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The effect of urban expansion on a range of soil properties, dependent on spatial patterns and land use change, around the city of Heraklion, Crete (Greece) with ArcGIS interpretation, and implications for potential soil management solutions

by

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Abstract

Modifications associated with land use can affect soil. With increasing urbanization around Heraklion in Crete, Greece, the city is extending towards rural areas in all directions, resulting in human conversion of unmanaged land to affected land use which includes concrete surfaces (residential/commercial areas, industrial areas and roads) and agricultural land. Therefore, the demands of soil quality for converted land use are becoming more and more significant. The aim of this paper is to identify whether there is a change in soil properties and soil quality in relation to different land uses around Heraklion and explore the main causes for these changes. The study area included Heraklion and the surrounding rural area with a research area of 13km (east-west) x 7km (north-south). A total of 12 natural phryganic shrublands, 9 young olive groves, 36 old olive groves and 9 bare lands were the land use types subject to analysis. This study examines whether there are spatial patterns between soil properties (and ultimately soil quality) in relation to different land use types. Due to the fact that if soil property is affected by land use, the soil property might have indirect effects on other soil properties, correlation between soil properties is taken in to account. The impact of different land use types on soil quality was evaluated by analysing 6 different soil properties: bulk density, organic matter, water content, electric conductivity, pH and nitrate. The laboratory results from the soil properties were combined in order to create a soil quality index. Kruskal-Wallis was undertaken for statistical relationships between soil properties and land use types, where the only significant relationship was electrical conductivity (P value: 0.004). ArcMap was used to create 1 topographic map, 6 soil property maps, 3 chronologically different land use maps (1960, 1997 and 2016) and a soil quality map. Some soil property maps (organic matter-electrical conductivity, nitrate-electrical conductivity, bulk density- water content and nitrate-organic matter) showed significant correlations, while the soil quality map suggested that rural areas had better soil quality than urban areas.

Key words: land use, soil properties, GIS, spatial analysis, spatial patterns, urbanization, soil quality, soil management.

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1.0 Introduction

Changes in land use are amongst the most important factors that have been known to affect soil properties, either positively or negatively (Lambin *et al,* 2001; Zucca *et al,* 2010). Worldwide, human activity is currently the major force in land use change and this is mostly down to unsustainable land management and soil sealing (Artmann, 2015; Serra *et al,* 2008). Historically, the conversion of unmanaged systems into agricultural or urban systems has been very important for the growth of human populations around the globe (Zhang *et al,* 2007). However, the conversion of unmanaged land into urbanized areas has accelerated in recent decades due to increasing urban population (Salvati, 2013; Xiao *et al,* 2013). This has become a concern to the surrounding environment as well as a threat to the urban soils which can have a consequence on biodiversity, with increased demand on agriculture and food quality (Zhang *et al,* 2007; Zhao *et al,* 2005). According to many studies, conversion of land use results in deterioration of chemical and physical soil properties, which can cause land degradation (Ayoubi *et al,* 2011; Biro *et al,* 2011; Feyera & Natarajan, 2011; Kiflu & Beyene, 2013; Sosnowska, 2012). Land degradation has become one of the largest environmental issues worldwide, and the underlying degradation of soil quality is becoming a priority (Bajocco *et al,* 2012).

The Mediterranean region is one of the first human populated areas (Blondel *et al*, 2010) and there has therefore been a considerable amount of human disturbance compared to other regions in Europe (Albaladejo *et al,* 1998). Notably, since the end of the Second World War, rapid urbanization has occurred and in particular around Mediterranean cities (Salvati, 2013) such as Heraklion in Crete. Recent accelerated socio-economic factors, such as introduction of tourism, migration from rural to urban areas, and increased infrastructure of industries after the 1960s in Mediterranean towns and cities, have led to population growth, urban expansion and agricultural intensification to cover demands (Khresat *et al,* 2008; Sarris *et al,* 2005). This in turn leads to a negative effect on the surrounding biodiversity and local underlying soil physical and chemical properties (Khresat *et al,* 2008; Pouyat *et al,* 2007; Salvati, 2013). The unsustainable use of rural and peri-urban areas through human pressure activities such as urban sprawl, intensive agricultural practices and tourism concentration is occurring widely in the Mediterranean region (Bajocco *et al,* 2012), and therefore the soil condition and the sustainable development of areas surrounding growing cities such as Heraklion has become very important for future needs (Sarah & Zhevelev, 2007).

According to Wang *et al* (2015), the worldwide urban population has reached 52% and will be rising by more than 0.5% per year for the next 50 years, meaning that urban centres will consequently convert more and more rural soils into urban soils, and therefore peripheral soils of cities need to be studied for the least possible conversion of high quality soils. In addition to urbanization issues, areas with characteristic landscape attributes, such as landscapes covered mostly by mountainous areas with steep slopes, attract human population in low altitudinal, accessible and fertile areas (Yaalon, 1997). In particular, Crete is a good example of this as its mountainous topography favours the concentration of population along the lower altitude and levelled north coast line compared to the very mountainous inland (Kairis *et al,* 2015) which is also represented in figure 1. This has led to the typical recent example of increasing population migrating from rural inland areas to the urban coastal areas (e.g. Heraklion), which has converted unmanaged areas into artificial areas and has increased intensive land use activities, resulting in soil land degradation (Mohawesh *et al,* 2015). The main land use types within and around the city of Heraklion include artificial concrete surfaces (built up areas & roads), agricultural land (olive groves & vineyards), and natural phryganic shrubland which are the least affected by human disturbance. Phryganic or phrygana shrublands are found in Mediterranean regions and consist of a dominant shrub layer between 30 and 60cm in height (Capitanio & Carcaillet, 2008).

Figure 1: Topographical map of Crete (Humanities, 2015)

Soil degradation within agriculture includes a range of processes such as increased soil erosion, salinization and acidification which can all lead to reduced top soil fertility (Lal, 2015). Soil fertility or soil quality is the ability of the soil to support diverse plant growth, and the quality is dependent on the availability of various components such as water, organic matter, nutrients and also the control of factors such as soil erosion and density of soils (Ayoubi *et al,* 2011; Vasilaki *et al,* 2008). The top layer of soil is affected the most since it is often physically disturbed and chemically polluted by human activities (Mao *et al,* 2014). Various human activities such as agricultural mechanisation, application of herbicides and paving the surface with concrete, cause negative impacts on the soil by restricting exchanges of gases, water and energy (Hereher, 2017; Symeonakis *et al,* 2007; Xiao *et al,* 2013). For example, intensive agricultural mechanisation on soil physically disturbs top soil by removing vegetation, adding pressure on top soil, and therefore potentially leading to water erosion. Soil degradation occurs due to the exposure of topsoil, where surface runoff can take place, in which the flow of the water carries away soil that may consist of rich organic matter and other soil properties (Abdullah, 2014; D'Hose *et al,* 2014; Fernandez-Getino *et al,* 2015; Gomez *et al,* 2009). In a similar manner to the decrease in organic matter, as land use modifications to soil properties display characteristic changes such as vegetation removal and soil exposure, this then leads to an extensive increase of pH values, electric conductivity and even increases in rates of nitrate which consequently affect plant growth (Laker, 2009; Pavao-Zuckerman, 2008). The level of pH can be significantly elevated by humans, either through importation of artificial chemical material which can release calcium in the soil, or by physical disturbance such as soil tillage (Craul, 1999). Similarly, electric conductivity can be increased through physical disturbance or fertilizer input, which also results in increased salinity in the soil. Soil electrical conductivity, which can be an indicator of salinization if the amount of salinity is excessive, can lead to limitation of nutrient availability which is vital for plant growth (Corwin & Lesch, 2005; Dunjo *et al,* 2003; Stadler *et al,* 2015; Zeng *et al,* 2013). Soil salinity is very important because it is very abundant in semiarid regions including Crete due to limited soil moisture, which leads to high concentrations of salinity (Laker, 2009; Sheldon *et al*, 2004). Soil nitrogen is a chemical property affected indirectly by other soil properties such as organic matter levels, rather than being directly affected by urban land uses (Hernandez *et al,* 2016). According to Hernandez *et al* (2016), the more the organic matter in the soil, the more stabilized and ideal nitrogen levels occur in the soil. This is because organic matter is the primary source of nitrogen, and the amount of nitrogen broken down from organic matter depends on the amount of plant litter and decomposition (Gerrard, 2000; Hernandez *et al,* 2016).

Soil sealing is another issue, whereby more and more surfaces are being covered by concrete due to urbanization (Bajocco *et al,* 2012). Increased soil sealing results in highly compacted urban soils and subsequent pressure is applied on the neighbouring non-sealed soils, which is measured in bulk density (Bajocco *et al,* 2012). Bulk density is the term that is used for the total density of the soil including material and pore space (Craul, 1999). The ideal bulk density which is well structured with enough space for root growth, aeration and infiltration should be below 1.10 g/cm^3 in most circumstances. Anything above 1.11 g/cm^3 can negatively affect root growth and reduce pore space within the soil (Zhang *et al,* 2007). According to Moges *et al* (2013), bulk density is affected by different land use types due to differences in the intensity of land management and land use history. This human pressure on the soil around cities can have negative impacts on soil quality and potentially expose soil to degradation (Biro *et al,* 2011). In addition, soil salt crust is another factor of soil sealing in semi-arid regions such as Crete, where saline soils are relatively abundant (Assouline *et al,* 2015; Laker, 2009). This is due to the lack of soil moisture in the topsoil, which can subsequently lead to high concentrations of salinization and potentially seal the soil surface with a salt crust (Costa *et al,* 2014; Sheldon *et al,* 2004). Human pressure is also linked to inappropriate land use management which can lead to loss of vegetation, soil organic matter, resilience, soil moisture and other important factors that contribute to the health of the soil (Moges *et al,* 2013).

Other effects which the urban environment can have on soils is to influence the availability of water due to the heat island effect (Garcia-Ruiz, 2010), thus reducing soil ability to enhance the surrounding ecosystem (Setala *et al,* 2013). Similarly to other soil properties, vegetation cover plays a significant role in the soil water content, either within or outside of an urban area (Davies & Hall, 2010). Heat island effect is the impact an urban centre such as Heraklion has on the local temperature of the area as well as the temperature of the underlying soils (Edmondson *et al,* 2016). Heat island effect, which is mainly affected by proximity to central urban centres and vegetation cover, has a direct impact on soil water content due to different temperatures (Edmondson *et al,* 2016).

Bare soils of urban areas differ from rural soils due to disturbance, but even woodland or agricultural soils within cities possess differences compared to soils of the same land use in the countryside (Oktaba *et al,* 2014). To start with, bare soils tend to be the poorest in terms of soil quality. High compaction rates due to surface pressure, removed vegetation and potential surrounding chemical material can reduce the ability of soil to provide ecosystem services such as nutrient cycling, and soil formation (Bajocco *et al,* 2012; Pavao-Zuckerman, 2008; Setala *et al,* 2013; Zhao *et al,* 2005). On the other side of the disturbance spectrum in this situation are unmanaged lands. Unmanaged lands such as phryganic shrublands are the least affected by humans, and therefore soil tends to exist in a better condition primarily due to high vegetation cover (Garcia-Ruiz, 2010; Zhao *et al,* 2005). For this reason, soil data from natural phryganic shrubland were used in this study as the original example of non-disturbed soils, in order to be compared with the converted land use of agricultural and built up area land uses. In between the poor bare soils and the rich unaffected soils, are the intermediate agricultural soils. Agricultural soils can vary in terms of quality due to soil management practices, but in general agricultural land such as olive groves covering most of the study area is poorer compared to unmanaged land, due to sparse ground cover in between olive trees, where soil erosion can accelerate (Gomez *et al,* 2009). On the other hand, dependent on the tillage of agricultural soils, compaction and restriction of plant growth is lower than urban soils due to the lower level of disturbance. However, extensive tillage can greatly affect compaction rates and therefore reduce organic matter, and alter soil pH and electric conductivity, which can result in soil degradation (Manandhar & Odeh, 2014; Marzaioli *et al,* 2010; Scharenbroch *et al,* 2005).

In this study, land use type was assessed as the primary factor for the soil quality results due to the various physical and chemical alterations that occur within soils of these different land use types (Marzaioli *et al,* 2010). This could create some interesting results because the study area covers both urban and rural soils, which can be as far as 5 km outside of Heraklion. However, urban soils are not always distinctly poorer compared to rural soils (Pavao-Zuckerman, 2008). For example, soil moisture is not only affected by distinctive urban-rural land use differences, but also by variety of places, slope position and relative elevation (Qiu *et al,* 2001). In addition, soils do not only differ in quality between urban and rural areas, but can also, for example, display significant differences within rural soils, such as agricultural soils tending to be poorer than soils covered by unmanaged land and woodlands (Biro *et al,* 2011).

Another soil property that was considered in this study, is organic matter level which in terms of urban soils can be quite variable, and old urban soils can contain a greater percentage of organic matter compared to younger urban landscapes (Park *et al,* 2010; Scharenbroch *et al,* 2005; Setala *et al,* 2016). Another soil variable that is potentially affected by age of urban areas is soil nitrogen (Park *et al,* 2010). According to Park *et al* (2010), soil nitrogen increases with age of urban area, which is potentially due to the higher percentage of concrete surface which is correlated with older urban areas. This means that excess nutrients from runoff are generated by impervious surfaces in higher intensity compared to younger urban areas with a smaller percentage of concrete surfaces (Park *et al,* 2010). This is due to the stability of a land use, where in an initial period after alterations occur, the change in organic matter reduction and other soil properties can be greater due to subtle modifications compared to a land use that has been in the same state for a long time (Khresat *et al,* 2008). On the other hand, in rural areas organic matter tends to be lower in cultivated soils than in unmanaged land soils, due to reduced plant litter and higher soil disturbance, which therefore negatively affects other soil processes (Solomon *et al,* 2000).

Soil mapping involves the location and identification of soils and their respective soil properties which can be represented as a map and can ease the understanding of potential spatial patterns in between soil variables (Sheng *et al,* 2010). Soil maps are created by a process names inverse distance weighting (IDW) that accurately predicts the variability of soils (Keshavarzi & Sarmadian, 2012; Robinson & Metternicht, 2006). Predictive maps are used extensively worldwide, and in particular soil mapping, by predicting a surface of a given area. Predictive mapping also includes the comparison of different regions at one time, or observation of changes of one region over a certain timescale (Symeonakis *et al,* 2007). Predictive mapping analysis which is undertaken on ArcMap, uses data and their representative sample location points and converts the whole study area, from the 75 sample locations, into a whole new surface that represents data of a soil property. The prediction of the covered surface using different soil variables is dependent primarily on the distance between two or more soil sample areas, and secondarily on variables such as topography, elevation and slopes (Gerrard, 2000).

Despite the fact that soil is a significant part of any ecosystem by positively influencing plant productivity, water purification and carbon cycling (Ferrara *et al,* 2014), soils have still not been taken into great consideration, resulting in poor understanding of soils surrounding cities (Xiao *et al,* 2013). This neglection of the importance of soil is noted by Lambin *et al* (2001), who claim that urbanization is ignored very often in studies related to land use change and the expectations of increasing urban population worldwide must raise the importance of land use management. In particular, soil studies that include soil mapping and investigation of land use impact on soil properties are neglected even more on Crete, and therefore there is little literature which considers the location of this study area. Results obtained from soil sampling, laboratory analysis and mapping analysis for this study can generate new outcomes on spatial patterns around Heraklion, and comparisons on soil properties between different land use in and around the city, which can then lead on to potential solutions. These solutions could possibly include both sustainable urban planning as well as preservation of the integral surrounding environment. The conducted soil data results which are derived through fieldwork sampling, laboratory analysis, statistical analysis and mapping spatial patterns will potentially provide answers to the following questions of the study:

1) Do soil properties vary across land-use types of Heraklion's urban and rural soils, and if so how?

