	1.99949802
	Sunflower	1.91108519	1.99999749
	groundnuts	1.96384602	1.99937143
	Maize	1.99994795	2
	Built-up areas	1.48776219	1.66370334
	Grapevines	1.87665927	1.99992941
	Natural Forest	1.3872627	1.71181367
Wheat	Olive	1.99961025	1.99996075
	Water	1.99995976	2
	Heathland	1.99133853	1.99967638
	Grassland	1.99998725	1.99999998
	Pine Forest	1.99999999	2
	Shrubland	1.99999871	2
	Sunflower	1.99999404	2
	groundnuts	1.996528	1.99776349
	Maize	2	2
	Built-up areas	1.994894	1.99999333
	Grapevines	1.99999999	2
	Natural Forest	1.99976729	1.99994204
Water	Olive	1.99919861	2
	Wheat	1.99995976	2
	Heathland	1.95111522	2
	Grassland	1.99919714	2
	Pine Forest	2	2
	Shrubland	1.99996726	2
	Sunflower	1.99997394	2
	groundnuts	1.99797368	2
	Maize	2	2
	Built-up areas	1.9582401	1.99998933
	Grapevines	1.99999983	2
	Natural Forest	1.99725306	2
Heathland	Olive	1.92395825	1.98998247
	Wheat	1.99133853	1.99967638
	Water	1.95111522	2
	Grassland	1.98929404	1.99999071
Comparing cover	**Cover type**	**Jeffries-Matusita**	**Transformed Divergence**

	Pine Forest	1.97519583	2
	Shrubland	1.99267864	1.99999807
	Sunflower	1.99008621	2
	groundnuts	1.9984512	1.99999985
	Maize	1.99999931	2
	Built-up areas	1.76480741	1.95556967
	Grapevines	1.99933558	2
	Natural Forest	1.87193256	1.98251497
Grassland	Olive	1.82500687	1.99537782
	Wheat	1.99998725	1.99999998
	Water	1.99919714	2
	Heathland	1.98929404	1.99999071
	Pine Forest	1.99993784	1.99993784
	Shrubland	1.69322165	1.86788326
	Sunflower	1.94985265	1.99860304
	groundnuts	1.91886262	1.98336538
	Maize	1.9999998	2
	Built-up areas	1.97654822	1.99999995
	Grapevines	1.99875143	2
	Natural Forest	1.75063411	1.99757927
Pine Forest	Olive	1.99861303	2
	Wheat	1.99999999	2
	Water	2	2
	Heathland	1.97519583	2
	Grassland	1.99993784	1.99999977
	Shrubland	1.99999415	1.99999994
	Sunflower	1.99998768	1.99999491
	groundnuts	1.99999999	2
	Maize	2	2
	Built-up areas	1.99991061	2
	Grapevines	1.99999993	2
	Natural Forest	1.99760238	1.99999421
Shrubland	Olive	1.9559353	1.99949802
	Wheat	1.99999871	2
	Water	1.99996726	2
	Heathland	1.99267864	1.99999807
	Grassland	1.69322165	1.86788326
	Pine Forest	1.99999415	1.99999994
	Sunflower	1.930471	1.97002831
	groundnuts	1.99063276	1.99624289
	Maize	2	2
	Built-up areas	1.96937368	1.99998892
	Grapevines	1.99999989	2

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Natural Forest	1.58547227	1.99775788
sunflower	Olive	1.91108519	1.99999749
	Wheat	1.99999404	2
	Water	1.99997394	2
	Heathland	1.99008621	2
	Grassland	1.94985265	1.99860304
	Pine Forest	1.99998768	1.99999491
	Shrubland	1.930471	1.97002831
	groundnuts	1.99776994	1.99992787
	Maize	1.99999988	2
	Built-up areas	1.98660685	2
	Grapevines	1.99992421	1.99999999
	Natural Forest	1.84127263	1.99455976
Groundnuts	Olive	1.96384602	1.99937143
	Wheat	1.996528	1.99776349
	Water	1.99797368	2
	Heathland	1.9984512	1.99999985
	Grassland	1.91886262	1.98336538
	Pine Forest	1.99999999	2
	Shrubland	1.99063276	1.99624289
	Sunflower	1.99776994	1.99992787
	Maize	1.99999969	2
	Built-up areas	1.98355732	1.99999999
	Grapevines	1.99998451	2
	Natural Forest	1.85908764	1.99915236
Maize	Olive	1.99994795	2
	Wheat	2	2
	Water	2	2
	Heathland	1.99999931	2
	Grassland	1.9999998	2
	Pine Forest	2	2
	Shrubland	2	2
	Sunflower	1.99999988	2
	groundnuts	1.99999969	2
	Built-up areas	1.99999541	2
	Grapevines	1.99992652	2
	Natural Forest	1.99996805	2
Built-up area	Olive	1.48776219	1.66370334
	Wheat	1.994894	1.99999333
	Water	1.9582401	1.99998933
	Heathland	1.76480741	1.95556967
	Grassland	1.97654822	1.99999995
	Pine Forest	1.99991061	2
	Shrubland	1.96937368	1.99998892

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Sunflower	1.98660685	2
	groundnuts	1.98355732	1.99999999
	Maize	1.99999541	2
	Grapevines	1.99941744	2
	Natural Forest	1.90659983	1.99527397
Grapevines	Olive	1.87665927	1.99992941
	Wheat	1.99999999	2
	Water	1.99999983	2
	Heathland	1.99933558	2
	Grassland	1.99875143	2
	Pine Forest	1.99999993	2
	Shrubland	1.99999989	2
	Sunflower	1.99992421	1.99999999
	groundnuts	1.99998451	2
	Maize	1.99992652	2
	Built-up areas	1.99941744	2
	Natural Forest	1.95039865	1.99991711
Natural Forest	Olive	1.3872627	1.71181367
	Wheat	1.99976729	1.99994204
	Water	1.99725306	2
	Heathland	1.87193256	1.98251497
	Grassland	1.75063411	1.99757927
	Pine Forest	1.99760238	1.99999421
	Shrubland	1.58547227	1.99775788
	Sunflower	1.84127263	1.99455976
	groundnuts	1.85908764	1.99915236
	Maize	1.99996805	2
	Built-up areas	1.90659983	1.99527397
	Grapevines	1.95039865	1.99991711

