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Narrative and Quantitative Analysis of Human Pressure, Land-use and Climate Aridity in a Transforming Industrial Basin in Greece

Salvati, L.[1] and Mavrakis, A.[2]

[1] Consiglio per la Ricerca e la sperimentazione in Agricoltura, Centre for the Study of Soil-Plant Interactions (CRA-RPS), Via della Navicella 2-4, I-00184 Rome, Italy

[2] Institute of Urban Environment and Human Resources, Department of Economic and Regional Development, Panteion University, 136 Syngrou Avenue, GR-17671, Athens, Greece

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ABSTRACT: The present study illustrates the long-term changes in selected socioeconomic variables (population, industrial activities, settlement dispersion, and land-use) together with climate aridity trends in Thriasio, the larger industrial area of Greece located twenty kilometers far from Athens. This region, originally devoted to agriculture, experienced fast industrial and economic development during the early 1990s coupled with growing population. According to statistical data covering the period between 1848 and 2011, human pressure increased rapidly in the area determining drastic changes in land-use. The analysis of climate regimes based on meteorological data collected between 1958 and 2010 also indicate a tendency towards aridity possibly contributing to air pollution, soil degradation and desertification. Without a sustainable land management strategy changes in bio-physical and socioeconomic variables are altering irreversibly the fragile ecological equilibrium leading to ecosystem degradation in a highly-populated area since millennia.

Key words: Population, Economic growth, Climate aridity, Mediterranean region, Regional planning

INTRODUCTION

Mediterranean ecosystems are experiencing environmental vulnerability due to climate change, soil degradation, forest fires, land-use changes, vegetation deterioration, and landscape fragmentation. Frequent drought episodes, the structural fragility of soil and limited vegetation cover as well as the land susceptibility to hydrological hazards make the area extremely sensitive to growing human pressure. All coastal cities in southern Europe have experienced massive urbanization and the United Nations Urbanization Prospects estimated that urban population will be more than 70% in all northern Mediterranean countries (United Nations, 2007). According to Blue Plan scenarios, population passed from 285 million people in 1970 to 427 million people in 2000 in the whole Mediterranean basin reaching 524 million people by 2025 (Blue Plan, 2010). These trends are in common with several other urban agglomerations around the world, especially in southern America, Africa and Asia (Martí-Henneberg, 2005; Chen *et al*., 2007; Angel *et al*., 2011). Urbanization drivers include the internal redistribution of population, rural-urban migration, tourism growth, and concentration of economic activities along the coastal areas. Unplanned settlements contributed to diffuse urbanization in the Mediterranean region (Bajocco *et al*., 2012). These changes result in a weak region, scarcely resilient (Sapuntzaki & Chalkias, 2005) where environmental quality is often sacrificed in the hope of an uncertain economic development (Chorianopoulos *et al*., 2010).

The metropolitan area of Athens underwent drastic economic and population changes during the last sixty years that strongly affected the environmental quality of the region (Kallis, 2010). In the most recent period, due to the Olympic infrastructure development, urban areas increased from 15% in 1990 to 18% in 2000. This rapid growth was driven by new infrastructures in outer areas extending for 58 km^2 (more than 2% of the region) and included the 'Attiki Odos' Motorway and the new International Airport (Stathopoulou *et al*., 2004; Christofakis, 2004; Bithas & Christofakis, 2006). The loss of forest land in Attica amounted to more than 100 km^2 especially due to summer fires. However, only 2.3 km^2 were converted to urban areas, whereas the remaining land gradually transformed to bush land through the process of natural regeneration. New forest land was being created on a surface area of 20 km^2 mainly due to agricultural land abandonment. As a result, the overall

*Corresponding author E-mail: luca.salvati@entecra.it

balance resulted in a loss of 83 km^2 forest land, corresponding to the 24% of the forest stock in Attica. Due to the concentration of industrial and logistic activities close to the inner city, atmospheric pollution represented one of the most relevant environmental problems in Athens. In order to stimulate the de-concentration of the industrial pole originally located in the centre of Athens, western Attica, and mainly Thriasio, experienced massive industrial growth in the last twenty years. While human settlements in Thriasio were found since the pre-historic period, this region faced a rapid development in the last years, becoming the main industrial area of Greece (Stathopoulou *et al.*, 2007). This resulted in environmental deterioration with special regards to air, water, and soil quality (Mavrakis *et al.*, 2008).