2) Do the values of soil properties indicate any spatial patterns leading from central Heraklion outwards to the countryside, and if so, in terms of which geographical factors?

3) If the land use type does affect soil properties, is there any indirect correlation between one soil property and another?

4) How can spatial patterns of soil data assist the future expansion of development of Heraklion, and what are the potential management practices that can be undertaken to allow a sustainable further expansion of the city?

2.0 Methodology

2.1 Study area

Crete (figure 2) is the largest island in Greece and 5th largest island in the Mediterranean Sea, covering a land area of about 8729 km^2 (Sarris *et al,* 2005; Vogiatzakis *et al,* 2008). Crete is situated between 34°91 and 35°68 latitude north and 23°55 and 26°29 longitude east. The island has a complex geography with an extremely mountainous landscape (Sarris *et al,* 2005), varying from sea level (0 metres) up to the highest peak of Crete on Mount Ida (Central Crete) at 2456 metres high (Siart *et al,* 2009). Olive groves and other forms of agriculture cover nearly 45% of the island, natural phryganic shrubland covers 35%, while the rest of the island is occupied by woodlands, built up areas and other minor landscapes (Sarris *et al,* 2005). With Crete being a typical Mediterranean island, the climate is semi-arid with extremely dry summers and periods of heavy rainfall during winter, with mean monthly temperatures varying from 10 °C in January up to 26 °C in July (Koutroulis *et al,* 2013).

The study focused on Heraklion, one of the largest growing cities in Greece (Tsilimigkas *et al,* 2016). The study area (figure 2) was 13 km east to west and 7 km south to north, with Heraklion being situated in the north central part of the study area and located south of the Aegean Sea. Heraklion is the 4th largest city in Greece and the capital city of Crete with an approximate population of 200,000 (Cretan Routes, 2017; Ellin Yacht, 2017). The study area consists of a complex topography consisting of altitudes from sea level (0 m) to around 250m elevation, with a few seasonal rivers cutting through the landscape (figure 3). The south part of the study area is relatively mountainous, whereas the central and north part of the study area are relatively flat and eventually lead down to the sea in the north. The mass percentage of the study area is covered by built up areas (54.8%), olive groves (30.5%) and to a lesser extent natural Mediterranean phryganic shrubland (11.6%) (table 1). The specific land use types that will be assessed in the analysis are the following: Young, olive groves, old olive groves, bare land and natural phryganic shrubland (figure 4). Olive groves in Crete tend to be planted in rows and any soil in between is often bare during the summer and consists a layer of grass during the winter. Natural phryganic shrubland is considered as natural vegetation consisting a dominant shrub layer of up to 60cm height (Capitanio & Carcaillet, 2008). Bare lands are usually previous agricultural fields that were later abandoned (Zhao *et al*, 2005) and are distinct due to the lack of vegetation cover.

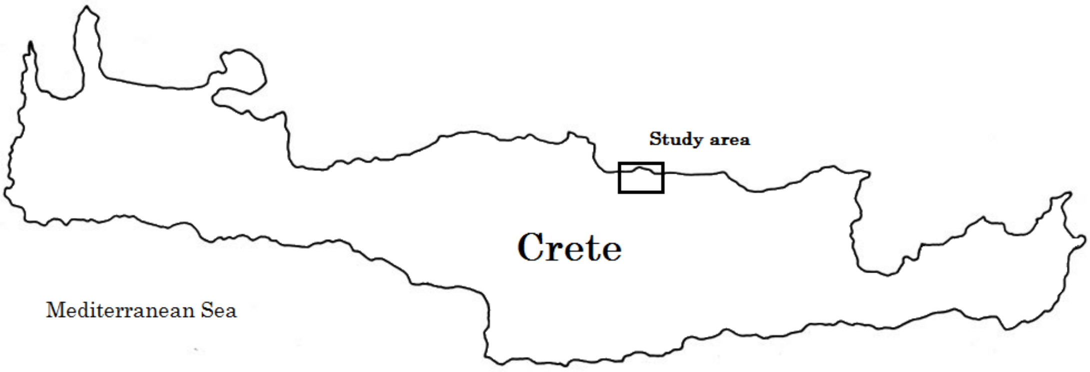

Figure 2: Crete and the location of the study area: Heraklion

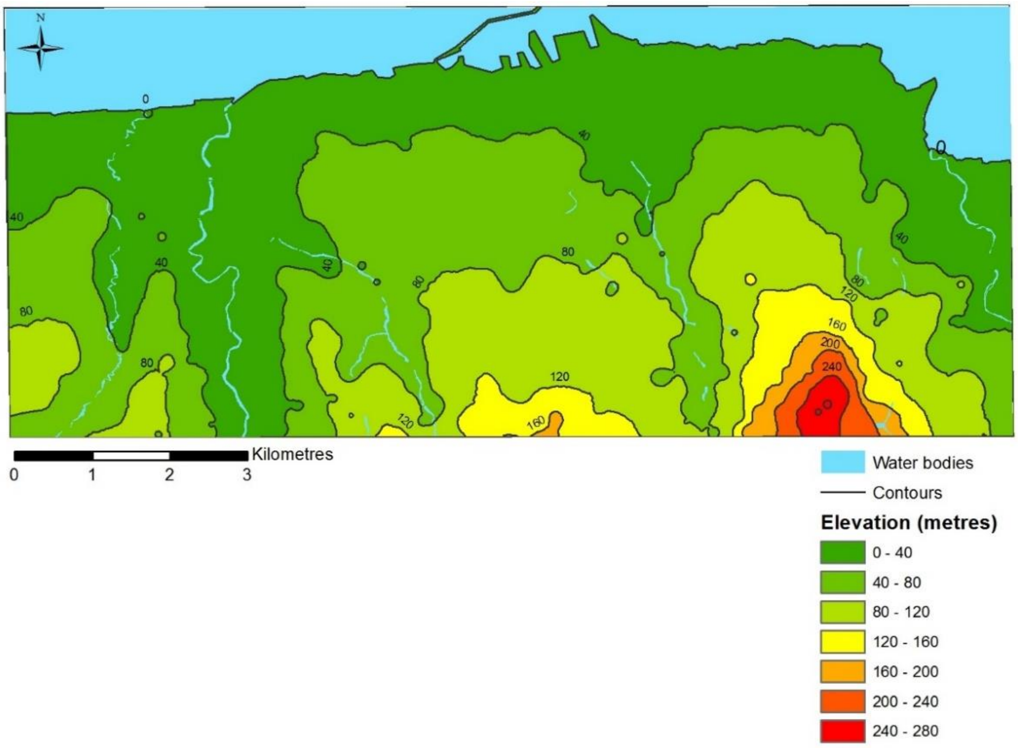

Figure 3: Topographic map of the study area

Table 1: Percentage (%) of land use within the study area between 1960, 1997 & 2016

	1960	1997	2016
Built up areas & Airport/military base	19.5	41.1	54.8
Natural phryganic shrublands	21.2	13.1	11.6
Olive groves	41.2	37.1	30.5
Vineyards	12.2	4.5	1.1
Grasslands	4.2	2.8	0.8
Inland water bodies (rivers)	1.7	1.4	1.2

Figure 4: Street view and view from above for each land use type. Young olive groves (top left), Old olive groves (top right), Natural phryganic shrubland (bottom left) and Bare land (bottom right). (Google Earth, 2016)

2.2 Collection of soil samples

The collection of the soil samples was undertaken between the 13th and 25th of October 2016 from locations in and around the city of Heraklion, Crete, Greece. In total, 140 soil samples were collected within the study area from 70 different areas in order to provide soil for laboratory analysis, as well as mapping and statistical analysis. The sample areas were randomly selected, where distance was proactively evened out between each sample location using Google Street map during the collection of the samples. This method of distance perception avoided clustered samples in very close proximity, or a very large empty part of the study area remaining without a collected soil sample. The random sample areas included all land use types. At each of the 70 random soil sample areas that were chosen, two replicate samples were collected 1m apart. The central part of Heraklion and the area of the airport were excluded areas for soil collection, either due to very high percentage of paved surface and lack of either agricultural or natural phryganic shrubland, or due to being prohibited areas.

Using a soil corer, soil cores were taken 1m apart at each site and up to 10cm depth in order to gather topsoil samples. The penetration of the soil corer to 10cm depth was not always possible, as the underlying earth was either very solid soil surface or rock and therefore the soil samples were collected elsewhere on the same site. The sample location and elevation was then recorded using a Garmin eTrex 10 GPS unit. Initially the geographical position and elevation of each sample area was determined using a GPS Garmin unit with approximately 3 metres accuracy (Owings, 2012). The coordinates that were noted provided an easy way of locating the areas on ArcGIS software. The next step was to crumble any larger particles of soil into smaller ones. The soil samples were weighed and noted down on the same day in which they were collected in order to find out the wet, or fresh, soil-weight. All the soil samples were collected following dry days without any rainfall, so that the effect of precipitation was avoided for best possible soil water content results. Additional notes such as sample number, elevation, and proximity to urbanized areas or main roads were noted down for later use. After soil collection, the samples were exposed to the sun for the following 3 days in an air-drying method where moisture was evaporated from the soil. The soil samples were then transported to the UK and stored in centrifuge tubes prior to analysis. The air-dried soils were reweighed in the laboratory on the 16th of January 2017, in order to find the dry soil weight and calculate soil water content.

2.3 Laboratory analysis

The soil was analysed in the Laud laboratories, on the Canterbury Christ Church University campus, between the 16th of January and the 17th of February 2017. Seven different soil properties were measured: Soil pH, electric conductivity, soil gravimetric water content, organic matter, bulk density and soil nitrate. Each soil property analysis was undertaken individually one at a time for all 140 samples.

Soil water content

The procedure underlying this analysis is the loss of weight between the initial soil weight, which contained water, and the dried soil, and is classed as the gravimetric soil water content (Krzic *et al,* 2010). The initial weight of each soil sample was weighed and recorded during the sample collection in October 2016 and was then left in the centrifuge tubes after air-drying. The soil samples were reweighed in the laboratory and the difference between the two weights gives the gravimetric soil water content. The difference was then converted into a percentage, which represented the total soil water content percentage within each soil sample.

$$\%\, Soil\ Water = \frac{weight\ of\ wet\ soil\ (g) -\ weight\ of\ dry\ soil\ (g)}{weight\ of\ dry\ soil\ (g)} \times 100$$

Soil pH

Soil pH was measured with the use of a pH Palintest Micro 500 meter. For each soil sample, 2 g of soil was mixed with 10 ml of distilled water in a glass McCartney bottle, giving a soil:water ratio of 1:5 (McLaughlin *et al,* 1994). Once the caps were fastened, 10 McCartney bottles were placed in a Brunswick Excella E25 Incubator shaker at a time. The McCartney bottles were shaken at a speed of 300 RPM for 120 minutes. Following this, the samples were removed from the machine, kept upright and left for 15 minutes for soil to settle before the pH measurements were taken. For each sample, the end of the pH probe was kept just above the surface of the soil and within the water of each sample for 60 seconds. The reading of the pH probe meter was then taken and recorded.

Electric conductivity

Electric conductivity was measured as a proxy for soil salinity (Hardie & Doyle, 2012; Scudiero *et al,* 2016). The analysis method for the salinity of the soil was very similar to the pH analysis, and therefore the same soil and water mixture was used and the two analyses were undertaken simultaneously. As with the pH, the electric conductivity probe was placed just above the surface of the soil in the glass tube and the reading was taken when it became stable. The probe was very sensitive, so it had to be held very still for the best possible reading. The electric conductivity reading was recorded in mS/m.

Bulk density

The bulk density of each soil sample was measured by finding the volume of the soil corer which was used to extract the soil samples in the field. This was achieved by measuring the height and diameter of the soil corer that was used. 10 cm was the depth that the soil corer penetrated the surface soil for all samples, and 1.6 cm was the diameter of the soil corer. Bulk density of each soil sample was calculated by dividing the weight of the dry soil (g) by the volume of dry soil in the soil corer (cm^3) (Abdel-Magid *et al,* 1987; Agriinfo, 2015, Wood, 2007). The unit that is used for soil bulk density values is g/cm^3.

$$\text{Bulk density (g cm}^3\text{)} = \frac{\text{(Dry weight soil (g) - stone weight (g)}}{\text{(Core volume (cm}^3\text{) - stone volume (cm}^3\text{)}}$$

Organic matter

In this analysis, loss on ignition was calculated as a proxy for organic matter content (Jock *et al,* 2013; Salehi *et al,* 2011). For each sample, 2 g of soil was placed in its corresponding labelled and pre-weighed porcelain crucible. The weight of the crucibles on their own and the crucibles with soil were recorded. Due to space constraints, 20 crucibles were placed in the muffle furnace at once on 550°C for 5 hours. The numbered crucibles were placed randomly in the oven and not in a sequence. This was done so that if there was the slightest variability in temperature within the furnace, the soil samples would have been affected randomly rather than in a sequence. The sample numbers of crucibles were mapped on a piece of paper representing their position in the oven, so that there was no confusion, as the marked numbers on the crucibles tend to fade away in the oven due to the temperature. The crucibles were placed very close to each other in the oven but without any contact in order to limit the potential for damage to the crucibles, such as cracking. After 5 hours, the oven was turned off and the crucibles were left in the oven to cool down until the following morning. The following day, the crucibles were removed from the oven and were reweighed. The difference between the initial weight and the reweighed crucible + soil was subtracted from the initial respective weight, and the difference was calculated as the loss on ignition. The difference was then converted into a percentage to give the final soil organic matter value.

$$\mathrm{LOI}\ (\%) = \frac{W_i - W_f}{W_i} \times 100$$

Nitrate

The soil nitrate content of the samples was measured with a LAQUA twin nitrate meter (Dimkpa *et al,* 2017). For each soil sample, 2 g of soil was added to McCartney bottles and diluted with 6 ml of distilled water to give a 1:3 ratio. The McCartney bottles were capped and placed in a Brunswick Excella E25 Incubator shaker for 60 minutes at a speed of 240 RPM. The samples were then removed and were left for 15 minutes in order for the soil to settle. With the use of a pipette, a few drops of a soil sample were dropped on the sensor of the nitrate meter. The reading was taken after it became stable in parts per million (ppm) units. After each soil sample, the filter paper was replaced with a new one and the area of the sensor was cleaned with distilled water and wiped very gently to avoid contamination of the subsequent soil samples.

2.4 Mapping analysis

ArcGIS 10.4.1 was used for all mapping analysis throughout the project. The first step of mapping analysis was carried out before the collection of the soil in October 2016. This involved the creation of a study area that included Heraklion and some countryside around it. The study area as mentioned earlier is around 13 km west to east and 7 km south to north. The following step was the digitisation of all the land use within the study area. Digitising meant the creation of polygons, polylines, lines etc. by copying what was seen on a Google Maps (Google Maps, 2016) satellite image. The assistance of Google Street View (Google maps, 2016) was also very important for confirmation of any obscure land areas. Historic land use maps of 1960 and 1997 were also digitised, by importing map images of these two periods obtained from the web, and using a georeferencing tool in order to align the images with the underlying base map. The land use areas are divided into: built-up areas (urbanization, industrial sites, main roads, airport/military base) olive groves, vineyards, grasslands, natural phryganic shrublands, and water bodies (sea, rivers). The final result was three completely new map layers (1960, 1997 & 2016), with different land use classified in different colours in order to show change in land use over time.