Land Cover map 1994

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
Olive	Wheat	1.65255086	1.98021208
	Natural Forest	1.58936769	1.8120972
	Water	1.9999997	2
	Heathland	1.75870931	1.92943716
	Built_up areas	1.75957379	1.97757616
	Grassland	1.97461592	2
	Pine Forest	1.99349321	1.99999997
	Shrubland	1.94415883	1.99974886
	Grapevines	1.9516665	1.999705
	Sunflower	1.9063237	1.99623147
	Groundnut	1.82332493	1.99999816
	Maize	1.83345782	1.99812475
Wheat	Olive	1.65255086	1.98021208
	Natural Forest	1.67237633	1.92552412
	Water	1.99475818	2
	Heathland	1.35023909	1.63753206
	Built_up areas	1.84467608	1.92247835
	Grassland	1.42438321	1.67708689
	Pine Forest	1.95619478	2
	Shrubland	1.9740012	1.99919605
	Grapevines	1.96342016	1.99997128
	Sunflower	1.98262215	1.99973765
	Groundnut	1.91358983	1.99923738
	Maize	1.75967266	1.96596719
Natural Forest	Olive	1.58936769	1.8120972
	Wheat	1.67237633	1.92552412
	Water	1.99994933	2
	Heathland	1.58758693	1.67624406
	Built_up areas	1.92529737	1.98949591
	Grassland	1.8850844	1.99952656
	Pine Forest	1.98723283	1.99990031
	Shrubland	1.28640315	1.52737654
	Grapevines	1.95230806	1.9996424
	Sunflower	1.23328721	1.56195065
	Groundnut	1.93843626	1.99508761
	Maize	1.56777851	1.84011148
Water	Olive	1.9999997	2
	Wheat	1.99475818	2
	Natural Forest	1.99994933	2
	Heathland	1.99143847	1.99999998
	Built_up areas	1.93333558	1.99999891
	Grassland	1.99947016	2
	Pine Forest	2	2

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Shrubland	1.99986375	2
	Grapevines	2	2
	Sunflower	1.99994396	2
	Groundnut	1.99999952	2
	Maize	1.99990445	2
Heathland	Olive	1.75870931	1.92943716
	Wheat	1.35023909	1.63753206
	Natural Forest	1.58758693	1.67624406
	Water	1.99143847	1.99999998
	Built_up areas	1.82492213	1.95886267
	Grassland	1.78410754	1.98936637
	Pine Forest	1.8477029	1.99999998
	Shrubland	1.86879392	1.99970563
	Grapevines	1.99886494	2
	Sunflower	1.84463186	1.99996411
	Groundnut	1.8428224	1.97097365
	Maize	1.93356933	1.99998273
Built_up areas	Olive	1.75957379	1.97757616
	Wheat	1.84467608	1.92247835
	Natural Forest	1.92529737	1.98949591
	Water	1.93333558	1.99999891
	Heathland	1.82492213	1.95886267
	Grassland	1.99739452	1.99998287
	Pine Forest	1.99996858	2
	Shrubland	1.99079423	2
	Grapevines	1.99780165	2
	Sunflower	1.90115438	1.99996788
	Groundnut	1.96638417	1.99936441
	Maize	1.95808293	1.99960745
Grassland	Olive	1.97461592	2
	Wheat	1.42438321	1.67708689
	Natural Forest	1.8850844	1.99952656
	Water	1.99947016	2
	Heathland	1.78410754	1.98936637
	Built_up areas	1.99739452	1.99998287
	Pine Forest	1.99762379	2
	Shrubland	1.96900883	1.99999182
	Grapevines	1.99325467	2
	Sunflower	1.98528955	2
	Groundnut	1.97365182	2
	Maize	1.85154705	1.9955003
Pine Forest	Olive	1.99349321	1.99999997
	Wheat	1.95619478	2
	Natural Forest	1.98723283	1.99990031

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Water	2	2
	Heathland	1.8477029	1.99999998
	Built_up areas	1.99996858	2
	Grassland	1.99762379	2
	Shrubland	1.99997044	1.99999885
	Grapevines	1.99999631	2
	Sunflower	1.99472979	1.99999999
	Groundnut	1.99999845	2
	Maize	2	2
Shrubland	Olive	1.94415883	1.99974886
	Wheat	1.9740012	1.99919605
	Natural Forest	1.28640315	1.52737654
	Water	1.99986375	2
	Heathland	1.86879392	1.99970563
	Built_up areas	1.99079423	2
	Grassland	1.96900883	1.99999182
	Pine Forest	1.99997044	1.99999885
	Grapevines	1.99992206	1.99999218
	Sunflower	1.56971502	1.9171112
	Groundnut	1.99676825	1.99998151
	Maize	1.98464899	1.99709603
Grapevines	Olive	1.9516665	1.999705
	Wheat	1.96342016	1.99997128
	Natural Forest	1.95230806	1.9996424
	Water	2	2
	Heathland	1.99886494	2
	Built_up areas	1.99780165	2
	Grassland	1.99325467	2
	Pine Forest	1.99999631	2
	Shrubland	1.99992206	1.99999218
	Sunflower	1.99997462	2
	Groundnut	2	2
	Maize	1.97270548	1.99552252
Sunflower	Olive	1.9063237	1.99623147
	Wheat	1.98262215	1.99973765
	Natural Forest	1.23328721	1.56195065
	Water	1.99994396	2
	Heathland	1.84463186	1.99996411
	Built_up areas	1.90115438	1.99996788
	Grassland	1.98528955	2
	Pine Forest	1.99472979	1.99999999
	Shrubland	1.56971502	1.9171112
	Grapevines	1.99997462	2
	Groundnut	1.92144307	1.98365492

