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Meeting on Implications of Climatic Changes on
Mediterranean Coastal Areas (Island of Rhodes,
Kastela Bay, Syrian Coast, Malta and Cres/Losinj Islands)

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IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON MALTA

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PREFACE

As part of the efforts of the United Nations Environment Programme (UNEP) to analyze the potential implications of predicted climate change and to assist the governments in designing policies and measures which may avoid or mitigate the expected negative effects of this change, or to adapt to them, the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP), in co-operation with several intergovernmental and non-governmental organisations, launched, co-ordinated and financially supported a number of activities designed to contribute to an assessment of the potential impacts of climate changes and to the identification of suitable policy options and response measures which may mitigate the negative consequences of the expected changes.

As part of these efforts, Task Teams on the implications of climatic changes were established in 1987 for six regions covered by the UNEP-sponsored Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South-East Pacific and South-Asian Seas) with the initial objective of preparing reviews of the expected impacts of climatic changes on coastal and marine ecosystems, as well as on the socio-economic structures and activities of their respective regions. Five additional Task Teams were established later, two in 1989 (West and Central African, and East African regions) one in 1990 (Kuwait Action Plan region) and two in 1992 (Black Sea and Red Sea).

During the work on the Mediterranean regional study, it was felt that while the general effects might be similar throughout the Mediterranean region, the response to these effects would have to be highly site-specific. Therefore in the framework of the Mediterranean Task Team six specific case studies were prepared (deltas of the rivers Ebro, Rhone, Po and Nile; Thermaikos Gulf and Ichkeul/Bizerte lakes) by the end of 1989. The first site specific case studies had concentrated on low lying deltaic systems including these of the Ebro, Rhone, Po and Nile rivers. Following their publication by UNEP, the reports of the Mediterranean Task Team were published commercially in Book form by Edward Arnold (Jeftic *et al.*, 1992, Climatic Change and the Mediterranean). In preparing these case studies it had become apparent that prediction of impacts was constrained by the absence of scenarios of future climates on a regional, sub-regional and local scale.

Accordingly the Climatic Research Unit of the University of East Anglia had been commissioned by UNEP to attempt to produce a Mediterranean Basin scenario and to develop scenarios of future local climate for the selected case study areas. The scale of existing Global Circulation Models is such that determination of future temperature and precipitation patterns at a local level involves considerable uncertainty concerning future conditions. Without such local scenarios assessment of future impacts involves even greater levels of uncertainty, reducing the value of such assessments for immediate planning and management purposes. A suite of scenarios for the Mediterranean region were developed using the output from the GCM's coupled with a finer scale meteorological database. Scenarios for local sub-regions and areas were subsequently developed for those areas which were to be examined in more detail during the second generation of case studies.

Using the experience of these initial case studies, in 1990 the preparation of the "second generation" of site-specific case studies was initiated for the island of Rhodes, Kastela Bay, the Syrian coast, the Maltese islands and the Cres-Losinj islands.

The objectives of these studies were:

- to identify and assess the possible implications of expected climate change on the terrestrial, aquatic and marine ecosystems, population, land- and sea-use practices, and other human activities;

- to determine areas or systems which appear to be most vulnerable to the expected climate change; and

- to suggest policies and measures which may mitigate or avoid the negative effects of the expected impact, or adapt to them, through planning and management of coastal areas and resources;

using the presently available data and the best possible extrapolations from these data.

The "second generation" case studies utilised the regional and local scenarios developed by the University of East Anglia in attempting to assess and evaluate the implications of future changes on specific islands and areas covered by the Mediterranean Action Plan.

The Task Teams assembled for each of the second generation case studies were composed of experts from a wide variety of natural and social science disciplines, with specific knowledge of the areas concerned. In addition, the national and local authorities responsible for planning and developments in these areas were brought into the work of the Task Team from an early stage. Thus for example the Municipal authorities of Rhodes included the work of the Task Team within their coastal development planning and the Municipal authorities of Cres and Losinj hosted several meetings of the Task Team.

In order to ensure that the Task Teams retained as wide a perspective of the problem as possible several UNEP experts on Climate Change Impact Assessment were included at all stages of the preparation of these individual assessments. The full list of Task Team members responsible for this report is given in the Appendix to this report. A final joint meeting of representatives of the Task Teams and UNEP experts was held in Malta in September 1992 at which the conclusions and recommendations of each Task Team were reviewed, compared and finalised.

This report represents one of the five site specific assessments covered during the course of this work. Whilst it is important to recognise that climatic changes and sea level rise will have an impact on future use and development of the Mediterranean coastal areas, it is equally important to recognise that the rate and scale of other sources of change, such as land-use patterns and demographic changes may be of more immediate concern in certain areas. In this context, actions designed to address the future impacts of climatic change and sea level rise must be founded on a sound basis of immediate actions designed to reduce the rate of adverse changes resulting from uncontrolled development and use of the Mediterranean coastal environment and its resources.

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FOREWORD

In 1988 global climate change became a major social and political issue, due in part to the Maltese Government initiative on climate change at the UN General Assembly. In response to increasing global awareness of the problem, WMO and UNEP established in that year the International Panel on Climate Change to assess *inter alia* the current state of knowledge concerning climate change. The IPCC gave clear scientific justification for the need to start the process of assessing the effects of climate change, at a national level. The inception of this present study is in line with this direction, in that it attempts to assess at a national level, the impact of climate change on Malta. The primary goals were:

to identify local socio-economic issues that are likely to be affected by global climate change;

to quantify, were possible, the extent of the impacts;

to make recommendations on the implementation of preventive and remedial measures that would combat the adverse effects of the predicted changes;

to make recommendations for improving co-operation with international organisations in monitoring the diverse changes; and,

to train, educate and make the public aware of the implications of climate change.

In line with IPCC's prediction, the study assumes that by the year 2100 a global change in climate would bring about a rise in the mean surface air temperature of 4.3 ° C and a rise in sea level of between 0.35 and 1.0 meters with a best estimate of 65 cm. These scenarios of global changes were applied to the Central Mediterranean and further scenarios of changes in the local climate were made. These scenarios constitute the core of this study. The effects on the atmosphere, lithosphere, hydrosphere and biological and human environments were then assessed by a selection of governmental and academic scholars. UNEP has, from the outset, provided invaluable assistance, advice and expertise without which the study would not have been accomplished.

This report advocates the need for urgent action if the adverse effects in certain areas are to be minimized or avoided. The uncertainties concerning the precise interaction of global climate changes on a particular locality are nevertheless great and it is within this context that the study attempts to point to issues that at first glance would appear to be threatened by climatic changes. It is hoped that this study will serve as a precursor to more specific assessments and analyses that will be conducted in the future as more reliable predictions become available.

Special thanks go to UNEP, and in particular MAP and Messrs Jeftic, Pernetta and Keckes for their sustained support in the preparation of this work.

David J. Attard
Co-ordinator

EXECUTIVE SUMMARY

A study carried out by the Climatic Research Unit of the University of East Anglia "The Temperature and Precipitation Scenarios for the Malta Region" suggests that annual temperature will increase by 0.8 to 0.9 ° C per degree Celsius of global change and that there will be little if any change in the annual rainfall amounts around Malta.

An analysis carried out on the meteorological data from Malta indicates a trend towards increasing extremes of temperature; namely an increase in the maximum and a decrease in the minimum temperature. In addition the mean annual temperature also shows an apparent increase. These data also suggest a trend towards lower annual total rainfall; an increase in the atmospheric pressure; and an increase in the number of days with thunderstorms. A decrease in cloud cover and in the number of hours of bright sunshine is also evident from these data.

These trends might suggest that a process of desertification is already in action on Malta. One could also deduce from existing trends that there is an increase in the number of suspended particles including pollutants, in the atmosphere over the island. These observations could be some of the results of ongoing climate change in the Central Mediterranean.

The only component of the local hydrosphere that will be significantly affected by global warming is the hydrological cycle. This determines the input and output of water in a particular locality and is largely controlled by local climate and catchment characteristics. In Malta natural sources of supply account for about 37% of all potable water in the public supply and for 84% of all irrigation water. Global warming affects the hydrological cycle in two ways; firstly through changes to relative sea level; and, secondly through changes in rainfall and evapotranspiration. An eustatic rise in sea level of around 65 +/- 35 cm by the year 2100 will adversely affect the existing extraction rates from Malta's principal aquifer making it more vulnerable to sea water intrusion. In contrast the direct climatic effect will be less pronounced, since only a small change in local precipitation is predicted to accompany global warming.

Climate is a fundamental factor influencing the nature of the soils of Malta. Consequently a change in climate will have a bearing on the pedosphere. Since an increase in temperature with little or no change in the rainfall totals is anticipated; evapotranspiration will increase, leading to an increase in aridity, and to soil degradation mainly due to salinization and alkalinization.

The effects of climatic changes on the Maltese islands, namely an increase in temperature; a shift in precipitation patterns; a decrease in water availability; and, a rise in sea-level, will have a strongly negative effect on agriculture and will change the quality of the vegetation and associated fauna, favouring an increase in xerophilic, thermophilic and halophilic species. These species would be mainly introduced, thriving at the expense of native species. It is predicted that the character of the vegetation will change from that typical of Mediterranean coastal lowlands, to associations typical of deserts.

This shift would also be favoured by factors such as soil erosion; increased soil salinity; and, increased exposure. Remedial action at a local level could include measures to prevent soil erosion by gradually changing to crops and trees which stabilise soils and which tolerate the new climatic conditions. A change in temperature could possibly lead to an increase in agricultural pests, whilst sea-level rise may cause inundation of low-lying agricultural land such as that at Pwales and of groves such as those at Salina Bay.

The impacts on fisheries may be less dramatic but changes in migration patterns of important fish such as lampuki; and the potentially adverse effects which competitive thermophilic seaweeds may have on the important *Posidonia* meadows may be of concern in the future. The effects on aquaculture are difficult to assess but may include an increase in pathogens. The control of pollutants and protection of the *Posidonia* meadows are recommended as well as sustainable use of fisheries resources.

The present coastal, near shore and freshwater ecosystems are threatened by a number of man-induced, non-climatic changes. Any additional impacts on these ecosystems resulting from climatic changes will have to be assessed in the light of such non-climatic effects, if the overall assessment of future impacts is to be accurate. Climatic change impacts, although difficult to predict are likely to occur in near-shore communities. Increased eutrophic conditions and increased water stratification are likely to occur in certain localities already influenced by other non-climatic human activities.

Coastal sandy beaches, sand dunes and saline marsh habitats are considered to be sensitive to predicted climate change impacts, through increased erosion, enhanced shoreline recession and increased environmental fluctuations. The extent of impacts on such habitats, under less severe climatic change scenarios, will largely depend on present and future land-use management practices.

Non-linear biological responses to climatic changes are discussed and may prove to be quite significant but equally difficult to predict, given our present state of knowledge.

According to the findings of the IPCC it is predicted that a global eustatic rise in sea level of 65+/-35 cm may occur by the year 2100. This would disrupt population and settlement patterns, as adjustments to the new conditions and land availability occur. Given the coastal topography, present drainage patterns and negligible land movement in Malta, the predicted rise in sea-level will have no impact on population growth and only a slight impact on the over all settlement pattern. Some settlements along the coast and especially those in the main drainage basins will become more susceptible to flooding and anticipatory action will be needed to address the consequential economic and social disruption. Disruption of coastal settlements is expected to occur as a result of temporary tidal and storm surges rather than as a result of permanent inundation.

Malta, because of its favourable climate, has often been considered an ideal place for the convalescence of invalids, particularly those suffering from chronic respiratory disorders. A change in climate would therefore have negative effects on the islands suitability for this purpose.

As a rise in sea-level may cause sewage systems to flood, new systems may have to be developed to reduce public health risks from such a hazard. Flooding of the sewerage system could increase the risks of epidemics of enteric disorders including typhoid fever. Salt water intrusion into aquifers would have a negative effect on human health through a reduction in the quantity and quality of potable water resources. Temperature rise would seriously impact human health and an increased frequency of higher temperatures, especially when combined with spells of high humidity, will put some population groups at risk from heat stress. Both the elderly and infants are particularly vulnerable during heat waves and the number of deaths is known to be high during such conditions.

Diseases presently confined to the tropics may spread to higher latitudes as global temperatures rise. Tropical and sub-tropical vector borne diseases may become more widespread, partly because vector survival will increase at higher latitudes and partly because the parasites may be able to complete their life-cycle more easily. Malaria may reappear in Europe, whilst Leishmaniasis, which has been under control in the recent past, seems already to be on the increase. This may be the result of recent increases in temperature and humidity.

Increased exposure to the sun during leisure time when combined with possible ozone layer depletion is a growing cause for concern. Accurate predictions of future consequences for human health are difficult to make but it is reasonable to suggest that a further rise in the incidence of both melanomas and non-melanotic skin cancer will be among the first biological effects seen with the ozone depletion. Exposure to increased ultra-violet radiation is expected to cause damage to the cornea and lens and an increased incidence of cataracts.

The effects of UV B radiation on the human immune system is far less well understood, but such effects have been noted in animal experiments. It is a well accepted fact however, that UV-light possibly acting through DNA damage, is an important precipitating factor of the auto-immune condition, systemic lupus erythematosus.

The tourist industry has for many years been one of the Islands' most important economic activities. 5.8% of the total working population, that is around 7,609 people, are employed full-time in hotels, tourist complexes and catering establishments. The percentage would be higher if one were to include those employed in tourism-related services. Although the island offers places of cultural and historic interest it has always attracted tourists mainly for the sun and the sea. If the climate conditions of the Maltese Islands change, the tourist industry could suffer, causing severe disruption to the Maltese economy and hardship to the population.

Sea-level rise will certainly have an impact on this site-dependent and coastal industry. Sandy beaches, already scarce on the island are the most vulnerable, due to increased erosion and inundation. The lack of potable water, already a problem in the hot summer months, at the height of the tourist season, will become worse.

The tourist industry is by its very nature, fragile and susceptible to political, economic and social upheaval. Climate change will add another element of uncertainty to this sector.

Transport in Malta depends entirely on roads whilst a ferry service connects the islands of Malta, Gozo and Comino and is also used around the Grand Harbour area. Road traffic would suffer in the event of flooding of the main traffic arteries as a result of severe storms, which will probably increase along with the anticipated increase in autumn precipitation. Being an island, Malta is entirely dependent on maritime and air links with the outside world, and provision of such services is another important sector of the Maltese economy generating foreign exchange earnings from tourist visitors. The maritime sector would certainly suffer if storms and gales increased, which would disrupt ferry and helicopter services, the only means of communication between the three islands. Increased storm frequency and intensity could cause damage to breakwaters and wharfs which are essential to the ship repair and ship building industry on the island. Air travel on the other hand would benefit if there was a decrease in the number of foggy days and in the amount of cloud cover, as a result of an increase in anticyclonic conditions.

Changes in climate are expected to have an effect on the patterns of energy demand to heat and cool buildings. Electricity generation which accounts for almost two thirds of primary energy consumption has grown on average by about 8.5% per year in recent years. Continuing economic development, essential for an economy in transition such as that of the Maltese Islands, appears likely to sustain the high growth in demand for electricity at least over the next decade. Future increases in energy demand by the end user could be offset by increasing the efficiency of energy conversion and eliminating waste.

Meteorological records for the past seventy years indicate a decrease in the number of bright sunshine hours in Malta. This could result in a decrease in available natural daylight levels which in turn would increase the use of artificial electric light.

The predicted average temperature increases would, theoretically reduce the need to provide heating, thereby saving energy. Given the low thermal performance of Maltese buildings an increase in ambient temperature may merely result in a more thermally comfortable interior, rather than saving of energy. In the commercial and industrial sectors, the internal heat generated by the use of machinery is high and an increase in ambient temperature may result in a need for cooling through increased ventilation and possibly an extension of the air conditioning season. The introduction of thermal insulation to the building envelope, would reduce both the heating demand in winter as well as the cooling demand in summer.

The displacement of fossil fuels by renewable energy sources particularly biomass and hydro power would reduce carbon dioxide emissions. In Malta there is good potential for development of solar energy, although land availability is a major obstacle. There is less possibility of harnessing wind energy on a large scale although wind energy is already widely used for water pumping in agriculture.

1. INTRODUCTION

1.1. Background to the Study

The greenhouse effect is among man's potentially most pressing long-term environmental problems, and one which presents major scientific challenges spanning a wide range of disciplines. Changes in global climate between now and the middle of the twenty first century are virtually certain and are likely to be dominated by the influence of global warming due to increasing concentrations of carbon dioxide and other "greenhouse gases" in the atmosphere. These greenhouse gases individually and collectively change the radiative balance of the atmosphere, trapping more heat near the earth's surface and causing a rise in global mean surface air temperature.

The Second World Climate Conference held in Geneva, 29 October - 7 November 1990 (Jager and Ferguson, 1991) concluded that without actions to reduce emissions, global warming may reach 2 to 5 °C over the next century, a rate of change unprecedented in the past 10,000 years. This warming is expected to be accompanied by a sea level rise of 65 cm ± 35 cm by the end of the next century. There remain uncertainties in predictions, particularly in regard to the timing, magnitude and regional patterns of climatic change, as well as in the numerous secondary impacts of this warming and sea level rise. In spite of these uncertainties, greenhouse gases seem to have accumulated in the atmosphere to such a level that the changes may already have started and their continuation may now be inevitable.

Scientific observations and analyses show that temperature is rising worldwide. Data from the Goddard Institute of Space Studies of the US National Aeronautics and Space Administration show an average increase of around 0.25 °C in the sixty years between 1880 and 1940, a decrease of 0.2 °C between 1940 and 1970 a further rise of 0.3 °C between 1970 and 1980. This increase continued in the 1980s with 1987 being the warmest year since reliable records began in 1850; 1990 and 1991 being among the warmest years in the combined land/ocean temperature record; and, the 1980s being the warmest decade. These figures are averaged over the whole globe. In certain areas of the earth, the increase in temperature is greater than the above figures while in other areas temperatures have declined.

This overall increase in temperature will definitely have an effect on the climate in different areas of the earth. A change in climate will in turn have an impact on the national economies and ways of life of peoples all over the world. Some countries will be adversely affected, others may benefit.

What will be the impacts of future climate change on the various sectors of the Maltese economy? How will an increase in temperature and a decrease in rainfall affect agricultural production? What will be the effect of a temperature increase on the tourist industry in Malta? How will an increase in sea surface temperature affect the local fishing industry? What will be the effect on the water resources of the Maltese Islands of a temperature increase and a decrease in rainfall? How will temperature extremes affect the energy sector and the production of electricity? How will the harbours, the beaches and the yacht marinas be affected by the predicted rise in sea level around the islands? What will be the effect of the change in climate on the health of the local population? These are some of the questions, amongst others, which need to be answered in order that effective steps may be taken to mitigate the adverse effects, of impending changes.

1.2. Background to the Island of Malta

1.2.1. The physical environment

The Maltese archipelago consists of the Islands of Malta, Gozo and Comino and two other uninhabited islands. This island group is situated roughly in the centre of the Mediterranean Sea between 36° 00' 00" and 35° 48' 00" North. The distance separating Malta from the nearest point in Sicily is 97 km and from the nearest point on the North African mainland, 290 km. The total area of the Maltese Islands is 316 km^2 of which Malta itself comprises 245.7 km^2 and Gozo 67 km^2. Along its long axis Malta extends to a maximum 27 km and is 14.5 km at its widest point. The Maltese Islands lie on the eastern edge of the North African continental shelf which extends from the Tunisian coast in the west, to the Ionian Sea in the east and from the Libyan coast in the south, to Sicily in the north.

Geologically the islands are composed almost entirely of marine sedimentary rocks, mainly limestones of Oligocene-Miocene age, capped by minor quaternary deposits of terrestrial origin. The main rock types in order of decreasing age are:

- Lower Coralline Limestone;
- Globigerina Limestone;
- Blue Clay;
- Green Sand; and
- Upper Coralline Limestone.

Erosion of each of these rock types results in a different characteristic topography. Lower coralline limestone forms sheer cliffs which bound the islands to the west. Inland, this rock type forms plateaux consisting of a barren grey limestone pavement, on which karst landscapes develop. The globigerina limestone on extensive exposed faces develops 45 degree talus scree over the underlying rock. The upper coralline limestone forms cliffs and limestone pavements, with topography similar to that of the lower coralline limestone.

Maltese soils are characterised by their close similarity to the parent rock material, their relatively young age, the low influence of the climate in producing mature soils and the dominant influence of human activities in modifying them.

There are two principal aquifers on the Maltese islands: the perched aquifer and mean sea-level aquifer. The perched aquifer is situated in the porous upper coralline limestone which lies directly above the impermeable blue clay formation. No salt water intrusion in the aquifer south of the Victoria line is possible since it is everywhere located well above sea level. To the north of this line however, the aquifer is in many places in contact with the sea water and intrusion is a problem. Private extraction by farmers, exploits this aquifer almost to the full, leaving only a small proportion for the public supply which comes largely from gravity springs and underground galleries.

The mean sea level aquifer is the most important and accounts for about 50% of the total public freshwater supply. The aquifer lies in the pores and cracks of the globigerina and lower coralline limestone situated around mean sea level. This freshwater body rests on a saturated zone but owes its existence to the fact that every winter the local rainfall adds more freshwater to the underground store than can be dissipated by direct discharge around the coast. There is no sharply defined plane of separation between the superficial fresh water and the saline water which is underneath. The equilibrium of this 'lens' is in a state of flux depending on the variations in rainfall, tides, extraction rates and other factors. Large areas in the central part of the island have a water table 2 - 3.5 m above mean sea level under static conditions. Sea water intrusion into this aquifer presents a permanent problem since the underlying rock is permeable and fissured. A series of gauging bore holes scattered all over the aquifer are used to monitor the lens and adjust pumping rates to minimise saline intrusion.

The climate of the Maltese islands is typically Mediterranean with a mild, wet winter invariably followed by a long dry summer. Rainfall is highly variable from year to year: some years are excessively wet, while others are extremely dry. Over the period 1854 to 1986 the extreme maxima and minima were 1,011.3 and 191.3 mm respectively. Rainfall is seasonal with a wet period from October to March, when 70% of the annual precipitation falls and a dry period from April to September. Daily mean temperatures range from around 13 ° C in winter to 25 ° C in summer. The average daily sunshine hours range from 5.1 in December and January to 11.8 in July.

Since a large proportion of the potable water of the islands is derived from rainfall, the rainfall pattern is very significant and rainfall records have been kept systematically for over one hundred years. The average annual precipitation from 1961 to 1990 is 553.3 mm and rainfall is heavy in October at the start of the rainy season.

There are no perennial surface streams in Malta and water only flows along the bed of major valleys for a few days after heavy downpours. About 6% of the total precipitation finds its way directly into the sea. The major surface drainage channels pass across the entire width of the Island from sources close to the western coast before entering the sea on the east. This gives the surface water maximum opportunity to penetrate into the underground aquifers and retards soil erosion. Field walls are also kept in good condition whenever possible, to retard soil losses. Roof catchments in towns and villages are mandatory by law, and every house has to provide a well-sealed cistern of 2 cubic feet capacity for every square foot of roof area.

1.2.2. The biological environment

In spite of the limited land area, the low habitat diversity, and the intensive human pressure on the natural environment, the islands support a rich, diverse wildlife, certain elements of which, are of particular scientific importance. There are some: 1,000 species of fresh water and terrestrial molluscs; more than 4,000 species of insects; 1 amphibian; 9 terrestrial reptiles; 13 resident, 57 regularly visiting and 112 migrant birds; and, some 21 species of mammals. A relatively large number of species of plants and animals are endemic to the Maltese Islands; at least 25 plants and 60 animals.

The main vegetational communities are:

- Maquis (scrub);
- Garrigue (low growing vegetation); and
- Steppe (dominated by grasses) .

Natural vegetation covers only about 21.3% of mainland Malta; 34.5% no longer supports vegetation cover, while around 44.1% is cultivated. The most widespread natural vegetation type is the garrigue with scrub and trees (maquis and forest areas) collectively covering only about 4% of the island area.

From an ecological point of view the coast is particularly important, because many coastal localities support habitat types which are rare elsewhere in the islands. Such habitats include sand dunes and saline marshlands. These localities are valuable as examples of their particular habitat and also, because they support specialized biota which is itself rare and some of which is endemic. The coast includes the only known localities of certain endemic species; type localities; and, important bird nesting and migratory bird feeding sites.

1.2.3. The human environment

The Maltese population is estimated at 358,623 giving an average population density of 1,094 persons km $^{-2}$. At the last Census in 1985 the enumerated population totalled 345,418, of whom, 319,736 resided in Malta, 25,652 in Gozo. This represents a rise of 12.6 % over the previous 1967 Census. The age distribution of the population has changed between the two censuses as shown in Table 1.