The next step was the importation of the recorded coordinates on ArcGIS which represented the exact locations of the 70 sample areas. When the laboratory analysis was complete, all the data from the 6 different analyses were imported alongside their respective sample numbers and coordinates on the attribute table. Subsequently, Inverse Distance Weighting (IDW) was analysed and separate maps were created for each of the 6 quantitative different soil properties (pH, organic matter, soil water content, nitrate, electric conductivity & bulk density). IDW maps use point data to predict the whole surface of the study area, regarding the equal weight distance between the closest sample points in any direction (Lu & Wong, 2008). The total surface of the study area is 7 x 13 km, so it is almost impossible to sample and analyse every square metre of the study area, as it would also require a substantial amount of time in order to achieve this. However, even though predictive mapping means that the representative soil samples do not cover every square metre of the study area, the maps can still be highly accurate. Large datasets of samples and locations can also increase the accuracy of the soil mapping analysis (Siqueira *et al,* 2014). The final step was the creation of a soil quality map which combined the 6 soil properties (pH, organic matter, soil water content, nitrogen, electric conductivity & bulk density). A quality index was created for each of the soil properties regarding the quality of plant productivity. Each soil property had an index of three levels of suitability: (1) poor, (2) intermediate and (3) ideal. Subsequently, the 6 soil properties index values were combined to create average soil quality values. The results were subcategorized into 4 scales of quality, whereby the higher the number, the better the overall soil function and quality for plant growth. The data that were acquired from this procedure were then analysed on ArcMap using IDW as previously, in order to create the final output which was the soil quality map.

Table 2: Tolerance ranges for plant growth on 6 soil properties

Soil properties	Optimum	Limiting	Restricting	Reference source
Electric conductivity (mS/m)	0 – 400	400 – 800	>800	(Janzen, 1993)
pH	6 – 7	7 – 8	>8	(Craul, 1999) *pH range below 6 is not shown as all values in the study were above 6
Bulk density (g/cm^3)	<1.1	1.1 – 1.3	>1.3	(Zhang *et al,* 2007)
Organic matter (%)	>8	4 – 8	0 – 4	(Marzaioli *et al,* 2010) *Method of the more is better
Soil water content (%)	>2.15	1.20 – 2.15	0 – 1.20	(Marzaioli *et al,* 2010) *Method of the more is better
Nitrate (ppm)	11 – 100	100 – 200	>200	(Zhang *et al,* 2007) *Nitrate range below 11 is not shown as all values were above 11

2.5 Statistical analysis

All statistical analysis was undertaken on Minitab 17. The initial test that was undertaken was the Anderson-Darling test, which was used in order to find out whether the data are normally or non-normally distributed. This test result showed that none of the 6 soil properties followed a normal distribution and therefore the following statistics had to be non-parametric tests. The main type of statistical analysis used involved statistics that analyse differences between datasets such as Kruskal-Wallis one-way analysis of variance. Kruskal-Wallis was used to determine if there are any potential differences between soil properties and different land use types. In all Kruskal-Wallis analyses, one axis included categories of land use types (all olive groves, old olive groves, young olive groves, bare land and natural phryganic shrubland) and the other axis included one of the 6 quantitative soil properties (pH, bulk density, electric conductivity, nitrogen, organic matter & water content). In order to be able to examine the human impact on soil properties, all agricultural and bare land soil samples were compared against the soil properties that were under natural phryganic shrubland land use type, due to it being the one with the most natural conditions. The final statistical analysis was Spearman's correlation matrix, which analysed all the soil properties against each other in order to identify any potential associations. The correlation coefficient (r) that was used was -1 to +1 and significant correlation was sited at P values below 0.05.

3.0 Results

3.1 Normality tests

Initially, the pH, bulk density, electric conductivity, nitrogen, soil water content and organic matter results of all the 140 soil samples were statistically tested for normality, in order to find out whether the numbers are parametric or non-parametric. Overall, all of the soil properties followed a non-normal distribution which meant that further statistical tests would be non-parametric tests. The normality test that was undertaken on Minitab 17 for the soil property results was the Anderson- Darling test. In detail, pH, electric conductivity, organic matter, nitrate and soil water content had a very low P value of below 0.005 and bulk density had a P value of 0.046, meaning that all of the data followed non-normal distribution.

3.2 Kruskal-Wallis one-way analysis of variance

With all the soil data being non-normally distributed, the non-parametric Kruskal-Wallis was used in order to discover whether there were any significant differences between the soil properties and the land uses. Each soil property was tested on the basis of whether there is a relationship between one soil property and the different land use types of each soil sample (split into older olive groves, young olive groves, natural phryganic shrublands, bare lands and all olive groves). From the 6 Kruskal-Wallis tests, 1 of the soil properties had a significant P value.

Soil electric conductivity versus land use type had a significant P value of 0.004. The land use type that had a significantly different value from the other land use types was the old olive groves. The mean electrical conductivity value for the old olive groves had a value of 237 mS/m. The land use types that had a similar electrical conductivity mean value with the old olive groves were natural phryganic shrubland with 244 mS/m, and all olive groves with a mean electrical conductivity of 266 mS/m. The highest electrical conductivity value was found in the bare land sites with a mean value of 532 mS/m (figure 5).

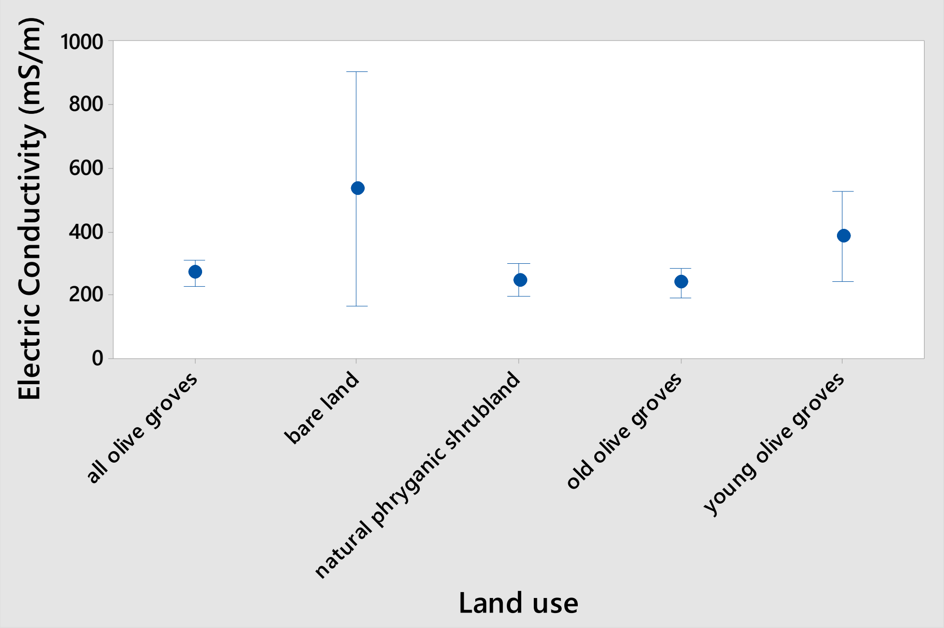

Figure 5: Mean electrical conductivity for different land use types

Soil pH had a non-significant P value of 0.144 against land use types. The land use type that had the highest mean value of pH compared to the remaining 5 land use types was bare land with a mean pH of 7.6, whereas the rest of the land use types ranged from 7.2 to 7.4 pH (figure 6).

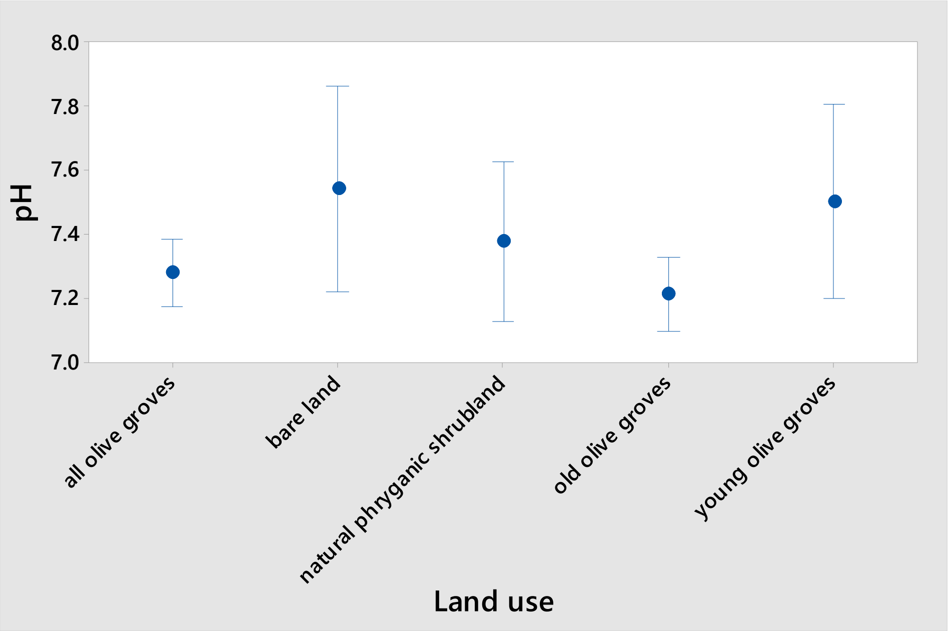

Figure 6: Mean soil pH for different land use types

The Kruskal-Wallis test on bulk density was not significant (P=0.242). All of the land use types had a relatively low value of bulk density (Mao *et al,* 2014), with bare land and young olive groves having the highest mean levels of around 0.86 g/cm³. Natural phryganic shrubland had the lowest mean bulk density value of 0.78 g/cm³. The rest of the land use types ranged between 0.79 and 0.85 g/cm³ (figure 7).

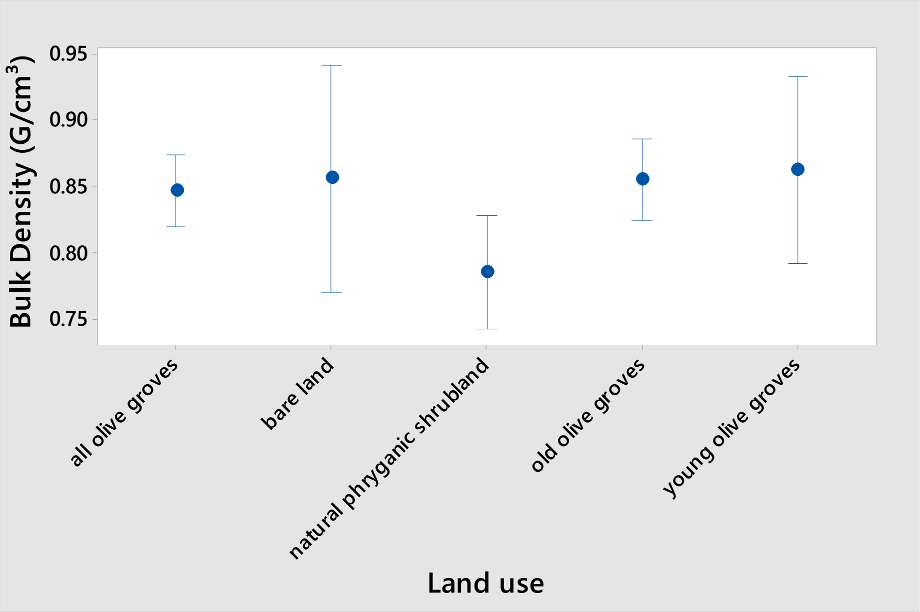

Figure 7: Mean bulk density for different land use types

Organic matter had a non-significant P value of 0.253 with the land use types having interesting differences in soil OM percentage. For example, the land use with the highest organic matter was natural phryganic shrubland with a mean organic matter of 9.8 %. Bare land, had the lowest mean organic matter of 7.4 %. All the agricultural land use types which included all olive groves, old olive groves and young olive groves were situated in between the values of natural phryganic shrubland and bare land with a range of 8-8.3 % of organic matter (figure 8).

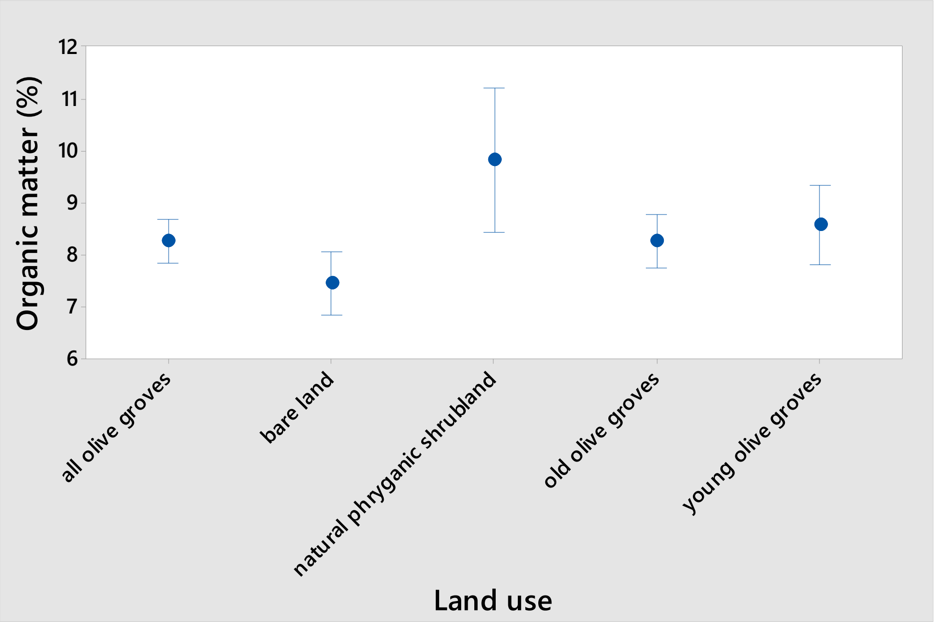

Figure 8: Mean organic matter for different land use types

Similarly to bulk density, soil water content had a non-significant P value of 0.140. The trend of the land use mean values were very similar to bulk density. Young olive groves had the highest mean soil water content with a value of 1.83 % in the soil, and natural phryganic shrubland had the lowest mean value of 1.42 %. The remaining land use types of all olive groves, old olive groves and bare land had a similar soil water content of approximately 1.60 to 1.70 % (Figure 9).

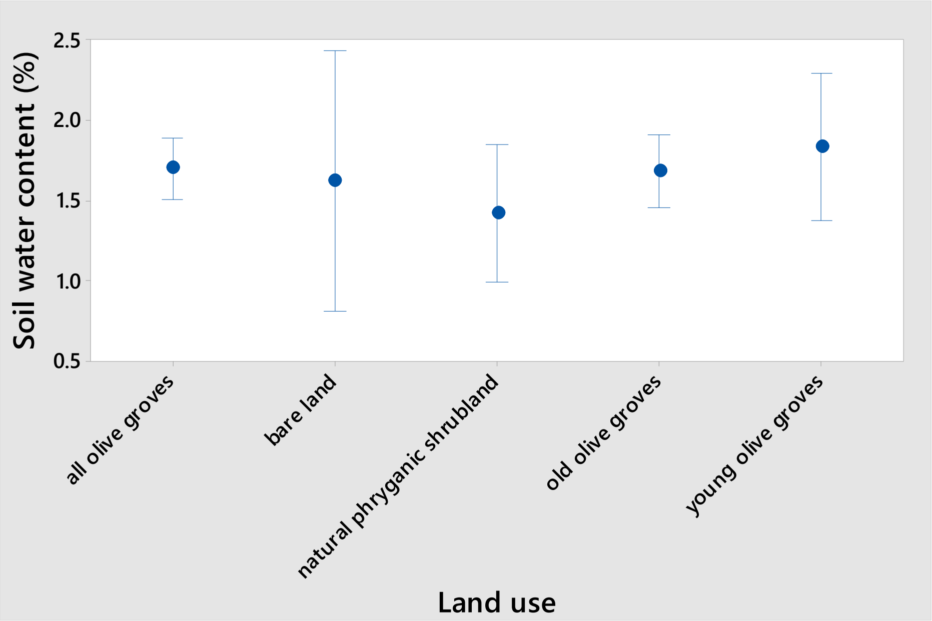

Figure 9: Mean soil water content for different land use types

The Kruskal-Wallis analysis between nitrate and land use types resulted in a P value of 0.832. Bare land and young olive groves had the highest mean nitrate levels between 177 and 208 ppm, whereas natural phryganic shrubland had the lowest mean value of 113 ppm. The rest of the land use types ranged between 130 and 140 ppm (figure 10).