A narrative study supported by quantitative long-term analysis of selected key variables was presented in this article in order to illustrate the (possibly unsustainable) developmental path of Thriasio, taken as a representative example of a large industrial basin in southern Europe. While Thriasio was renowned as an important area inhabited since millennia and a sacred place for the celebration of ceremonies (including the famous Elefsinian Mysteries in ancient Greece), nowadays it is mainly known for the concentration of industries, mostly oil refineries, steel industries, steelwork and chemical industries, and cement industries. Apart from some unpublished, technical reports mainly available in Greek, the restricted information about the sustainability of the socio-economic and ecological system suggest a specific investigation on this region taken as a paradigmatic example of rapid and uncontrolled local economic development.

The aim of the present study is to illustrate how the lack (or the ineffective application) of environmental policies at the local and regional scale and a diffused culture of 'law derogation' and 'spontaneous' or 'unauthorized' development determined a growth path possibly leading to extensive natural resource degradation and even loss in social cohesion. The study also introduces an assessment scheme for population and industrial activities increase over time and the consequent changes in land-use coupled with the analysis of climate aridity. Models estimating the relationship between population increase and the number of established activities allows for continuous monitoring of the expanding urban agglomerations together with the (possibly changing) climate regimes and pollution trends. The illustrated framework may contribute to inform policies for the sustainable management of land in industrial and suburban areas.

MATERIALS & METHOS

Thriasio plain (Attica, central Greece) was renowned in ancient times as a sacred place devoted to ceremonies (e.g. the Elefsinian Mysteries). Unfortunately, nowadays it is known for the concentration of industries, mostly oil refineries, steel industries, steelwork and chemical industries, and cement industries. In its current form, Thriasio consists of three municipalities (Elefsis, Aspropyrgos, Mandra) and a community (Magoula) located 20 km west of Athens (Fig. 1). The surface area of the four local authorities' areas is: Aspropyrgos (69 km^2), Elefsis (19 km^2), Mandra (207 km^2 of which only 25 km^2 belongs to the study area) and Magoula (13 km^2). The investigated area is surrounded by high relief with a mostly smooth surface morphology, slightly inclined towards the sea, with slope less than 3%. Climate is mainly dry (with average annual precipitation below 400 mm) and hot in summer (annual air temperature averaging 19°C). Soils are dry for the largest part of the year and the area lacks of perennial water sources.

The statistical data used in this work have been obtained from the National Statistical Service of Greece (ESYE) and mainly derived from the Census of Population, Industry, and Agriculture. Trends in land-use derived from a specific survey carried out by the ESYE every ten years together with the General Census of Agriculture. Urban planning information as well as additional data concerning the number of established activities were provided by the Bureau of Pollution Control and Environmental Quality (BPCEQ) of the Thriasio Plain Development Association of Municipalities and Communities (TPDAMC) and mainly derive from Stamatiadis (1993). Data on urban development were complemented with information obtained from the electronic press.

Meteorological data were obtained from the Hellenic National Meteorological Service (HNMS) station located in the airport of Elefsis (38^{0}04' N, 23^{0}33' E), and covers the period between 1958 and 2010 at the month base. The station (code: LGEL in the World Meteorological Organization network) is located at an elevation of 31 metres above the sea level. By computation of precipitation and temperature month data De Martonne aridity index was calculated according to the following equation:

$$I = \frac{P}{T + 10}$$

P is the annual rainfall level measured in [mm] and T is the average annual value of air temperature [^{o}C] (de Martonne, 1926). This well known index was chosen for its computational simplicity and classifies years according to the observed aridity regime into four classes (Arid: $I < 20$, Dry: $10 < I < 20$, Semi-dry: $20 < I < 25$, Dry sub-humid: $I > 25$). Two study periods (1959-1984 and 1985-2010)