TABLE 1

Age distribution of the Maltese population at the 1967 and 1985 censuses

AGE GROUP	1967	1985
0 - 4	8.41	8.10
5 - 24	41.67	30.80
25 - 44	23.33	31.40
45 - 64	18.21	19.83
65 +	8.38	9.87
TOTAL	100.00	100.00

The crude birth rate stands at 15.3 per thousand population, while the crude mortality rate stands at 10.0 per thousand population. Life expectancy is estimated to be 71 years for males and 76 years for females. The net emigration, after allowing for returned migrants is marginal and the natural growth rate of the Maltese population is about 0.6% yr^{-1}. The Maltese population is expected to reach 371,000 by the year 2000.

The Real Gross Domestic Product, as represented by value added measured at constant 1975 prices, has grown on average at a rate of 7% *per annum* over the last two decades. This growth has not been constant and following a recession in the early nineteen seventies, the average annual rate for the 1973-1982 period was just under 9 percent, slowing to half that over the period 1982-1988. During the last three years the economy has again seen average growth rates of over 7 per cent. The GNP *per capita* reached US$5,483 in 1991.

1.3. Methodology and Assumptions Used in the Study

1.3.1. The IPCC scientific assessment

In the Executive Summary of the IPCC Working Group I final report issued in 1990, it is stated that:

(a) there is a natural greenhouse effect which already keeps the earth warmer than it would otherwise be; and,

(b) emissions resulting from human activities are substantially increasing the atmospheric concentration of the greenhouse gases, carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the natural greenhouse effect, resulting on average in additional warming of the earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

Based on current model results, the group predicted that:

(a) under the IPCC Business-as-Usual scenario for emissions of greenhouse gases (Scenario A) a rate of increase of global mean temperature of about 0.3 °C per decade (with an uncertainty range of 0.2 to 0.5 °C per decade) is anticipated during the next century; this is greater than any increase seen over the past 10,000 years; this rate will result in a likely increase in global mean temperature of about 1 °C above the present value by 2025; and 3 °C before the end of the next century;

(b) under the other IPCC emission scenarios which assume progressively increasing levels of controls, rates of increase in global mean temperature of: about 0.2 °C per decade (Scenario B); just above 0.1 °C per decade (Scenario C); and, about 0.1 °C per decade (Scenario D) will occur;

(c) that land surfaces warm more rapidly than the ocean and high northern latitudes warm more than the global mean in winter;

(d) regional climate changes are different from the global mean; increases in southern Europe and central North America are predicted to be higher than the global mean and to be accompanied on average by reduced summer precipitation and soil moisture; the warming would be about 2 °C in winter and 2 - 3 °C in summer; precipitation would increase in winter and decrease in summer (by 5-15%); soil moisture should decrease by 15 to 25% in summer; and,

(e) under the IPCC Business-as-Usual emissions scenario, an average rate of global mean sea level rise of about 6 cm per decade (with an uncertainty range of 3 to 10 cm per decade) mainly due to thermal expansion of the oceans and the melting of some land ice will occur, resulting in a predicted rise of about 20 cm in global mean sea level by 2030 and 65 cm by the end of the next century. It is expected that there will be significant regional variations.

The Group also maintained that there were many uncertainties in their predictions particularly with regard to the timing, magnitude and regional patterns of climate change, due to their incomplete understanding of:

(a) sources and sinks of greenhouse gases, which affect predictions of future concentrations;

(b) clouds which strongly influence the magnitude of climate change;

(c) oceans, which influence the timing and patterns of climate change; and,

(d) polar ice sheets which affect predictions of sea level rise.

The working group concluded by stating that the complexity of the system may give rise to surprises.

1.3.2. Regional and sub-regional climate scenarios

Kim *et al.* (1984) examined the statistical relationship between local and large-scale, regionally-averaged values of two meteorological variables: temperature and precipitation. They then used these relationships, developed using principal component analysis techniques; to look at the response of local temperature and precipitation to the predicted change at GCM grid points. The area of study used by Kim *et al.* (1984) was Oregon State (U.S.A.) and although this paper contains certain statistical flaws, the underlying idea of statistically relating local and large-scale data is sound. The method of Kim *et al.* (1984) has been extended and refined by Wilks (1989) and Wigley *et al.* (1990).

Guo *et al.* (1991) have modified the methods of Kim *et al.* (1984) and Wigley *et al.* (1990) for application in the Mediterranean region. In the model validation exercise carried out for the Mediterranean project (Palutikof *et al.*, 1992) it was established that no single GCM can be identified as being always the best at simulating current climate. This being the case, there is little merit in presenting scenarios based on only one model. Presentation of scenarios for each of the four models avoids this problem, since the task of deciding which model is "best", and/or of synthesizing the information to obtain a best estimate, is left to the impact analyst. Information from the four models has been combined into a single scenario for each variable, according to the method described below.

The problem with presenting the scenarios in this form is that resulting scenarios may be biased by the different equilibrium responses of the individual models. The global warming due to a doubling of CO_2 for the four GCMs, ranges from between 2.8 °C for the OSU model to 5.2 °C for the UKMO model run. We would therefore expect that the warming indicated by the UKMO GCM for the Mediterranean Basin would be greater than that suggested by the OSU model, even though the sensitivity of the region to climate change when compared to the global sensitivity might be the same. The individual model perturbations have therefore been standardized by the equilibrium (global annual) temperature change for that model prior to the calculation of the four-model average.

A generalized computer program was needed that would be applicable throughout this geographically complex area and could be used with meteorological records of variable length and density. After investigating a number of approaches to the problem, Guo *et al.* (1991) the procedure summarized below was adopted:

1. data sets of monthly mean temperature and total precipitation have been compiled for the area surrounding the Mediterranean Basin. Stations used in this study of the north-eastern Mediterranean are listed in Palutikof *et al.* (1992). Where possible, each record should be complete for the period 1951-88. Any station with a record length less than 20 years in the period 1951-88 for over six months out of twelve was immediately discarded;

2. then, for every valid station, the temperature and precipitation anomalies from the long-term (1951-88) mean were calculated. For this part of the work, which is the first step in the construction of the regression equations (the calibration stage), only the data for 1951-80 were used. The 1981-88 data were retained to test the performance of the regression models (the verification stage (Palutikof *et al.*, 1992). For the calculation of the temperature anomaly At_{ij}, the simple difference was used:

$$At_{ij} = t_{ij} - T_j$$

where t_{ij} is the mean temperature of month j in year i; and T_j is the long-term mean for month j. The precipitation anomaly Ap_{ij} was expressed as a ratio of the long-term mean:

$$Ap_{ij} = (P_{ij} - P_j)/P_j$$

where P_{ij} is the monthly total precipitation in month j of year i; and P_j is the long-term mean for that month. If P_j is less than 1 mm, then this equation is modified to:

$$Ap_{ij} = (P_{ij} - P_j)/1.0$$

3. the individual station anomalies are used to calculate regionally-averaged anomalies.

The procedures used by the Climatic Research Unit of the University of East Anglia, to develop regional and sub-regional scenarios of future climate are described in detail in Palutikof *et al.* (1992). In order to develop these procedures, a vigorous investigation of the validity of the method has been carried out. In particular, Guo *et al.* (1991) have looked at:

- the use of other predictor variables in the regression equations;
- performance and verification of the regression equations;
- auto-correlation in the data; and,
- multicolinearity in the predictor variables.

These aspects are discussed in detail in the University of East Anglia Final Report (Palutikof *et al.*, 1992) which justifies the approach, and also presents sub-grid-scale scenarios for the Mediterranean Basin, constructed according to the method outlined. The temperature perturbations are presented as the model average change, in degrees Celsius, per °C global annual change. The precipitation perturbations are given as the percentage change for each 1 °C global annual change. The resultant values for Malta are provided in Table 2.

TABLE 2

Scenarios of future climate in Malta deduced from scenarios suggested by IPCC and the University of East Anglia

SCENARIOS	TIME HORIZON		
	2030	2050	2100
IPCC GLOBAL			
Temperature	+1.8°C	-	+2 to +5°C
Sea level	+ 18 cm +/- 12 cm	-	+ 65 cm +/- 35 cm
IPCC Southern Europe			
Temperature	+2°C winter +2 to + 3°C summer	-	-
Rainfall	+ 0 to + 10% winter - 5 to + 15% summer	-	-
Soil moisture	- 15 to - 25% summer	-	-
Univ. East Anglia Med.			
Rainfall	for each °C Global + 3% winter - 3% summer		
UNEP Task Teams			
Temperature	-	+ 1.5 to + 3°C	-
Sea level	-	+ 38 +/- 14 cm	-
Univ. East Anglia for Malta	for each °C Global + 0.8 to + 0.9°C	for each °C Global + 0.8 to + 0.9°C	for each °C Global + 0.8 to + 0.9°C
Rainfall* Annual	no change	no change	no change
Winter	- 9%	- 9%	- 9%
Spring	- 15 to - 12%	- 15 to - 12%	- 15 to - 12%
Summer	no prediction	no prediction	no prediction
Autumn	+ 14%	+ 14%	+ 14%
Operative Scenarios for Malta			
Temperature	+ 1.4 to + 1.6°C	+ 1.8 to + 2.0°C	+ 2.8 to 3.2°C
Sea level	+ 18 +/- 12 cm	+ 38 +/- 14 cm	+ 65 +/- 35 cm
Rainfall* Annual	no change	no change	no change
Winter	- 16.2%	-20 3%	- 31.5%
Spring	- 27 to - 21.6%	- 33.8 to - 27%	- 52.5 to - 42%
Summer	no change	no change	no change
Autumn	+ 25.2%	+ 31.5%	+ 49%

* Percentage change in rainfall should be related to present values.

The problem with expressing the scenarios in this form is then to scale the values up (or down) in relation to some realistic estimate of the temperature perturbation to be expected from the greenhouse effect. The IPCC Report (Houghton *et al.*, 1990) provides one such family of estimates. For their Business-as-Usual scenario of emissions, the likely increase in global mean temperature by the year 2050 is predicted to be about 1 °C above the present level. By the end of the next century, the increase is estimated at 3 °C above present-day. On this basis, the temperature and precipitation scenarios for Malta can be related directly to changes between now and the year 2050.

Annual and seasonal scenarios for both temperature and precipitation change were produced for the Mediterranean region. For temperature, the greatest sensitivity to the greenhouse effect was found in the mainland areas to the northeast. Temperature increases less than the global mean temperature change were indicated for the southwest of the region. The scenarios for precipitation are much more difficult to evaluate. At the annual level, precipitation is shown to increase in the west and east, and to increase in the southeast, by up to 6% per °C global temperature change. The problems associated with the construction of regional scenarios of precipitation change associated with the greenhouse effect are discussed at length in the Final Report for the UNEP Mediterranean Project (Palutikof *et al.*, 1992). The confidence that can be placed in sub-grid-scale scenarios of precipitation is low.

2. IDENTIFICATION AND ASSESSMENT OF THE POSSIBLE CONSEQUENCES OF CLIMATIC CHANGES

2.1. Climate Conditions

2.1.1. Analysis of past meteorological data for Malta

2.1.1.1. Temperature

The Meteorological Office started making weather observations in 1922 at Gwardamangia. In 1927 the Office was moved to St. John's Cavalier in Valletta and in 1947 it was moved to Luqa. Only the temperature records from 1927 to 1988 are taken into consideration in the following analysis since there is no overlap of records for both Gwardamangia and Luqa. On the other hand, temperature was recorded simultaneously in Valletta and Luqa for a period of five months from January to May 1947. Figures 1 and 2 present data from Luqa for the period 1947-1988 in the form of 10 year running means while Figures 3 and 4 present maximum and minimum mean annual temperatures for the period from 1947 to 1990. A low-pass filter (the Binomial Coefficient method) was used to smooth out fluctuations in the temperature data (Figures 1 and 2). The same low-pass filter was also used to smooth out fluctuations in some of the rainfall data.

The graphs derived by plotting records for maximum and minimum temperatures at Luqa against those from Valletta indicate that the maximum temperature at Luqa is higher than that at Valletta and in contrast the minimum temperature at Luqa is lower than that at Valletta. This conclusion is both plausible and acceptable because Luqa is an inland station and Valletta a coastal one. Regression equations were derived and the observations of Valletta maximum and minimum temperature (T_{max}, T_{min}, respectively) amended by using the following regression equations:-

$$\text{Luqa } T_{max}\,^{\circ}C = \{(\text{Valletta } T_{max}\,^{\circ}C) \times 1.0329\} - 0.1361$$

$$\text{Luqa } T_{min}\,^{\circ}C = \{(\text{Valletta } T_{min}\,^{\circ}C) \times 1.0395\} - 1.5322$$

This allows the 20 years of temperature records from Valletta to be added to the 42 years available for Luqa.

Another series of graphs (Figures 5 to 10) were derived by using the temperature observations made at the University of Malta in Valletta from 1865 to 1953. Seven years of simultaneous temperature observations are available for both the University station in Valletta and Luqa, the Valletta temperature series can therefore be extended by amendment of the Luqa temperatures using the following regression equation:

$$\text{Valletta Temp. } ^{\circ}C = (\text{Luqa Temp. } ^{\circ}C \times 0.96333) + 1.1852$$

thereby adding nearly 36 years of data to the Valletta long term temperature series.

2.1.1.2. Precipitation

Measurements of rainfall began in 1840, and for only very brief periods during the past 150 years or so is there no acceptable record from the Valletta locality. The rainfall records for the Valletta region were added to those of Luqa because of the length of the records, 150 years, as opposed to 42 years from the Luqa station. This analysis uses the standard series for Valletta as prepared by P.K. Mitchell (October 1963) who used rainfall totals corresponding to the natural break of the seasons. Consequently the annual cycle commences in August and ends in July. For the period 1962 to 1988 the rainfall records of the Argotti Gardens in Floriana were used to extend the records of Mitchell to 1988. Figures 11 and 12 show the plots of 10 and 20 year running means for Valletta.

In the calculation of the 5 and 10 year running means for Luqa, calendar year totals have been used (Figures 13 and 14). The 10 year running means for the days with precipitation equal to or greater than 2, 1, 0.1, 10 and 50 mm (Figures 15 - 19) are based on data available from Luqa covering the period 1951 to 1990. Similar records for Valletta are not available.

A further series of graphs (Figures 20 - 25) were derived from the Mitchell series, the Argotti readings in Floriana, and the Luqa readings (from 1980 to 1990). The year was divided into two six month blocks (Figures 20 and 21) or four seasons (Figures 22 - 25) representing spring, March, April and May; summer, June, July and August; autumn, September, October and November; and winter, December, January and February, respectively.

2.1.1.3. Other meteorological parameters

Atmospheric pressure readings taken by the Meteorological Office at Gwardamangia, Valletta and Luqa were used in this analysis. The pressure readings were all reduced to mean sea level by using standard procedures. Since all pressure readings have been reduced to a standard level, the difference in localities should not affect the homogeneity of the records. Consequently the 10 year and 20 year moving means (Figures 26 and 27) were derived from available Meteorological Office records from 1923 to 1990.

The hours of bright sunshine for the years 1928 to 1990 have been recorded regularly at Valletta and at Luqa by means of a Campbell-Stokes recorder. This instrument focuses the heat radiation from the sun to burn a trace on a specially treated card used specifically with this instrument.

The mean yearly values for the number of hours of bright sunshine for Valletta from 1928 to 1946 together with those for Luqa from 1947 to 1988 were used to derive the 10 year running means plotted in Figure 28.

Cloud cover is observed every half hour and is measured in octas (eighths). The values used in this analysis are those for three-hourly synoptic observations of cloud cover made at Luqa at 00, 03, 06, 09, 12, 15, 18 and 21 UTC (Co-ordinated Universal Time). The Luqa mean monthly values for the years 1951 to 1990 were used to derive the 10 year means plotted in Figure 29.

Wet and dry bulb temperature readings are taken every half-hour and the vapour pressure is determined from these two parameters every three hours to derive three-hourly synoptic observations, as for cloud cover. The Valletta readings from 1928 to 1946 were added to the Luqa values (1947-1990) to derive the 10 year moving means plotted in Figure 30.

The data used to plot the graphs shown in Figures 31, 32, 33 and 34 all refer to the observations made at Luqa Airport during the period 1947 to 1990.

The maximum rainfall recorded in a 24 hour period in each year from 1922 to 1990 is shown in Figure 35. These observations, include those taken at Gwardamangia and at Valletta in addition to those from Luqa.

The mean monthly wind speed from 1959 to 1990 was used to derive the mean for each year (Figure 36). The observations were taken at a height of 10 metres at Luqa Airport, using a cup anemometer (Munro type).

2.1.2. Past variability and trends

Climate data may be subject to temporal variations or oscillations due to changing environmental conditions or random processes. The trends are often hidden in the rather large inter-annual variations which occur in meteorological data series. However, a number of statistical techniques have been employed to detect long-term changes and to smooth out short-term irregularities.

A frequently used method of smoothing out the short term fluctuations from meteorological time series is to use some type of weighted mean. The commonest is the running or moving mean. Any method of analyzing a time series may itself introduce spurious cycles which must be distinguished from those which have physical validity. The practice of using overlapping means derived from a series of completely random numbers may produce sine curves so that it is not clear whether the features of the smoothed curve are due to a physical phenomenon or the analytical process. Generally, a much more rigorous analysis is necessary (Thom, 1958). However, in this study, the running or moving mean method of analysis was applied to the data, since the objective was to detect trends rather than cycles.

All the parameters that have been analyzed show cycles when the 5, 10 or 15 year running means were plotted against time. However, the graphs also indicate the existence of some trends indicated by the regression line plotted on each graph. The maximum temperature (Figure 2) has a positive gradient, indicating a trend towards higher mean monthly maximum temperatures. In contrast, the minimum temperature (Figure 1) has a negative gradient, suggesting a decrease in the mean monthly minimum temperature.

The monthly maximum temperature at Luqa from 1980 to 1990 has shown an increase in the months of January, April, June, July, August, September, October and November whilst the monthly minimum temperature at Luqa over the same period has decreased in the months of January, March and July. The highest ever mean sea level pressure of 1040.9 hPa was recorded on the 2nd of January 1992.

Figures 9 and 10 covering the period 1865 to 1990 show an increase in the annual mean temperature for Malta. Similar trends appear in Figures 5, 6 and 8 which illustrate mean monthly temperatures in summer, spring, and winter respectively. This trend is most marked in summer. Surprisingly enough, the autumn curve (Figure 7) shows a decrease in temperature of about 0.5 °C over the 136 year period. All the figures with the exception of that illustrating the winter period show an increase in temperature from 1980 onwards. The highest temperature recorded each year at Luqa (Figure 3) shows a marked increase in the last 10 to 12 years.

All but two of the rainfall curves for Luqa and Valletta based on 5, 10 and 20 year running means have a negative trend. Surprisingly, the summer rainfall curve from 1865 to 1990 shows a positive trend whilst the autumn curve shows no trend. Overall we can conclude that there is a trend towards lower total annual rainfall in Malta as indicated by Figures 11, 12, 13, 14, 20 and 21.

Also interesting are the Luqa 10 year running means for the number of days with rain greater or equal to different amounts (Figures 15 - 19). Whilst the number of days with more than 0.1 and 10 mm of rain a year has apparently not changed over the period covered by the records, the number of days a year with rain greater or equal to 1, 2 and 50 mm of rain all show a decreasing trend.

Both plots of atmospheric pressure (Figures 26 and 27) indicate an increase in atmospheric pressure over the Maltese Islands suggesting a trend towards an increase in anticyclonic conditions.

The 10 year moving means of the monthly cloud amount in octas for Luqa over the period 1951 to 1990 are plotted in Figure 29. The graph shows a trend towards a decrease in the amount of cloud cover over Malta confirming the trends in rainfall, pressure and temperature. An increase in atmospheric pressure diminishes frontal activity and enhances atmospheric subsidence, both of which inhibit cloud formation. This would lead to a decrease in the average amount of cloud cover, which is borne out by the analysis discussed here.

Figure 28 which illustrates the duration of bright sunshine shows a downward trend in the number of daily sunshine hours over the period 1928 to 1990. This apparently contradicts the earlier observations concerning trends in pressure, rainfall and temperature. If anticyclonic conditions are increasing over Malta, frontal cloud should decrease and atmospheric subsidence should increase thereby resulting in an increase in the hours of sunshine. Since there is a trend towards a decrease in the amount of cloud cover, the observed decrease in bright sunshine hours is certainly not due to an increase in cloud cover, and hence another factor must be the proximate cause.

The number of days with gusts greater than 34 knots shows a downward trend from 54 per year to about 35 per year (Figure 31). This observation conforms to the fact that anticyclonic conditions and hence slack pressure gradients are becoming more frequent and that there is an increase in the atmospheric pressure in Malta (Figure 26).

The number of days with thunder shows an upward trend from about 25 to 32 per year (Figure 32). This implies that convective type rainfall is on the increase since maximum temperatures have been observed to be increasing over the last 70 years or so (Figure 2). The existence of convective rainfall implies an increase in the daily maximum rainfall, since this type of rainfall is of short duration and often heavy. Such an increase in the daily maximum rainfall between 1922 and 1990 is shown in Figure 35, notwithstanding the fact that the absolute number of days with rain greater than 1, 2 and 50 mm is decreasing (Figures 15 - 19).

Two other interesting trends are shown in Figures 33 and 34. The number of days with fog at Luqa shows a decrease from 11 to about 8 per year. This is also borne out by the fact that the vapour pressure from 1928 to 1990 (Figure 30) also shows a downward trend implying an overall decrease in the atmospheric water vapour in the Central Mediterranean area. The number of days with hail has also decreased from about 13 to around 5 or 6 a year (Figure 34). Again this could be attributed to the increase in daily maximum temperatures since thunderstorms are on the whole more frequent during the afternoon and evening when the convective process is at its maximum. The wind speed graph (Figure 26) does not show any significant long term trends.

2.1.3. Past trends and future prospects

The UNEP report No.27 "Implications of Expected Climate Changes in the Mediterranean Region: An overview" (Sestini *et al.*, 1989) suggests that an overall global warming of 0.5 °C has occurred in the past 100 years. The Maltese data for temperature and rainfall suggest that for a global warming of 0.5 °C over the last 125 years, the following changes have occurred in Malta:

mean annual rainfall has decreased by 30 mm;	- 6.0%
mean annual temperature has increased by 0.2 °C;	+ 1.0%
spring rainfall has decreased by 3 mm;	-10.0%
summer rainfall has increased by 1.3 mm;	+52.0%
autumn rainfall has decreased by 1 mm;	- 1.0%
winter rainfall has decreased by 7 mm;	- 7.0%
spring temperature has increased by 0.3 °C;	+ 1.9%
summer temperature has increased by 0.8 °C;	+ 3.3%
autumn temperature has decreased by 0.4 °C;	- 1.9%
winter temperature has increased by 0.05 °C;	+ 1.0%
April to September rainfall has decreased by 8 mm;	-10.0%
October to March rainfall has decreased by 20 mm.	- 4.4%

Over the last 70 years or so:

minimum temperature has decreased by 1.5 °C;	- 9.4%
maximum temperature has increased by 1.0 °C;	+ 4.7%
atmospheric pressure has increased by 1.5 hPa;	+10.0%
the number of hours of bright sunshine has decreased by 0.6 hours;	- 7.1%
vapour pressure has decreased by about 0.5 hPa.	- 3.1%

Over the last 40 to 45 years:

The number of hours of bright sunshine has decreased by 350 hours per year;	-11.0%
cloud cover has decreased by 0.2 octas;	- 5.9%
the number of days with thunderstorms have increased by 8;	+32.0%
the number of days with gusts > 34 knots has decreased by 20;	-36.4%
the number of days with fog has decreased by 3.5;	-30.4%
the number of days with hail has decreased by 8;	-61.5%
the maximum rainfall in a single day has increased by 15 mm;	+27.3%
the highest temperature recorded each year has increased by 1 °C;	+ 2.8%
the lowest temperature recorded each year has decreased by 0.8 °C.	-20.0%

Two studies carried out by the Climatic Research Unit of the University of East Anglia: "The Temperature and Precipitation Scenarios for the Malta Region", included in Table 2; and, "Composite Global Climate Models (GCM) Scenarios for the Mediterranean" (the sub-grid scale scenario of the climatic changes for the Central Mediterranean) indicate that between now and the year 2050:

a. Annual temperature will increase by 0.8 to 0.9 °C per degree of global change;

b. There will be little if any change in the annual rainfall amounts around Malta;

c. The summer (June, July and August) temperatures should rise by slightly more than the global average, namely 1.05 °C per degree of global change;

d. No prediction could be made for the summer precipitation;

e. The winter (December, January and February) temperature should rise by 0.9 °C per degree of global change;

f. The precipitation amount for winter should decrease by 9% per degree of global change;

g. The spring (March, April and May) temperature should rise by 0.8 °C per degree of global change;

h. The precipitation amount for spring should decrease by 13% per degree of global change;

i. The autumn (September, October and November) temperature should increase by 0.8 °C per degree of global change; and

j. The autumn precipitation should increase by 14% per degree of global change.

The confidence that the CRU places in the above precipitation scenarios is low. The General Circulation Models (GCM) scenarios for precipitation are slightly different from those indicated by the sub-grid scenarios. The GCM scenarios indicate that for a one degree Celsius global temperature change:

annual rainfall should increase by 1%;
winter rainfall should show no change;
spring rainfall should increase by 1%;
summer rainfall should show no change; and
autumn rainfall should show a 3% increase.