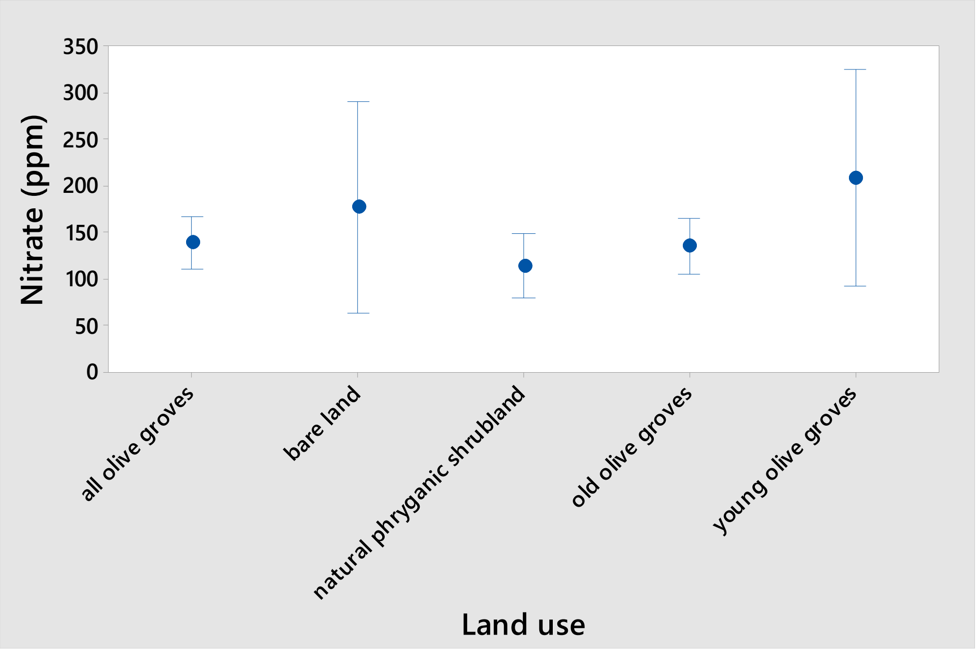

Figure 10: Mean nitrate for different land use types

3.3 Soil property and soil quality maps

The production of maps that was based on soil properties along with the correlation matrix (Table 3) showed some spatial patterns relating to land use cover. In particular, organic matter and electric conductivity followed the same pattern. For example, in most areas of 8.41 % of organic matter or more, electric conductivity was more than 575 mS/m, whereas where there was below 145 mS/m salinity, organic matter is below 5 %, which is supported by the significant correlation value between electric conductivity and organic matter with a P value of 0.000 (Table 3). Bulk density had 3 patches of relatively high values in the study area, where two of them are within urbanization or industrial areas. The third patch of high bulk density is found in high altitudes. The map on pH shows a shift of low soil pH towards the east of the study area where agriculture is the major land use cover. High pH of more than 8 is found north-west of the map near the coast and within suburbs of Heraklion. The water of the soil collected during the fieldwork was very low, ranging between 0 and 6.2 %, and therefore the extremely low percentage of soil water content is a substantial indication of the ability plants have on Crete to grow in such dry conditions. There is a significant correlation between soil water content and bulk density with a P value of 0.003 (Table 3). In addition, there are two patches of relatively high % of water for this study: one is situated in the area of the highest altitude within the study area of around 170 m, and the other is around the main industrial area of Heraklion. The final soil property map is the nitrate map, where high values of 150 ppm and above mostly cover urbanized areas, whereas values between 12-100 ppm are found in agricultural areas towards the south and south-eastern section of the study area. The nitrate significantly correlated with organic matter with a P value of 0.000 and electrical conductivity with a P value of 0.000 (Table 3). The soil quality map, which is the combination of all 6 soil properties into a soil quality index, is categorized on a scale from 1 (poor soil) through to 4 (good soil). Built up areas cover more percentage in the areas of poor soil quality 1 and 2. Areas of good soil quality are mostly covered by agricultural land and natural phryganic shrubland.

Table 3: P values of correlations between soil properties (significant correlations in red)

	SWC	pH	EC	OM	BD
PH	0.311				
EC	0.891	0.427			
OM	0.431	0.473	0.000		
BD	0.003	0.290	0.906	0.336	
N	0.227	0.064	0.000	0.000	0.218

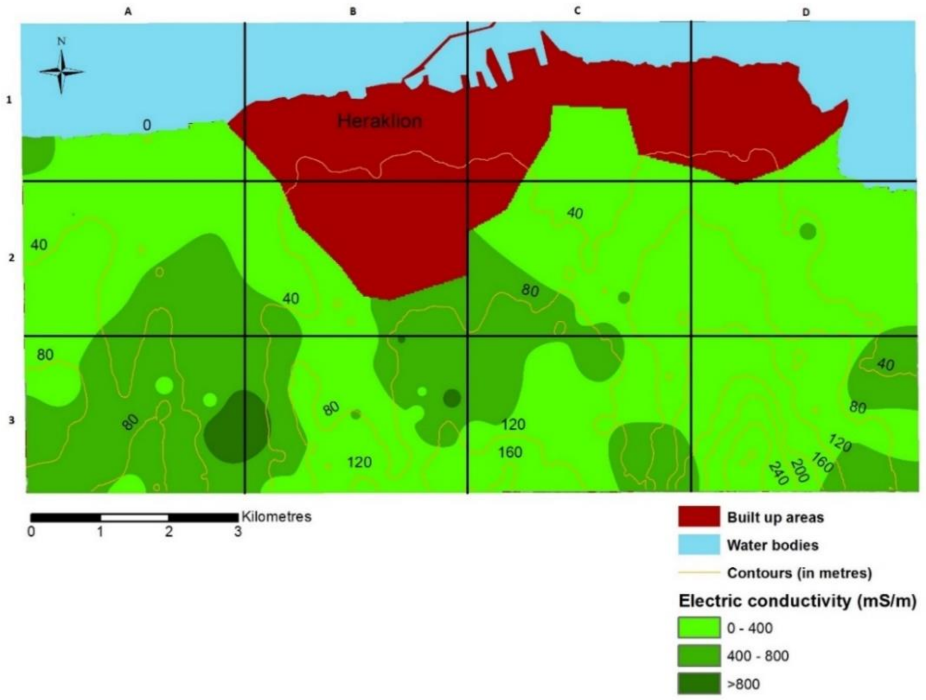

Figure 11: Electrical conductivity map in ppm (separated into 3 categories: 0-440 optimum, 400-800 limiting and <800 restricting to plant growth)

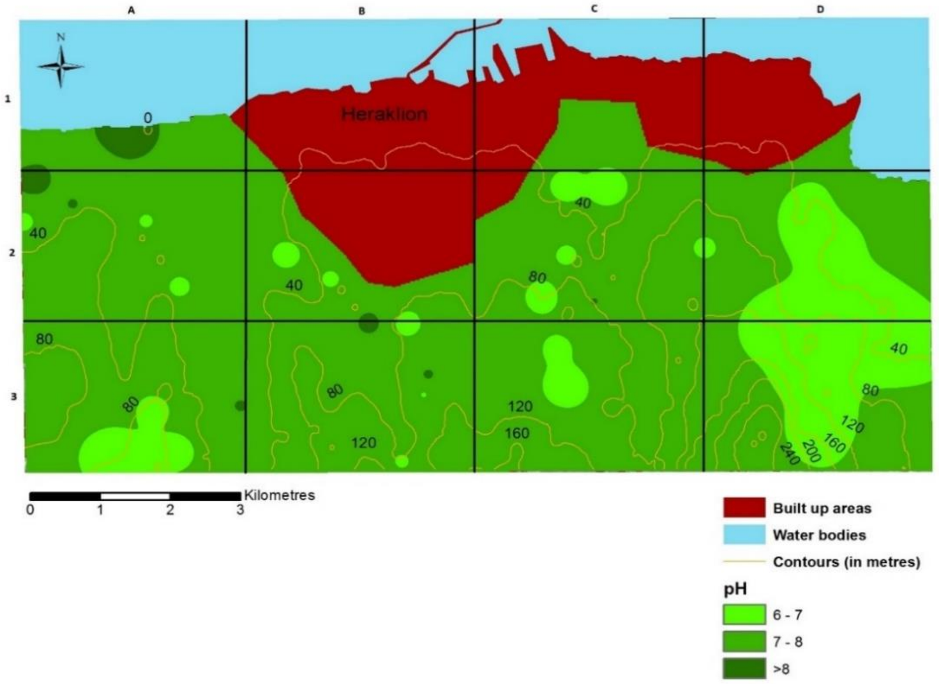

Figure 12: Soil pH map (separated into 3 categories: 6-7 optimum, 7-8 limiting and <8 restricting to plant growth)

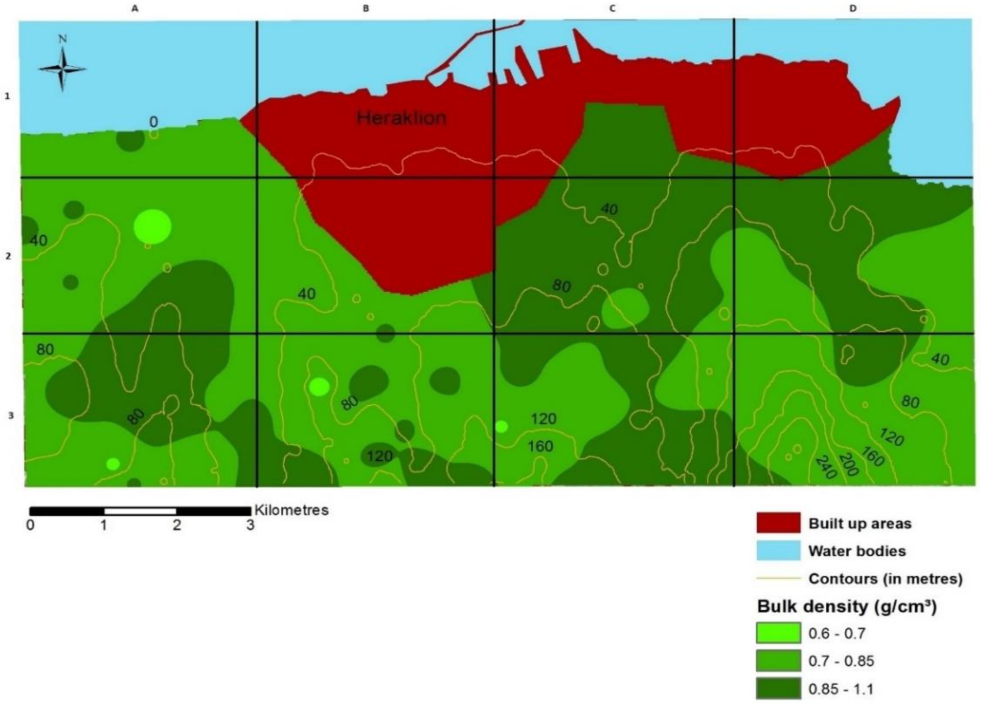

Figure 13: Bulk density map in g/cm³ (separated into 3 categories: 0.6-0.7 optimum, 0.7-0.86 moderate compaction and 0.85-1.1 excess compaction)

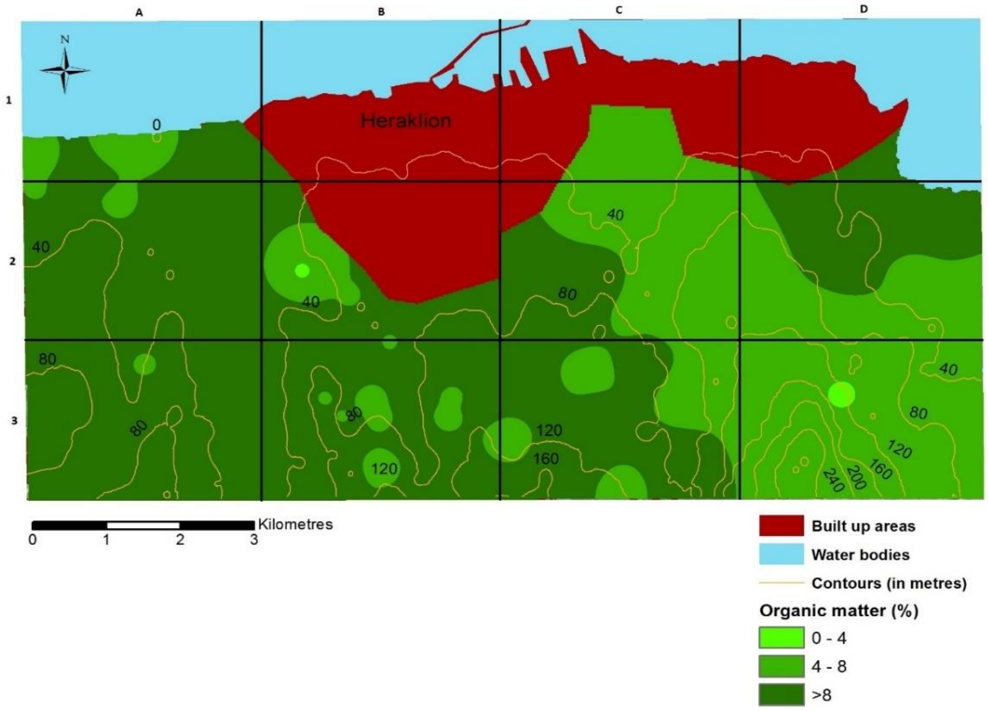

Figure 14: Organic matter map in % (separated into 3 categories: >8 optimum, 4-8 limiting and 0-4 restricting to plant growth)

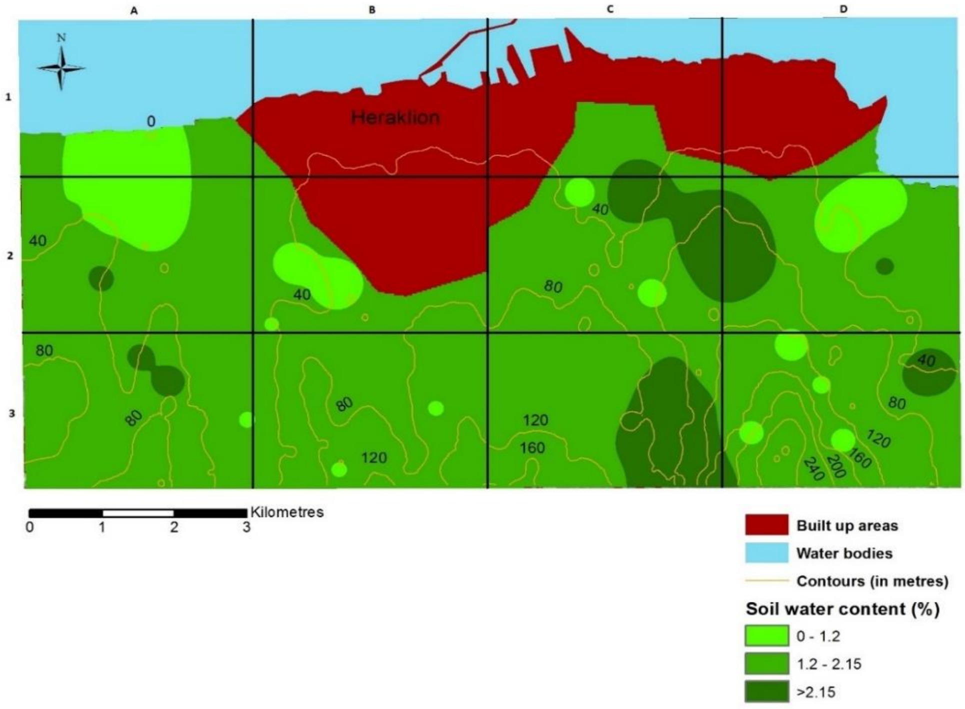

Figure 15: Soil water content map in % (separated into 3 categories: >2.15 optimum, 1.20 - 2.15 limiting and 0 - 1.20 restricting to plant growth)