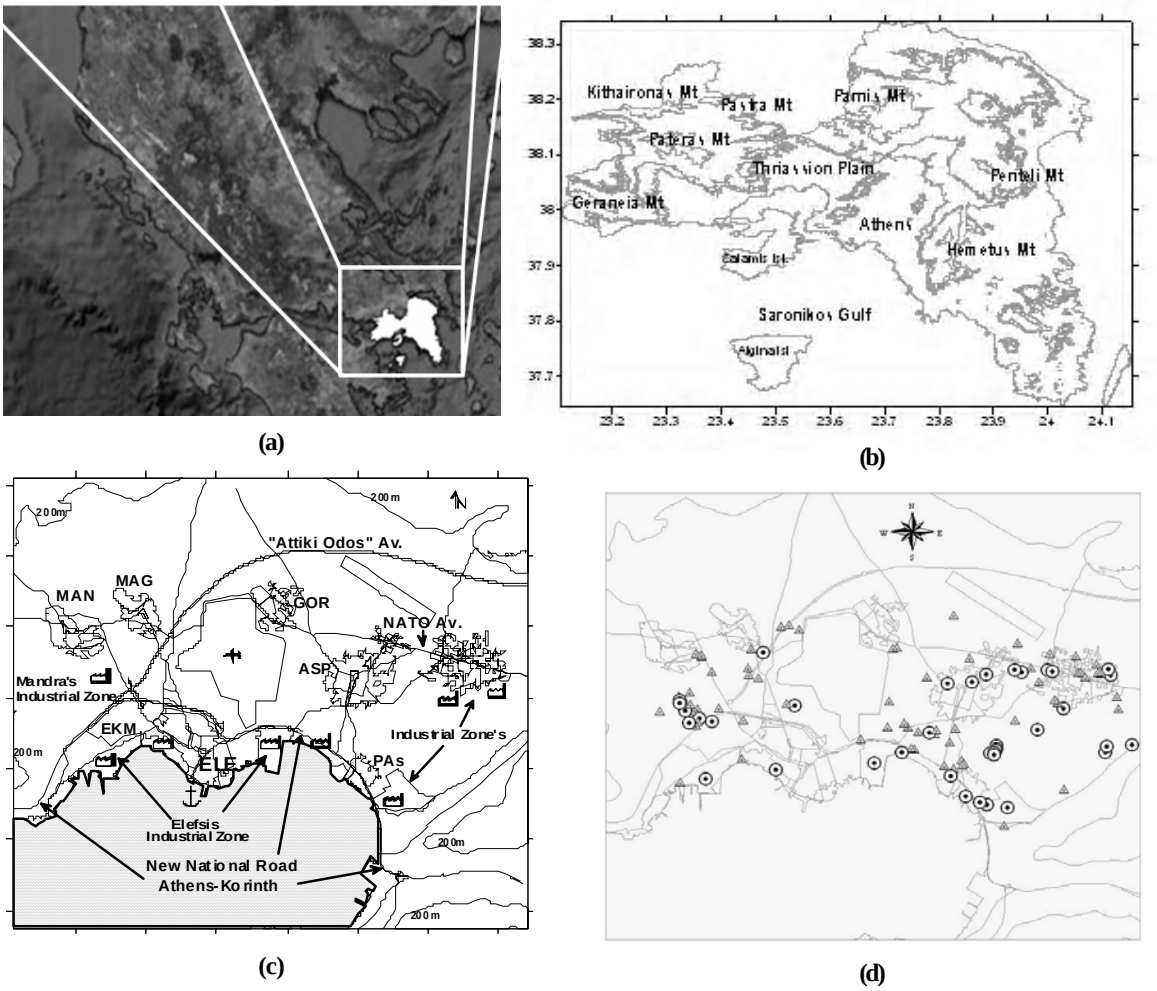

Fig. 1. (a) The geographical position of Thriasio in Greece; (b) map of Thriasio and Athens basin with the names of the surrounding mountains; (c) Map of Thriasio with the boundaries of statutory areas and the main road axes(ELE: Elefsis, ASP: Aspropyrgos, MAN: Mandra, MAG: Magoula, Pas: Paralia Aspropyrgou, EKM: Mandra's Labor Complex, GOR: Goritsa); (d) Industrial activities in Thriasio (triangles indicate activities with medium air pollution emissions and circles represent activities producing high air pollution emissions)

were analyzed in order to test if climate aridity in Thriasio has been increasing in the last years using the non-parametric Mann-Whitney U-test with a probability threshold fixed at $p < 0.01$.