2.1.4. Conclusions concerning future scenarios

It is pertinent to point out at this stage that observed temperature trends over the last 100 years or so should not be compared with Global Climate Model (GCM) predictions as the observed trends do not cater for the expected increases in greenhouse gases and other forcing factors eg. methane, ozone, sulphur etc. inherent in the GCM models.

A plausible hypothesis to explain the trend towards a decrease in the hours of bright sunshine at Malta could be due to the fact that there is an increase in the density of suspended particles in the atmosphere. This increase is significant enough to affect the transparency of the atmosphere especially at low solar elevations, particularly around the times of sunrise and around sunset. An increase in the dust and smoke particles of a size comparable with, or larger than, the wavelength of light could be scattering the incoming short wave radiation from the sun as it passes through the earth's atmosphere. The increase in dust/smoke particles may be due to a number of factors which include atmospheric pollution.

The results of the analysis of the other parameters studied fit into a pattern. An increase in atmospheric pressure diminishes frontal activity, which necessarily implies less rainfall. Furthermore certain anticyclonic situations enhance subsidence thereby restricting convection and hence rainfall. Less cloud cover would increase the maximum temperature during the day and decrease the minimum temperature during the night. An increase in atmospheric pressure also implies an increase in anticyclonic conditions which in turn implies more low level inversions. These inversions trap the atmospheric pollutants which are not dispersed by the wind due to the slack pressure gradients associated with such conditions. This would necessarily increase the incidence of haze.

Extremes in the maximum and in the minimum temperatures are typical of desert regions. Trends towards these conditions in Malta lead one to conclude that a process of desertification is already occurring at the latitude of Malta. The Maltese Islands are situated on the edge of one of the largest deserts in the world namely the Sahara and present trends suggest that the area of atmospheric subsidence is shifting northwards from the Sahara, thereby enhancing a desert type of microclimate. It is pertinent to point out at this stage, that the shift in the location of deserts is one of the possible effects of the "greenhouse" mechanism that is threatening the world at large.

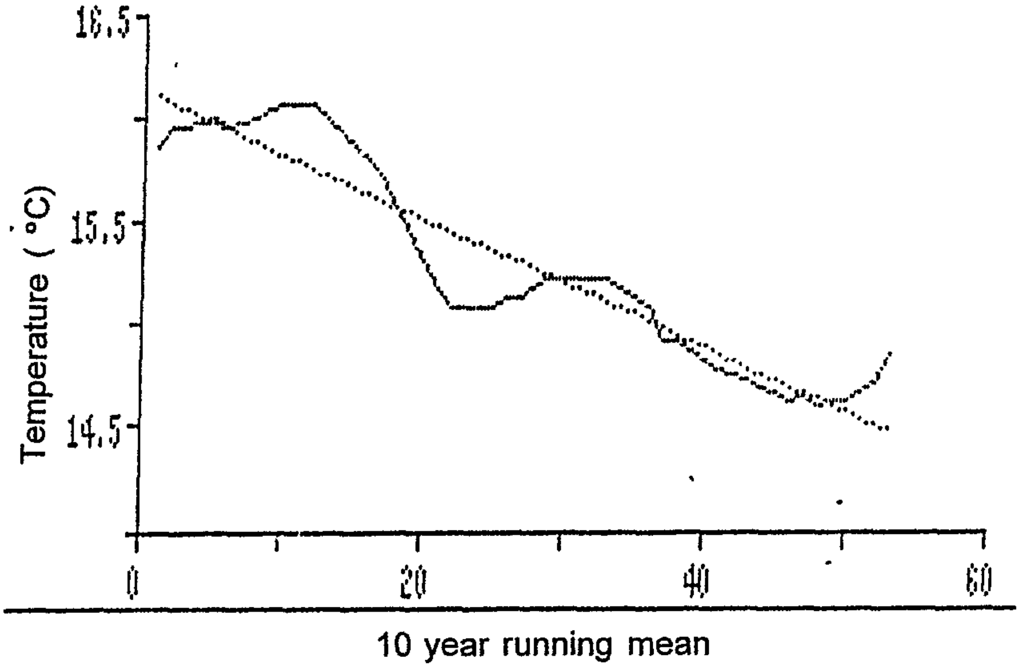

Figure 1 - Ten year running mean, minimum annual temperature (° C) at Luqa, Malta over the period 1947 to 1988, combined with adjusted data from Valletta for the period 1927 to 1947

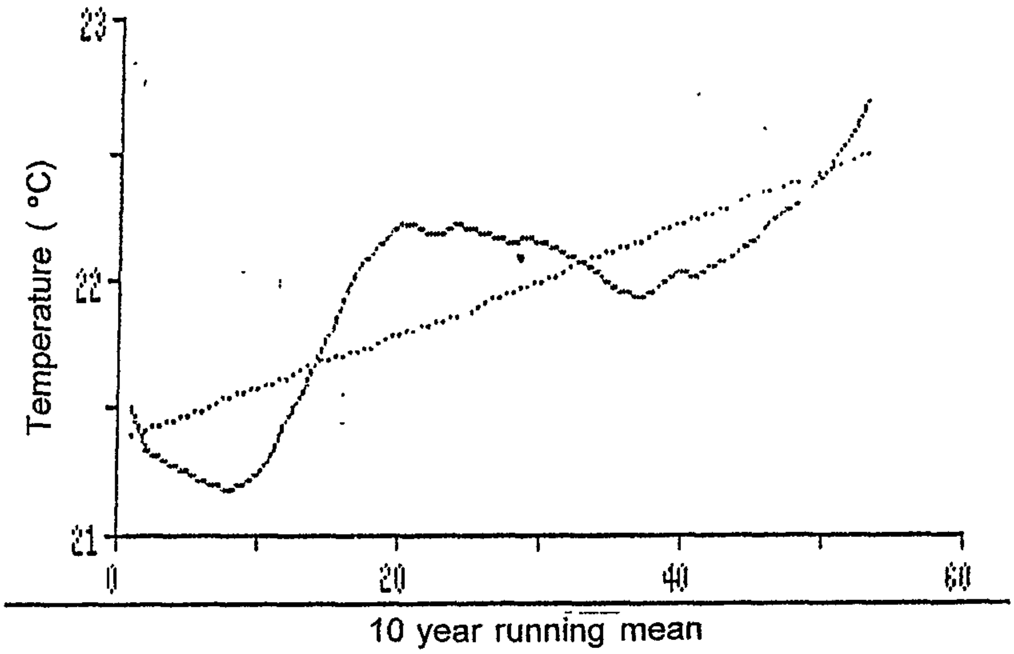

Figure 2 - Ten year running mean, maximum annual temperature (° C) at Luqa, Malta, over the period 1947 to 1988 combined with adjusted data from Valletta for the period 1927 to 1947

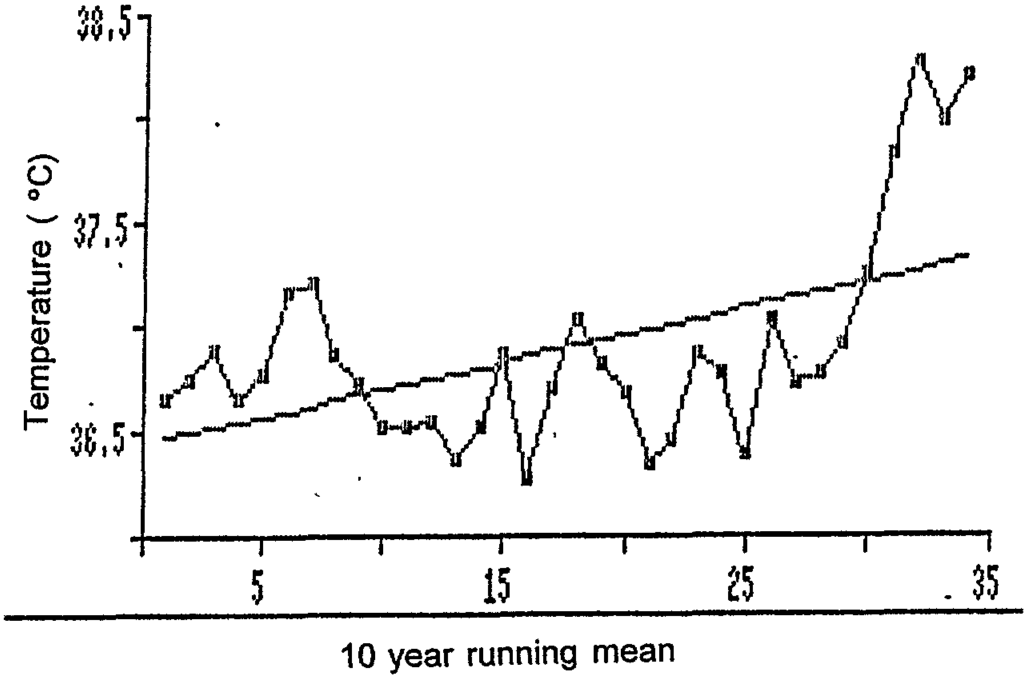

Figure 3 - Ten year running mean annual maximum temperature (° C) recorded at Luqa, Malta, during the period 1948-1990

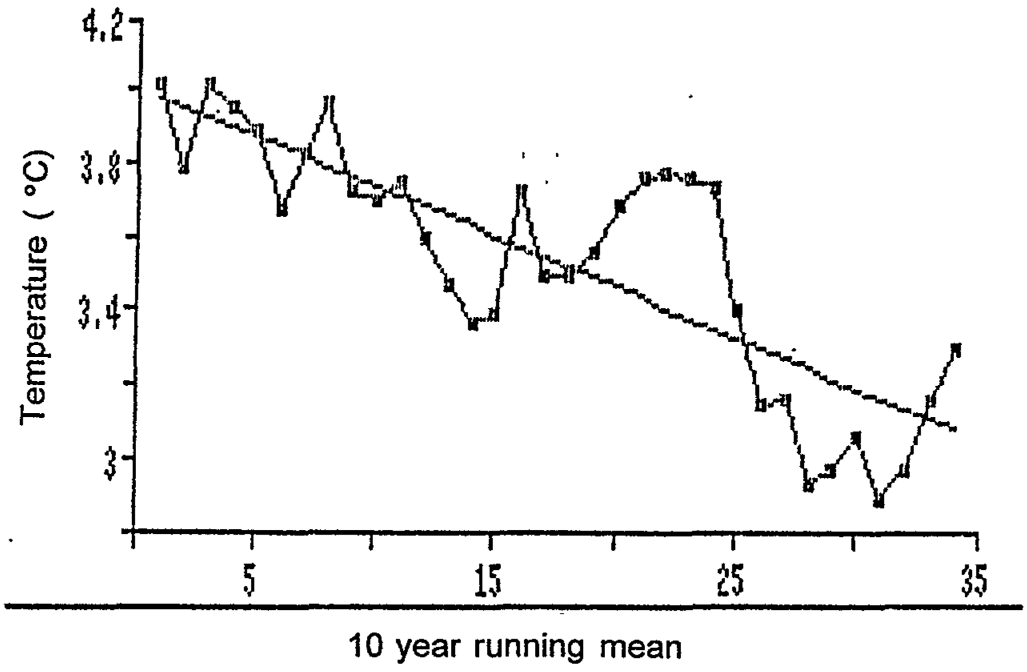

Figure 4 - Ten year running mean annual minimum temperature (° C) recorded at Luqa, Malta, during the period 1948-1990

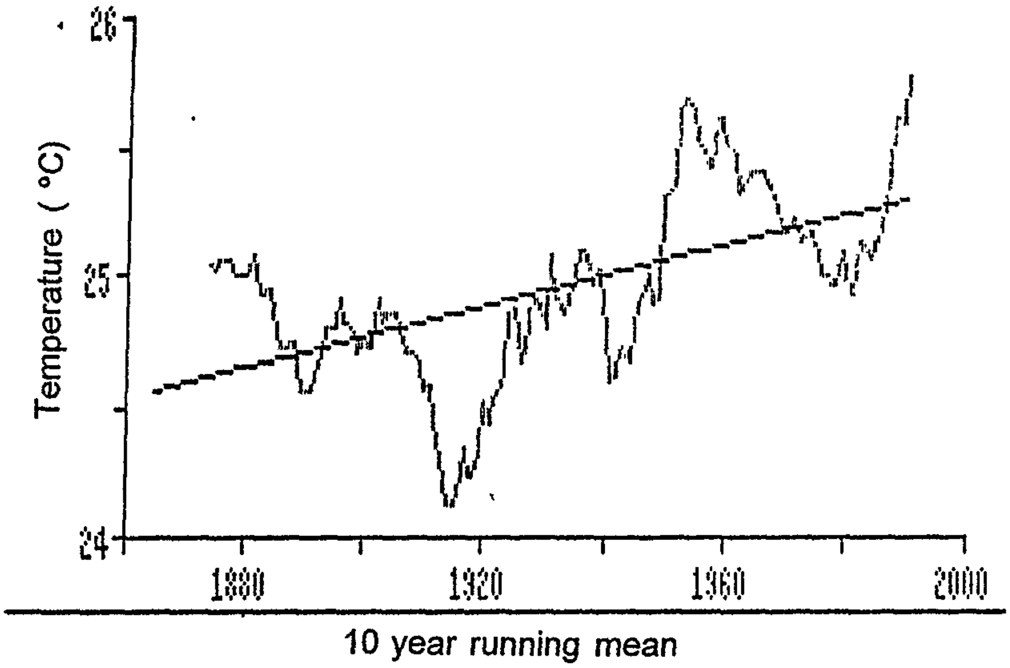

Figure 5 - Ten year running mean summer temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988

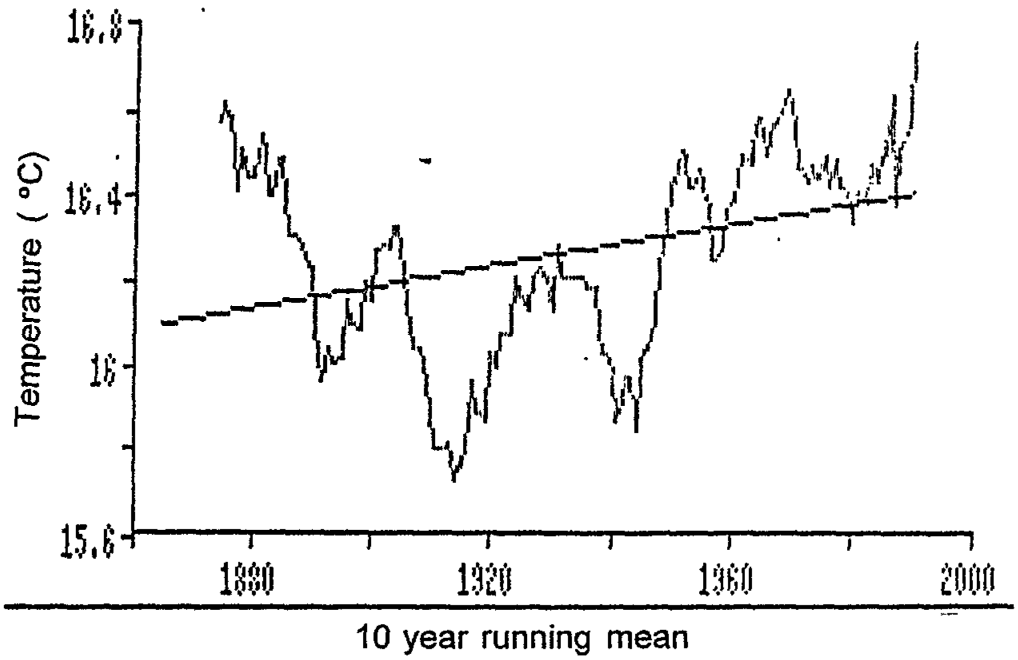

Figure 6 - Ten year running mean, spring temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988

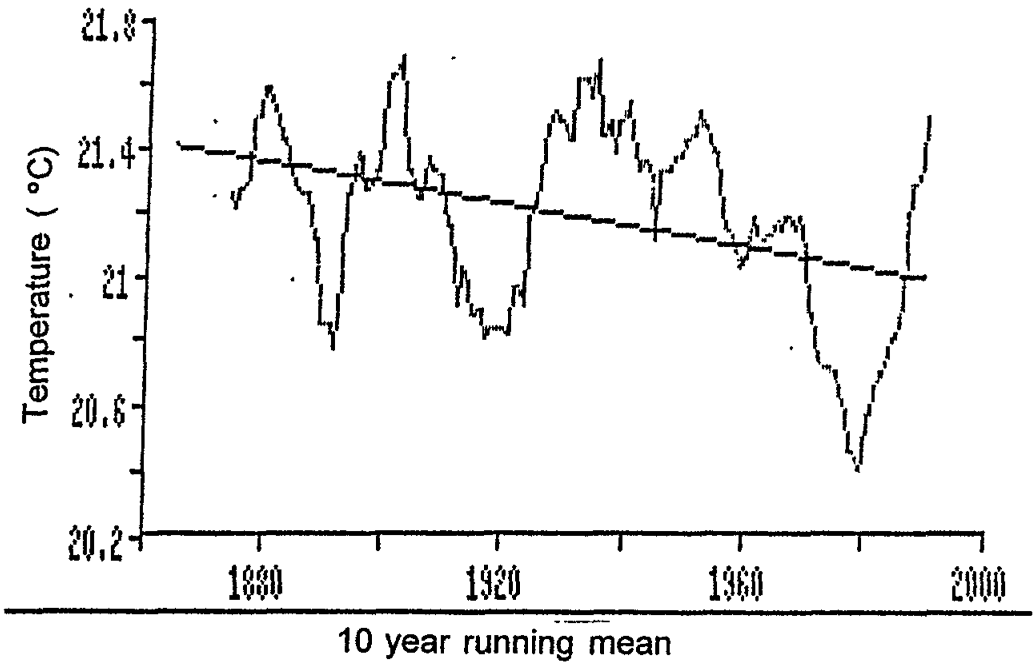

Figure 7 - Ten year running mean, autumn temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988

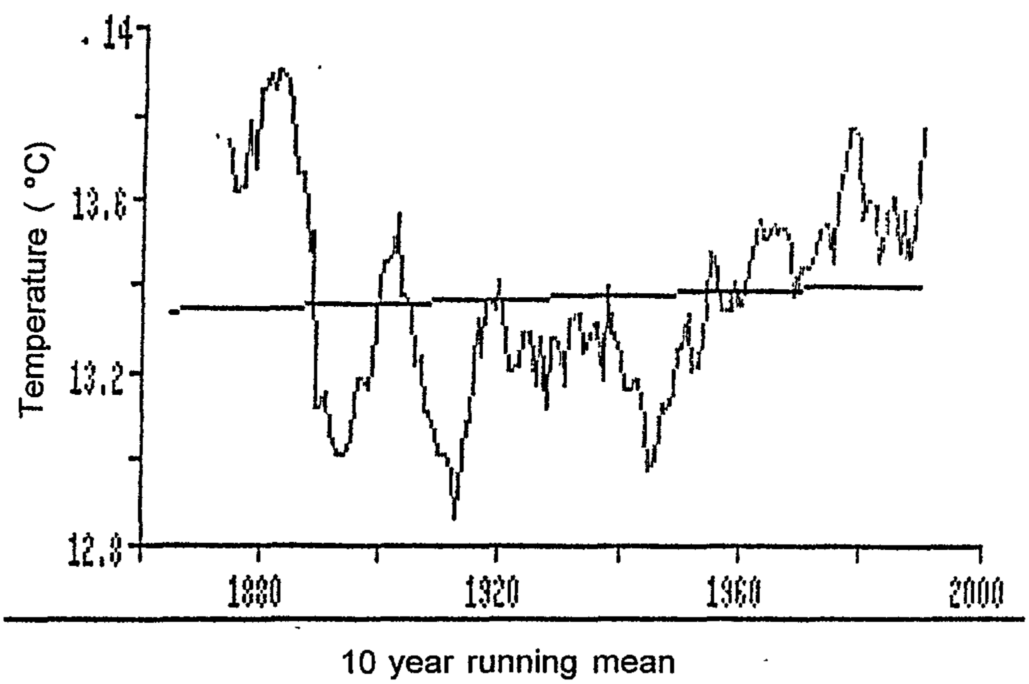

Figure 8 - Ten year running mean, winter temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988

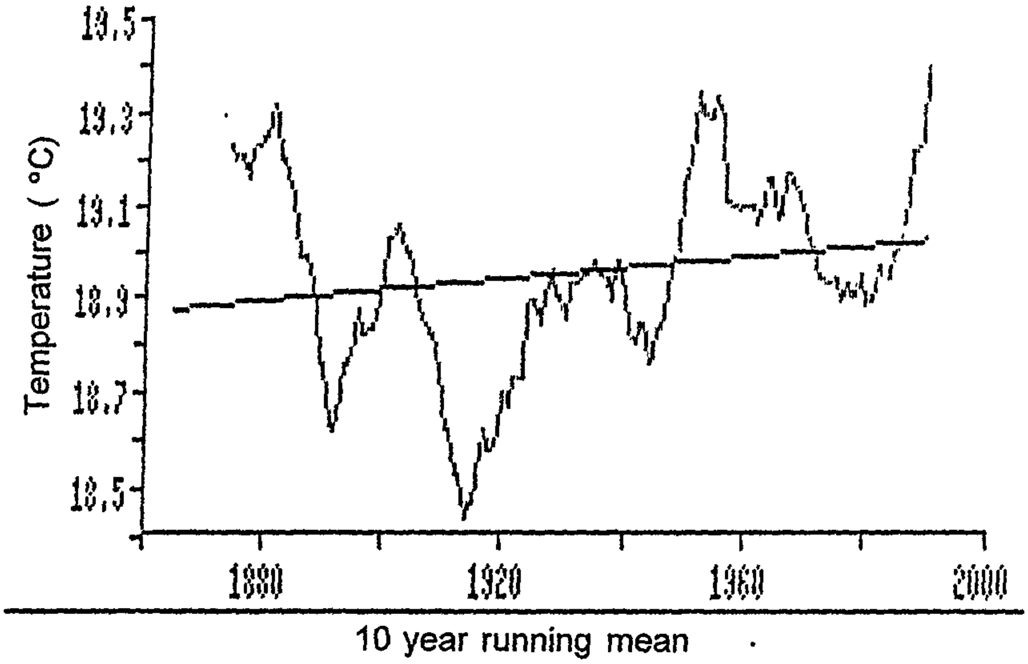

Figure 9 - Ten year running mean, annual temperature (° C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988

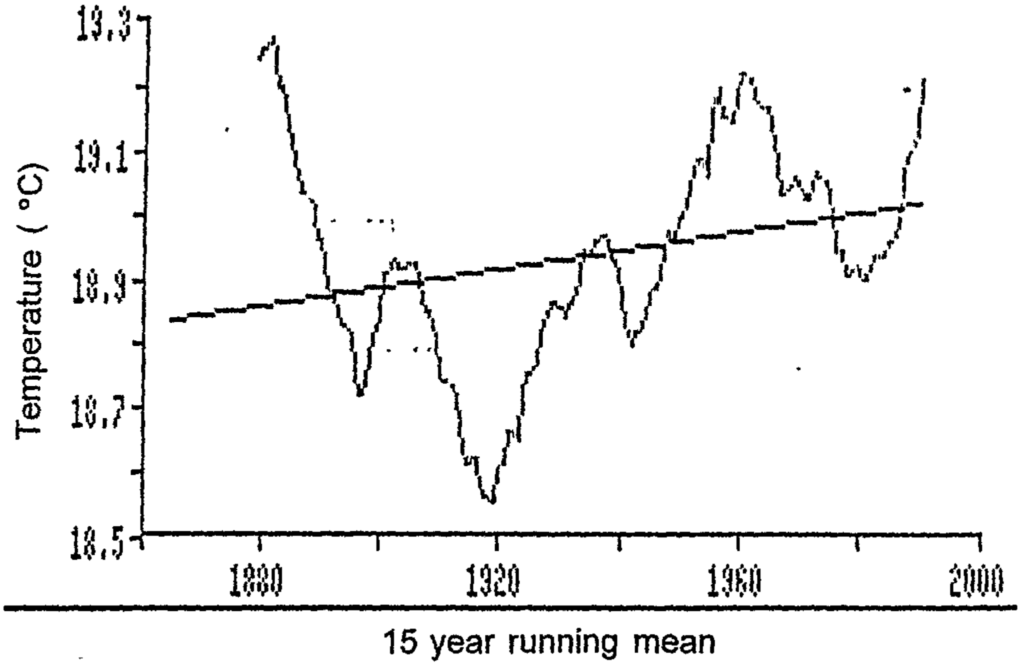

Figure 10 - Fifteen year running mean, annual temperature (° C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988