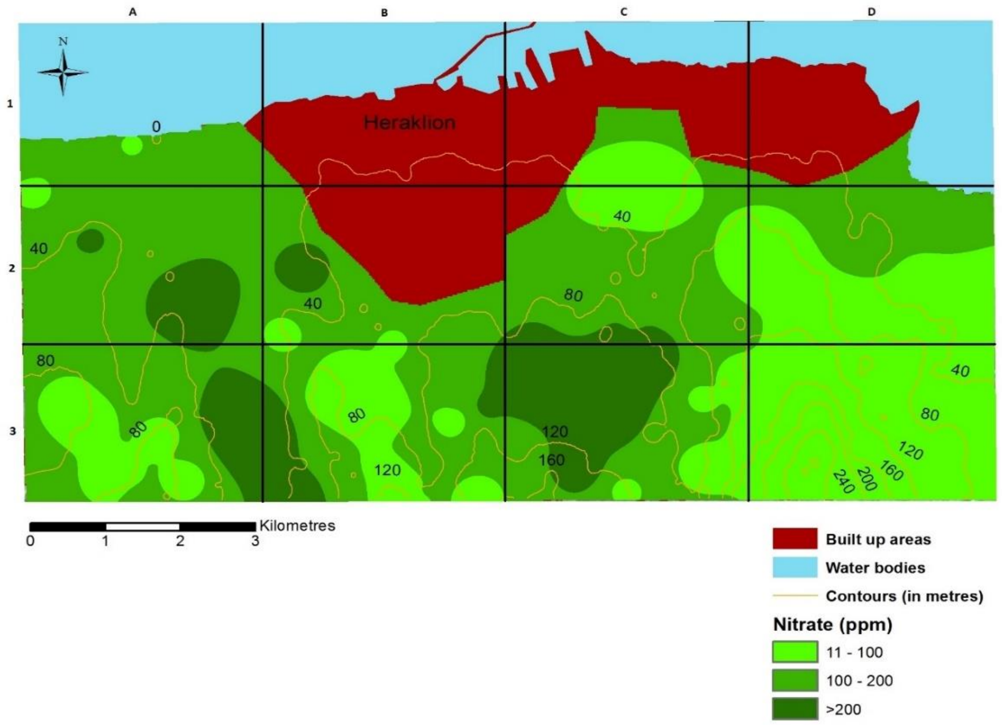

Figure 16: Nitrate map in ppm (separated into 3 categories: 11 - 100 optimum, 100 - 200 limiting and <200 restricting to plant growth)

3.4 Land use maps of Heraklion in 1960, 1997 and 2016 (figure 17, 18 and 19)

The land use cover in the study area has changed substantially since 1960. The only land use that has increased in cover area within the study area is built up areas and airport/military base, rising from 19.5% of the study area, to 41.1% in 1997 and reaching 54.8% in 2016 (table 1). Due to the increased land cover of built up areas covering more than half of the study area, a loss of other land use types has occurred. For example, natural phryganic shrubland has declined from 21.2% in 1960, to 13.1% in 1997 and to a very low 11.6% by 2016. Olive groves, vineyards and grasslands have also followed a similar pattern in land cover, where the decline has not ceased since 1960 (table 1).

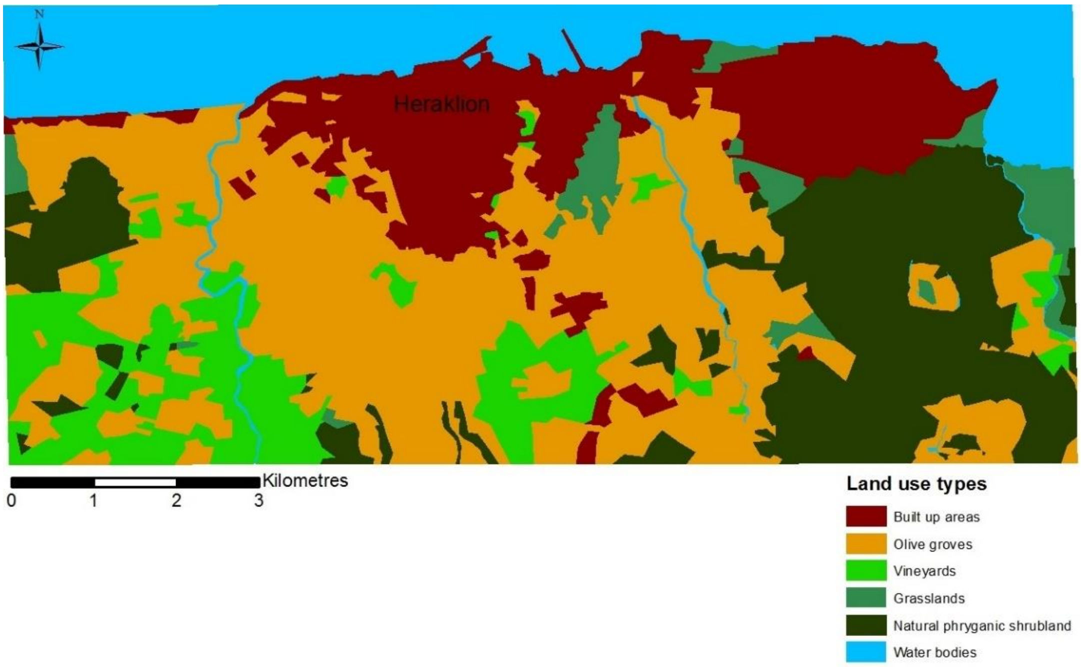

Figure 17: Heraklion land use cover map in 1960

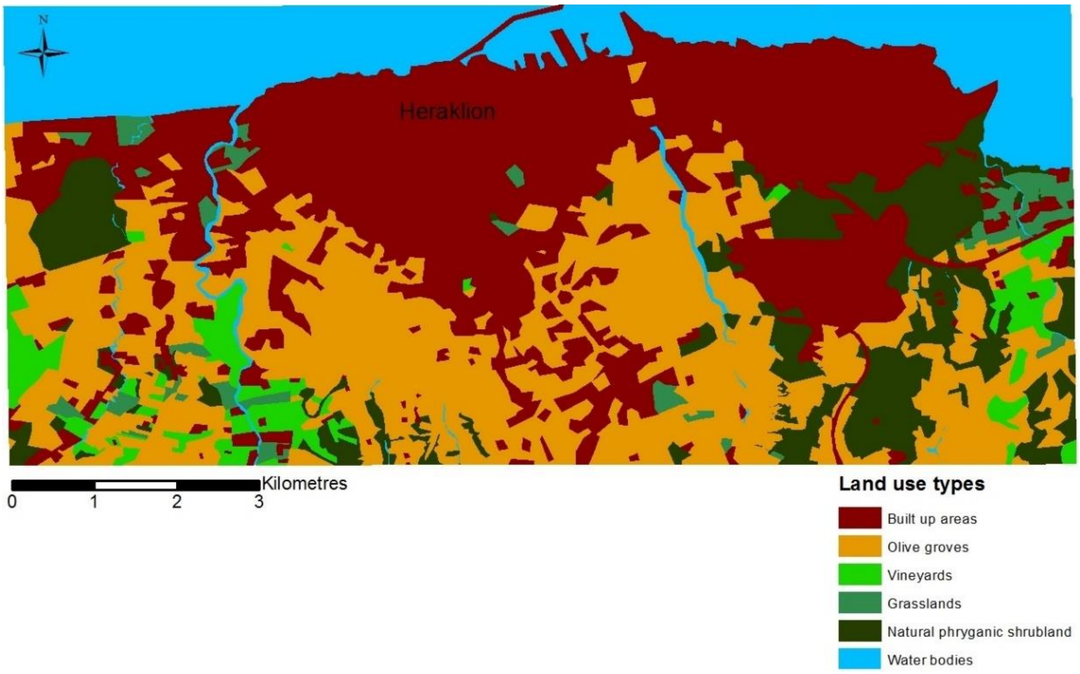

Figure 18: Heraklion land use cover map in 1997

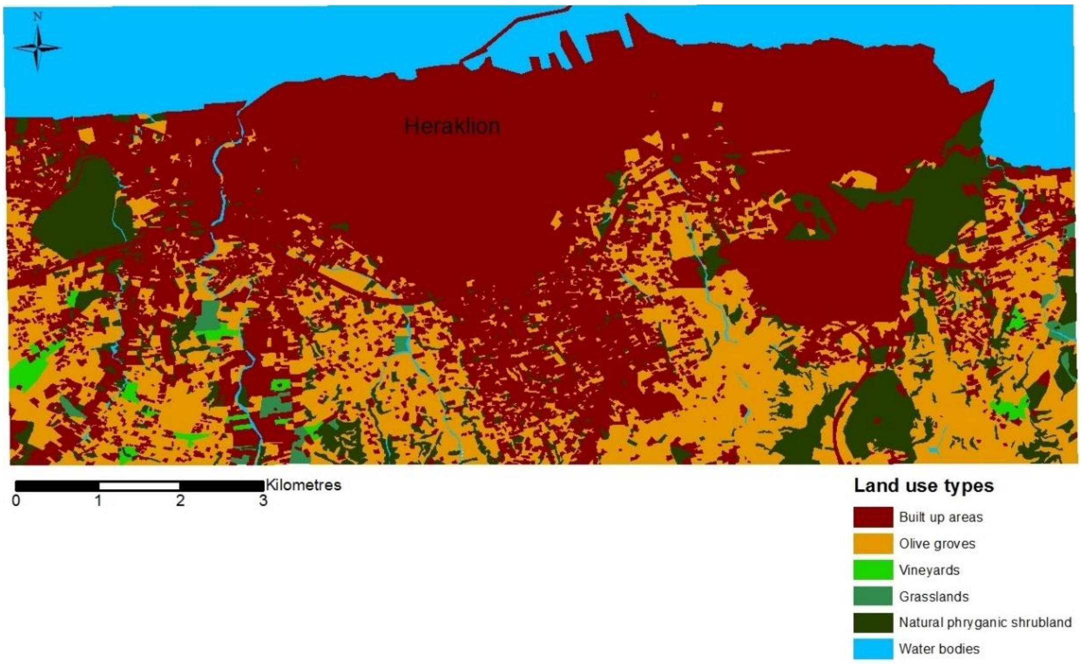

Figure 19: Heraklion land use cover map in 2016

4.0 Discussion

4.1 Comparison between 1960, 1997 and 2016 land use maps (figures 17,18 & 19)

Several Mediterranean cities such as Heraklion have undergone rapid expansion around the urban area since the 1980s (Khresat *et al,* 2008; Salvati *et al,* 2013). This supports the change in land use around the city of Heraklion. For example, the urban rapid expansion of the 1960s is demonstrated in Heraklion, where the built-up area of 19.5% of the overall study area in 1960 had more than doubled (41.1%) 37 years later in 1997 (table 1). Urban expansion continued to increase rapidly, and in 2016 concrete sealed surfaces occupied 54.5% of the total study area with, more importantly, olive groves, vineyards and other land use continually decreasing since the 1960s. This change is due to several reasons. Firstly, a transition from a more compact model to a dispersed form of urban expansion occurred in the 1960s, meaning there was high conversion from agricultural and natural phryganic shrubland to built-up settlements (Salvati *et al,* 2013). Another reason for the continual increase around many Mediterranean cities including Heraklion, is the shift of the population moving from the agricultural and rural mainland towards the coasts which provided opportunities in tourism combining with the increasing population (Sarris *et al,* 2005). This started occurring in Heraklion, and generally on Crete, several years after the second world war, where there was a trend of recovery, and therefore Crete slowly started to become a popular European destination (Kizos *et al,* 2014). The trend of urban expansion is well correlated with the decreasing rural land and in particular natural phryganic shrublands and vineyards which have decreased from 21.2 – 11.6% and 12.2 – 1.1% respectively between 1960 and 2016. Thus, the increase of artificial surface cover correlated to the decrease in agricultural and natural surface cover means that sealed surfaces are constantly increasing pressure on non-sealed areas (Scalenghe & Marsan, 2009). Soil quality is becoming more and more demanding and the use of it is important to be assessed in relation to land use and spatial patterns around the city of Heraklion.

4.2 Electric conductivity versus land use change

Amongst the statistically significant analysis between electric conductivity and different land uses, bare land had the highest electrical conductivity mean value of around 550 mS/m compared to the other land use types, which is excessive and extremely saline (Figure 5). This indicates potential limitation on soil nutrient availability, and therefore the soil will possibly fail to provide the optimum available quantity of nutrients for plant growth. In general, most plants have a tolerance level of salinity of up to 400 mS/m (Janzen, 1993). Between 400 and 800 mS/m soil electric conductivity, salinity limits plant growth, and any soils with electric conductivity higher than 800 mS/m will have a severe effect on the restriction of plant growth. However, the salinity tolerance of olive trees is slightly different, with a tolerance range between 0 and 250 mS/m where the productivity is maximum, but increasing issues of productivity will start to occur in soils with salinity higher than 300 mS/m (Chartzoulakis, 2005). According to Biro *et al* (2011), bare land sites compared to other agricultural sites have higher electric conductivity values due to soil leaching and therefore reduction in soil carbonate. Dunjo *et al* (2003) states that abandoned environments such as bare lands tend to have increased electrical conductivity due to lack of vegetation and potential disturbance. In their study, both olive trees and natural phryganic shrubland had low electric conductivity levels which supports this study, situating the two land use types within the optimum level of salinity. However, cultivated olive trees in Dunjo *et al* (2003) which correspond to the young olive groves in this study, had higher electrical conductivity than the natural phryganic shrubland and uncultivated olive groves, with 400 mS/m, which places them as saline soils and therefore potentially restrictive to plant growth. Young olive groves may have higher electrical conductivity than all olive groves and old olive groves, because of excessive irrigation practices. Inappropriate irrigation practices and input of various fertilizers can cause increase in the electrical conductivity of a soil (Schwab *et al,* 2015). Increased electrical conductivity is found in young olive groves and other land use types, which may be down to the increased recharge following transformation from phrygana shrub communities into agricultural land (Manandhar & Odeh, 2014).

4.3 Relationship between electrical conductivity and other soil properties

Some of the most influential soil properties on electrical conductivity are soil water content and organic matter (Korkanc *et al,* 2008; Siquiera *et al,* 2014). Organic matter can influence salinity through the release of soluble salts that can be produced after the procedure of litter decomposition (Gimeno-Garcia *et al,* 2001). Soil water content is also important, because lack of water content within the top soil can allow the concentration of salt in the soil to increase and therefore affect electrical conductivity values (Bai *et al,* 2013; Costa *et al,* 2014; Sheldon *et al,* 2004). Saline soils can be relatively abundant in semi-arid areas such as the study area (Laker, 2009). However, in this study the mean values between the electrical conductivity and soil water content values did not correlate significantly with a P value of 0.891 (Table 3). On the other hand, the significant correlation between electrical conductivity and organic matter with a P value of 0.000 (Table 3), is possibly due to the litter that decomposes into organic matter which can contain salts and therefore increase the electrical conductivity of a soil (Do Carmo *et al,* 2016; Korkanc *et al,* 2008). Another possible reason for the correlation between electrical conductivity and organic matter, is the negative effect high salinity levels can have on the bacterial abundance, which can then influence the rate of litter decomposition (Morrissey *et al,* 2014).