RESULTS & DISCUSSION

Since the last fifty years, Thriasio underwent massive industrialisation coupled with a remarkable population growth (Fig. 2). The area experienced immigration for the first time in 1922, where Greeks escaping from Turkey settled in Elefsis, the main urban centre of the region. Before World War I only ten important industries were active in the area, among which a cement industry and several glass industries. Population grew by 5.7% in this period with a rate ranging from 0.8% in Magoula to 7.3% in Elefsis (Table 1). In the 1950s the massive industrialisation of the area led to the transformation of land from rural to urban uses and the concentration of workers from the whole country. After 1971 Mandra and Magoula showed a faster rate of population growth, the latter also having been boosted by the construction of social housing at the borders with Elefsis. During 1981-1991 population growth rate doubled, as far as a large number of small industrial units, scattered across the area, were established, resulting in a parallel concentration of labour migrating from other parts of Greece.

Based on the 2001 census of population, Aspropyrgos become the highest populated municipality of Thriasio plain, growing by 8% *per year*, as a result of the three aforementioned factors. At the last census (2001), only 10% of the economically-active population

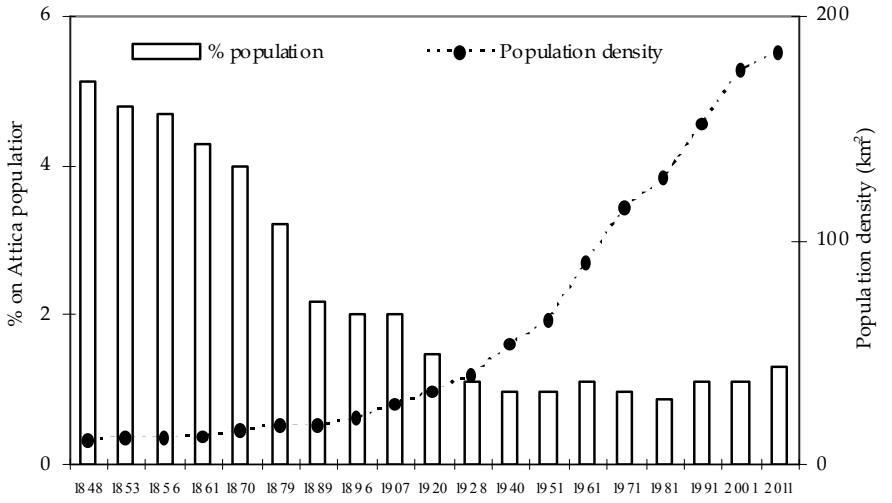

Fig. 2. Trends in population distribution and density (inhabitants/km²) in Thriasio by year

Table 1. Population and industrial activities in Thriasio (absolute figures by year and municipality)

Variable	Year	Aspropyrgos	Elefsis	Mandra	Magoula	Total
Population	1896	2,012	1,356	1,594	235	5,197
	1907	2,339	1,230	1,811	282	5,662
	1920	2,730	3,248	4,011	558	10,727
	1940	4,880	9,154	3,410	458	17,902
	1951	5,855	11,190	3,908	432	21,385
	1961	8,162	15,527	5,503	675	29,867
	1971	11,183	18,535	8,042	1,214	38,974
	1981	12,541	20,320	8,804	1,915	43,580
	1991	15,405	23,041	11,642	2,743	52,831
	2001	27,741	25,863	12,792	4,005	77,881
	2011	30,160	30,140	---	---	78,190
% growth (1896-1951)		3.5	7.3	1.5*	0.8*	5.7
% growth (1951-2011)		6.9	1.7	2.3*	8.3*	4.4
Industrial Activities	1969	140	213	80	10	443
	1979	243	286	108	33	670
	1989	470	315	187	75	1,047
	1993	1,138	369	326	162	1,995
	2000	1,473	488	436	235	2,632
	2005	2,407	2,098	918	355	5,778
% growth (1969-1989)		2.4	0.5	1.3	6.5	1.4
% growth (1989-2005)		4.1	5.7	3.9	3.7	4.5

* Calculated on the period 1951-2001.

in Thriasio worked in the primary sector, while the secondary and tertiary sectors occupied respectively 65% and 25% of the economically-active population. Interestingly, only 45% of workers were permanent residents in Thriasio. In summary, from 1951 to 2011, population increased by 4.4% with a rate ranging from 8.3% in Magoula and 1.7% in Elefsis. In this period the peripheral municipalities of Aspropyrgos and Magoula experienced the largest growth compared to the previous period (1896-1951) when population growth was mainly observed in Elefsis.