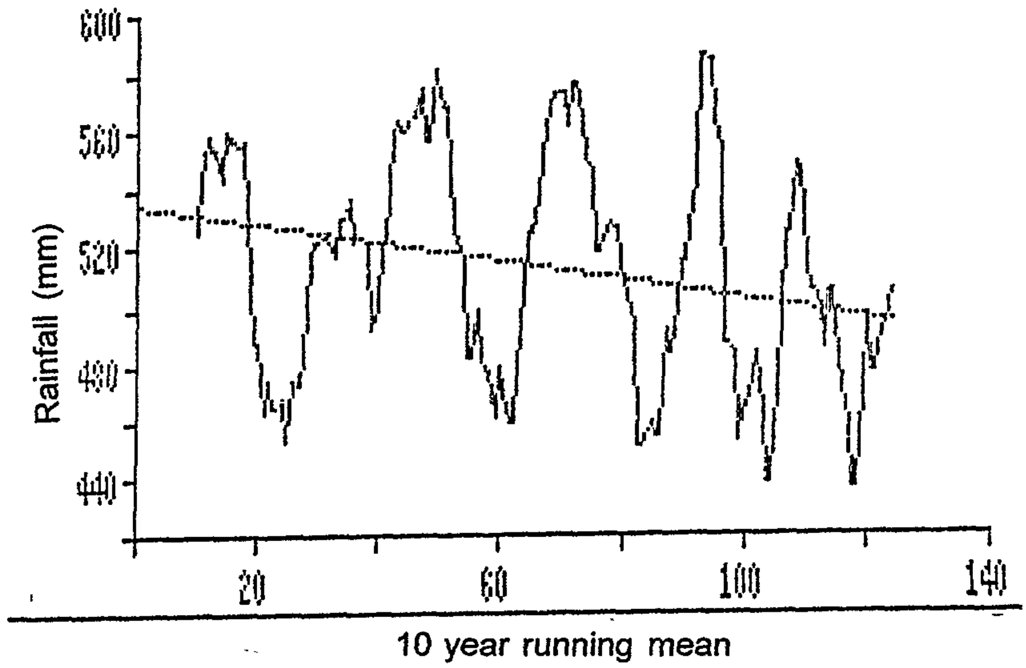

Figure 11 - Ten year running mean, annual (12 months August to July) rainfall (mm) in Valletta, 1865 to 1988

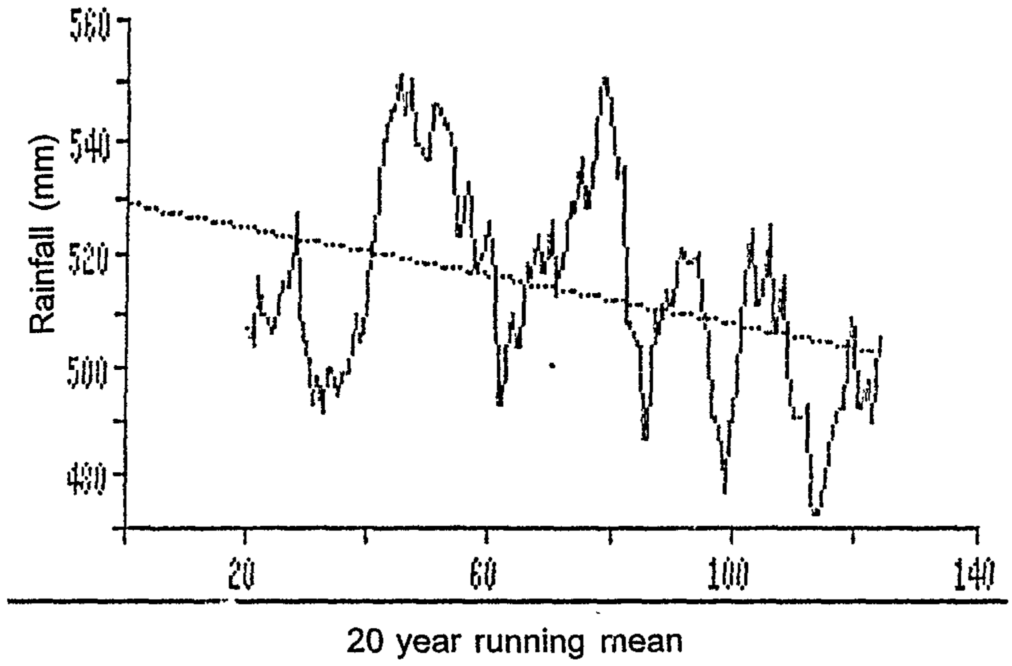

Figure 12 - Twenty year running mean, annual (12 months August to July) rainfall (mm) in Valletta, 1865 to 1988

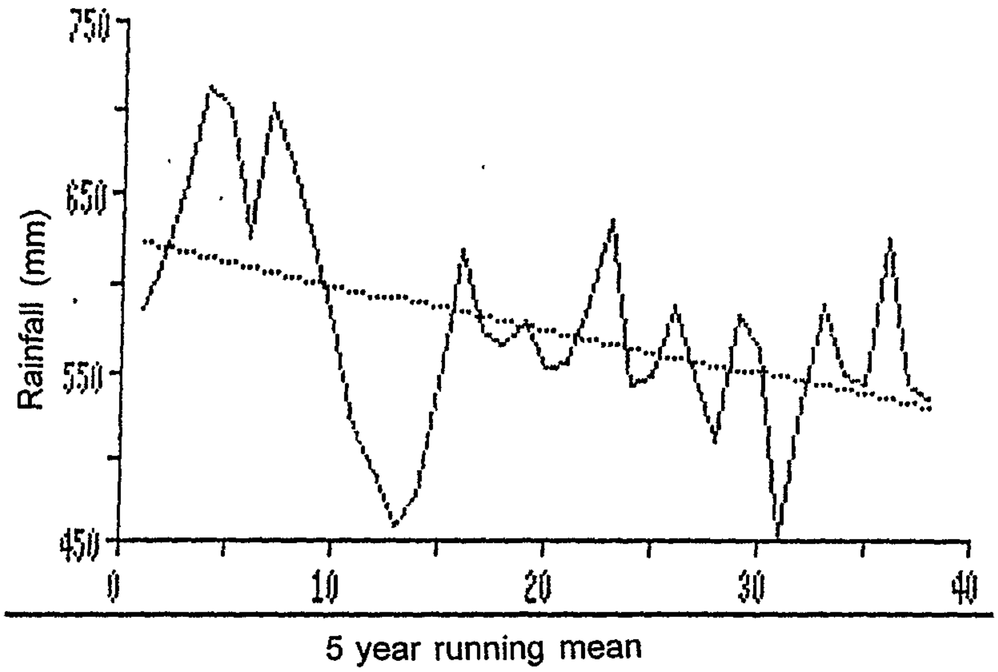

Figure 13 - Five year running mean, annual (January to December) rainfall (mm) at Luqa, 1947 to 1988

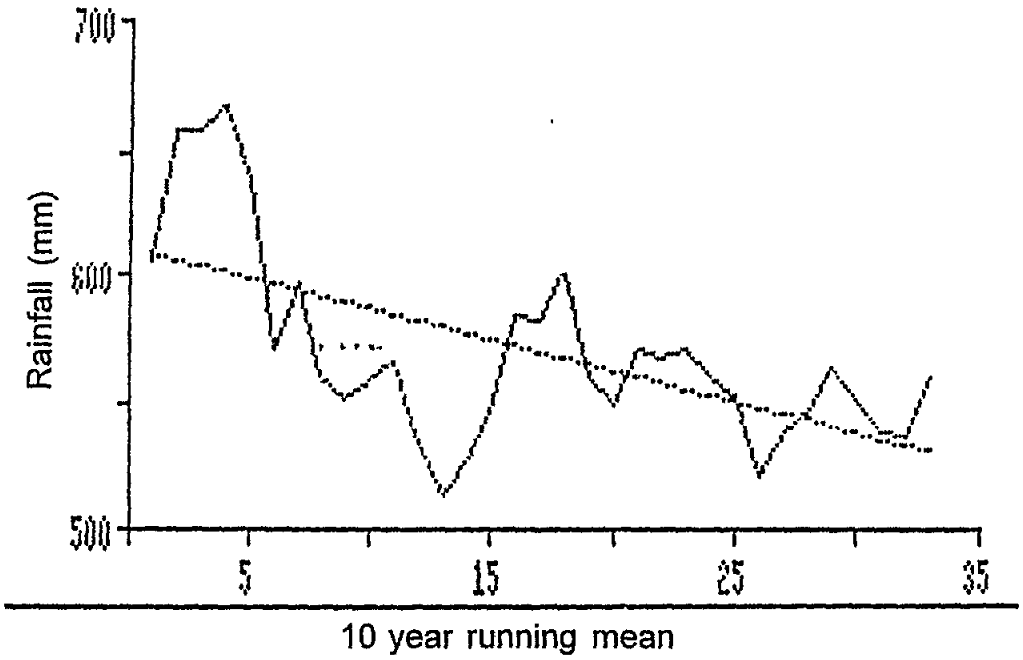

Figure 14 - Ten year running mean, annual (January to December) rainfall (mm) at Luqa, 1947 to 1988

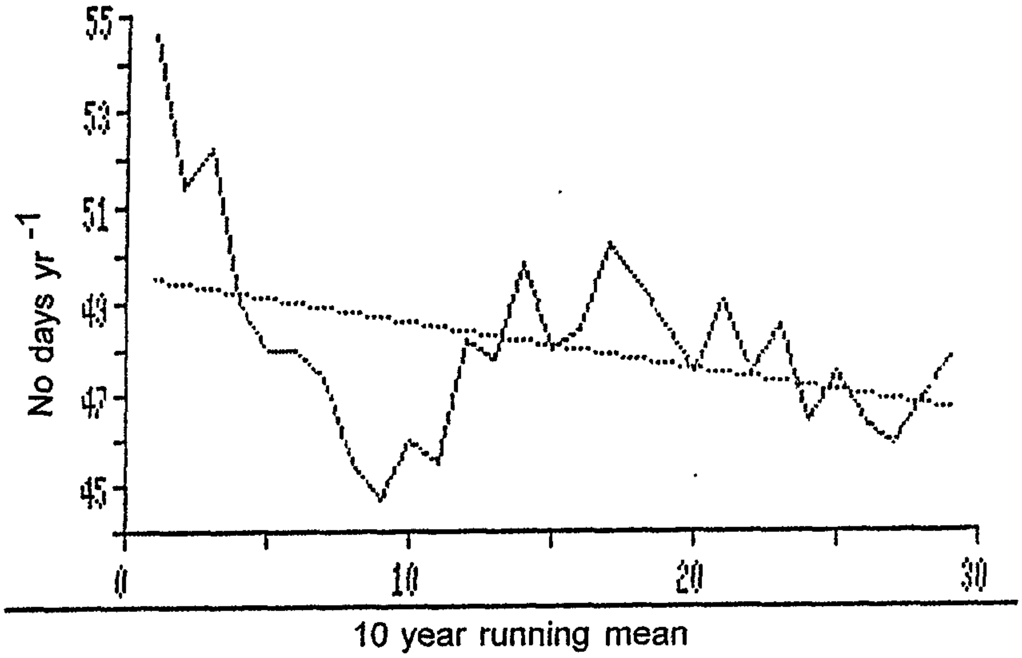

Figure 15 - Ten year running mean, of number of days a year having more than 2 mm rainfall

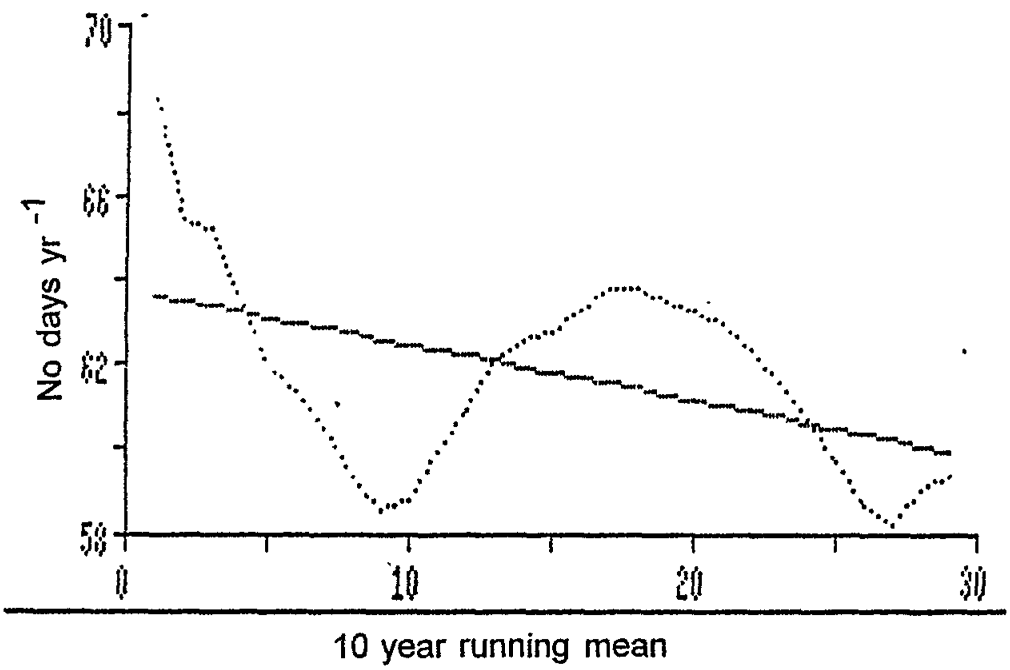

Figure 16 - Ten year running mean, of number of days a year having more than 1 mm rainfall

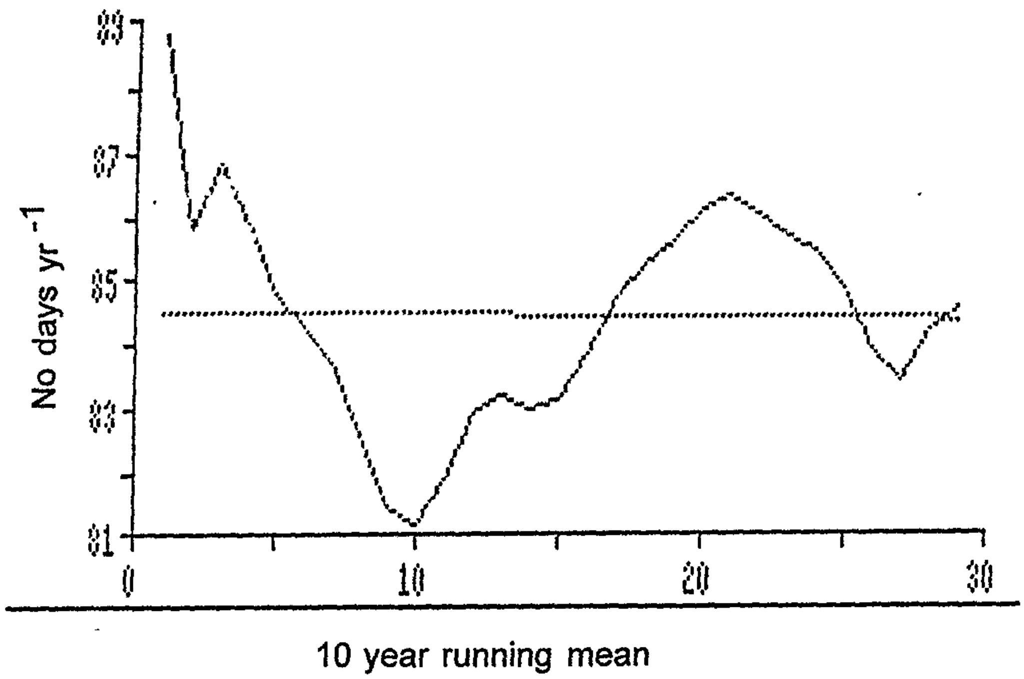

Figure 17 - Ten year running mean, of number of days a year having more than 0.1 mm rainfall

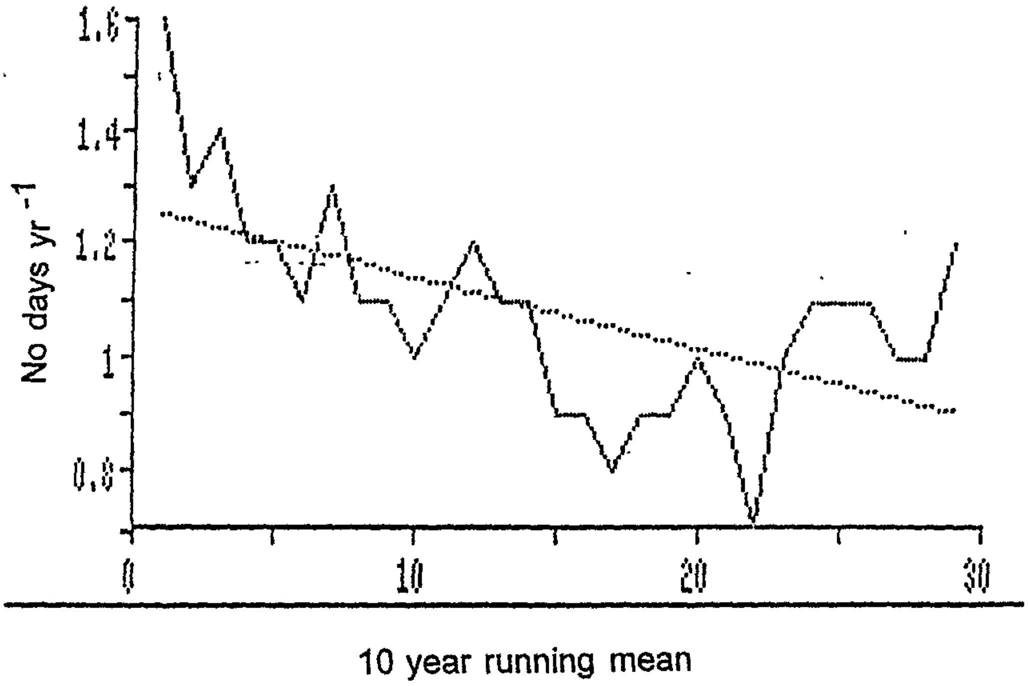

Figure 18 - Ten year running mean, of number of days a year having more than 50 mm rainfall

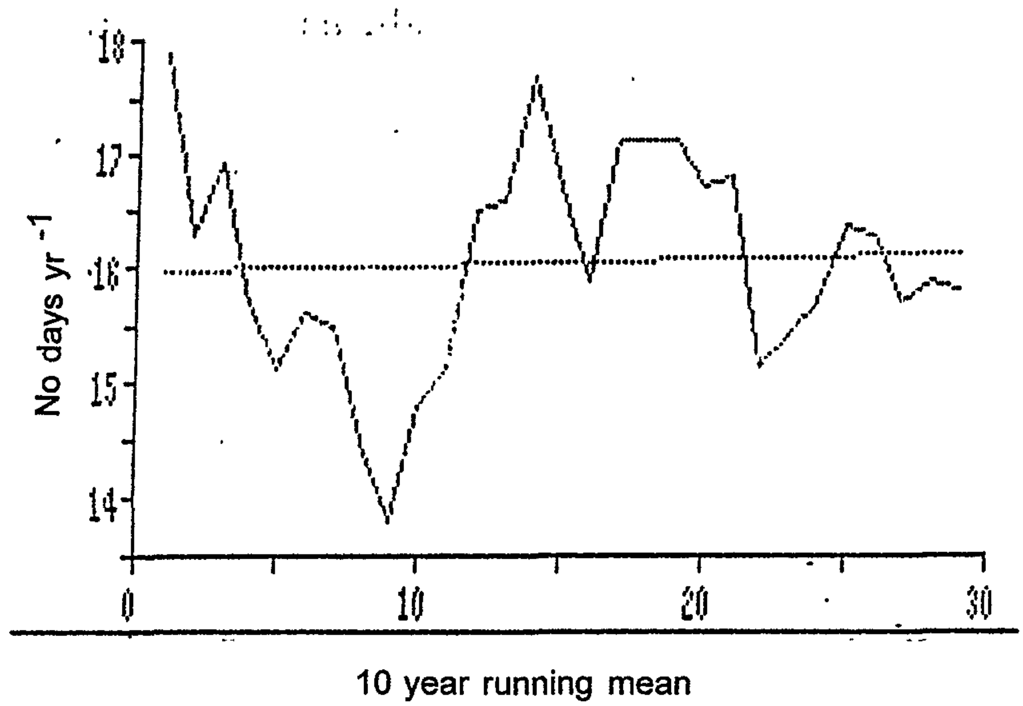

Figure 19 - Ten year running mean, of number of days a year having more than 10 mm rainfall

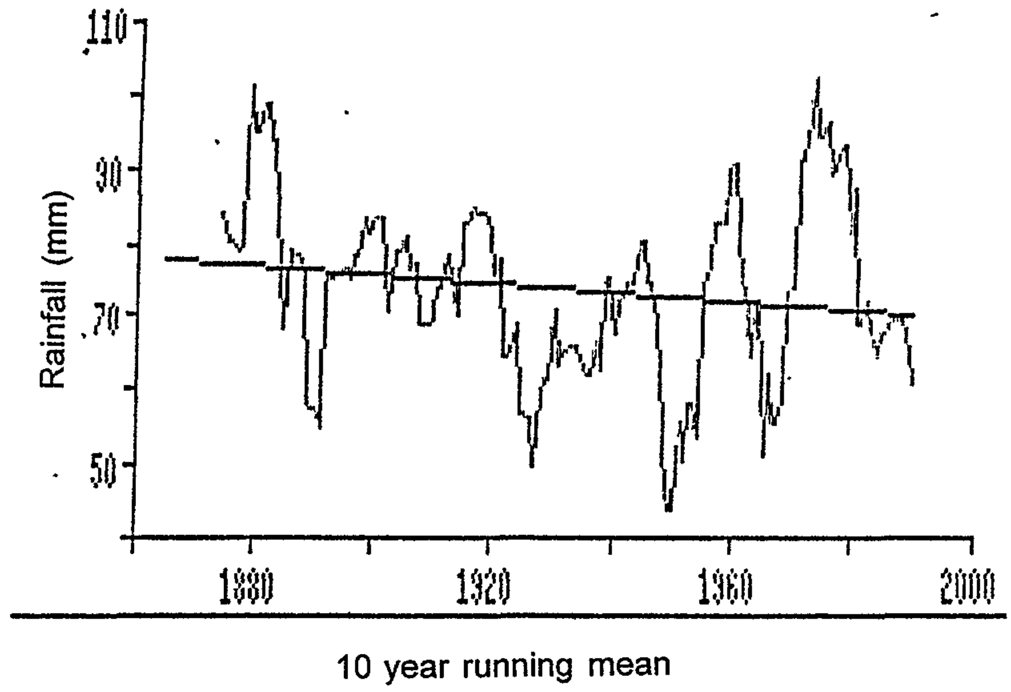

Figure 20 - Ten year running mean, of total rainfall (mm) between April and September at Valletta, 1865-1988

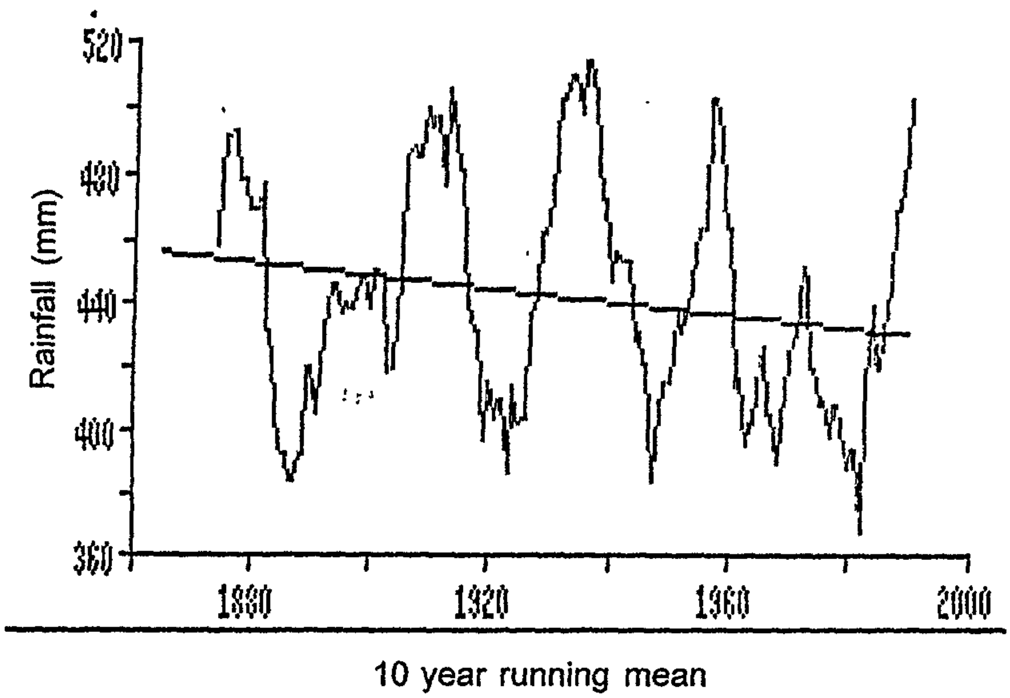

Figure 21 - Ten year running mean, of total rainfall (mm) between October and March at Valletta, 1865-1988