4.4 Electrical conductivity spatial patterns

Apart from interactions between soil properties and land use changes, soil pH maps have been used in several studies (McBratney *et al,* 2003; Robinson & Metternicht, 2006; Weaver *et al,* 2003) and can be very important and show patterns that cannot be shown on a graph, or an interaction between factors. In terms of the electrical conductivity map (figure 11), it has followed spatial patterns with land use cover. The lighter green an area is on the map, the more saline it is and therefore the poorer the soil is going to be. It can clearly be seen that the areas of A4 where there is a main road from the city centre to the south west of the study area and B1, B2 and B3 which contain suburbs and industrial areas, have relatively saline soils. On the other hand, part of A1 and A2 on the map (figure 11) where the salinity levels fall within optimum range for most plants which are 0 and 400 mS/m (Janzen, 1993) are covered by natural phryganic shrubland. This could be either due to the use of de-icing salt on roads during the winter which can elevate soil electrical conductivity (Zeng *et al,* 2012), or to increased soil water content and compaction rates that can determine the amount of air and water in the pore spaces in the soil and affect soil salinity (Bai *et al,* 2013). Another distinctive spatial pattern is noted in the suburbs south of the city centre in southeast B2, southwest C2 and northwest C3, where the salinity is more than 285 mS/m showing again the negative impact urbanization is having on the soil health. Optimum soil salinity is also found in other areas of mass natural phryganic shrubland and agricultural land use such as A3, D2 and D3. The electrical conductivity and nitrate map also represented some spatial patterns, with the correlation analysis between electrical conductivity and nitrate data, showing a significant P value of 0.000 (Table 3). The same areas mentioned which possessed salinity above 285 mS/m, also have nitrate above 150ppm, which justifies the significant correlation between soil electrical conductivity and nitrate levels. In terms of the similarity between the soil water content map and the electrical conductivity map, the correlation was non-significant (P value: 0.891) and therefore there is not much spatial similarity between them.

4.5 Soil pH versus land use types

Soil pH, which is measured on the scale of acidity and alkalinity, is a very important indicator of the health of a soil. In Crete and across mainland Greece, soil pH has a value range between 5.9 – 8.1 (Chytry *et al,* 2010; Papafilippaki *et al,* 2008; Shaw, J. W & Shaw, M. C., 2014). The Kruskal-Wallis test showed that there is non-significant difference between the pH of the different land use types (figure 6). However, according to Wang et al (2001), soil properties such as soil pH values are highly associated with differences in land use and landscape position, with vegetation cover being one of the factors that can affect it. Soil pH in Crete tends to be higher in phrygana communities than other land use type, which justifies why the natural phryganic shrubland has the second highest mean pH of 7.2 after bare land (Chytry *et al,* 2010). The non-significant difference between soil pH and land use types could be down to interactions with other soil properties, whereby for example variation in soil water content can have a direct effect on pH values (Chytry *et al*, 2010).

All olive groves and old olive groves have a mean pH of about 7.2 which is close to the optimum pH of the soil where many plant nutrients are available (Craul, 1999). Olive groves tend to thrive in soils between 6-7 pH but can still tolerate between 5.5 and 8 soil pH (Leake, 2001; Olive Planting & Growing Guide, 2017). On the other hand, young olive groves have a slightly more alkaline pH of around 7.4 which can limit nutrient availability. Most nutrients will be available to plants in slightly acidic soils, whereas most of the nutrients in very alkaline soils can be converted into solid minerals which will therefore limit their availability to plant uptake (Costa *et al,* 2014; Miller *et al,* 2016). However, increase in pH could be due to increased tillage practice, which happens more in young olive groves than old olive groves, where potential crops can be planted in between (Busari *et al,* 2015). Even though young olive groves have a higher mean pH, olive groves in general favour within the range of 5.5-8 pH (Leake, 2001). In addition, the larger canopies of the old olive groves, compared to the smaller in cover canopies of the younger olive groves, could be the factor influencing a more ideal pH in the old olive groves. Canopy cover can enhance soil infiltration by reducing the impact of direct precipitation on the surface of the agricultural land, which can result in more soil leaching and therefore reduce soil pH (Khresat *et al,* 2008). Land that has been altered by humans can elevate the soil pH through either the physical disturbance of the top soil (0-10cm) or by the release of calcium through weathering of building rubble that can be comprised of cement and plaster (Craul, 1999). With bare land being the most disturbed land use type, this potentially justifies the reason behind the mean value of 7.4 pH, which is the highest pH amongst all land use types of the study area. To conclude, productivity increases with decreasing soil acidity, but too much decrease in soil acidity could mean increasing alkalinity which can also negatively affect productivity. Complexity in soil pH can be an indication of higher levels of pH and therefore lower productivity (Schuster & Diekmann, 2003).

4.6 Relationship between pH and other soil properties

Soil pH values are not only related to the change of land use types that cover the soil, but can also be related to other soil properties. Interactions between soil properties leading to direct or indirect effects in the top soil are frequent. One of the properties that pH depends on is soil water content, in which the percolation of rainwater can cause cation leaching and therefore affect soil pH (Chytry *et al,* 2010). According to Chytry *et al* (2010), soil pH and precipitation correlate, indicating that local soil pH is affected by the amount of precipitation that is infiltrated in the top soil. In this study, although there is a slight correlation between soil water content and pH, the correlation matrix analysis showed that there is no significant correlation (P value: 0.311) between the two soil properties (Table 3). To support this, McCauley et al

(2017) state that the less precipitation, the smaller the possibility of pH leaching, and as Crete is characterised as a semi-arid region with limited precipitation, this could be the reason behind the poor correlation between pH and soil water content.

Along with the importance of pH, organic matter is one of the most important soil properties and plays a major driving role in the quality of a soil. According to Iwegbue *et al* (2012), pH and organic matter did not follow similar patterns in urban and semi urban areas, while in rural areas there was correlation between pH and organic matter. This is down to the quantity of organic matter within the soil (Iwegbue *et al*, 2012). The smaller percentage of organic matter is found within the soil, the poorer the effect on pH levels and therefore the poorer correlation between organic matter and pH (Iwegbue *et al*, 2012). According to Korkanc *et* al (2008), the soils with high pH values had low organic matter %, while low pH soils had high organic matter. However, this does not seem to agree with the findings of the study where there is a lack of patterns, as the correlation analysis was non-significant with a P value of 0.473 (Table 3).

In terms of the relationship between soil pH and electrical conductivity, there does not seem to be a pattern. The pH of a soil does not have a direct effect on soil electrical conductivity, but can still have an effect on the solubility of salts which can therefore have an influence on electrical conductivity (Jim, 1998; Mohd-Aizat *et al,* 2014). Nitrate, being another important soil property, requires a relatively neutral pH for a positive balance for plant growth (Gimeno-Garcia *et al,* 2001). In terms of correlating results, in most circumstances nitrate has exceeded the optimum level and therefore it is not very relevant with the soil pH values. However, even though, according to Mao *et al* (2014), compacted and degraded soils are usually alkaline and not suitable for growing plants, the correlation between soil pH and bulk density was non-significant with a P value of 0.290 (Table 3). Mao *et al* (2014), argues that even though compacted and alkaline soils follow similar patterns, this is due to effects from third factors such as surface concrete sealing rather than a relationship between pH and bulk density.

4.7 Soil pH spatial patterns

Even though the soil pH was above 7 in most areas, it was quite acidic in the eastern part of the study area (figure 12) D2 and D3, where it is a relatively rural part of the study area with a mass percentage of agricultural and natural phryganic shrubland. On the other hand, in the northwest of the city 1A which is a built up area, the pH is alkaline. However, the relationship of acidic soils in rural areas and alkaline soils in urban areas was not significant enough, as the results did not show any spatial pattern as was expected. For instance, in B2 and C2 (figure 12) the built up areas are relatively dense, but despite an expectation of alkalinity, in some spots the pH within these two grid cells is very acidic. Urban soils tend to have pH values higher than rural soils due to the sources such as concrete material, which can increase soil alkalinity through weathering (Craul, 1999; Jim, 1998; Stets *et al,* 2014; Ware, 1990). In addition, pH can also be affected by elevation, where the higher the elevation, the higher the pH value (Manandhar & Odeh, 2014). On the other hand, Charan *et al* (2013) and Kidanemariam *et al* (2012) state that soil pH becomes more acidic in higher altitude due to either higher mean precipitation and therefore enabling more leaching of ions within the soil which can decrease soil pH or due to cumulating salt accumulation towards the lower altitudes. Despite the contradictory papers, neither of the views occur in this study, with soil pH showing minor changes relating to elevation which is also supported by Saeed *et al* (2014).

4.8 Bulk density versus land use types

The Kruskal-Wallis test showed that there is no significant difference in bulk density values between the several land use types. As all bulk density values are below 1.10 g/cm^3, they have the optimum density for plant growth. Interestingly, all values are within 0.06 g/cm^3 of each other. The two land use types that have the highest and lowest bulk density levels in this study, are young olive groves which had the highest bulk density with a mean value of 0.86 g/cm^3, and natural phryganic shrubland with the lowest bulk density mean value of 0.80 g/cm3 (figure 7).

The structure of soil surfaces is probably the most influential factor for bulk density as it is a soil property affected physically and not chemically. The presence and density of vegetation on the surface of the soil is very important as it acts as a natural cushion against forces of disturbance such as human trampling and other damage (Jim, 1998). In addition, the exposure of soil to temperature and precipitation can also have an effect by increasing the bulk density of bare soil (Khresat *et al,* 2008). This supports the slight difference between the slightly lower bulk density of natural phryganic shrubland which has a considerable cover of vegetation, and the slightly higher bulk density value of the bare land. The more vegetation on the surface of the soil, such as the shrub layer on natural phryganic shrubland, the higher the protection against disturbance, and therefore the lower the bulk density. On the other hand, bare land is highly unprotected and vulnerable to disturbance due to the lack of a natural cushion of vegetation, and therefore the impact of disturbance is more severe which results in increase of bulk density and therefore poorer soil structure compared to the well-structured natural phryganic shrubland (Jim, 1998) which can lead to non-favourable aeration for plants (Khresat *et al,* 2008). In terms of the remaining three land use types (old olive groves, young olive groves & all olive groves) ,they had bulk densities in between the previous bare land/other and natural phryganic shrubland. Similarly to Jim (1998), Scharenbroch *et al* (2005) and Mohawesh *et al* (2015) state that the more the vegetation activity and biomass on the surface, the greater the reduction in bulk density. Olive groves are a mixture of vegetated land and bare land. In between olive trees, the land tends to be bare, with some trampling from machinery and rainsplash which can both contribute to even more compaction of the soil and increase bulk density (Biro *et al,* 2011).

Rainsplash can cause runoff of the soil and therefore the removal of silt and sand, resulting in a mostly clay surface, allows further compaction of the soil surface (Biro *et al,* 2011; Jim, 1998) whereas, trampling of agricultural machinery can lead to reduction of porosity and therefore an increase in soil density (Chyba *et al,* 2014; Soracco *et al,* 2015). However, for the reduction of bulk density there will be a zone around each olive tree including the tree trunk, roots below the surface and olive tree canopy which can all have a positive effect (Scharenbroch *et al,* 2005). The possible reasons for the non-significant results between bulk density and land use types could be: firstly, limited precipitation in Crete, and therefore reduced rainsplash, and secondly the limited use of agricultural machinery in Crete due to the mountainous terrain, which could result in lower bulk density values compared to other studies such as Chyba *et al,* (2014) and Soracco *et al,* (2015).

4.9 Relationship between bulk density and other soil properties

One of the strongest relationships within the soil is bulk density and soil water content (Mao *et al,* 2014). This is due to the holding capacity of soil water content which is dependent on bulk density (Albaladejo *et al,* 1998). Different compaction rates will increase or decrease the space for water and air circulation and will therefore have an effect on soil water content values

(Bakker *et al,* 2005; Cannavo *et al,* 2014). Even though bulk density and soil water content are said to be poorly correlated under dry conditions and extremely low soil moisture (Albaladejo *et al,* 1998), the correlation between the two soil properties in this study is significant with a P value of 0.003 (Table 3). Even if the two soil properties have a poor direct correlation, soil sealing can play an influential role by increasing bulk density and simultaneously altering the soil water content levels in urban areas (Bajocco *et al,* 2012; Bakker *et al,* 2005). Organic matter is highly porous and therefore the more organic matter in the soil, the greater the porosity, which then results in a less compacted soil (Ayoubi *et al,* 2011; Moges *et al,* 2013; Scharenbroch *et al,* 2005). There is a slight spatial pattern in this study between the bulk density values and organic matter. However, the correlation between bulk density and organic matter is non-significant with a P value of 0.336 (Table 3).

One other soil property which is potentially related to bulk density, is soil pH. Bulk density and pH do not seem to have any direct interactions between each other, but follow the same patterns, possibly because of disturbance and land use interference. In particular, in urban soils the more compacted a soil is, the more alkaline it tends to be (Mao *et al,* 2014). According to one of the examples provided by Mao *et al* (2014), soils in close proximity to transportation and residential areas were characterized by high pH and bulk density. However, bulk density values are within optimal values, and therefore they do not directly relate to the alkaline pH values of some land use types.

4.10 Bulk density spatial patterns

Although, all bulk density results were within optimum range for plant growth, the bulk density map was categorized within three different optimum ranges of bulk density so that even small differences could be represented on the map (figure 13). The highest bulk density values were either around built and industrial areas A3, C2 or in areas of very uneven terrain C3 (figure 13). Most of the other areas had below 0.86 g/cm^3 which is well within the optimum range for plant growth, appropriate soil porosity and ideal infiltration rate. The only significant spatial pattern between bulk density and other soil properties is with soil water content (P value: 0.003).

4.11 Organic matter versus land use types

Soil organic matter is considered the most powerful indicator of soil quality both in terms of the contribution to soil structure and porosity as well as being the main source of nutrients for potential productivity of successful plant growth under varied land uses (Ayoubi *et al,* 2011; Dunjo *et al,* 2003; Fontaine *et al,* 2003). The more organic matter occurring in the soil, the better the soil is going to function for plant growth (Wang *et al,* 2001). As to the disturbance of the topsoil (0-10 cm), it can have negative effects on organic matter as it is the layer with the highest amount of organic matter (Ayoubi *et al,* 2011; Gimeno-Garcia *et al,* 2001). However, the results from Kruskal-Wallis statistical analysis were not significant with a P value of 0.426 (figure 8).

The land use with the highest percentage of organic matter was natural phryganic shrubland which is clearly the land use with the densest vegetation cover on the soil surface (figure 4). According to Marzaioli *et al* (2010), plant cover is an important requirement in order to improve soil properties such as organic matter, and it also protects the soil from soil erosion. In addition, more plant cover almost always means a larger amount of plant litter, and therefore more decomposition into organic matter (Garcia-Ruiz, 2010; Khresat *et al,* 2008; Mainuri & Owino, 2013). Both these factors justify why natural phryganic shrubland possessed the highest amount of organic matter in the soil (9.8%). Consequently, bare land had the least organic matter (7.4%) compared to the rest of the land use types. Lack of vegetation on the surface of the soil can deteriorate soil properties, resulting in soils that are more susceptible to erosion and therefore reduced in soil organic matter (Celik, 2005). As previously mentioned, lack of vegetation means reduced input of plant residues for decomposition, which along with the combination of increased decomposition rate and redistribution of organic matter due to disturbance, means these two factors potentially contribute to the reduction of organic matter within the soil of the bare land (Solomon *et al,* 2000) which is also supported by similar findings by Wang *et al* (2001). Similarly to bulk density results, all agricultural land had similar organic matter including all of the olive grove land uses ranging between 8-8.3%.