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
			1.99715014
	Maize	1.75226424	
Groundnut	Olive	1.82332493	1.99999816
	Wheat	1.91358983	1.99923738
	Natural Forest	1.93843626	1.99508761
	Water	1.99999952	2
	Heathland	1.8428224	1.97097365
	Built_up areas	1.96638417	1.99936441
	Grassland	1.97365182	2
	Pine Forest	1.99999845	2
	Shrubland	1.99676825	1.99998151
	Grapevines	2	2
	Sunflower	1.92144307	1.98365492
	Maize	1.99080174	1.99998899
Maize	Olive	1.83345782	1.99812475
	Wheat	1.75967266	1.96596719
	Natural Forest	1.56777851	1.84011148
	Water	1.99990445	2
	Heathland	1.93356933	1.99998273
	Built_up areas	1.95808293	1.99960745
	Grassland	1.85154705	1.9955003
	Pine Forest	2	2
	Shrubland	1.98464899	1.99709603
	Grapevines	1.97270548	1.99552252
	Sunflower	1.75226424	1.99715014
	Groundnut	1.99080174	1.99998899

Land-cover map 1984

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
Olive	Wheat	1.99454081	1.99999944
	Natural Forest	1.66328191	1.86301992
	Water	1.9743554	2
	Heathland	1.85902934	1.87750744
	Built_up area	1.91346766	1.97691383
	Grassland	1.76761327	1.9864357
	Pine Forest	1.99417338	1.99769412
	Shrubland	1.78115475	1.88716302
	Grapevines	1.98581807	1.99999938
	Sunflower	1.9239628	1.99427957
	Groundnuts	1.6407049	1.90824667
	Maize	1.99520884	2
Wheat	Olive	1.99454081	1.99999944
	Natural Forest	1.99993487	2
	Water	1.99247662	2
	Heathland	1.99999807	2
	Built_up area	1.99995829	2
	Grassland	1.9999602	1.99999998
	Pine Forest	2	2
	Shrubland	1.99999989	2
	Grapevines	2	2
	Sunflower	1.9971437	2
	Groundnuts	1.99999932	2
	Maize	1.99999979	2
Natural Forest	Olive	1.66328191	1.86301992
	Wheat	1.99993487	2
	Water	1.99608161	2
	Heathland	1.4939044	1.52761211
	Built_up area	1.85725035	1.90861161
	Grassland	1.99012496	1.99997967
	Pine Forest	1.91368008	1.99268353
	Shrubland	1.72300309	1.76854482
	Grapevines	1.99280141	1.99999887
	Sunflower	1.98182635	1.99977233
	Groundnuts	1.96661468	1.99984778
	Maize	1.93286826	1.99999997
Water	Olive	1.9743554	2
	Wheat	1.99247662	2
	Natural Forest	1.99608161	2
	Heathland	1.99531148	2
	Built_up area	1.87736116	1.99999666
	Grassland	1.99265261	2
	Pine Forest	1.99995812	2