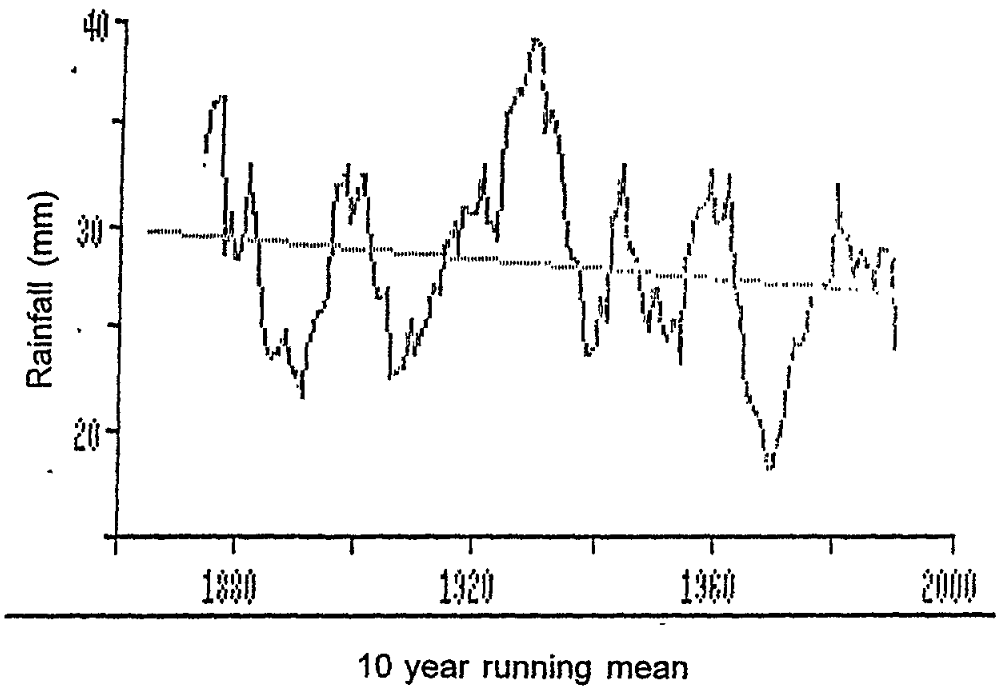

Figure 22 - Ten year running mean, of total spring (March, April and May) rainfall (mm) at Valletta, 1865-1988

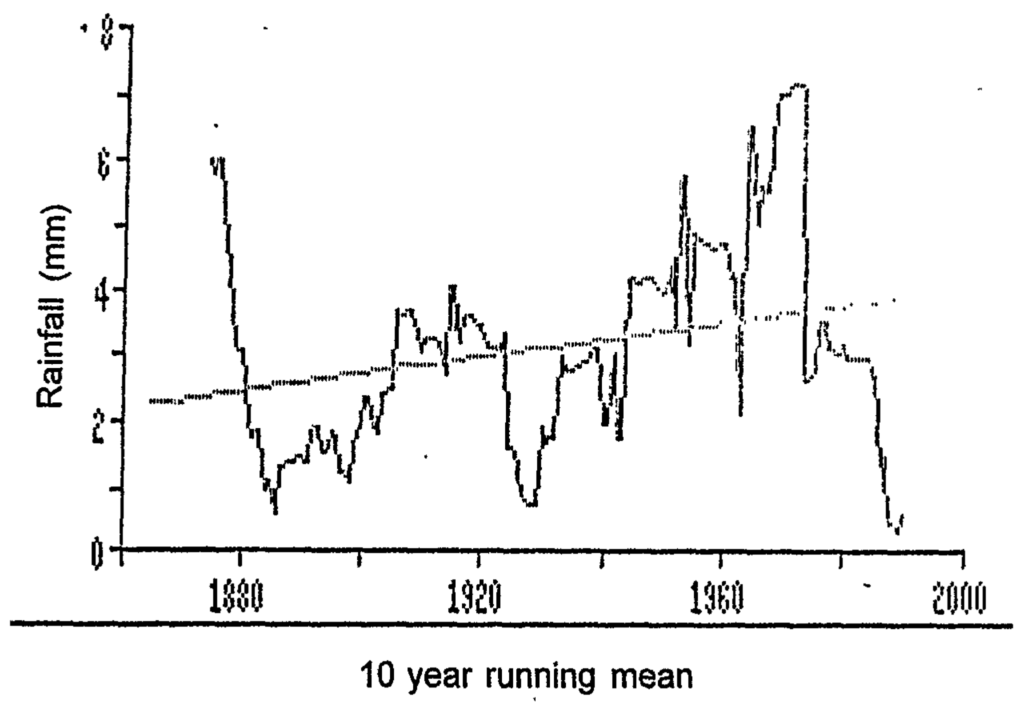

Figure 23 - Ten year running mean, of total summer (June, July and August) rainfall (mm) at Valletta, 1865-1988

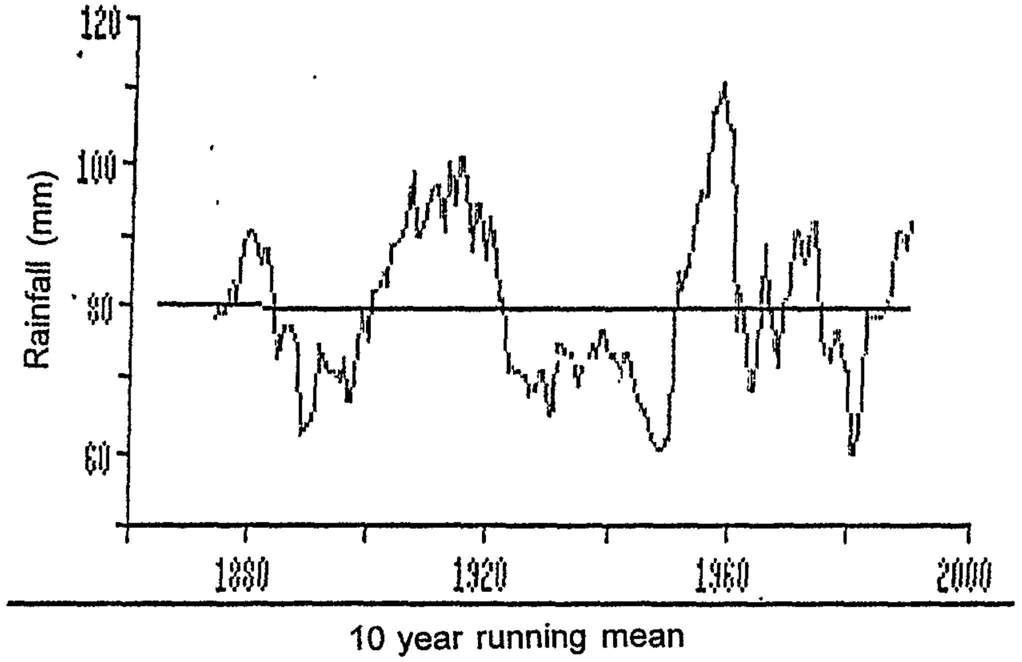

Figure 24 - Ten year running mean, of total autumn (September, October and November) rainfall (mm) at Valletta, 1865-1988

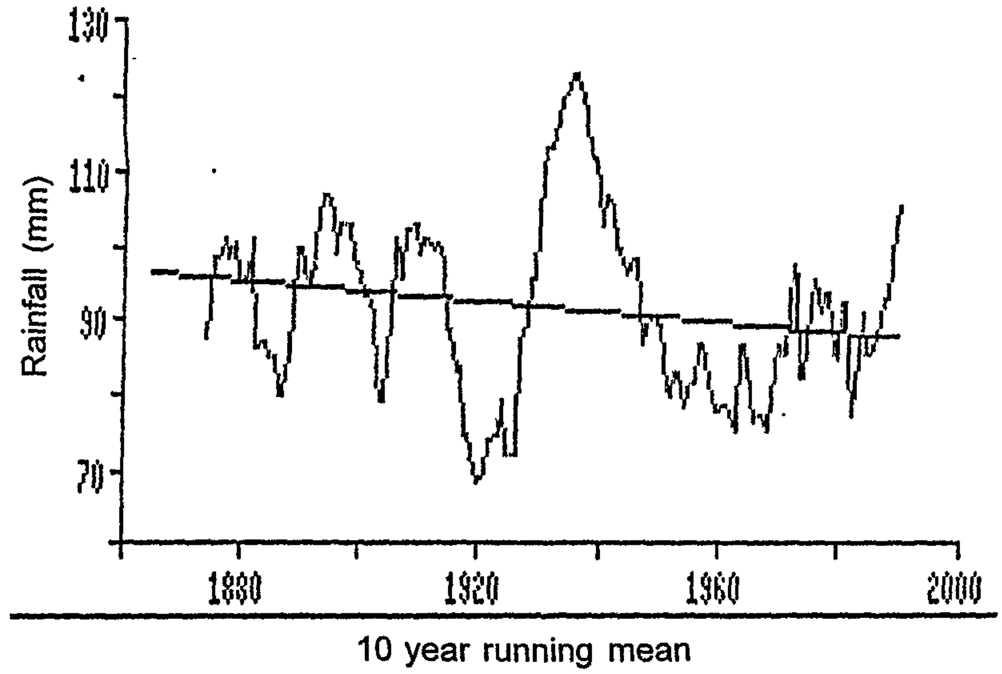

Figure 25 - Ten year running mean, of total winter (December, January and February) rainfall (mm) at Valletta, 1865-1988

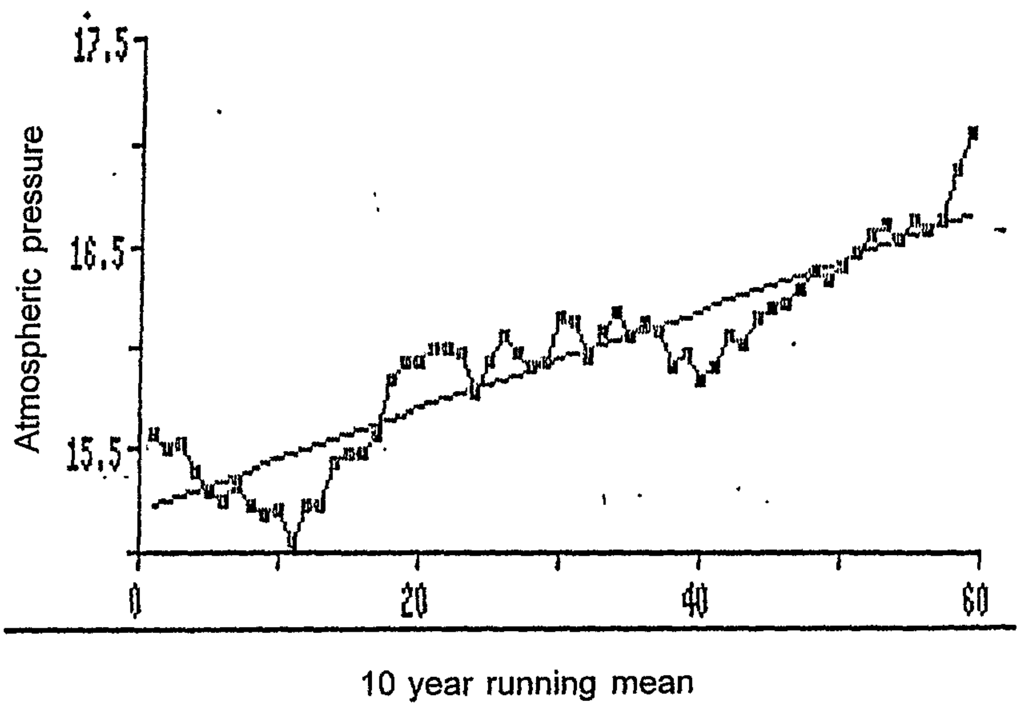

Figure 26 - Ten year running mean, of atmospheric pressure (adjusted to mean sea level) taken at Gwardamangia, Valletta and Luqa, 1923-1990

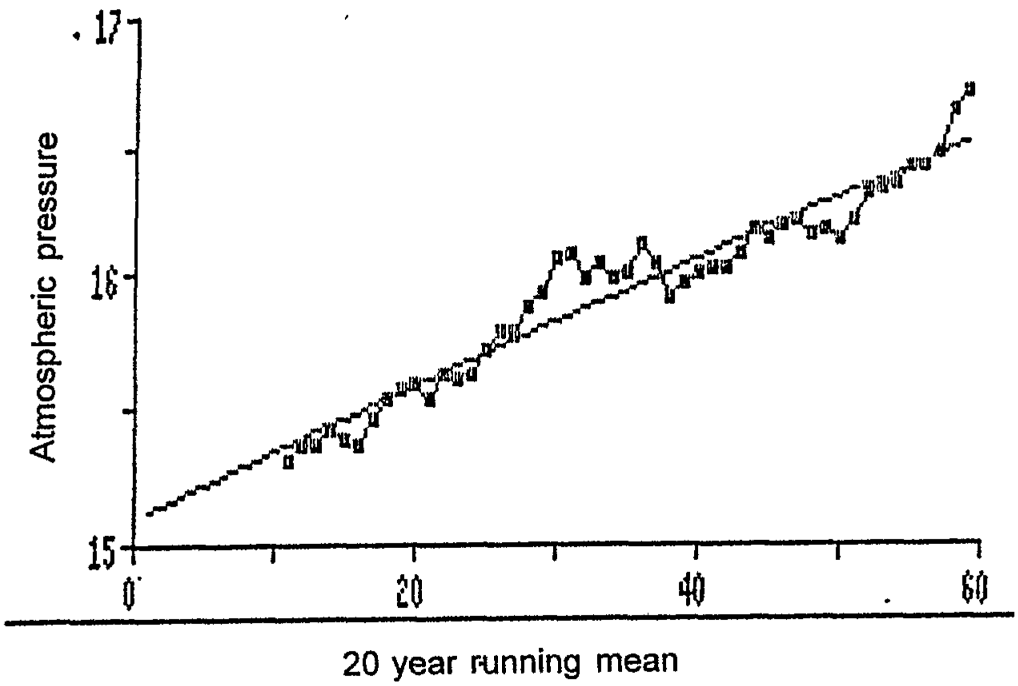

Figure 27 - Twenty year running mean, of atmospheric pressure (adjusted to mean sea level) taken at Gwardamangia, Valletta and Luqa, 1923-1990

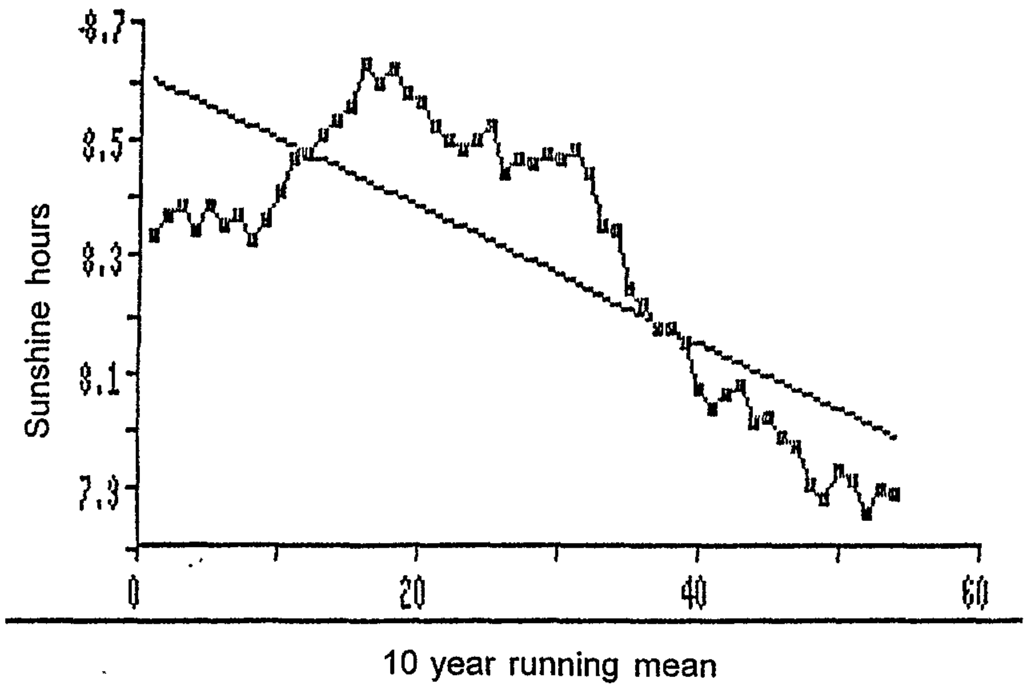

Figure 28 - Ten year running mean, of mean daily bright sunshine hours at Valletta, 1928-1946 and Luqa, 1947-1988

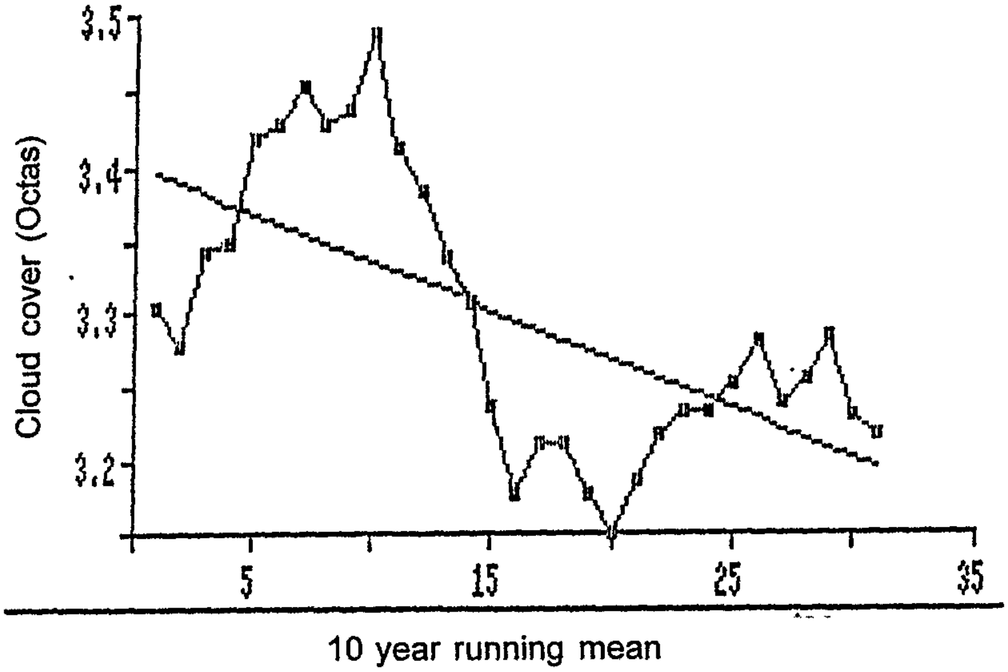

Figure 29 - Ten year running mean, based on mean monthly values derived from synoptic three hourly observations of cloud cover (in octas) at Luqa, 1951-1990

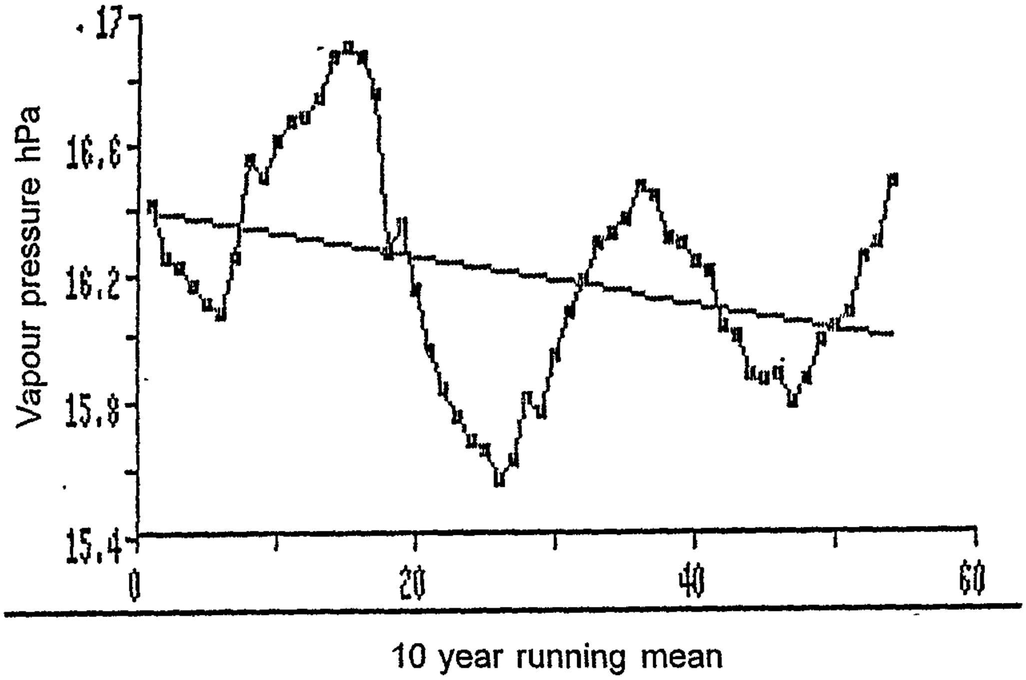

Figure 30 - Ten year running mean, of vapour pressure (hPa) based on mean monthly values derived from synoptic three hourly observations of wet and dry bulb thermometer reading taken at Valletta from 1928 to 1946 and Luqa from 1947-1990

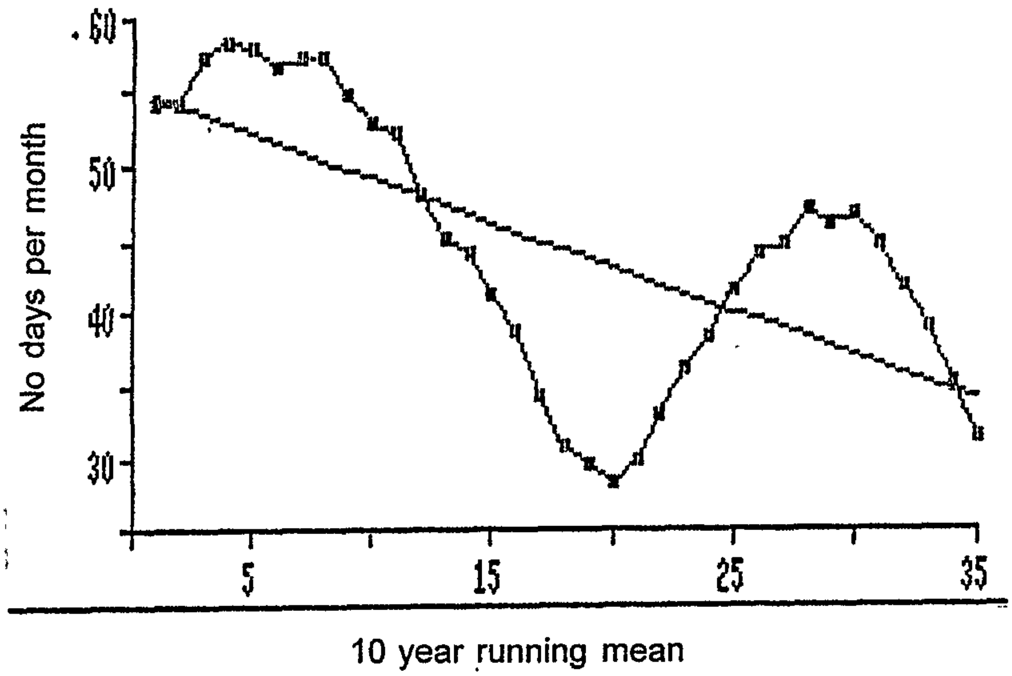

Figure 31 - Ten year running mean, of number of gusty days (> 34 knots) a year at Luqa airport, 1948-1990

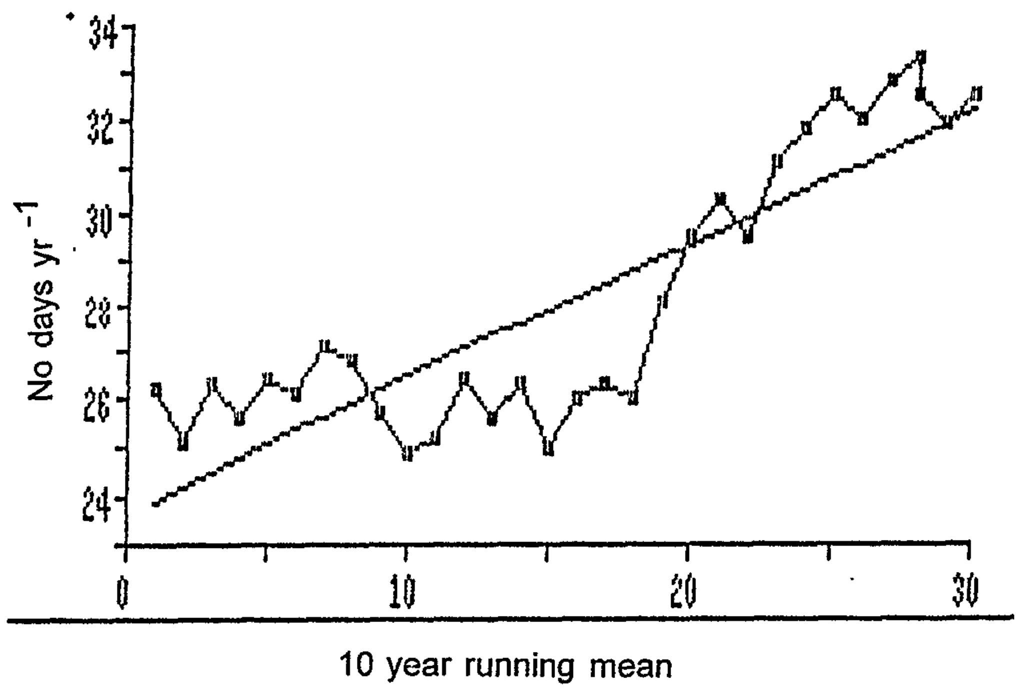

Figure 32 - Ten year running mean number of days a year with thunder at Luqa airport, 1951-1990