According to Celik (2005), conversion from unmanaged to agriculture tends to lead to loss of organic matter. This argument is supported by this study, where at the location C2 and D3 (figure 14) the largest single mass of phryganic shrubland existed in 1960 and to a lesser extent in 1997, but by 2016 had been converted to a mixture of residential, industrial and agricultural land with some parts remaining as natural phryganic shrubland. The conversion has possibly affected the soil organic matter negatively, where it is clear in C2 and D3 (figure 14) that the lowest organic matter values are around that part of the study area. In line with this study, the work of Mohawesh *et al* (2015) sustains the fact that unmanaged land has the highest organic matter content, followed by orchards and cultivated land. This is attributed to several causes including removal of natural vegetation, top soil replacement, as well as tillage practices of the top soil (Scharenbroch *et al,* 2005) which all apply to the olive groves and bare land of this study. In addition, smaller amounts of organic matter in olive groves (8-8.3%) compared to natural phryganic shrubland (9.8%) could be a result of the lignin-rick litter of olive trees which do not easily decompose (Van Leeuwen *et al,* 2015). Overall, the importance of plant cover in reducing erosion and increasing litter for decomposition, protects soils against potential degradation (Albaladejo *et al,* 1998). However, the statistically insignificant differences between olive groves and natural phryganic shrubland could be due to effective soil management such as reduced and sustainable tillage, which is usually applied in between olive tree lines where the risk of soil erosion is minimal (Vasilaki *et al*, 2008).

4.12 Relationship between organic matter and other soil properties

Amongst the land use types, bare land is the one land use type where organic matter is very low and nitrate levels (177 ppm) are high, near the threshold (200ppm) of becoming harmful to potential plant growth (Zhang *et al*, 2007). Nitrate is another soil property which is closely tied to organic matter (Jim, 1998). This is supported by the study undertaken by Dunjo *et al* (2003), in which the organic matter results trend with the nitrate results. In this study there is a significant correlation between the organic matter and nitrogen mean values with a P value of 0.000 (Table 3). As discussed in the bulk density section, the relationship between soil organic matter and bulk density do not show a significant pattern. Soil water content is another influential soil property, which can have both direct and indirect effects on organic matter. The indirect effects stem from bulk density, where low organic matter may mean high bulk density compaction and therefore low soil water content and vice versa (Cannavo *et al,* 2014). Direct effects include the very high amount of soil moisture, where saturated soil does not allow decomposition of litter (Mainuri & Owino, 2013). However, this tends to happen in saturated land use types such as wetlands, which are not apparent in the study area. Similar trends between organic matter and soil water content in the study could be attributed to the interference factor of bulk density that can indicate a relationship between organic matter and soil water content.

4.13 Organic matter spatial patterns

The organic matter map does not have any significant spatial patterns. The only distinctive patterns are the high organic matter in natural phryganic shrublands and the high organic matter content south west of the study area where the elevation is higher (figure 14). Dai *et al* (2014) states that previous studies including their own reveal a high correlation between soil organic matter and elevation, where the higher the elevation, the more the amount of the organic matter in the soil. The main reasons for this correlation are firstly, the lower temperature in higher altitudes which favours organic matter accumulation and secondly, the trend where in higher elevation areas, access is more difficult and therefore the conversion of unmanaged areas to agriculture is minor (Feng-bo *et al,* 2015). This has probably occurred in this study, not only in the south west of the study area, but also in the lower part of C3 and D3 where the highest altitude in the study areas aligns with high amounts of organic matter (figure 14). Urbanization does not seem to cause any fluctuations in organic matter values in a general overview such as the map but has effects in more specific situations such as land use patterns.

4.14 Soil water content versus land use types

Soil water content is an integral factor in the survival of plants and well-structured soils. Due to the semi-arid climate in Crete, soil water content is limited during most months of the year and in particular in the low altitude areas (Grayson *et al,* 2006). A good example is Heraklion and the surrounding study area, where variation in soil moisture is more affected by land use type rather than topography (Qiu *et al,* 2001). However, as the most abundant land use type in Crete, olive trees are drought resistant plants and therefore can survive in very dry conditions (Melgar *et al,* 2009; Steduto *et al,* 2012). In addition, natural phryganic shrubland is another land use, whereby its shrubs are very efficient users of moisture, and thus can survive in extremely dry conditions (Manevski *et al,* 2012). With increasing elevation, average precipitation increases and average temperature decreases (Molina *et al,* 2014). This results in decreasing evaporation rates and therefore higher elevation areas have higher soil moisture content than low elevation areas (Molina *et al,* 2014; Van Leeuwen *et al,* 2015).

Even though statistical tests between soil water content and land use types were not significant, with a P value of 0.205 (figure 9), there are some interesting results. Higher density of trees and shrubs tend to create shade, especially in the summer months, which is very important because soils are less exposed, and therefore soil moisture surface evaporation is reduced (Davies & Hall, 2010; Garcia-Ruiz, 2010; Qiu *et al,* 2001). Furthermore, higher density of vegetation can also play a major role in soils by controlling water runoff and therefore maintaining ideal amounts of moisture (Kairis *et al,* 2015). However, this has not occurred in the study, whereby, for example, natural phryganic shrubland has a smaller percentage of soil water content (1.42%) than bare land (1.60%) and other land use types. This could be linked to other factors, where for example vegetation in natural phryganic shrublands may be collecting the limited moisture from the soil and then losing its moisture through the evapotranspiration process, due to the semi-arid Mediterranean climate (Qiu *et al,* 2001). The idea of higher percentage of water content in denser plant covers seems to occur between bare land (1.60%) and the young olive groves (1.83%), where the shade from the canopy of olive groves may limit evaporation levels compared to the uncovered bare land (Espejo-Perez *et al*, 2016; De Luna *et al*, 2000). However, according to Albaladejo *et al* (1998), changes in soil water capacity resulting from removal of vegetation were not statistically different, which could be seen as support for the mean values of soil water content between bare land and natural phryganic shrubland. To conclude, all the soil water content data was extremely low even for a semi-arid region, so appropriate plants such as olive trees and phrygana shrubs are very important and effective in such conditions. It is hypothesised that the extreme low percentage of all the soil water content data could be due to no precipitation between the Spring of 2016 and the period when collection of the soil samples was undertaken.

4.15 Relationship between soil water content and other soil properties

One of the soil properties that significantly relates to soil water content is bulk density (Albaladejo *et al,* 1998). As discussed earlier in the soil water content section, correlation between the two soil properties was significant with a P value of 0.003 (Table 3). Compaction reduces pore space (Cannavo *et al,* 2014), but in this situation all bulk density values had enough pore space for water holding capacity. According to Wang *et* al (2012), nitrate and soil water content are indirectly related through their effect on plant growth, but in this study the correlation was non-significant with a P value of 0.227 (Table 3). Due to very low soil water content values of below 6.2 % in the study area, potential correlation with other soil properties, excluding bulk density, was poor.

4.16 Soil water content spatial patterns

The soil water content map did not show any distinctive patterns concerning proximity to urbanization. Van Leeuwen *et al* (2015), states that soil moisture is correlated with elevation, where the higher the altitude, the more the soil moisture. In the study area of Heraklion, the lowest altitude is sea level along the coast, where in A1 and D2 there are two patches of very low soil water content % (figure 15). The highest elevation is found in the south central section of the study area of about 275 metres altitude. In that area (C3) there is a patch of relatively high soil moisture compared to the surroundings, which correlates to the elevation in that area. In addition, there are random patches of different soil water content values in random areas of the study area. Random patches could be down to soils that are drying unevenly due to different land use types or slope interaction (Da Costa *et al,* 2014). According to Garcia-Ruiz (2010), urban environments can decrease soil moisture through the heat island effect. This effects is dependent on the high percentage of paved surfaces and limited vegetation which can cause rise in the local temperature of a city such as Heraklion and therefore reduce soil moisture. However, in this study there are not any differences in soil moisture between rural and urban areas. This could be due to extremely low soil water content in the rural areas and therefore resulting in similar soil moisture content with urban areas.

4.17 Nitrate versus land use types

Nitrogen is an important component in the soil for plant growth (Masclaux-Daubresse *et al,* 2010). Plants tend to require large quantities of nitrogen in order to grow (Kleijn *et al,* 2005) because nitrogen is the main component of amino acids, which are the building blocks of proteins (Jamtgard, 2010). Soil nitrogen is then converted into the form of nitrate and ammonium which becomes available for plant uptake and is used in the formation of plant protein (Gallitz, 2009; Miller *et al,* 2007). However, nitrate that is within the soil must be within the optimum range, which is up to 100 ppm. Nitrate levels below 11 ppm are low and can limit plant growth, whereas nitrate levels above 100 can be a threat for the quality of the soil (Zhang *et al,* 2007; Zhi *et al,* 2014). Excessive soil nitrogen levels can lead to nitrogen leaching which can result in the following issues: firstly, components of nitrogen such as nitrate can be harmful to human health, and secondly nitrogen leaching can alter the nutrient balance within the soil and can lead to limited plant growth (Riley *et al,* 2001; Stuart *et al,* 2015). The Kruskal-Wallis test on the nitrate levels versus land use types were not significant (P value: 0.989), meaning nitrate levels between land use types were not significantly different from each other (figure 10). However, most of them exceeded the threshold of optimum range for nitrate, including bare land and all the land use types of olive groves. According to Mao *et al* (2014), urban soils tend to have excessive amounts of nitrate which can potentially degrade soils. Excessive amounts of nitrate can lead to salinization of surface soil and consequent limitation of plant growth (Ju *et al*, 2007). This is possibly what has happened to bare land, where high nitrate levels (between 177 -208 ppm) have consequently lead to high electrical conductivity levels of 532 mS/m. In addition, excessive nitrate can lead to nitrate leaching, which can result in contamination of water within the soil (Oelmann *et al*, 2007). The possible explanation of high nitrate levels in olive grove land use types compared to the natural phryganic shrubland is human interference where the excessive input of nitrate fertilizers in the olive grove sites would increase nitrate levels (Van Leeuwen *et al,* 2015). The nitrate levels of natural phryganic shrubland (113 ppm) is very close to the optimum tolerance range (11-100 ppm) for appropriate soil quality levels, which shows that this land use type operates without much disturbance, and therefore follows the principles of a well-structured soil.

4.18 Relationship between nitrate and other soil properties

Nitrate is majorly affected by soil pH, where pH values below 5.5 and above 7.5 can limit the plant availability of nitrate (Schwab *et al,* 2015). However, the correlation between pH and nitrate is non-significant with a P value of 0.064 (Table 3). Organic matter is not only another soil property that is related to nitrogen levels but it is also the primary source of soil nitrogen, and therefore the higher the level of the plant litter and decomposition, the more the abundance of nitrogen in the soil (Gerrard, 2000; Hernandez *et al,* 2016). This supports the study where the correlation between soil nitrogen and organic matter is significant with a P value of 0.000 (Table 3). However, even though nitrate and organic matter correlate significantly, there can be high variations between nitrate levels and organic matter when there is an increase in soil temperature which can cause higher rates of microbial decomposition (Khresat *et al,* 2008). The land use type that is within the optimum range of nitrate levels for plant growth (natural phryganic shrubland), is the one with the highest organic matter levels. This possibly means that the higher the organic matter levels in a soil, the more stabilized the breakdown of nitrogen to nitrate will be, and therefore the more the balanced and optimal nitrate levels will be apparent in the soil (Hernandez *et al*, 2016). One other significant correlation was between electrical conductivity and nitrogen with a P value of 0.000 (Table 3). Increased salinity in the soil can cause stress to soil microorganisms and therefore lead to reduced mineralization of nitrogen (Zeng *et al,* 2013; Zhou *et al,* 2016).

4.19 Nitrate spatial patterns

In terms of the nitrate map, the suitable range of nitrate for plant growth (11-100 ppm) are the lighter green areas which are found in rural sections of the study area, especially in the east, where the mass percentage of land use is either agricultural or natural phryganic shrubland. There is a similar occurrence in A3 and part of B3, where the land use is mostly agricultural (figure 16). On the other hand, the areas that are covered in white and have nitrate levels above 150 ppm mostly include suburbs of Heraklion, or industrial sites which could possibly mean that nitrogen leaching has taken place through human interference with natural processes (Stuart *et al,* 2015). The nitrate map follows very similar patterns to the electric conductivity map, where very high salinity values correlate with very high nitrate values. This may be an indication of soil degradation in these areas which are mostly covered built up areas rather than rural land.

4.20 Soil quality

Soil quality is essentially the ability of the soil to function in favour of vegetation productivity, water availability and control of soil erosion, not only for agricultural land but for natural vegetation (Ayoubi *et al,* 2011; Vasilaki *et al,* 2008). As soil is a non-renewable resource and its function for ecosystem services is constantly being threatened by various factors in recent years, it must be considered as a priority in terms of managing the environment (Biro *et al,* 2011). Even though soil quality is affected by various climatic, biological, geological and human factors (Bahrami *et al,* 2010), human factors have been claimed to be the main factors through both land use change and lack of sustainable management which are having a negative effect on overall soil qualities of soil systems (Vasilaki *et al,* 2008; Virto *et al,* 2015). Soil degradation includes many processes within the soil and above the soil surface, such as reduction in soil fertility, accelerated soil erosion, acidification, and salinization, as well as loss in biodiversity (Lal, 2015).

The soil quality map was created through the combination of the six soil properties (electric conductivity, pH, organic matter, soil water content, nitrate and bulk density). Each of the soil properties had an index representing how suitable a value is for plant growth (Table 2). The combination of each of the soil properties for each data type produced the soil quality map (figure 20). In figure 20, the map key of soil quality is separated into 4 scales of quality, where the higher the number, the better the soil quality of the area. It is clearly distinctive that the main sections of urbanization areas (A1, B2, C1 and part of C2, C3 and A2) are under poor soil quality (figure 21).

On the other hand, areas of 3 or 4 quality cover natural phryganic shrublands and agricultural land mostly made up of olive groves, with the only area of exception being between C2 and D2, where there is another industrial zone but the quality of the soil is good. The only possible explanation behind the good soil quality of this industrial area in C2 and D2, is that previous historical maps show that there was a large area of natural phryganic shrubland in the same area which the industrial zone now occupies. This conversion from natural phryganic shrubland to industrial area, is one of the most recent conversions within the study area which suggests why the soil quality is good. In addition, historical maps reveal that the only urbanized area that was converted from a natural phryganic shrubland into an urbanized area is the industrial zone in the east part of C2 and west of part of D2. The development in other areas of the city into built up areas were converted from agricultural land instead. With regards to the soil quality map (figure 20), soils of areas within close proximity to urbanized areas are possibly degrading, whereas rural soils need to be sustained and remain unaffected by human disturbance. This is important because soils that are under stable surfaces and good plant conditions can improve distribution of organic matter, reduce erosion potential and generally restrict soil degradation that is occurring within urban areas (Garcia-Ruiz, 2010; Zhao *et al,* 2005). It is important to note that bulk density, which is one of the most important soil components, is found to have optimum range within the whole of the study area that was examined.