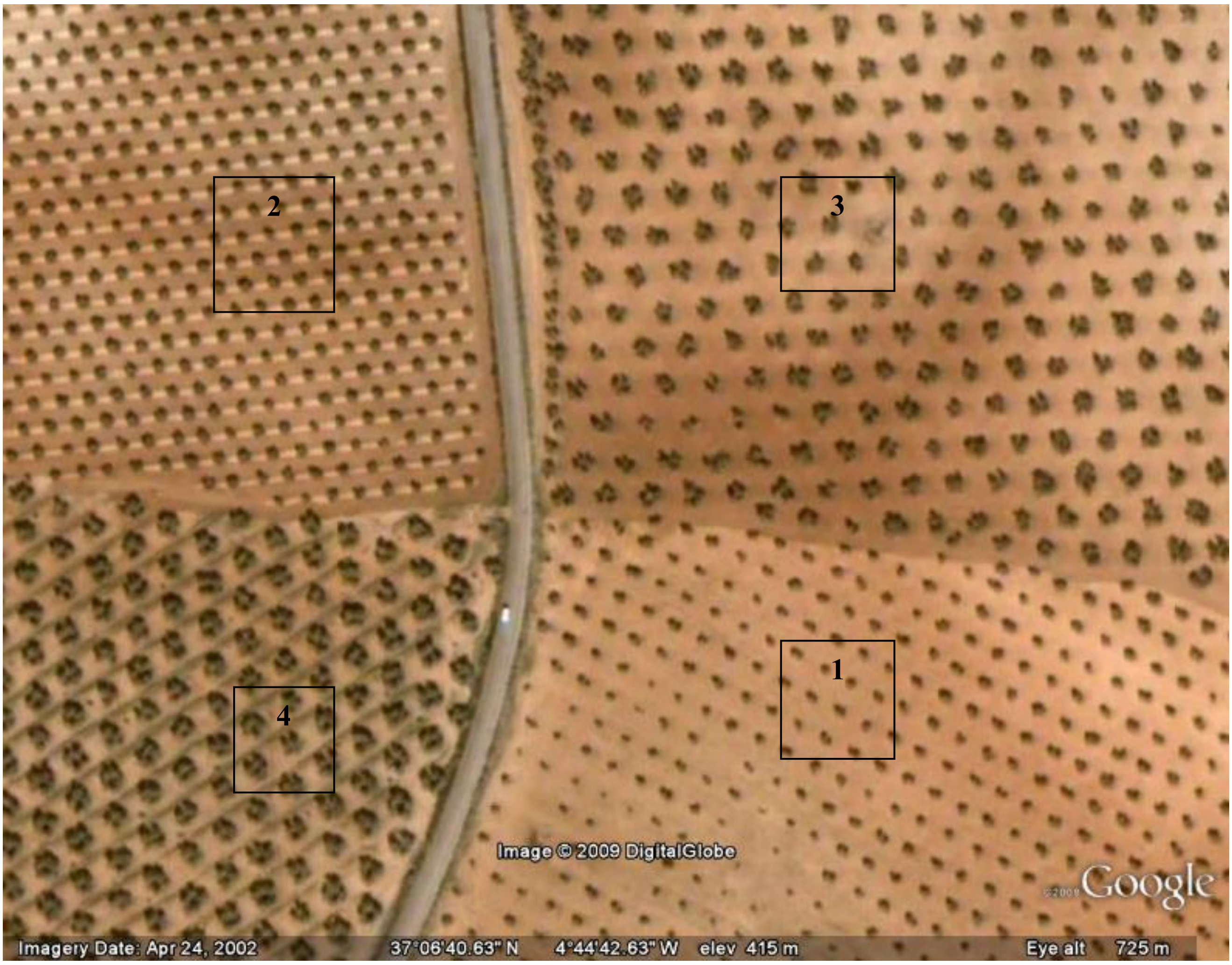
Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Shrubland	1.99499938	2
	Grapevines	1.99999995	2
	Sunflower	1.87684528	2
	Groundnuts	1.99770953	2
	Maize	1.99061821	2
Heathland	Olive	1.85902934	1.87750744
	Wheat	1.99999807	2
	Natural Forest	1.4939044	1.52761211
	Water	1.99531148	2
	Built_up area	1.59120721	1.73442816
	Grassland	1.99990687	2
	Pine Forest	1.94539978	1.99996994
	Shrubland	1.51822898	1.75547943
	Grapevines	1.99947881	1.99999952
	Sunflower	1.98222766	1.99999974
	Groundnuts	1.99969264	1.99999998
	Maize	1.84084276	1.99997523
Built_up area	Olive	1.91346766	1.97691383
	Wheat	1.99995829	2
	Natural Forest	1.85725035	1.90861161
	Water	1.87736116	1.99999666
	Heathland	1.59120721	1.73442816
	Grassland	1.99981926	2
	Pine Forest	1.9997923	2
	Shrubland	1.59752353	1.68020584
	Grapevines	1.99945054	2
	Sunflower	1.79221116	1.94416446
	Groundnuts	1.99909535	2
	Maize	1.90427534	1.99999577
Grassland	Olive	1.76761327	1.9864357
	Wheat	1.9999602	1.99999998
	Natural Forest	1.99012496	1.99997967
	Water	1.99265261	2
	Heathland	1.99990687	2
	Built_up area	1.99981926	2
	Pine Forest	1.99992034	1.99994876
	Shrubland	1.99995268	1.99999923
	Grapevines	1.99927198	1.99999962
	Sunflower	1.98915038	2
	Groundnuts	0.92266635	0.9973382
	Maize	1.99999981	2
Pine Forest	Olive	1.99417338	1.99769412
	Wheat	2	2
	Natural Forest	1.91368008	1.99268353

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Water	1.99995812	2
	Heathland	1.94539978	1.99996994
	Built_up area	1.9997923	2
	Grassland	1.99992034	1.99994876
	Shrubland	1.97947711	1.99925398
	Grapevines	1.99999998	2
	Sunflower	1.99999969	2
	Groundnuts	1.99968706	1.99996838
	Maize	1.99999988	2
Shrubland	Olive	1.78115475	1.88716302
	Wheat	1.99999989	2
	Natural Forest	1.72300309	1.76854482
	Water	1.99499938	2
	Heathland	1.51822898	1.75547943
	Built_up area	1.59752353	1.68020584
	Grassland	1.99995268	1.99999923
	Pine Forest	1.97947711	1.99925398
	Grapevines	1.99941831	1.99999874
	Sunflower	1.98854982	1.9979906
	Groundnuts	1.99909995	1.99989488
	Maize	1.91411328	2
Grapevines	Olive	1.98581807	1.99999938
	Wheat	2	2
	Natural Forest	1.99280141	1.99999887
	Water	1.99999995	2
	Heathland	1.99947881	1.99999952
	Built_up area	1.99945054	2
	Grassland	1.99927198	1.99999962
	Pine Forest	1.99999998	2
	Shrubland	1.99941831	1.99999874
	Sunflower	2	2
	Groundnuts	1.99999415	1.99999984
	Maize	1.980793	2
Sunflower	Olive	1.9239628	1.99427957
	Wheat	1.9971437	2
	Natural Forest	1.98182635	1.99977233
	Water	1.87684528	2
	Heathland	1.98222766	1.99999974
	Built_up area	1.79221116	1.94416446
	Grassland	1.98915038	2
	Pine Forest	1.99999969	2
	Shrubland	1.98854982	1.9979906
	Grapevines	2	2
	Groundnuts	1.99711921	1.9999999

Comparing cover	Cover type	Jeffries-Matusita	Transformed Divergence
	Maize	1.97866355	2
Groundnuts	Olive	1.6407049	1.90824667
	Wheat	1.99999932	2
	Natural Forest	1.96661468	1.99984778
	Water	1.99770953	2
	Heath land	1.99969264	1.99999998
	Built-up area	1.99909535	2
	Grassland	0.92266635	0.9973382
	Pine Forest	1.99968706	1.99996838
	Shrub land	1.99909995	1.99989488
	Grapevines	1.99999415	1.99999984
	Sunflower	1.99711921	1.9999999
	Maize	1.99999695	2
Maize	Olive	1.99520884	2
	Wheat	1.99999979	2
	Natural Forest	1.93286826	1.99999997
	Water	1.99061821	2
	Heath land	1.84084276	1.99997523
	Built-up area	1.90427534	1.99999577
	Grassland	1.99999981	2
	Pine Forest	1.99999988	2
	Shrubland	1.91411328	2
	Grapevines	1.980793	2
	Sunflower	1.97866355	2
	Groundnuts	1.99999695	2