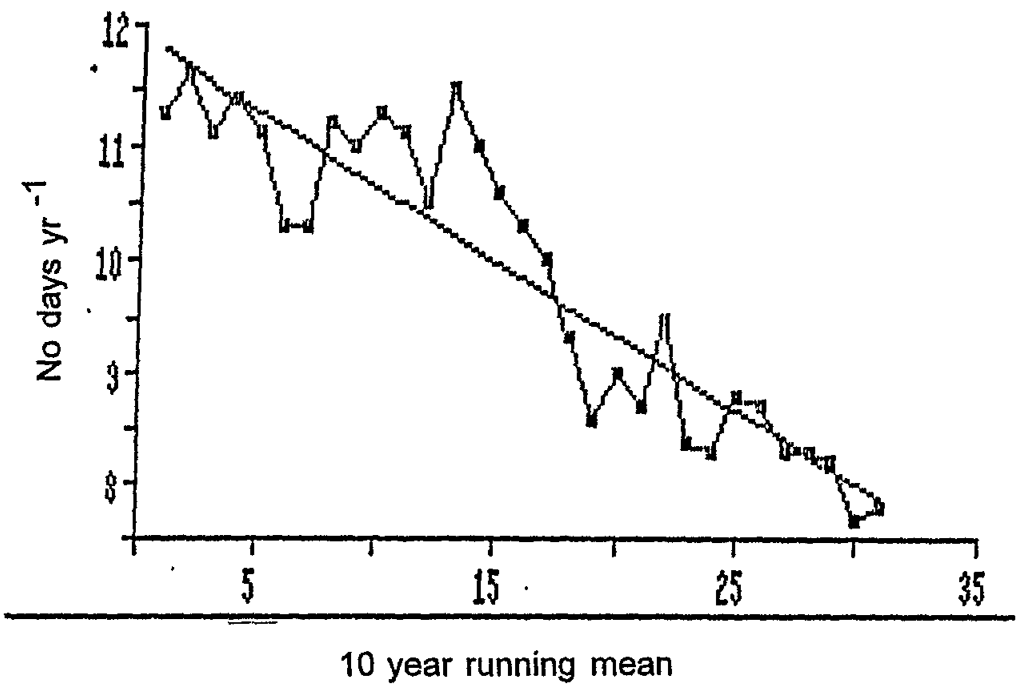

Figure 33 - Ten year running mean, of number of foggy days a year at Luqa airport, 1951-1990

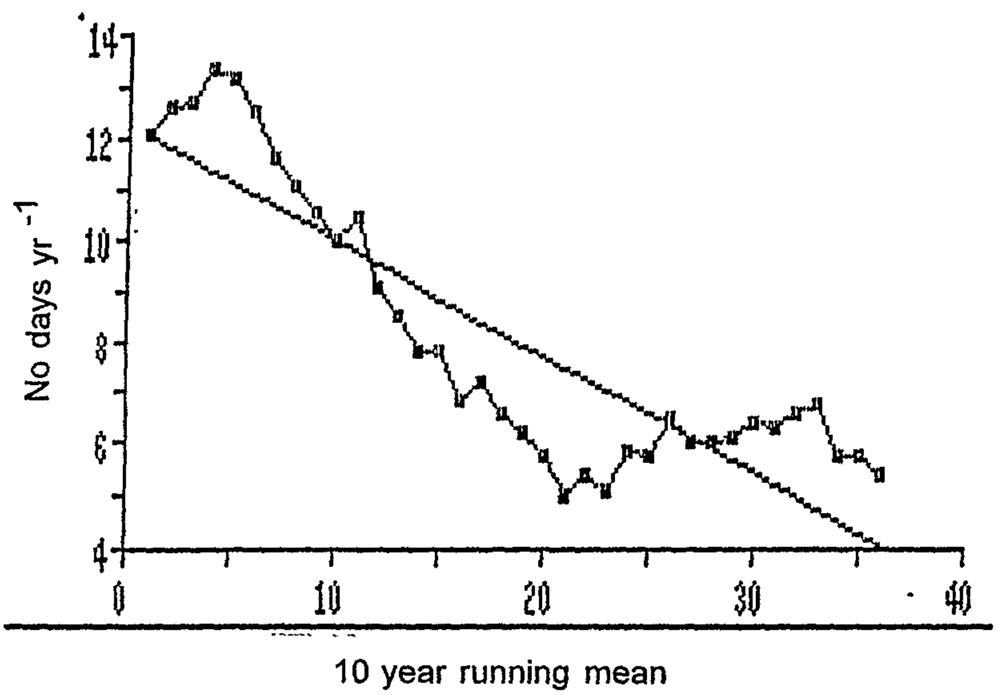

Figure 34 - Ten year running mean of number of days with hail a year at Luqa airport, 1946-1990

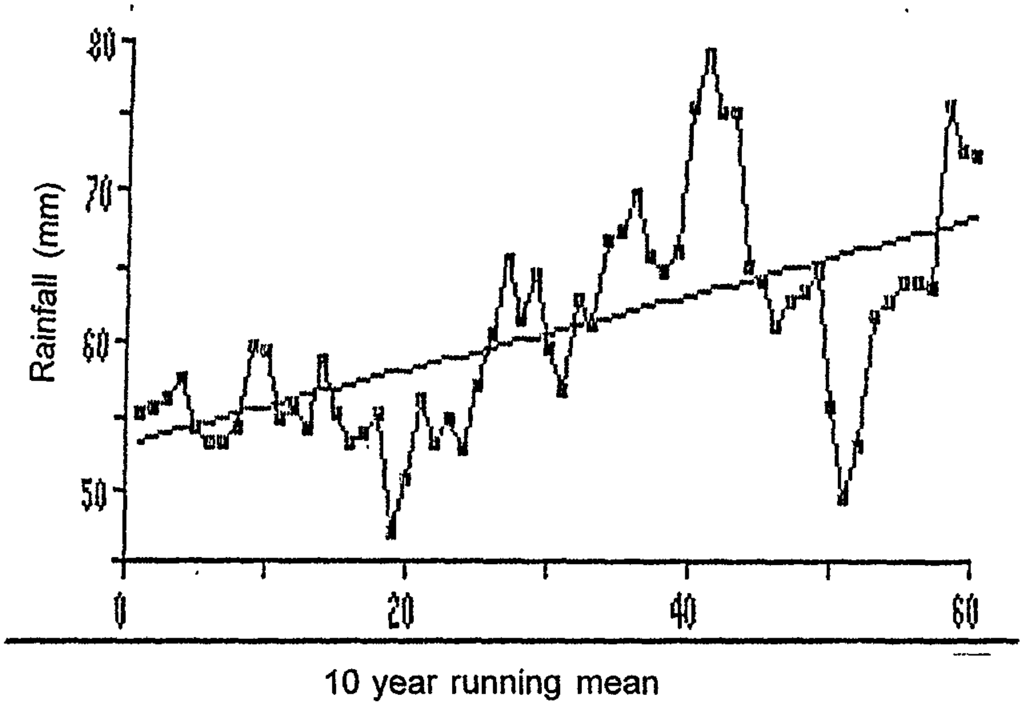

Figure 35 - Ten year running mean of maximum 24 hour rainfall (mm) based on data from Gwardamangia, Valletta and Luqa for the period 1922 to 1990

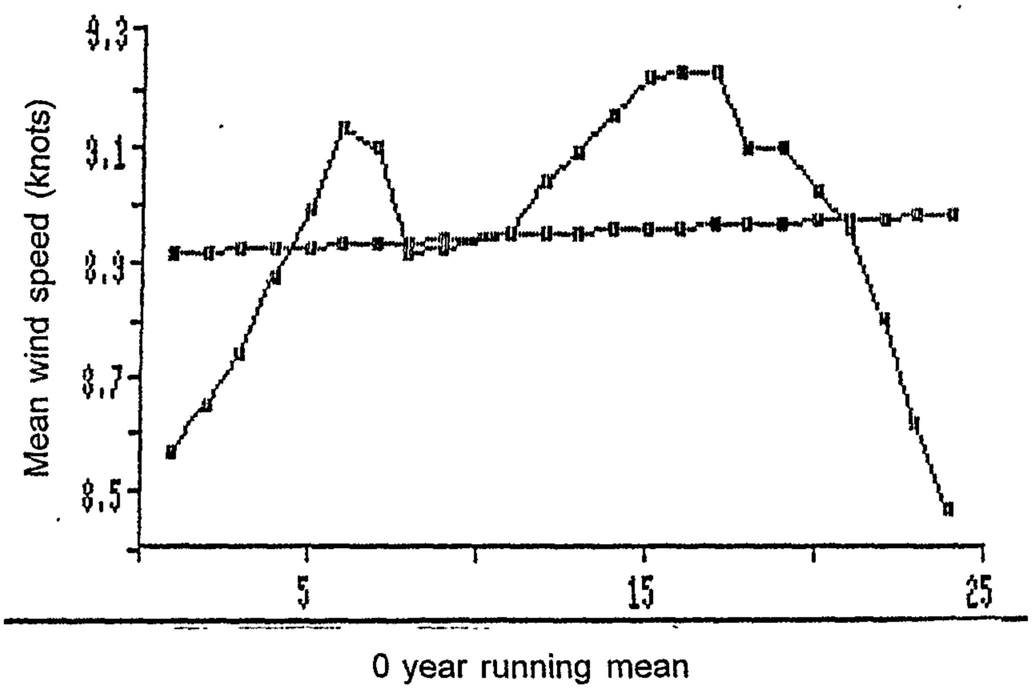

Figure 36 - Ten year running mean of mean wind speed (knots) at Luqa airport, 1959-1990

2.2. Lithosphere

2.2.1. Physical characteristics of the Islands

Malta has very few geological resources of which limestone and salt are the commercially important minerals, although a high proportion of the salt consumed is imported. One of the parameters of the lithosphere of importance to Malta's economic welfare is the pedosphere due to the fact that agriculture is a major activity in the Islands. According to the last census of agriculture (1983) the population working in agriculture included 4,500 full-time and 10,900 part-time farmers together with 5,000 full and part time labourers. There are around 12,200 agricultural holdings ranging in area from less than one to 10 hectares, the majority being of small size. Of these holdings about 11,500 hectares are arable land, 800 hectares are irrigated, 200 semi-irrigated, and the rest is dry cultivated land.

The Maltese Islands, consist of Malta itself, Gozo, Comino and the smaller islets like Comminetto and Filfla. They are located in the Mediterranean Sea roughly 97 kilometres south of Sicily, and 290 km from the nearest point on the North African mainland. The total area of the islands is 316 km^2 of which Malta itself occupies 245.7 km^2; Gozo 67.1 km^2 and Comino 2.8 km^2.

According to the 1985 Census figures the total population was 345,418 of whom 319,736 lived on Malta; 25,652 on Gozo and 30 on Comino; giving densities of: 1,216 km^{-2} on the main island and 540.5 km^{-2} on Gozo. On the main island about 30 percent of the population is classified as rural while in Gozo, the whole population is considered rural. Malta has very few natural resources, and tourism, small scale industries and dockyard facilities are new developments that have been undertaken to strengthen the economy. Agriculture, however, continues to be an important basis for the country's economy and will need to be revitalized: to provide higher living standards; increase import-substitution of human food and animal feeds; and, also increase exports such as strawberries, out-of-season vegetables, flowers, seed and cuttings.

2.2.2. Geology of the Maltese Islands

The spatial distribution of soil in Malta is directly related to the surface geology of the Islands. In particular, weathering of the Blue Clay and the middle Globigerina Limestones provide very fertile soils which contribute to the agricultural productivity of the Islands. The Islands display a layer-cake succession of Oligo-Miocene, marine sediments mainly comprising two shallow, warm water carbonate platform sequences: the Lower and Upper Coralline Limestone formations. These are separated by deeper shelf limestones and marls of the Globigerina Limestone formation, and marls and clays of the Blue Clay formation. An erosional surface separates this marine sequence from the overlying minor Quaternary continental deposits.

The islands are intersected by numerous near vertical normal faults mainly striking NE-SW, the most important of which is the Victoria Line fault. Less common are the younger generation of SE-NW trending faults, the most prominent of which is the Maghlaq fault on the southwest coast of the Islands, which probably is the cause of the slight regional dip to the northeast, as a result of which the oldest rock formations are exposed along the cliffs of the southwest coast.

The oldest exposed unit, the Lower Coralline Limestone, mostly consists of parallel bedded, restricted shelf/lagoonal miliolid limestones at the base, overlain by thick algal rodolith beds and patch reefs. The sequence is capped by thick beds of cross-bedded coarse grained limestones with abundant fragments of echinoid tests. An unconformity often marks the contact with the overlying Globigerina Limestone formation.

The Globigerina Limestone represents a deeper-shelf facies and has been subdivided into a lower, middle and upper member. The thickness of these members varies across the Maltese Islands, but in general the formation is thickest in the Marsaxlokk and Valletta areas and thins towards the Comino Straits. It thickens again towards NW Gozo. The lower member consists of a sequence of thick, massive, intensively burrowed pale yellow, fine grained limestones, rich in foramiferids. The top of the unit is marked by a widespread phosphorite pebble bed. Above this bed the middle unit consists of fine grained white or grey, often finely laminated limestone with chert nodules. A second widespread pebble bed marks the contact with the Upper Globigerina Limestone which consists of massive yellow limestone alternating with minor beds of grey marl. The unit rapidly passes to the Blue Clay formation which is composed of pale grey or green to dark bluish grey marls and clays. This formation represents the only unit in the whole sedimentary sequence, with a significant content of terrigenous clastics.

The overlying Greensand and Upper Coralline Limestone formations represent a return to a shallow water regime. The Greensand is represented by greenish to brown marls. The name derives from the abundance of glauconite associated with this formation. The unit is often capped by a yellowish brown bioclastic limestone rich in *Heterostegina*, and represents shallow submarine elongated sand bars. Its distribution over the Maltese Islands is very irregular and the formation is absent in some areas.

As the sources of terrigenous sediments gradually disappeared a typical shallow, warm water carbonate platform was developed. Because of the complexity of the Upper Coralline Limestone shallow water carbonate platform environment, the formation has been subdivided into twelve beds grouped into three members. The lower member consists of a coralgal bioherm with brown coarse grained limestone to the west and white fine-grained limestone to the east. These are overlain by a very coarse grained biostromal unit associated with patch reefs rich in colonies of *Porites* coral. To the east the patch reef deposits pass into well bedded, subtidal limestones of deltaic origin. The upper member which caps the sequence generally consists of finely laminated limestones and Stromatolites. The Oligo-Miocene succession is unconformably overlain by Quaternary deposits rich in *terra rossa*, such as raised beaches, fan-glomerates and cave infills.

2.2.3. Soil development

There are five factors involved in the development of soil and of these, probably three, parent material, climate and time are of most importance in the production of the soils of Malta. Topography, the fourth factor, is largely dependent on the first three, since landscape is largely moulded by erosion and deposition related to the parent structure, processes and time. The fifth factor, biological influences, is presently dominated by men's activities, the effects of which although secondary, are nonetheless sometimes profound producing modifications of the existing patterns.

Maltese soils are all rather young or immature since pedological processes are slow in calcareous soils such as are found on the islands where acidic drainage water is very limited in quantity. Certain soils, including the red brown clays of the Terra group, are believed to have formed largely under the influence of processes which no longer occur. Under a changed climate the new and very much slower processes have so far resulted in little change to the soil profile. These red brown clay soils are, in a sense, relic soils, but at the same time very immature (young) since the recent climate, has produced so little change to their characteristics.

In the San Biagio series, very young, man-made, raw carbonate soils, dating only from when they were mined from the rock, are found in front of undermined terrace back walls. Only a few yards away much older soils, xero-rendzinas are developed from the same parent rock. While the raw soil has been subjected to natural processes for less than 50 years, the xero-rendzinas has been developing over several hundred years. Thus time is an important factor in the soil's development.

The climate of Malta and Gozo is a good example of the Mediterranean type. It consists of hot dry summers, having a high rate of evaporation and no rain; warm and showery autumns normally with a rainfall deficit; and short cool winters with enough rainfall for agriculture in most years, but leaving insufficient reserve in the soil to combat the warm drying springs again having a rainfall deficit. The variation on sites of the same type is obviously small, but between deep-set valleys, north-facing scarp slopes and the main open plateaux or south-facing slopes there are often well marked differences in vegetation, both weeds and crops. The difference is striking because of differences in insolation, and thus of the surface temperature regime. However, soil profiles show virtually no difference between different sites, and it is only in exceptionally wet locations that the normal pattern of aridity is sufficiently overcome to allow the development of noticeable humus horizons.

In the past there have been broad oscillations of climate responsible for the production at different times of widely differing soil materials such as the 'red soil' (red brown Terra clays), stony calcareous debris and aeolian sands which are now the parent materials of the present soils. The present climate is not one under which leaching occurs. This uniformly arid climate is in strong contrast to that of some other latitudes, for example that of Britain, and may be the reason for the restricted range of soil types found in Malta and Gozo.

The parent rocks from which the soils develop are all closely similar in chemical terms, and only moderately variable in physical characteristics. Thus only a limited range of soil types is to be expected. However, the massive, well-jointed limestones have developed karst landscapes since they favour percolation and solution more than do the porous but nearly impervious finer-textured limestones. In the karst areas, red brown terra clays have developed on almost completely de-calcified residues from the limestone, but on other landscapes there has been a minimum of decalcification and the soils are chemically very similar to the parent materials as in the case of carbonate raw soils and xero-rendzinas. Thus, the composition of trace minerals in the limestones from which they were originally weathered mainly determines the nature of the Terra soils. In the case of soils developed over blown calcite however, the calcium carbonate content is higher than in the parent material. The parent material type is therefore important in determining what pedological processes can take place and hence in determining the nature of Maltese soils.

Topography generally influences the development of the soil in a variety of ways, chiefly through modifications of climate, variable conditions of drainage, and influence on erosion and transportation processes. It has been noted that in Malta and Gozo the topography results in sites with very different insolation conditions, but the effect of these differences on soil processes is negligible. It is only in the extremely well drained conditions of some hill tops, where lime crust yermas are found on parent materials of fine sandy loam texture that the effect of topography on drainage conditions can be thought to be sufficiently great to produce modification to soil structures. Flooding with sea water may be attributed to topography, and in the Alcol series at Salina Bay, for example, slight soil salinity results from such influences.

The effect of topography on erosion, transportation and deposition is more noticeable. Under the former, cooler climatic conditions, solifluction took place, while under present conditions sheet or gully erosion occurs during the violent showers of late autumn. The result is that there are strikingly different eroded and alluvial phases of the same soil series in some locations. On the Blue Clay soils the alluvial, light clay type is more favourable for agriculture than the eroded heavy clay type which is alkaline or saline-alkaline in places.

Apart from man's activities, biotic factors are of relatively little importance in the development of the soils of Malta. Humus horizons are only developed under well established and long undisturbed vegetation, which is very rare. The surface horizons of cultivated soils are deficient in humus and organic matter and the soil fauna seems to be very limited in abundance.

The modifications of the soil pattern produced by man are most profound. Apart from the large areas of Malta which have been covered by human habitation, factories, airfields and military installations and where the soil has been bulldozed or covered up and is unrecognisable the pattern of soils in agricultural areas has been changed. Firstly, nearly all the land in Gozo and most of the land in Malta has been terraced, on slopes so steep that the terraces are of necessity very narrow, with very high retaining walls. The back walls of the terrace are often cut into the solid rock and the resulting rock flour mixed with the soil material, while the floor of the terrace is quarried, made flat and then covered with rubble before the soil material is replaced on it.

Terracing of this type is very widespread in cultivated areas except on alluvial parent materials, and gives rise in the karst lands to a complex of soils described as I-Iklin complex, which range from carbonate raw soils to Terra-like soils, dependent on the amount of rock flour and rubble added to the original Terra soils during terracing.

Where quarries have been dug, the soil has been replaced in a similar way, with added rubble, refuse and rock flour in terraces which have been built up at several levels in the quarry. The resultant mixed soils have been referred to as the Tad-Dawl complex, which is rather similar to l-Iklin. The use of inorganic town refuse on the soils and the large-scale dumping of soil material derived from building sites adds to the generally rather confused nature of many of the soils. An unspecified but quite high percentage of the total soil cover is moved in this way to give rise to widespread changes in soil structure on a large scale.

The effects of human use of soils has produced widespread and profound modifications of the original pattern of soils. Table 3 which is based on Kubiena's classification (1953) illustrates the small range of soils found in Malta and Gozo. There are no sub-aqueous soils, and only a small fraction of one percent of the soils are secondarily saline and thus classified as semi-terrestrial. Some of the present soils such as Alcol, are developed on alluvial, semi-terrestrial soils, formed during an earlier climatic era.

TABLE 3

Classification of the soils of Malta and Gozo according to the system of Kubiena (1953)

DIVISION	CLASS	TYPE	SUB-TYPE	VARIETY	SERIES
A. Sub-aqueous	not represented in Malta				
B. Semi-terrestrial	BD Salt soils		Secondary salt soils		
	CA Terrestrial raw soils	Syrosem (raw soil)	Carbonate syrosem		Fiddien Nadur Ramia San Lawrenz
	CB not represented in Malta				
	CC Rendzina-like soils				Alcol San Biagio Tal-Barrani
C. Terrestrial	CD not represented in Malta				
	CE Terrae Calxis	Terra	Terra fusca	Earthy Terra fusca	Tas-Siagra
	CF		Terra rossa	Siallitic terra rossa	Xaghra
	CG not represented in Malta				
	CH not represented in Malta				
	CI not represented in Malta				
	CJ not represented in Malta				

Through cultivation and irrigation man attempts to influence the disposition of water in favour of his crops, and by using fertilisers and herbicides or pesticides attempts to influence the chemistry and biology of the soil. The present agricultural needs in terms of improving soil fertility, are not simple to assess and are unknown in Malta. A fertile soil is considered as one which is in the optimum condition for the growth of crops, and this is dependent on a variety of physical, biological and chemical factors.

2.2.4. Soil development and agricultural production

A soil which has a poor physical structure may not support good crops, because water cannot be easily obtained by the plant, or because the soil aeration is poor. The heavy clay soils of the Fiddien series have poor structure, and it is likely that the difficulty of wetting these soils rather than their chemistry (which often has a rather high concentration of exchangeable sodium and soluble salts) causes them to be nearly useless for agriculture. The majority of Maltese soils have a reasonably good structure, and the only other soils which appear to be ill-favoured are the heavy-textured soils of the Xaghra series. In this case the subsoil is often very compact indeed, and the separation between structural units is minimal. Where such soils are worked, and more particularly where they are irrigated, the structure seems to be much improved, partly because of increased and active microfauna. While irrigation is probably difficult to extend, the use of improved cultivation practices on these soils would probably increase their organic matter content and improve their structure.

Practices such as the use of nitrogenous fertilisers; improved rotation; encouragement of root growth; avoidance of decomposition of root-derived organic matter through unnecessary turning of the soil; and, the avoidance of pulling cereals for harvesting, might result in considerable improvement in soil fertility. The application of animal manure in irrigation water as already practised locally in Malta also appears to be effective in increasing the organic matter content of the soil.

One of the chief problems facing all crops in Malta is restricted water availability. Certain of the lighter textured soils are extremely dry, and conservation of rainwater rather than extension of irrigation must be the answer since domestic water needs are already difficult to satisfy. Apart from practices designed to diminish evaporation losses, especially the early removal of weeds by hoeing, it is probable that increasing the organic matter content would considerably increase water retention by the soil. An additional simple method might be to marl some of the lighter soils with calcareous clays such as the Fiddien heavy clay which is not currently in agricultural use. In addition this might make more nutrients available in the soil.

As far as aeration is concerned, it seems unlikely that this is limiting in most soils at present; but the widespread use of a rotary tillers is believed to decrease aeration through soil compaction. It is possible that an increase in soil CO_2 would be beneficial in calcareous soils, reducing the pH of the soil solution to a level at which there is greater availability of most nutrients, particularly those, such as phosphorus, which are deficient.