In the 1990s, Greek emigrants, coming mainly from areas of the former USSR, settled in areas within the

municipal borders of Aspropyrgos. At the same time communities of Roma and Sinti established unauthorized settlements mainly in Elefsis and Aspropyrgos. A large number of foreign immigrants (mainly from Albania) lived and worked in the area. According to the mayor of Aspropyrgos "the Greek ministry of Interior plans to transfer here 2,500 people. They have friends, relatives, and … lawyers. We estimate, therefore that as many people would be flowing daily through the region. The town cannot take it!". However, the mayor excludes any form of racism in the local population. The municipality's population is formed for 25% by immigrants. In past, the local community has been received, without particular problems, both the refugees of Greek origin from the former USSR, the Roma settlers and the rest immigrants. To the contrary, social conflicts are arising between both the resident population and the old immigrants with the Roma new–comers who are stealing electricity, water and stuff from the nearby warehouses, which are all barbwire-fenced.

The industrial activities in Thriasio are concentrated in the flat area close to the urban centre of Elefsis and Aspropyrgos which covers nearly 120 km^2. Fig. 1 shows the statutory borders of the residential areas, the main road network, as well as the authorized borders of the industrial area. However, a number of factories have been settled outside the authorized limits. The increase in industrial and logistic units was evident from 1969 to nowadays (Table 1) with growing rates ranging from 1.4% in 1969-1989 to 4.5% in 1989-2005. As already observed for population increase, the diffusion of industrial settlements was not homogeneous in the study area following a centre-periphery gradient moving from Elefsis to Aspropyrgos.

The existing industrial and residential settlements together with the geographic characteristics of the region determined heavy pollution in the investigated area also due to weakness of regulations on waste disposal. The lack of social and economic infrastructures including water supply, sewage disposal, transportation, and energy consolidated a process of environmental deterioration over time (Stamatiadis, 1993). Notably, the risk of an industrial accident in Thriasio has risen considerably. Moreover, three highways pass through the area determining an increase of traffic volume from 30 million vehicles *per year* to 50 million vehicles (Christides *et al.*, 2005). However, contrary to what happens in the urban area of Athens, it was demonstrated that pollution emissions in Thriasio are produced primarily by industrial activities and only secondarily by traffic (Mavrakis *et al.*, 2008).

A dump operates at the borders of Thriasio plain to serve the greater Athens area, currently receiving more than 1,570,000 tons of urban waste per year, whereas the dump processing unit manages about 1,200 tons daily. In addition, 23.000 tons of solid industrial wastes are disposed in the dump per year, of which 4,500 tons are toxic, 8,500 tons are oil waste and the remaining 10,000 tons are non-toxic. Dump operations impact water table determining pollution within a distance of 1 km southwest of the dump (Karavitis *et al.*, 2001). A natural stream (Aghios Georgios) carries liquid industrial waste and landfill leach from the dump to the sea. The stream has been set up as the outlet channel of industrial waste (Prefecture Decision 17823/21-12-1979, Official Journal of the Hellenic Republic, 1132B), under the provision of full waste process in order to observe specified pollutant concentration limits (Mavrakis *et al.*, 2007). Finally, out of 15 km of coastline, 12 km are occupied by port activities of industrial and manufacturing units. Products from 5,500 ships transited annually at the 13 Elefsis' docks working with an amount of goods weighing 2.5 times more than the equivalent amount operated at the Piraeus Port Authority, which is the main port of Greece.

Data illustrating trends in the economic activities settled in Thriasio indicate how the municipality of Aspropyrgos experienced the most rapid changes in land-use due to land availability (Chen *et al.*, 2007). The relationship between the concentration of the economic activities and population density is positive with high correlation coefficient ($R^2 = 0.99$, $p < 0.0001$). The correlation between population dynamics and industrialization in Thriasio is also shown in Fig. 3. However, economic growth is not uniform in all investigated local authorities with the municipality of Aspropyrgos showing the higher rate of increase in both population and industrial activities. Elefsis, on the other hand, experienced a drastic population growth compared to the increase of activities acting as the political center of Thriasio and the prefecture of western Attica. A number of human and natural factors affecting population density (Martí-Henneberg, 2005) are at work in the investigated area. Population increase was triggered by the great number of established activities offering employment opportunities, as well as by land availability.