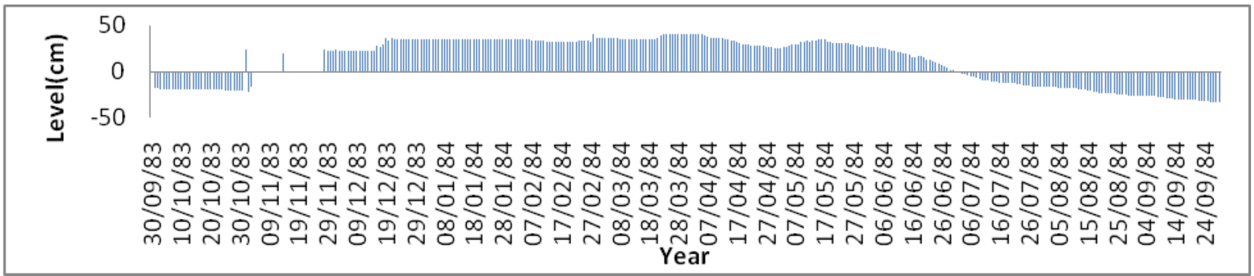
Appendix 2: Photo of olive canopy sizes for different olive age stands

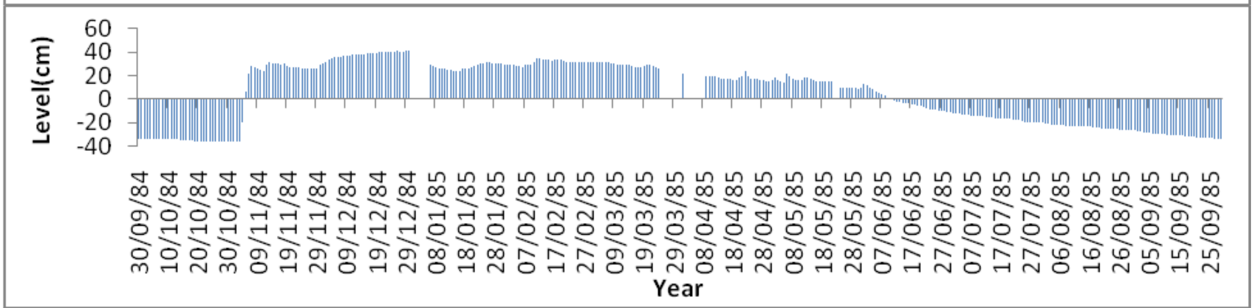
(1-new; 2-young; 3-medium; 4-old)

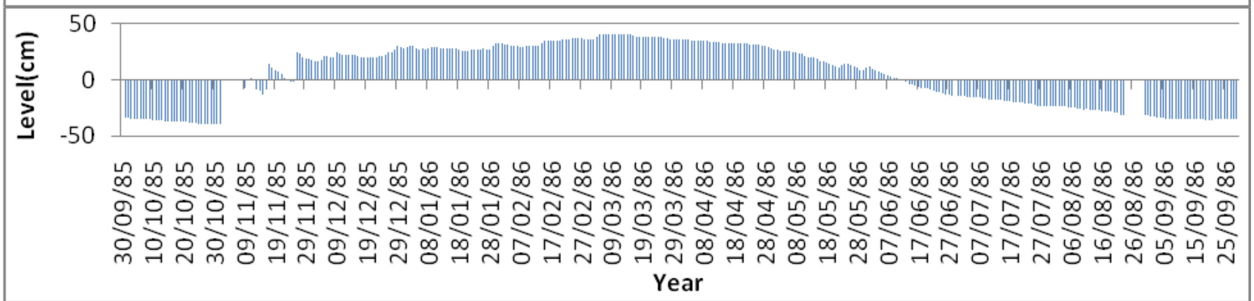


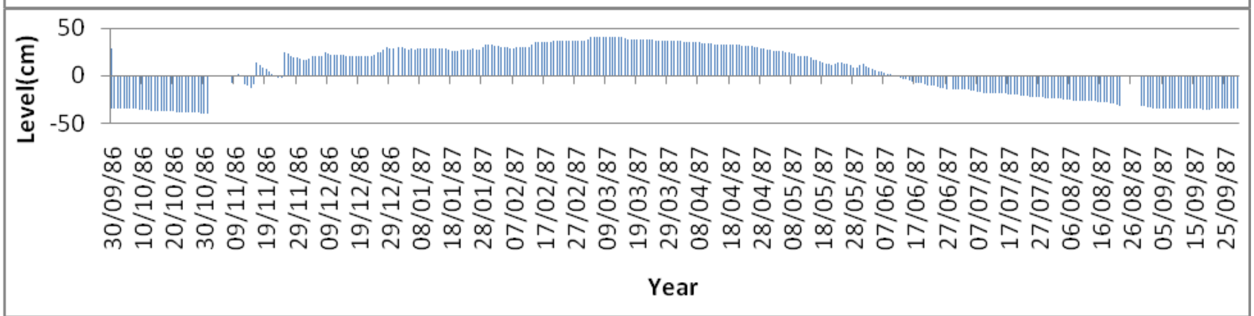
Source: Google Earth (2009)

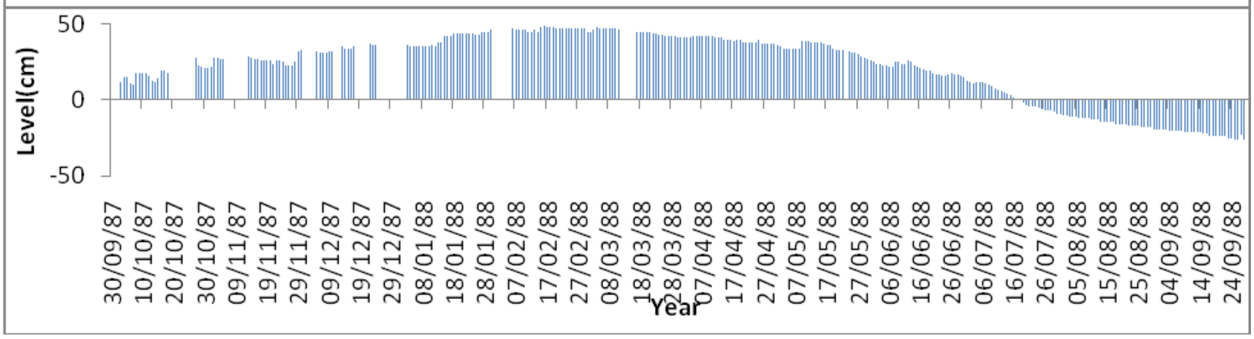
Appendix 3: Trends in Lake Piezometer readings depicting different hydrological years for the period 1984 to 2009.