In addition to other limitations it seems likely that nutrient deficiencies are the most important factor resulting in low soil fertility in the Maltese Islands. Despite the generally healthy appearance of crops, some symptoms of nutrient deficiencies have been observed, however, it is not possible to identify which nutrients are limiting since:

- there is no simple relationship between analytical data and availability of nutrients to plants;
- existing analytical data are few and have not been correlated with field crop performance; and,
- satisfactory chemical data for calcareous soils are more than usually difficult to obtain and compare.

It is obvious that only experimental comparison of fertiliser application with crop yield, can give definitive answers concerning nutrient limitations.

A few soils in Malta are affected by saline ground water; a limited number of plots are being irrigated with brackish water and although this has not been directly observed, probably some are also affected by saline spray. The result is an increasing soluble salt content in the lower part of the soil profile, but up to the present the concentration has not been great enough to cause noticeable effects on crops. The potential ill effects of saline water can be avoided by making certain that through-drainage takes place from time to time, in order to carry away some of the dissolved salts. The occasional use of soluble calcium salts in the irrigation water is a further aid. This is difficult or impossible to undertake without proper drainage and irrigation and soils with a high saline ground water table are probably untreatable although their condition may not be worsening very rapidly.

2.2.5. Possible consequences of climatic changes

Water loss by evapotranspiration is a critical factor in determining both the overall water balance in Malta and the prospects of developing irrigated culture particularly when the available water is moderately saline. Theoretical, semi-empirical and empirical methods based on the energy balance or the aerodynamic approach or a combination of both have been found to give accurate estimates of evapotranspiration under diverse climatic conditions and crop covers. These methods require a few fairly simple, readily observed meteorological, physical and geographical data sets which include temperature, daytime hours (based on latitude and time of year) solar radiation, actual sunshine hours, actual vapour pressure and saturation vapour pressure.

The water balance is essentially the relationship between: water requirements, as expressed by potential evapotranspiration (PET) rates; and, the availability of water from precipitation. Table 4 gives mean monthly values of PET computed according to the method suggested by Thornthwaite (1948). Assuming temperatures and rainfall scenarios for the Malta Region as presented by the Climatic Research Unit of the East Anglia University, one would expect a further increase in the moisture deficit for the whole year even if one assumes a temperature rise of 3 degrees and no change in the yearly rainfall amount.

TABLE 4

The present water balance of Malta

MONTH	TEMPERATURE °C	RAINFALL (mm)	PET (mm)	MOISTURE		REAL E.T
				Surplus	Deficit	
JANUARY	12.4	89.0	25.4	63.6	-	25.4
FEBRUARY	12.4	61.3	25.4	35.9	-	25.4
MARCH	13.4	40.9	35.6	5.3	-	35.6
APRIL	15.5	22.5	53.3	-	30.8	22.5
MAY	19.1	6.6	81.3	-	74.7	6.6
JUNE	23.0	3.2	119.4	-	116.2	3.2
JULY	25.9	0.4	162.6	-	162.2	0.4
AUGUST	26.3	7.0	157.5	-	150.5	7.0
SEPTEMBER	24.1	40.4	119.4	-	79.0	40.4
OCTOBER	20.7	89.7	86.4	-	3.3	86.4
NOVEMBER	17.0	80.0	48.3	31.7	-	48.3
DECEMBER	13.8	112.3	33.0	79.3	-	33.0
ANNUAL	18.6	553.3	947.6	219.1	613.4	334.2

Soil formation involves a series of chemical reactions which depend on heat and moisture, and although the parent rock, the natural vegetation and the presence of bacteria are important, the dominant factor in soil formation is climate (Branijan and Jarett, 1975). In Malta, the parent rocks are all very similar chemically, differing only moderately in physical characteristics. Nevertheless, from these rocks quite dissimilar soils are formed under the influence of climatic conditions. The De Martonne (1929) method of classifying climate involves the calculation of an aridity index which is defined as the ratio of the mean annual rainfall to the mean annual temperature as given by the following equation:

$$I = \frac{P_m}{T_m + 10}$$

where I = aridity index;
P_m = mean annual precipitation (mm); and,
T_m = mean annual temperature (°C).

On the basis of this index De Martonne described six climate regions from the perspective of aridity (Table 5). Using present day average Maltese values for temperature (18.6°C) and precipitation (553.3 mm) one derives an index of 19.4 which puts the island just inside the range of values characteristic of semi-arid (Mediterranean) climates. If one adopts the University of East Anglia's scenario for global warming then a temperature increase of 3°C and no change in rainfall, scenario (1), would give an index value of 17.5, somewhat nearer to the arid climate category.

TABLE 5

De Martonne climate types based on the Index of Aridity

TYPE OF CLIMATE	ARIDITY INDEX
Extremely arid	0 - 5
Arid	5 - 15
Semi-arid (Mediterranean)	15 - 20
Semi-humid	20 - 30
Humid	30 - 60
Extremely humid	>60

The index of aridity for different Scenarios is presented in Table 6.

An increase in mean annual temperature of 3°C and a decrease of 16% in annual precipitation would put the climate of Malta into the Arid category.

An index of the precipitation effectiveness based on mean temperature can be calculated using the equation of Thornthwaite (1931) to derive the precipitation to evaporation ratio (P/E):

$$P/E = 1.65\ \{(P/T+22.2)\}^{10/9}$$

The present P/E ratio for Malta is 29.9. With a temperature increase of 3°C and no increase in precipitation the P/E ratio is reduced to 27.6 (Table 6). This suggests a decrease in precipitation effectiveness will occur by the end of the next century.

TABLE 6

Aridity Index, and precipitation evaporation ratios for Malta under present and projected future climate scenarios

	TEMPERATURE		RAINFALL		INDEX OF ARIDITY	P/E RATIO
	Annual mean °C	Change °C	Annual Total (mm)	% Change		
Present	18.6	0	553.3	0	19.4	29.9
	21.6	+ 3	553.3	0	17.5	27.6
	22.6	+ 4	559	+ 1	19.6	
	21.6	+ 3	480	- 13	14.7	
	21.6	+ 3	470	- 16	14.8	

2.2.6 Other aspects of rainfall, evaporation, and hydrological balance

In relation to salinisation and alkalinization, the FAO/UNEP consultation (1978) advised the use of the ratio P/PET (P = precipitation; PET = potential evapotranspiration) as a parameter for rating the hazard of potential salinization and alkalinization of soils, noting that:

> "salinization and alkalinization are frequent for (P/PET)<1 and their intensity is inversely proportional to this index"

In the case of Malta the ratio of P/PET is less than one from April through to September (Table 4) and the months of March and October have values close to being <1. With the expected increase in temperature and a possible change in the rainfall amount for these two months, PET values are expected to increase in all months of the year thereby relegating March and October to the moisture deficit category in Table 4. This would mean that soil degradation due to salinization and alkalinization could occur in eight months of the year instead of six as at present.

Apart from its role as a basic climatological parameter, temperature is a fundamental determinant of the rate of many physical, chemical and biological processes. Biological degradation is characterized by the decomposition of organic matter. The latest (1979) index for evaluating this process aims to combine the effects of temperature and moisture in the form:

$$\text{HI (the humolytic index)} = 1/12 \sum_{1}^{12} e^{ct} \times M$$

where:

c = 0.1065;
t = mean temperature for the month in degrees Celsius;
M = (P/PET) if (P/PET)<1, otherwise M = 1
where: P = precipitation in mm; and,
PET = evapotranspiration in mm.

Using the 1961 to 1990 annual means for temperature and rainfall and a PET for the whole year of 947.6 mm one would arrive at a Humolytic Index of 4.9. With an increase in temperature of 2 to 3 degrees; an associated increase in PET of 5 to 10%; and, a rainfall total of 553.3 mm, the index would rise to around 6.0 indicating an increase in the rate of biological degradation.

One further point must be considered namely the fact that there is an upward trend in the daily maximum temperature and a downward trend in the daily minimum temperature (see Section 2.1 above) in Malta, indicating a trend towards an increased diurnal temperature range. Wide temperature extremes are characteristic of desert climates and the impact of this trend on the soils of Malta has yet to be evaluated.

2.3. Hydrosphere

2.3.1. Background

Many climatologists today support the idea that the increase in concentration of carbon dioxide in the atmosphere due to the burning of the fossil fuels will result in an increase in the mean surface air temperature of the earth. The atmospheric concentration of CO_2 has already risen by about 25% since 1850. The concentration of three other radiatively active gases is also on the increase and may also contribute to this global warming: ozone in the lower atmosphere; nitrous oxide; and, methane. Prospects for reducing the rate of increase in atmospheric concentrations of these gases are unfortunately very low.

Man's influence on the climate and the impact of a climate change on the hydrological cycle is being studied under WMO's World Climate Programme. This major undertaking is providing valuable information, on the basis of which, the impacts on hydrological cycles in various parts of the globe may be assessed.

The report of the IPCC Working group I outlines various general circulation models and produced various scenarios of climate change. These models agree quite well in forecasting a modest increase in global mean surface temperature. Less consistent however are scenarios concerning the expected geographical distribution of changes in air temperature and the redistribution of precipitation. These are very complicated processes and only general conclusions can be drawn from existing climate models.

The objective of this section is to assess the impact of global climate changes on the hydrosphere of the Maltese Islands. The impacts on hydrology are potentially significant, and have serious economic implications. In order to assess these impacts the components of the hydrological cycle of the Maltese Islands are considered in detail.

2.3.2. The hydrological cycle

The availability of natural water in any locality depends on the local hydrological cycle which determines the nature of the various processes by which the inputs and losses of water occur. This cycle is largely influenced by climate and the catchment characteristics of the locality concerned (Figure 37).

Despite the arid superficial appearance of the Maltese Islands, the local catchment characteristics are very favourable for the storage of rainwater. The hydrological cycle provides a generous supply of freshwater which undoubtedly contributed to the early settlement of the islands. Natural freshwater resources account for around 37% (45,500 m^3 day^{-1}) of all potable water in the public supply, the rest being derived from expensive desalination plants. Natural supplies also account for about 84% (17,300 m^3 day^{-1}) of all irrigation water. The economic value of these resources is therefore substantial and the identification of ways in which they can be more effectively managed and used to achieve improvements in the social welfare of the Island has always been a priority of every governing body as early as the first settlement of the Knights of St. John. Where possible, the catchment characteristics have been modified by the construction of dams and water development has been managed to maximize the economic benefit.

The hydrological cycle of the Maltese Islands is relatively simple (Figure 38) and can be described in terms of a few basic processes:

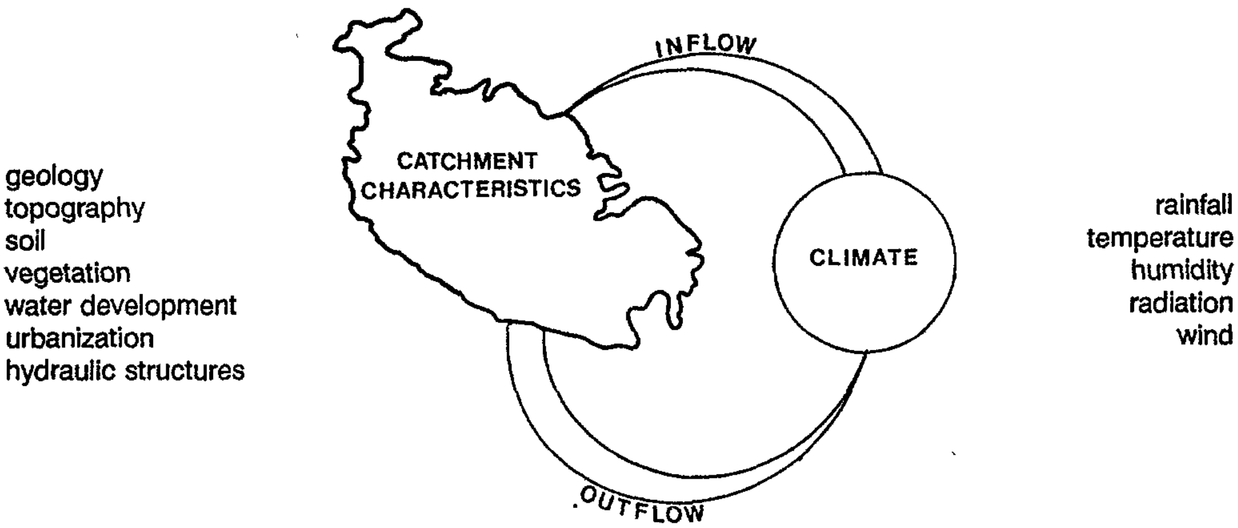

Figure 37 - Diagrammatic representation of the components of the hydrological cycle

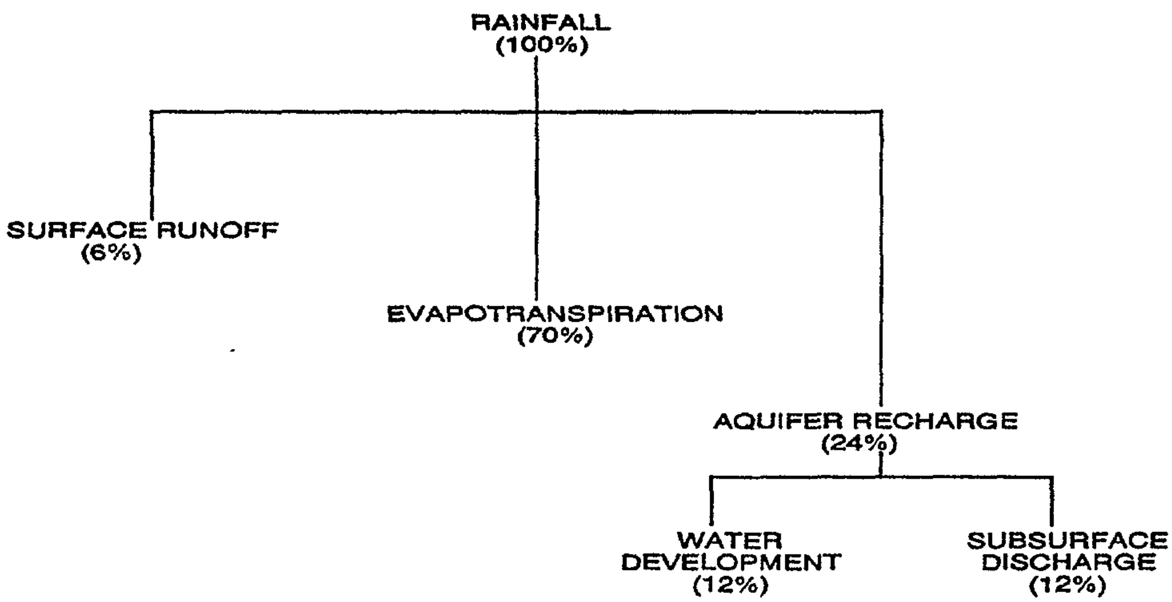

Figure 38 - Freshwater budget for the Maltese Islands

- climate determines the distribution and availability of rainfall which is the only significant source of water in the cycle;

- a small percentage (6%) of this water is lost directly to the sea as surface run-off; geology, topography, urbanization and dams determine the extent of run-off which contrary to public opinion is only of minor significance;

- the rest of the rainfall percolates through the ground where it is partly retained by the soil; retained water is eventually lost to the atmosphere by evaporation from the soil surface and by transpiration from the vegetation; evapotranspiration losses, which amount to about 70% of the total precipitation, are largely determined by the nature of the soil, vegetation cover and climatic factors such as humidity, wind, temperature and solar radiation;

- water that percolates through the root-zone (24%) drains through the fissures and fractures in the rock formations until it reaches the aquifers as recharge water; irrigation and leaks in the water distribution system also contribute to groundwater recharge; and, the characteristics of these natural underground stores of water are largely controlled by the local geology; and,

- recharge water is eventually extracted from the aquifers by local water development practices and some is ultimately returned to the sea by natural subsurface discharge along the coast.

Climate determines the quantities and distribution of rainfall which is the primary source of natural water in the cycle. Rainfall is particularly important in the hydrological cycle of small islands such as Malta where the possibility of obtaining water from distant areas via rivers does not exist. Other minor sources of water are dew, and recycling through leakages in the public supply and irrigation.

Malta enjoys a Mediterranean climate with well defined seasons. The mild, wet winter is invariably followed by a long dry summer. The rainy season proper, starts in October when rainfall is heavy, and continues through November, December and January when the bulk of the rainfall occurs. Since rainfall has been the only source of potable water until recently, this rainfall pattern is very significant and daily rainfall records have been kept systematically for nearly 150 years. Official rainfall records started in 1840 with one station at Valletta and an average annual precipitation of 553 mm has been recorded over this period. At present there are 128 stations scattered across Malta and 7 stations in Gozo. The distribution of precipitation for the period 1950-1970 is shown in Figure 39.

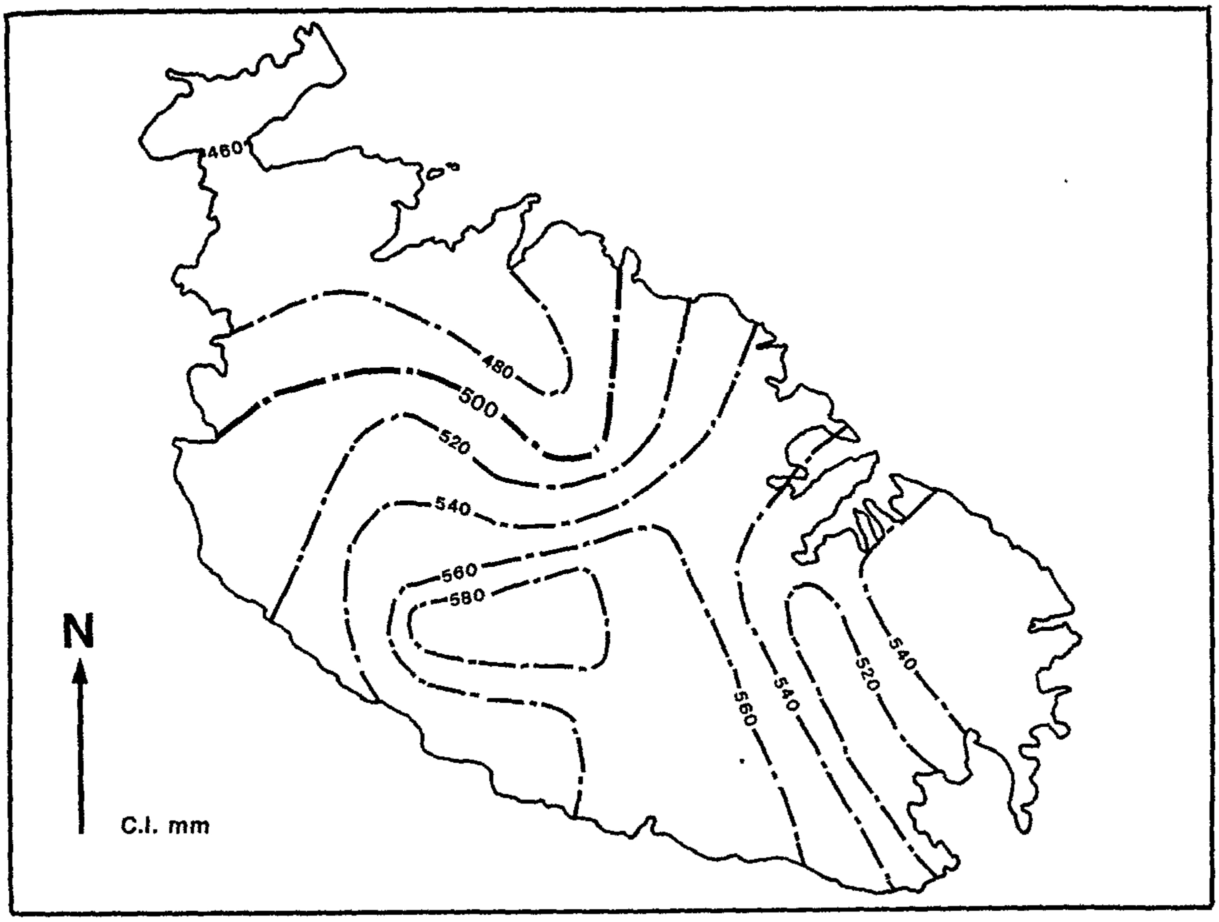

Figure 39 - Isohytal map of Malta (1950-1970)

Freshwater surface run-off to the sea is comparatively small due to: favourable topography; high water storage capacity of the soil; high infiltration into the rocks; and run-off interception by numerous dams and cisterns.

Structurally, Malta slopes gently to the east giving rise to a topography that is high along the western shores and reaching down to sea level along the eastern shores. This results in surface drainage lines crossing the entire width of the Island from their source close to the western shore, before entering the sea on the east. This provides the surface water, with maximum opportunity to seep into the ground and thus minimizes run-off losses to the sea. Only about 6% of the total precipitation, measured over many years by run-off recorders located at the exit points of major drainage areas such as Burmarrad, Msida and Marsa, finds its way into the sea.

Most run-off occurs following heavy downpours when temporary surface water flows along the beds of major valleys for a few days at most. To retain this storm discharge a large number of dams have been constructed across the drainage lines (Figure 40). Open reservoirs have also been constructed along recently made roads to minimize run-off.

A large number of private cisterns constructed to hold water for use in irrigation during the dry season, also reduce the surface run-off. In addition, every house in Malta has, by law, a water cistern for storage of rainwater.

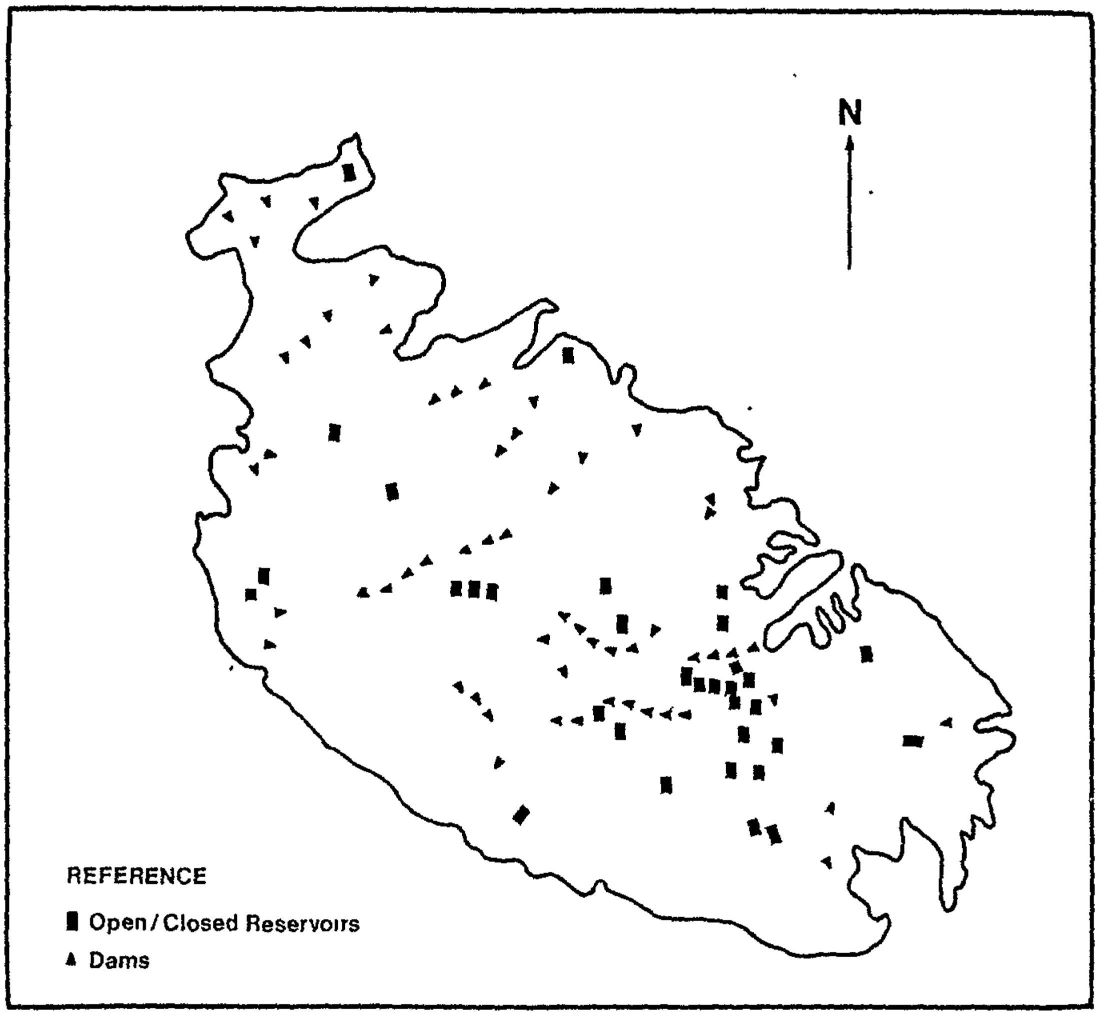

Figure 40 - Location of storm water dams and reservoirs on the island of Malta

Most of the land surface of Malta is covered by a thin layer of soil which has a relatively high water storage capacity. This is the major source of water loss in the hydrological cycle since all the water that is retained in the soil is ultimately lost to the atmosphere by evapotranspiration. Infiltration of rainwater into the underlying rocks only occurs when the entire storage capacity of the soil is exceeded. Evapotranspiration losses are not constant across the island but vary with topography, soil characteristics, exposure and land use.