The rapid establishment of activities and the resulting changes in land-use, transforming traditional rural areas into urban areas, can be particularly harmful for the environment when occurring without a strategic planning. Thriasio is characterized by unregulated industrial development and spontaneous settlements. More than half of the working factories are placed outside the statutory borders of the industrial area. As a result, production units are scattered across the region, determining land fragmentation and habitat deterioration. The area lacks in service networks, whereas at the same time the quality of life of resident people declined gradually (Karavitis *et al.*, 2001).

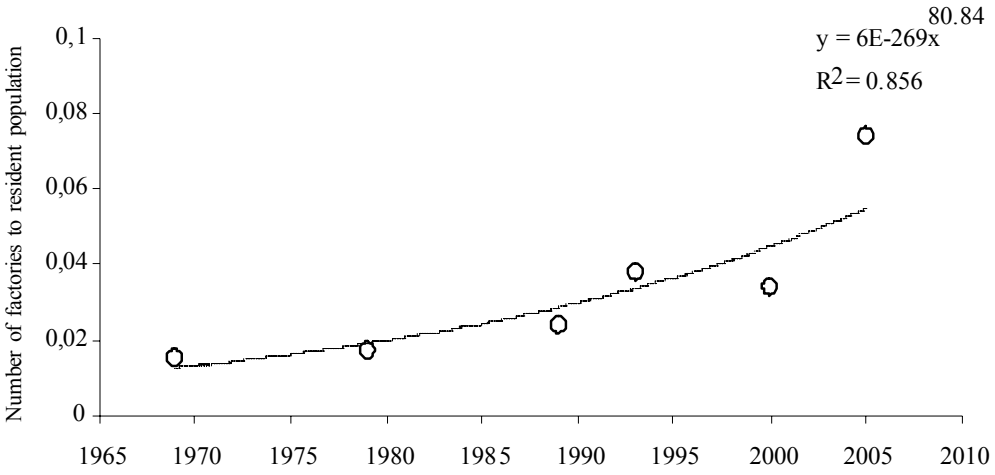

Fig. 3. The ratio of industrial activities to resident population in Thriasio by year

Thriasio plain was classified as an Industrial Area (IA) in the local development scheme approved by the Hellenic Ministry of the Environment (Christofakis, 2004). According to this model, IA is defined by the presence of a Promotion Production Unit (PPU) of secondary and tertiary activities and the spatial concentration of small and medium-sized enterprises (SMEs) with activity focusing on one specialized sector and defined stages of the production process. SMEs cooperate with PPU in the various stages of the production process. However, this model was not applied in Thriasio resulting in spontaneous and unplanned industrial development (Economou, 1997; Konsolas *et al.*, 2002; Tassopoulos *et al.*, 2003). On the other hand, the lack of housing policies for Thriasio has led to the imbalanced development of towns. All local authority areas appear considerably compact, with the total of residents living within the respective agglomerations and the rate of available greenery and public space per resident in Elefsis is only 5 m^2. In addition, the large-scale transport projects, serving as development instruments (OECD, 2004; Papadaskalopoulos *et al.*, 2005, 2007; Christofakis & Papadaskalopoulos, 2008) attracted a large number of activities in the area deteriorating the environment (Symeonidis *et al.*, 2003).

A progressive degradation of rural areas has been observed in Thriasio due to population increase, forest fires, unauthorized urban expansion and infrastructure development. The region represents the most degraded area in the whole Attica as far as vegetation and landscape quality is concerned. Interestingly, although agriculture plays a secondary role for Thriasio, some areas are yet destined to olive groves and vegetable crops the products of which are sold in the local market. Table 2 shows long-term land-use changes from 1960 to 2000 in selected municipalities of Thriasio: Elefsis and Aspropyrgos. It was clear how in both municipalities urban areas were growing rapidly during both 1960-1980 and 1980-2000 at the expenses of forests and pastures (Elefsis) and agricultural areas (Aspropyrgos).

Finally, based on meteorological data collected in Elefsis, De Martonne aridity index was calculated for two time periods (1959-1984 and 1985-2010). In accordance to similar studies carried out in greater Athens (Philandras *et al.*, 1999; Repapis *et al.*, 2007), the index values (Fig. 4) highlight a significant shift towards drier climate conditions in the most recent years (Mann-Whitney U test, $p < 0.05$). It is also worth mentioning that, during the examined time period, only three years have been

Table 2. Percent distribution of four land-use classes between 1960 and 2000 in selected municipalities of Thriasio