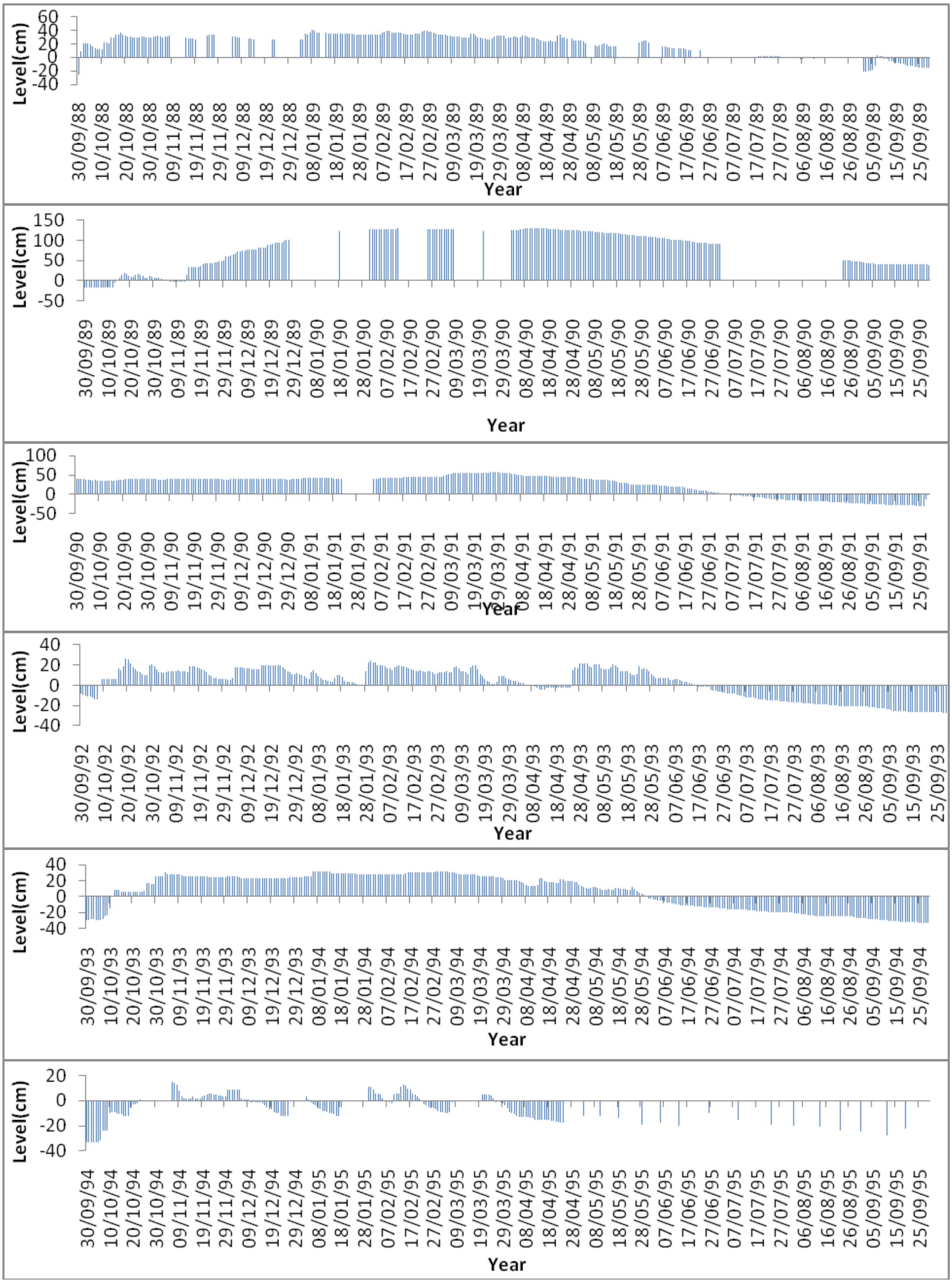








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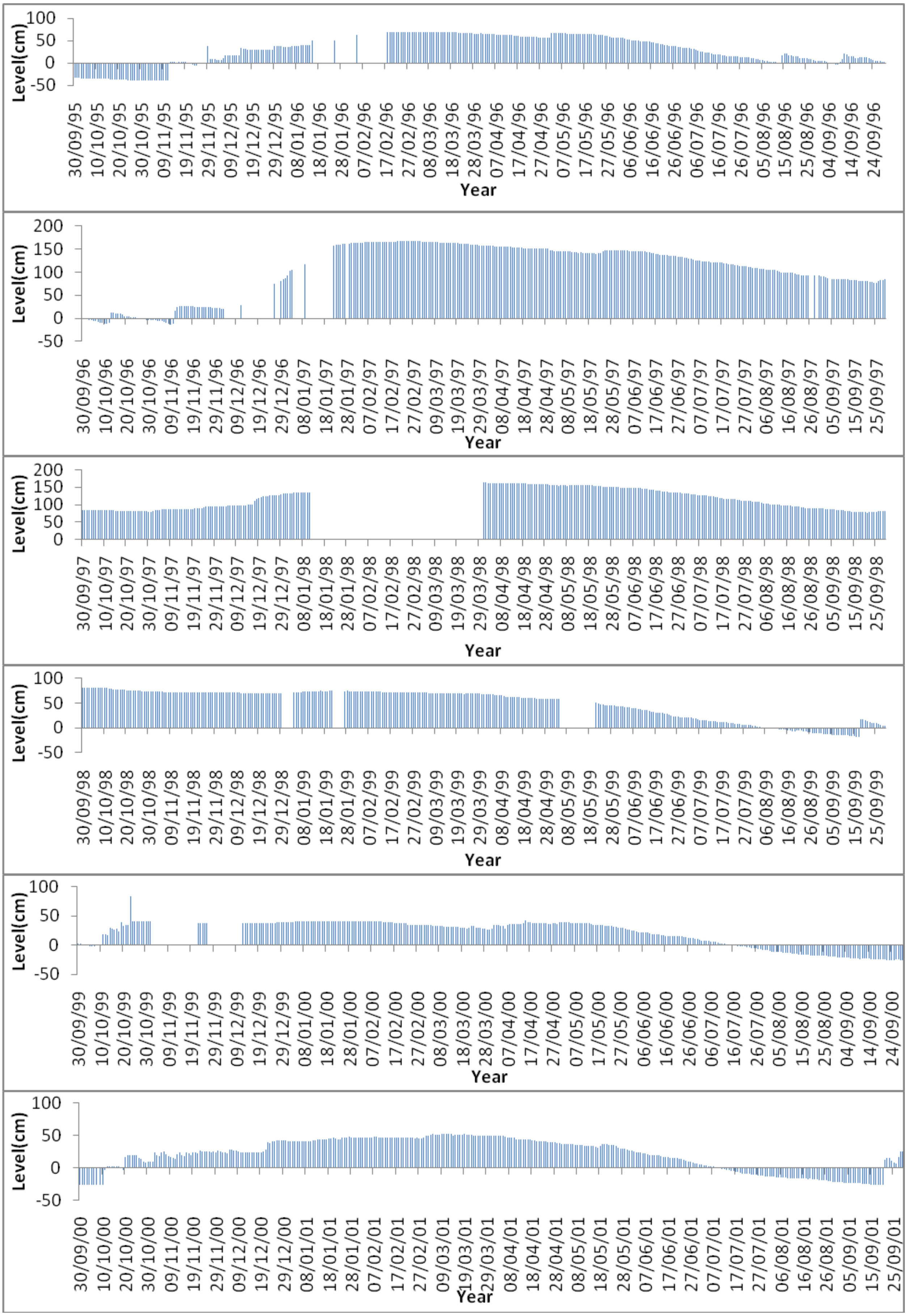
Year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Year
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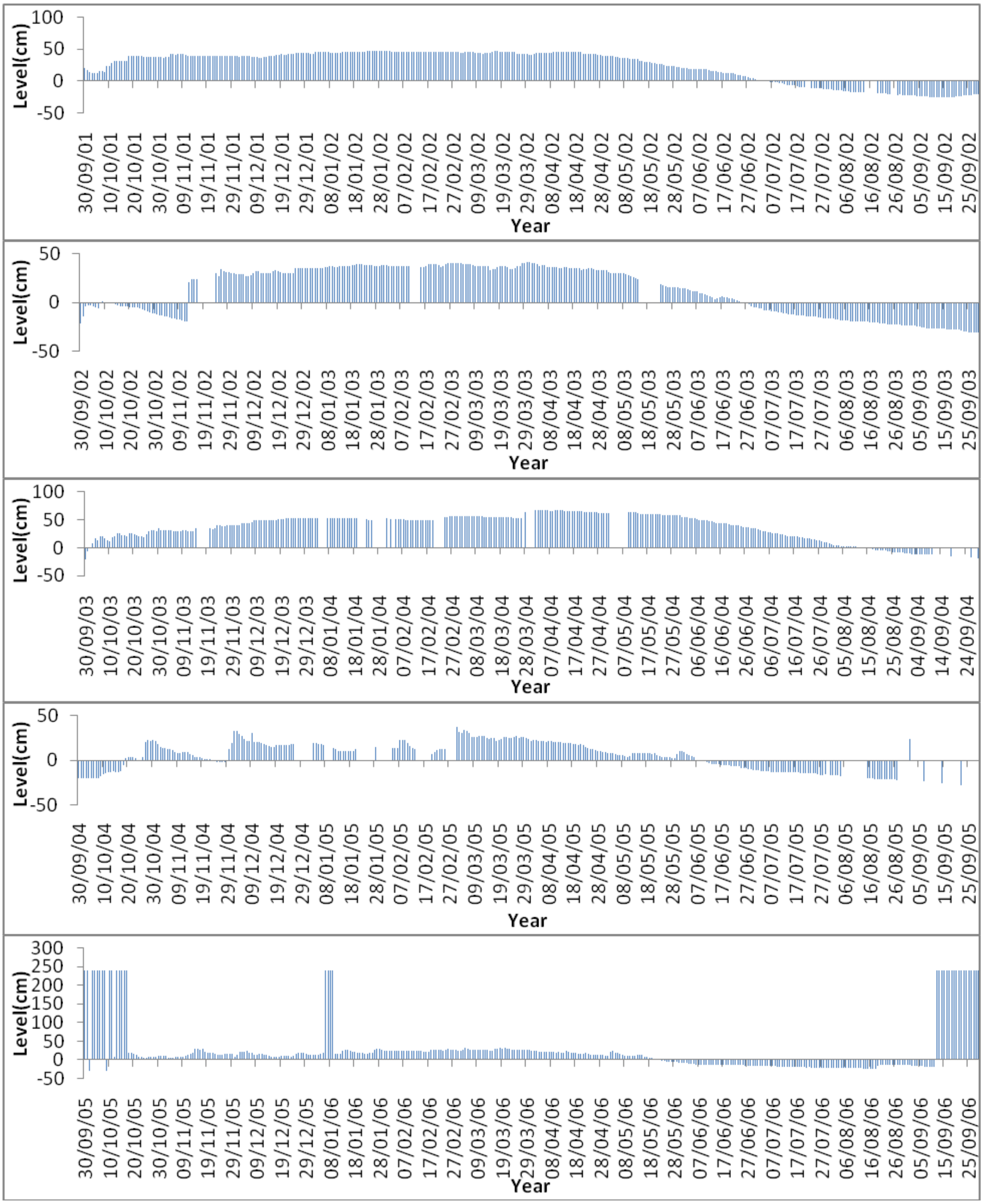
Year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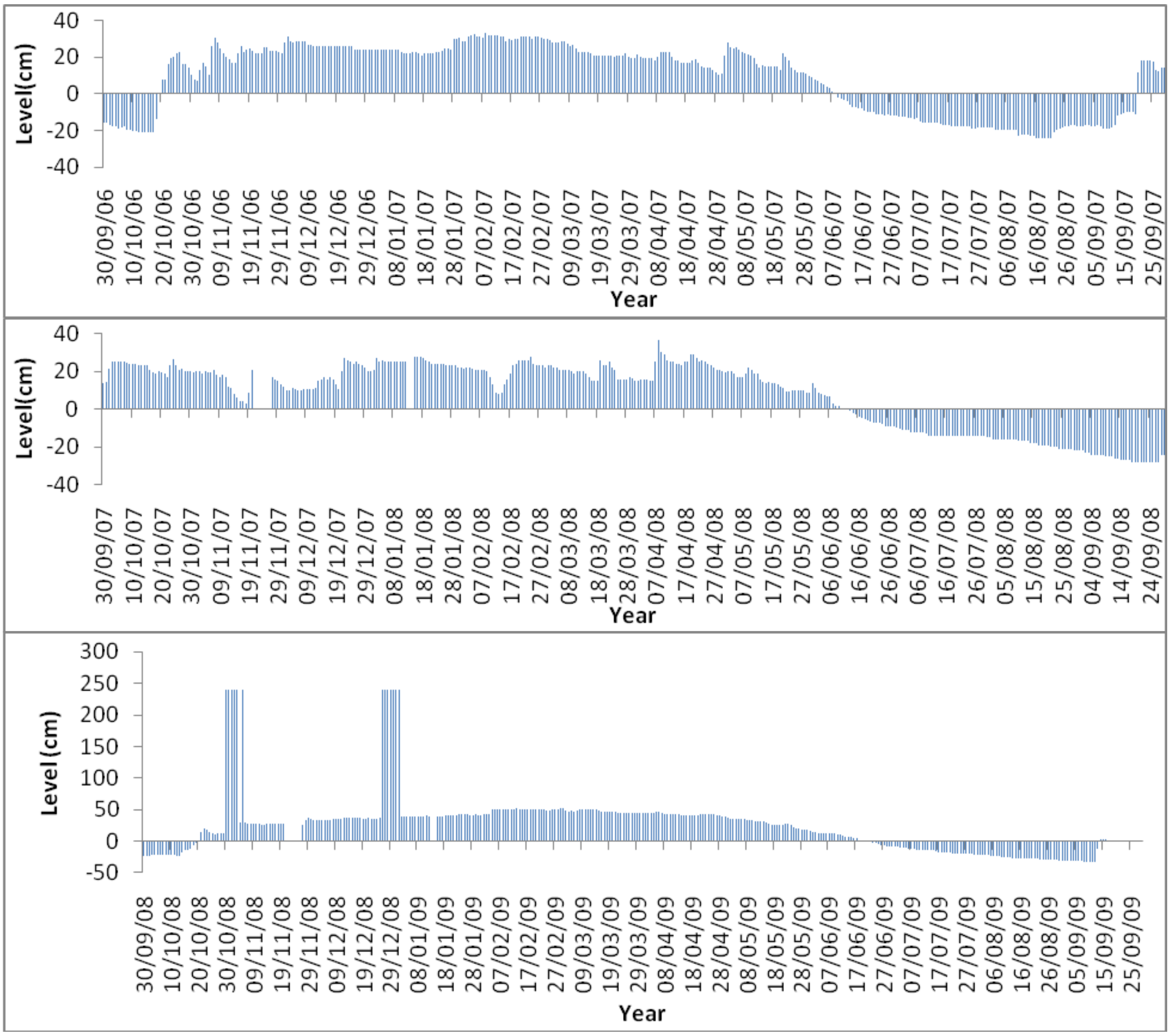
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-20
-40