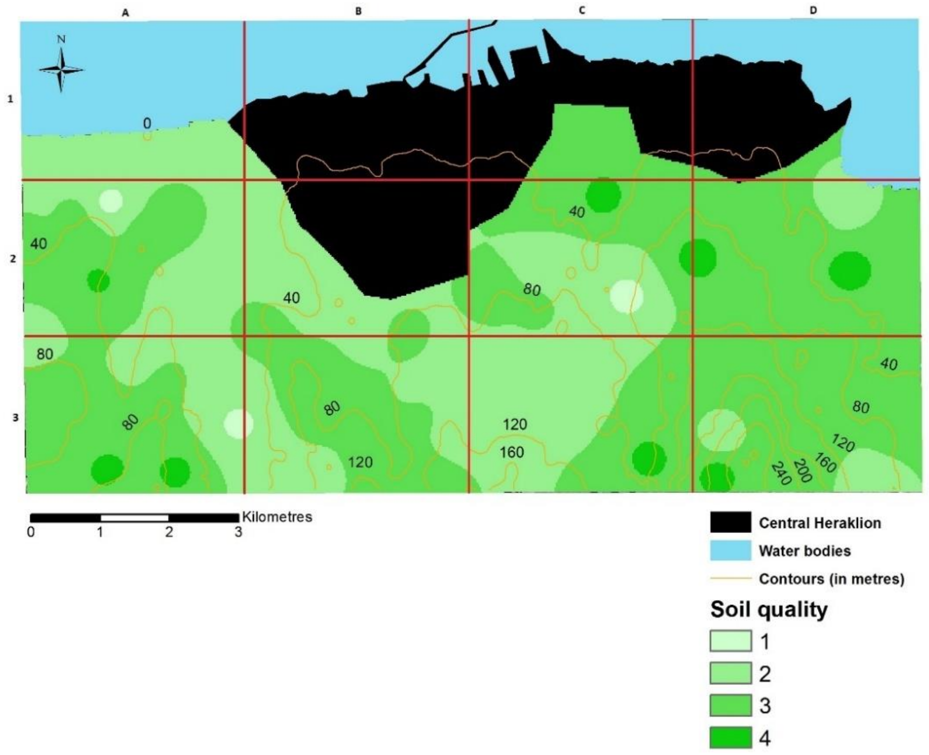

Figure 20: Soil quality map (the darker the green, the better the soil quality)

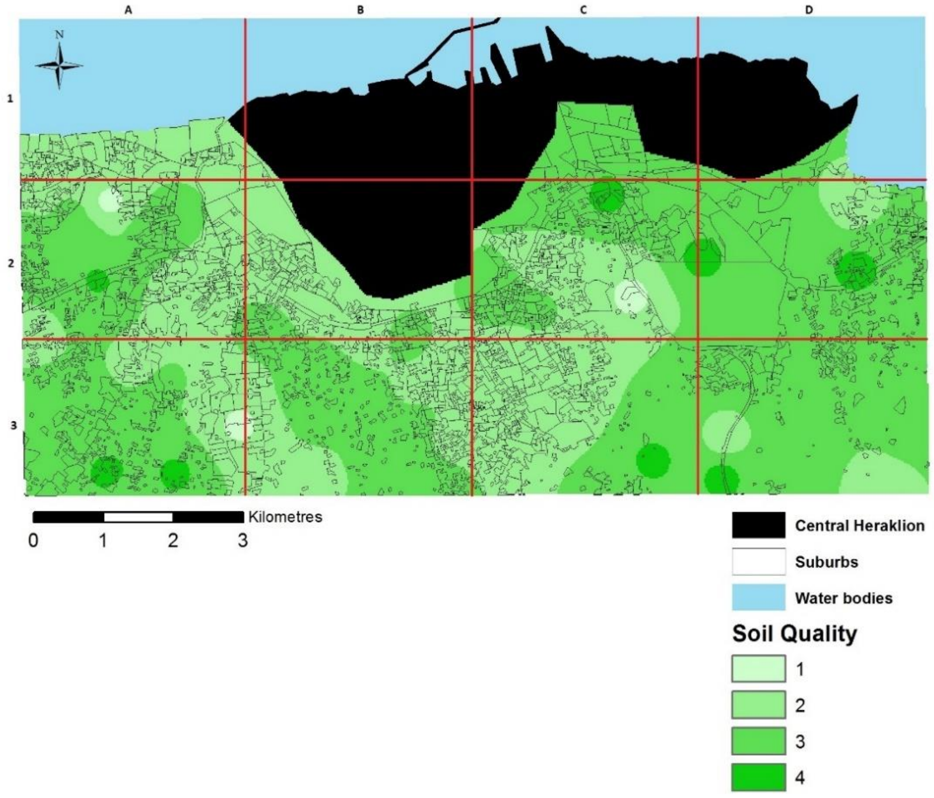

Figure 21: Soil quality map covered by both central Heraklion and suburbs (2016)

5.0 Soil Management

Recent rapid increases in land use conversion have been an influential negative factor impacting on soil quality, where the less stable and natural the land is, the larger the likelihood of a soil degrading (Raclot *et al,* 2016). Soil management is an integral part of an environment as it can have either direct or indirect impacts on plant productivity, environmental sustainability and human health (Virto *et al,* 2015; White *et al,* 2012). Effective soil management can provide a sustainable and healthy soil that has the ability to provide an ideal habitat for most living organisms, as well as maintaining a physical and chemical condition of its soil properties that can contribute to successful plant growth (White *et al,* 2012). In contrast, a lack of effective soil management can lead to soil erosion, minerals within the soil that can be deficient or toxic to plants, which can further lead to soil degradation and therefore contaminate water sources leading to consequences on crop production and human health (White *et al,* 2012). In this study, due to the semi-arid climate, the steep slopes and the extensive agriculture that is evident on Crete, the island is under one of the most severe environmental threats: desertification (Croke *et al,* 2000; Garcia-Ruiz, 2010; Raclot *et al,* 2016; Tsakona & Gekas, 2007; Vasilaki *et al,* 2008). Desertification can restrict the support of some essential soil sources to plant growth (Munson, 2013). However, this limitation may limit the survival of some species, but can favour drought resistant crops (Vasilaki *et al,* 2008). The land use types analysed in the study will be given soil management solutions (olive groves, natural phryganic shrubland and bare land).

Olive groves

Olive groves cover 30.5% of the land within the study area (Table 1), as well as a significant percentage in the whole of Crete (20.59%), which also makes them the most common form of agriculture occupying approximately 48% of Crete's total agriculture (Sarris *et al,* 2005). Therefore, it is essential that soils of olive groves are managed sustainably. Olive trees tolerate drought and salinity very effectively and therefore can adapt to degraded soils in Mediterranean climates (Raclot *et al,* 2016; Vasilaki *et al,* 2008). They are also the most suitable type of agriculture on Crete compared to vineyards and croplands, and can control soil erosion effectively (Vasilaki *et al,* 2008). Consequently, soil management through potential conversion of saline soils from vineyards or croplands to olive groves could be an effective solution. However, one of the main issues with soil erosion in olive groves, and especially on slopes, is the intensive tillage that is being practised by farmers in bare patches around olive trees (Abdullah, 2014; Vasilaki *et al,* 2008). Tillage can lead to exposed topsoil that can very easily be eroded and therefore directly and indirectly affect soil quality (Abdullah, 2014; Fernandez-Getino *et al,* 2015; Vasilaki *et al,* 2008). Soil erosion can have negative effects on soil water content and bulk density, as well as result in loss of nutrients (Fernandez-Getino *et al,* 2015). The solution to the reduction of soil erosion in olive groves is reduced tillage, and where tillage is necessary it must occur between the tree lines which act as barriers on slopes (Vasilaki *et al,* 2008). This could solve the issue with the extremely low soil water content in the study. Another solution to the reduction of soil erodibility, but also an increase in biodiversity and improvement of soil properties, is the establishment of vegetation or even residue management between the olive tree rows (Soriano *et al,* 2016; Vasilaki *et al,* 2008). Leaving the plant residue from the previous year, is an effective and cheap way to reduce soil erosion. In addition, planting of cover crops in the whole field of olive trees in spring can reduce soil erosion and increase nutrients in the soil (Kosmas *et al,* 1997; Zhao *et al,* 2005). However, in a semi-arid region, the planting cover of crops can introduce competition for the limited soil moisture that is present (Soriano *et al,* 2016; Vasilaki *et al,* 2008).

In terms of soil water management and the conservation of fresh water supplies for other uses, the use of saline water is considered to be an ideal option for olive groves, as olive trees are saline tolerant plants (Chartzoulakis, 2005). Even if electrical conductivity increases to a threshold range, the reduction of fertilizers can keep soil salinity to lower levels (Bahrami *et al,* 2010). In terms of organic matter improvement, residue management, which involves leaving crop residue from the previous years, is an effective and inexpensive way to decrease erosion and increase levels of organic matter (Abdullah, 2014). According to Mohawesh *et al* (2015) and Virto *et al* (2015), the separation of fields into different layers of elevation and the construction of stone walls, especially in fields that are on steep slopes, clearly influence the thickness of the surface which can increase organic matter, conserve nutrients and control soil erosion, therefore improving water availability. However, these methods are most importantly aimed at reducing soil erosion in this study, because as in terms of organic matter, the levels in this particular case are within optimum range, so therefore solution for organic matter could be assessed for future potential issues.

Natural phryganic shrubland

Phrygana land can be considered as natural vegetation, where relative human disturbance is minimum (Chytry *et al,* 2010). It consists of a dominant shrub layer of spiny, aromatic, and deciduous shrubs up to 50 cm in height (Diamantopoulos *et al,* 1994). Compared to olive groves and other agricultural land, phryganic shrublands control soil erosion due to vegetation cover which acts as a support to the soil surface against wind and water runoff (Blanco & Lal, 2010; Marzaioli *et al,* 2010). However, phryganic shrublands and their soils in Crete are threatened by other factors (Tsakona & Gekas, 2007). Overgrazing of natural phryganic shrubland by the main livestock (sheep and goats) on Crete is a significant threat to soil degradation and desertification (Tsakona & Gekas, 2007). Therefore, the overgrazing of certain areas for long periods or even permanently must be avoided. The combination of intermediate grazing in larger areas, and the shifting of grazing to other areas, is a solution enabling the grazed phrygana land to remain as a sustainable environment rather than in a critical situation (Perevolotsky & Seligman, 1998) in which vegetation becomes sparse, water is being lost constantly, and favourable conditions are likely to be created for soil erosion (Graetz & Tongway, 1986; Mekuria *et al,* 2007). In addition, intermediate grazing can have a positive influence on the biodiversity of phrygana shrublands, which can also contribute to the soil quality (Perevolotsky & Seligman, 1998; Radacsi, 2005). However, in the north part of Crete overgrazing is not a substantial issue, but it is occurring in the south of Crete. In terms of soil water content, phrygana species are drought tolerant species, and therefore can adapt to long periods of drought (Rhizopoulou & Psaras, 2003). This seems to occur in the study, where phryganic shrublands thrive despite the very low soil water content. In addition, the reduction in overgrazing means less trampling and therefore decrease in bulk density which favours plant growth (Radacsi, 2005). Similarly to olive groves, plant residue management, which does not incur any cost, is an effective solution for the increase of soil organic matter (Abdullah, 2014).

Bare land

Bare lands tend to be previous agricultural fields that had initially undergone severe desertification and were later abandoned (Zhao *et al,* 2005). Intensive agriculture with lack of sustainable management in a semi-arid region like Crete can lead to soil degradation and desertification which can restrict plant growth to an irreversible critical point, where the rehabilitation of bare land to vegetated land is almost impossible (Dupouey *et al,* 2002). This is because most soil properties such as bulk density, organic matter, soil water content and nutrients have reached a critical point. In addition, acidification and excessive salinity levels are also an indication of severe soil degradation. In order to restart using bare land for any agriculture use or even just for replantation, there is a certain strategy that should be followed (Tsakona & Gekas, 2007). Due to the poor levels of water availability and nutrients in bare land, the direct planting of crops would lead to unsuccessful results (Tsakona & Gekas, 2007). Accordingly, recovery of extremely degraded ecosystems such as bare land has to be started by smaller vegetation species that are drought resistant, and preferably native species which do not require any significant practices. Some plants that are characterized as successful for soil remediation include xerophytes, cacti, peas and sunflowers (Tsakona & Gekas, 2007). Other plant species that can be used for soil remediation include the Carob tree and the Mastic shrub, which are also drought tolerant species and have the ability to inhabit disturbed land (Vasilaki *et al,* 2008). The gradual increase of vegetation cover will improve species richness and soil quality, and reduce soil surface exposure to temperature and direct rainfall (Khresat *et al,* 2008; Raclot *et al,* 2016). For the productivity of the soil in the initial period of revegetation, some input such as wood residue and animal manure is advised in order to stimulate microbial activity and provide the soil with nutrients (Sheoran *et al,* 2010). Even though solutions to the vegetation rehabilitation of bare land is important, the priority is to avoid desertification of further agricultural land into bare land. The addition of mycorrhizal fungi is another solution which is essential for plant uptake nutrients such as nitrogen and phosphorus in order to enhance plant growth (Sheoran *et al*, 2010). Further protection for bare land that is under reclamation of vegetation, is by restricting the use agricultural machinery and grazing in order to minimize compaction (Sheoran *et al*, 2010).

Vineyards

Vineyards are considered to be one of the most, if not the most, erosive land uses in the Mediterranean region (Garcia-Ruiz, 2010). One of the reasons behind the high erosion rates in vineyards is due to the fact that the soil tends to be bare between November and April and therefore vines offer limited vegetation cover (Garcia-Ruiz, 2010). Limited vegetation cover in combination with anthropogenic factors such as machinery trampling and tillage increase the erodibility rates even more (Prosdocimi *et al,* 2016). Non-conservation practices in the Mediterranean have accelerated soil erosion in vineyards, and soil management to prevent soil degradation is very important for sustainable agriculture of vineyards (Prosdocimi *et al,* 2016). Similarly to the olive groves, one way to reduce soil erosion is the practice of no tillage or reduced tillage which can have a significant effect on soil erosion control (Abdullah, 2014; Prosdocimi *et al,* 2016). Another practice that can enhance soil quality and control erosion rates when the surface has no vegetation, is the use of barley straw residues on the bare patches between vineyards (Cerda *et al,* 2016). Barley straw residues have been used widely in the Mediterranean region, where the barley straw residue acts as a barrier to water runoff and therefore limits the acceleration of water runoff on the soil surface (Cerda *et al,* 2016; Prosdocimi *et al,* 2016). The limitation of water runoff means that the productive top soil is not lost (Vasilaki *et al,* 2008).

6.0 Conclusion

On the combined basis of the findings and soil management, land use change over time has been rapid around the area of Heraklion in recent decades and the study suggests the need of deceleration in land use conversion: firstly, because conversion of unmanaged land into more disturbed land such as agriculture and built up areas inevitably leads to decrease in soil quality and function mainly due to natural vegetation removal and compaction. The 1.5 % decrease in unmanaged land cover to agriculture and built up areas since 1997 is a proportional loss of 11.5%, whereas the proportional increase of urban land cover since 1997, is 33.3%. Secondly, an environment that remains stable and is under appropriate and conservative soil management over a long period of time tends to enhance overall soil quality, and therefore minimizes the possibilities of potential soil degradation.

As Crete has a semi-arid climate, water availability is becoming more challenging due to increasing human demands, as well as more limiting due to climate change, which is the basis of longer periods of drought in the summer months and short periods of heavy rainfalls during the winter. As evident in the study results, soil water content was extremely low for nearly every soil sample across the study area, which suggests the importance of soil moisture sustainability. Water availability is a major priority and the effective soil management in any land use types must deal with the preservation of water as well as the sustainable use of it. In addition, the significantly higher electric conductivity levels in bare lands in this study indicate the potential salinization of soils in Crete, with desertification as a major factor leading productive land to degraded bare lands. In terms of relationships between soil variables, electric conductivity is linked with organic matter and nitrate, nitrate is linked with organic matter and bulk density is linked with soil water content. All these links between the soil variables need to be taken closely into account when soil management is undertaken because one soil variable can be affected by several other soil variables.

In terms of the soil quality map which presents an overall picture of spatial patterns and soil functionality, urbanization has clearly had a negative impact on soil variables, whereas unmanaged lands are the least affected. Finally, the maintenance of good soil quality is very important, and in summary some of the most essential ways to manage land are the reduction of soil erosion through various approaches, the avoidance of intense agriculture and the avoidance of overgrazing in natural phryganic shrublands. In addition, even though the Greek economic crisis has affected infrastructure development in Greece over the last few years, and has also lead to a slight decline in the Greek population, Crete, is one of the exceptions, where there is a constant yearly rise in the human population as well as a continual expansion of Heraklion suburbs towards the rural areas. Expansion of built up areas around Heraklion needs to be taken into account, and somehow result in sustainable urban planning that minimizes land conversion from natural or agricultural areas into concrete surfaces. Finally, the global change model projection is predicting longer periods of droughts and severe rainfall events in the future which will result in either direct or indirect effects on soil quality.

7.0 Reference List

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