Year	Agriculture	Pastures and forests	Water	Urban
		Aspropyrgos		
1960	47.4	49.7	0.6	2.4
1980	43.0	50.4	0.5	6.1
2000	41.0	43.1	0.2	15.7
		Elefsis		
1960	45.8	9.0	0.0	45.3
1980	32.4	10.8	0.0	56.8
2000	36.0	7.0	0.0	57.0

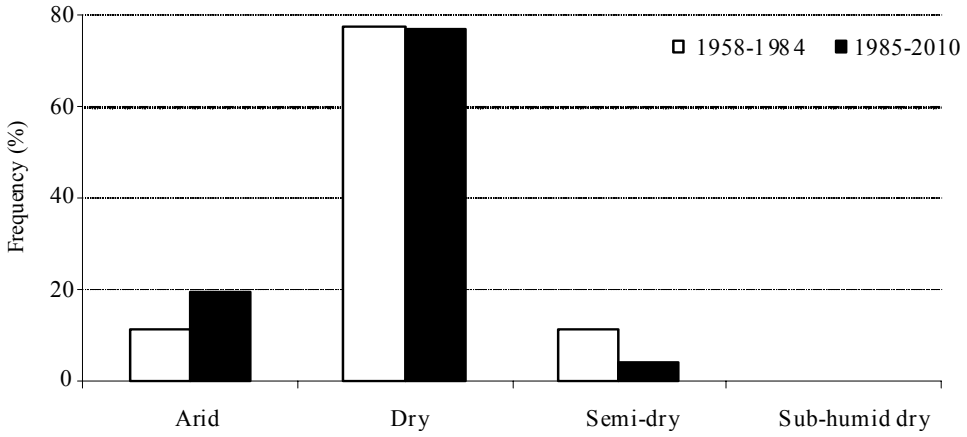

Fig. 4. Percent distribution of arid, dry, semi-dry and sub-humid dry years according to De Martonne classification in two time periods in Elefsis

classified as semi-dry or dry sub-humid, while in the majority of years, Thriasio climate was characterized as arid. As far as the relationship between climate change and air pollution, preliminary results indicate that a positive correlation exists between various indices of air pollution and aridity (Mavrakis *et al.*, 2011). As a matter of fact, drier climate conditions contribute to photochemical pollution which is typical of the area (Kalabokas & Kotzias, 2004; Lykoudis *et al.*, 2008).

CONCLUSION

The present study illustrates changes in selected human pressure indicators (population distribution, industrial concentration, land-use) in the largest industrial area of Greece and examines the correlation between population increase and industrial activities together with changes in climate aridity. The diachronic analysis of statistical data at the most detailed resolution (i.e. municipalities and urban districts) provides insights in the complex transition from a system based on agriculture towards a developing region with conflicts for land-uses. The overall results can be summarized as follows.

Thriasio carried the burden of the country's post-war development with the establishment of activities of all kinds without developing the necessary infrastructures. This fact caused a drastic growth of population primarily due to the internal migration of specialized workforce. The exponential establishment of activities resulted also in the degradation of the natural environment, the abandonment of the primary sector, the fragmentation of the olive groves, the gradual shrinking of new unauthorized agglomerations. The transportation projects developed in the last years accelerated the establishment of activities, while exacerbating the traffic problems in the area.

Together with the rapidly increasing human pressure, the climate regime of Thriasio shifted towards drier conditions with important consequences for the local environment. Since the region was classified as a prone area to land degradation (Bajocco *et al.*, 2012), climate and land-use changes contribute to determine a higher risk of desertification (Pielke, 2005). As a conclusion, the ineffectiveness of planning policies in Thriasio, partly due to a culture of 'spontaneity' and 'planning deregulation', determined ecological conditions that are harmful for the environment and the well-being of resident population. We also demonstrate how this development path led to natural resource degradation, loss in social cohesion, and uncertain economic growth. Interestingly, the available data on fuel consumption in Thriasio show that diesel consumption has decreased dramatically in the most recent years also due to the economic crisis and has been partly replaced by natural gas, while increasing electricity consumption (Mavrakis, unpubl. data). This shift provides a first evidence of de-industrialisation of the area and, at the same time, the establishment of economic units, such as logistics, with lower emissions. However, apart from the possible, positive effects of the economic crisis on the environment (which is a deserving issue that needs further research), the illustrated case study claims for integrated policies in the environmental, social, and economic dimensions aimed at sustainable management of land in rapidly evolving industrial regions.

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