30/09/07 10/10/07 20/10/07 30/10/07 09/11/07 19/11/07 29/11/07 09/12/07 19/12/07 29/12/07 08/01/08 18/01/08 28/01/08 07/02/08 17/02/08 27/02/08 08/03/08 18/03/08 28/03/08 07/04/08 17/04/08 27/04/08 07/05/08 17/05/08 27/05/08 06/06/08 16/06/08 26/06/08 06/07/08 16/07/08 26/07/08 05/08/08 15/08/08 25/08/08 04/09/08 14/09/08 24/09/08
Year
Level (cm)
300
250
200
150
100
50
0
-50
30/09/08 10/10/08 20/10/08 30/10/08 09/11/08 19/11/08 29/11/08 09/12/08 19/12/08 29/12/08 08/01/09 18/01/09 28/01/09 07/02/09 17/02/09 27/02/09 09/03/09 19/03/09 29/03/09 08/04/09 18/04/09 28/04/09 08/05/09 18/05/09 28/05/09 07/06/09 17/06/09 27/06/09 07/07/09 17/07/09 27/07/09 06/08/09 16/08/09 26/08/09 05/09/09 15/09/09 25/09/09
Year

Appendix 4: Field Data sheets

LAND USE/COVER SAMPLING DATA FORMS					
Date:	**Observers name:**				
Plot size :	**Plot No:**				
GPS X:					
Y:					
Species	**Percent Cover**	**Dominant Spp**	**Percent cover**	**Land use**	**Remarks**