Areas with a shallow water-table, such as those at Marsa and Burmarrad, where the aquifer is located just below the root-zone, have high evapotranspiration rates. Despite the small size of the islands the topography is relatively high and low lying catchment areas such as these are few. There are also large tracts of land with barren rocky outcrops or a thin gravel cover with sparse vegetation. Here rainwater enters the ground directly, with little retention, and evapotranspiration losses are very low. Vegetation accelerates the process of evapotranspiration and the intensive use of land for agriculture in certain areas contributes to high water loss.

Climatic factors such as temperature, humidity, hours of sunshine and wind intensity have a decisive influence on evapotranspiration losses. Temperature ranges from a minimum of 6 ° C in winter to a maximum of 32 °C in summer, whereas the daily sunshine hours range from 5.1 in December/January to 12.6 hours in July (Figure 41).

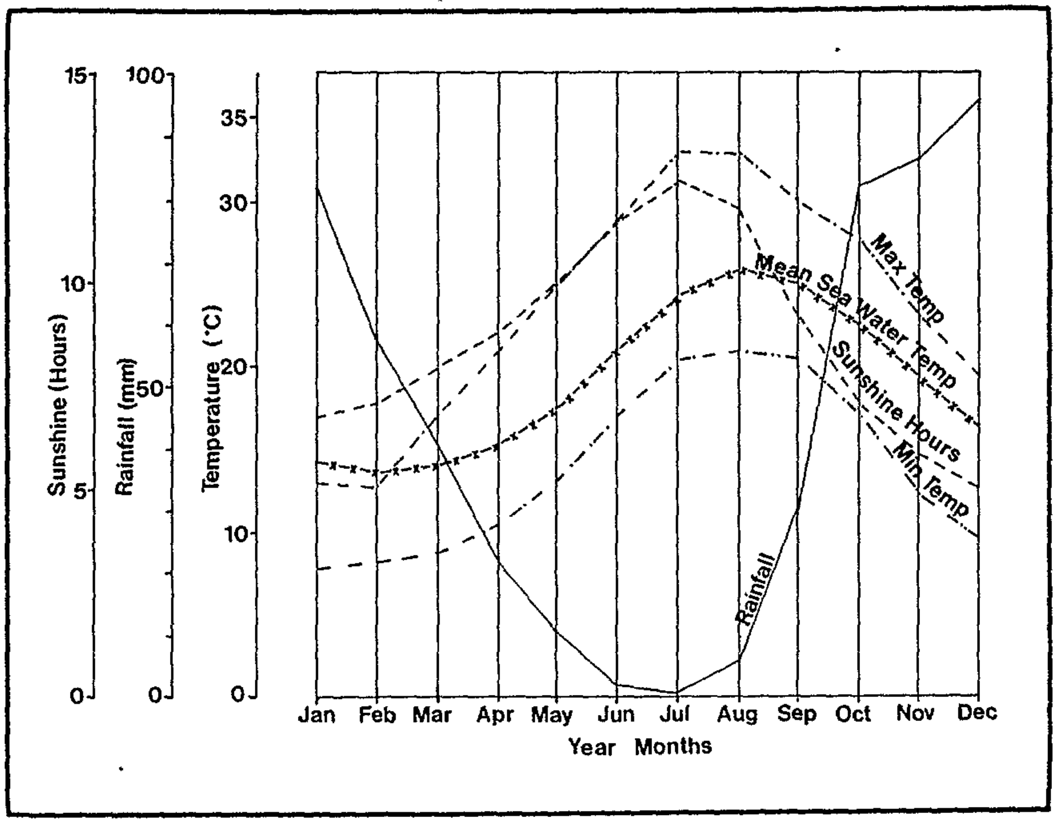

Figure 41 - Monthly variation in various meteorological parameters for Malta

2.3.3. Aquifers and groundwater resources

Geologically, the Maltese Islands are made up of a simple succession of five gently dipping calcareous layers of Miocene Age. Taken as a whole this structure provides particularly favourable conditions for the infiltration of rainwater and its underground storage in two main aquifers: the perched aquifer; and, the mean sea level aquifer (Figure 42a).

(a) The perched aquifer

This aquifer is contained in the porous Upper Coralline Limestone which lies directly above the impervious Blue Clay. It is also sometimes found in the permeable Greensand which is located in some areas at the base of the Upper Coralline Limestone.

(b) The mean sea level aquifer

This is by far the most important aquifer and accounts for 98% of all potable groundwater on the Islands. It lies in the pores and fissures of the Lower Coralline and Globigerina Limestones located at sea level. This body of fresh water is in the form of a "lens" with the thicker part situated in the central region of the island where presently it reaches a height of 4 m above mean sea level. This height reduces gradually towards the coast where it finally levels off to zero. The aquifer "floats" on underlying saline water by virtue of its lower density. The lens exists as a consequence of the fact that each winter the rainwater that percolates through the ground beyond the root zone adds more freshwater than can be dissipated by direct discharge to the sea at the coast. It is best defined by the Gheyben-Herzberg model with the base of the "lens" being at a depth below sea level, 36 times its height above sea level (Figure 42b).

(c) Other aquifers

A number of smaller aquifers of secondary importance such as those at Marfa Ridge, Mizieb Valley, Mellieha Bay and Pwales Valley are found in the north of Malta, north of the Victoria Fault Line. These are mostly semi-confined sea level aquifers contained in the Greensand and Upper Coralline Limestone at sea level. Perched aquifers also exist at Mellieha Ridge and Mgarr-Wardija Ridge. These small disjunct aquifers are not large enough to warrant economic, large scale exploitation and are exclusively used by the local farmers for irrigation water.

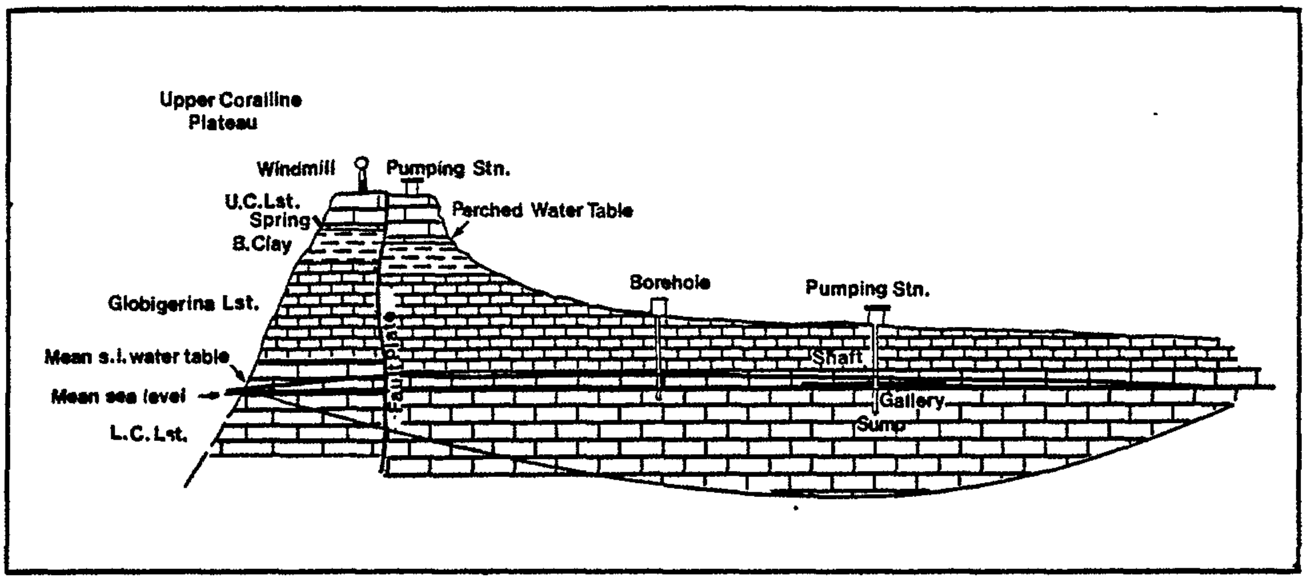

Figure 42a - Section Across Malta Showing the perched and the mean sea level aquifers

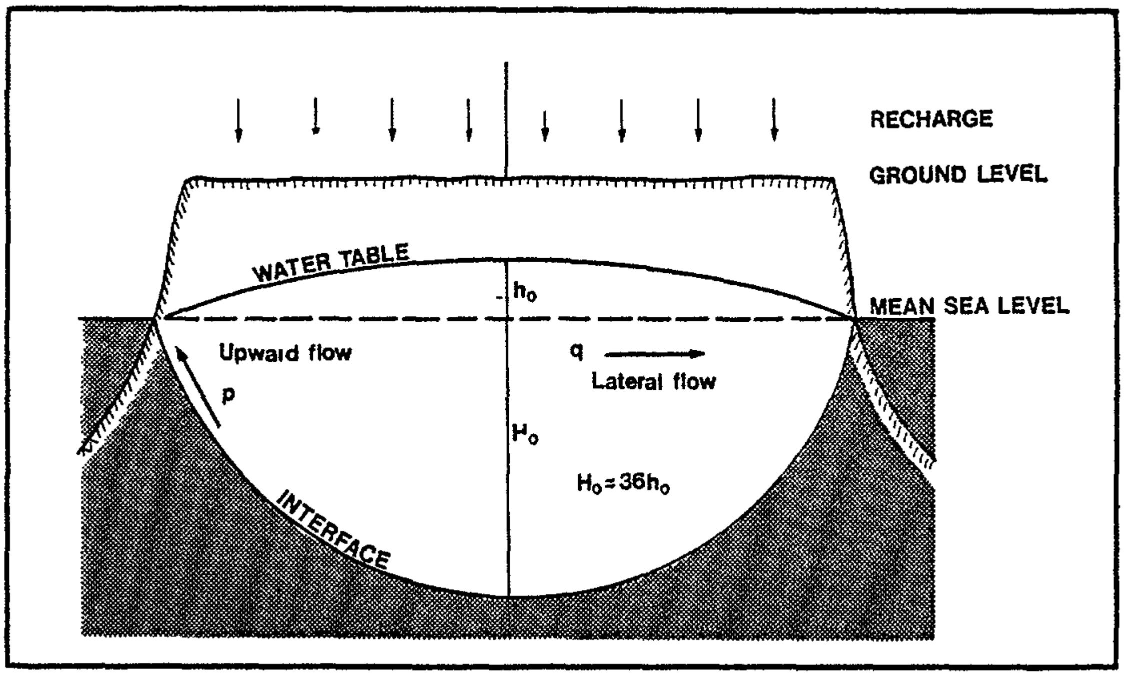

Figure 42b - Schematic cross section of a mean sea level aquifer

2.3.4. Water resource development

Extraction of fresh groundwater from the aquifers accounts for about 37% of all potable water on the Islands, the remainder being produced by desalination plants. 98% of this natural groundwater is extracted from the mean sea level aquifer and 2% from the perched aquifer.

Production from the mean sea level aquifer has reached the maximum safe limit and amounts to some 10 million gallons a day (45,500 m^3 day^{-1}). Extraction is achieved by means of a system of 36 kilometers of underground galleries located at about sea level together with a complex network of around 100 boreholes spread across the Island (Figure 43). The galleries are excavated into the rock from which the freshwater seeps out and is channelled to central sumps under gravity. The water is chlorinated in the sumps before being pumped to surface reservoirs for subsequent distribution. In the case of boreholes, these are drilled to a depth within the aquifer where water collects, is chlorinated, and pumped to surface reservoirs.

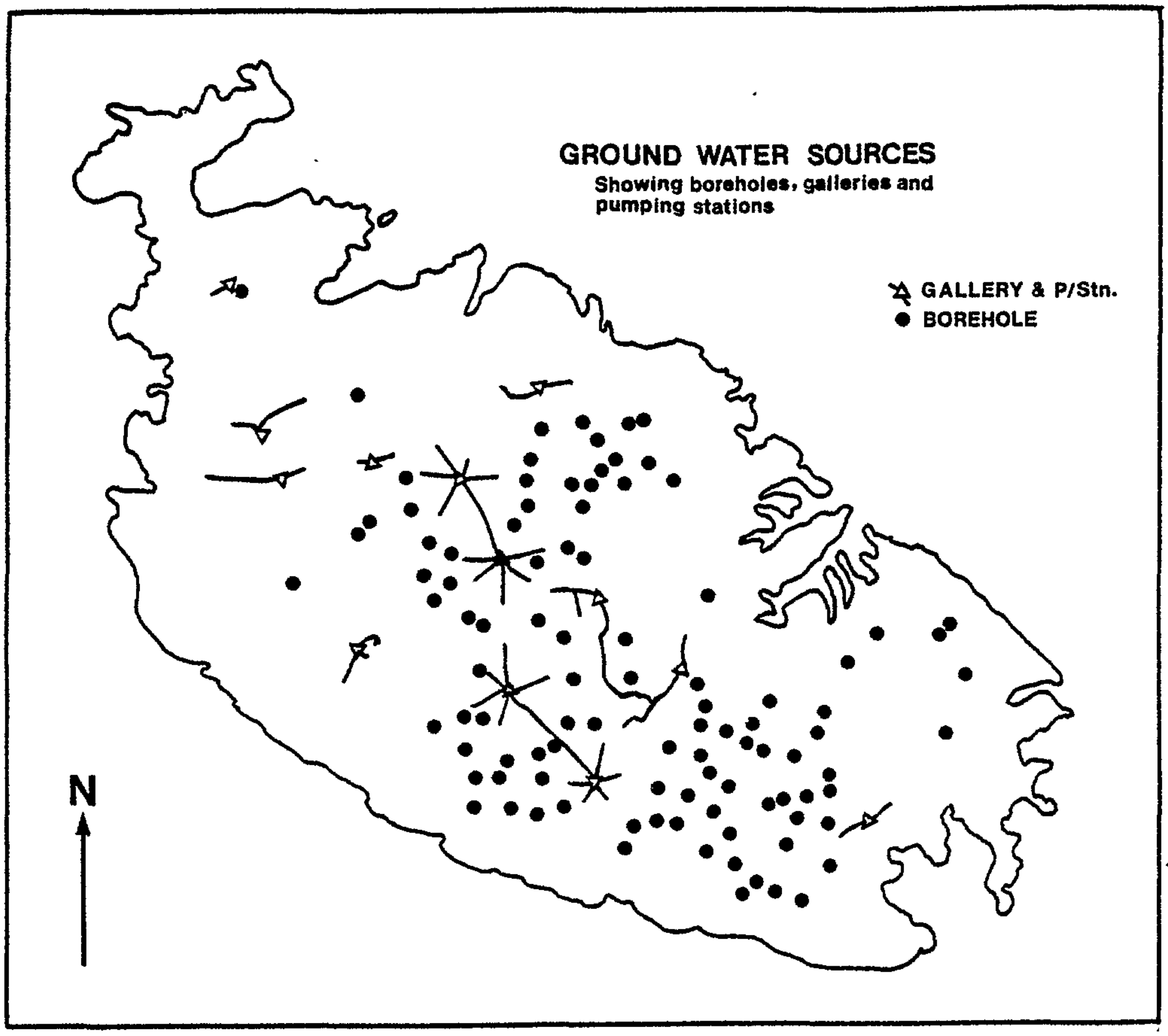

Figure 43 - Groundwater extraction points on the island of Malta

Private extraction by farmers exploits the perched aquifer almost to the full, leaving only about 250,000 gallons daily (1,100 m^3 day^{-1}) for drinking water supply which is extracted from 4.2 kilometers of galleries excavated at the base of the aquifer.

The recharge water that reaches the aquifer flows away more or less horizontally and that which is not extracted by means of galleries and boreholes, continues its outward journey to the coast where it is finally discharged into the sea. This outflow of freshwater into the sea takes place all around the coast of the Islands. In Malta, the major coastal springs are located at Burmarrad, Marsa, Msida, Marsaxlokk Bay, Blue Grotto, Fomm ir-Rih, St. Paul's Bay, Mistra and Mellieha Bay (Figure 44). An upward flow of freshwater also occurs at the fresh-saltwater interface resulting in coastal discharge from the aquifer via submarine springs.

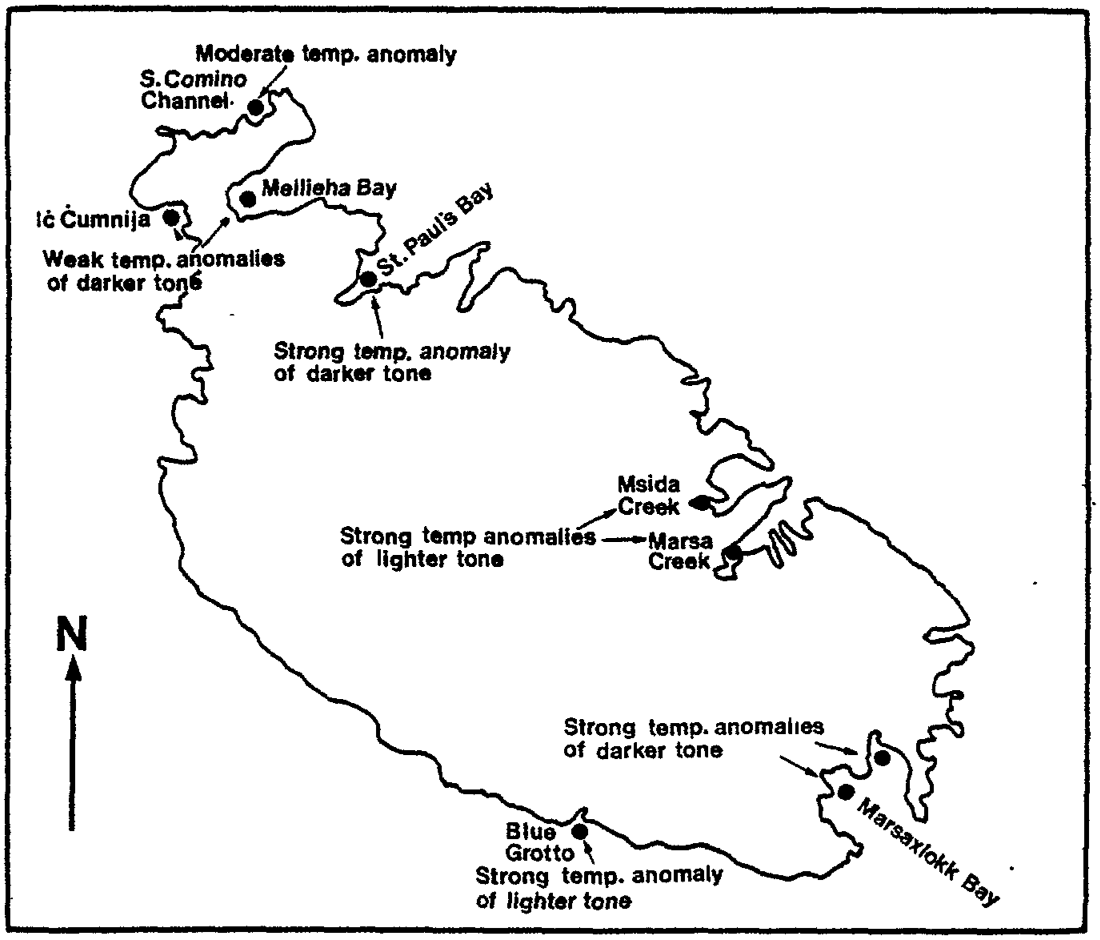

Figure 44 - Major subsurface discharge points around the coast of Malta

2.3.5. Impacts of a climatic changes and sea level rise

Global warming will affect the hydrological cycle in two ways, firstly through changes in sea level and secondly through the climatic changes themselves. While assessing the impacts of sea level rise is rather straightforward, assessing the impacts of changes in climatic factors is more complicated. This results from the difficulty of evaluating the complex regional variations in atmospheric conditions as the global climate changes, which gives rise to uncertainties in predicted changes in local climates, particularly in terms of precipitation.

This assessment is based on IPCC's Business-as-Usual Scenario-A combined with the University of East Anglia sub-grid scale scenarios of climatic change for the Central Mediterranean. This combination gives best estimate scenarios of a rise in sea level of 65 cm by the year 2100 and only a slight, if any, change in total annual precipitation.

2.3.5.1. Rise in sea level

Most climate models predict a rise of between 3 and 5 °C in the global mean surface air temperature by the end of the next century. The poles will however warm considerably more than the global mean and some land based ice at high latitudes may melt. Together with thermal expansion of the surface waters of the oceans this will result in a rise in sea-level of between 0.3 and 1 metres by the year 2100 with a best estimate of 65 +/- 35 cm. This means that all aquifers located at sea level will be affected.

Since the main aquifer in Malta is located at sea level the potential impacts of a rise in mean sea level is of major concern and has considerable implications for the development of water resources on the Island. The most important effect is that a rise in sea level will put the majority of the 40 km. of galleries in Malta at a level that is no longer optimal for the safe extraction of fresh groundwater. As a result the extraction of groundwater from these galleries will become more prone to seawater intrusion depending on the extent of the rise in sea level. A rise of 1 m will force a reduction in production by as much as 40% in order to maintain a safe extraction rate.

The major economic benefit of extracting groundwater from galleries compared with other methods of extraction would therefore be lost. At present 50% of all groundwater extraction is via such galleries hence the magnitude of this problem is great. To compensate for this loss three solutions could be applied:

- drill more boreholes at an estimated capital cost of about 0. 6 million Maltese Lira in today's money;
- undertake structural alterations to the galleries; the price of this is prohibitive for a large rise in sea level; and
- substitute the lost production by means of desalinated water at an estimated cost of 3 to 5 million Maltese Lira per year.

The impact on groundwater boreholes is less pronounced. The effective depth of the boreholes within the aquifer would be increased by the rise in sea level and hence they will reach deeper into the lower saline parts of the aquifer. Corrective measures are relatively simple and cheap in this case and consist of plugging the bottom saline levels of the boreholes with cement. Production rates could remain relatively unaffected by this correction.

Because of favourable topography, the impact of a 1 meter rise in sea level on the catchment area is negligible hence there will be no reduction in the recharge rate from this cause.

2.3.5.2. Change in local climate

Climatic factors influencing the hydrological cycle include precipitation, radiation, temperature, humidity and wind. By and large the most significant factor is precipitation and the impacts of changes to this component of the hydrological cycle are the most significant.

Although there is no state-of-the-art climate model that can accurately predict the redistribution of precipitation on a local scale, tentative and approximate scenarios of changes in annual precipitation in the Northern Hemisphere have been published. For the Central Mediterranean, the following scenarios (Table 7) for the area around Malta have been produced by the Climatic Research Unit of the University of East Anglia:

TABLE 7

Rainfall scenarios for the central Mediterranean region around Malta

GLOBAL WARMING	CHANGE IN THE NORM OF PRECIPITATION	YEAR
1.0 C	0 cm	2000
1.5 C	0 cm	2025
3.0 C	little change	2050
4.3 C	little change	2100

According to these forecasts, no appreciable change in precipitation is expected before 2025, following which, only small changes in total annual precipitation are suggested.

The relationship between run-off, evapotranspiration, aquifer recharge and precipitation are not constant but change with the annual quantity and seasonal pattern of precipitation. The small changes in absolute volumes of rainfall suggested by these scenarios would suggest correspondingly small changes in the run-off, evapotranspiration and recharge components of the hydrological cycle.

The problem of assessing possible changes in evapotranspiration rates which might be attributed to changes in other meteorological variables such as solar insolation, temperature, humidity and wind is more difficult and the results even less reliable. However, it is likely that the impact of changes to these variables will be much less pronounced than the impact of changes in precipitation. Considering the low level of confidence in scenarios of future precipitation, no accuracy is lost by neglecting them in this assessment.

2.4. Atmosphere

2.4.1. Introduction

The atmosphere is defined as the envelope of air that surrounds the earth and is held in place by gravity. It sustains life, including that of humans, and contains the air we breathe. From it falls the water we drink and through it passes the life-producing energy of the sun.

Understanding the mysteries of the atmosphere was already a goal of pre-Socratic Greek philosophers and scholars. But only as late as the 18th century did scientists such as Priestley, Lavoisier and Cavendish prove that the major constituents of the atmosphere are nitrogen and oxygen with lesser amounts of water and carbon dioxide. Thereafter many prominent chemists and physicists documented the presence of the noble gases as well as small quantities of methane, hydrogen, ozone, carbon monoxide, the oxides of nitrogen, sulphur dioxide and hydrogen sulphide. The ions of nitrate, sulphate, chloride and ammonium dissolved in rainwater, were also subsequently discovered. It is now well established that the atmosphere acts as a reservoir for a multitude of trace gases and small liquid and solid particles other than water. Some of these are of natural origin, but many are man-made. Some of these components have an impact on the environment, despite their relatively low concentrations. Some gases, because of their toxicity, affect plant, animal and human life; others influence climate. Small dust particles and aerosols, filter out sunlight and can affect cloud formation, precipitation patterns and the chemical composition of rain.

The atmosphere is a self-renewing resource. The oxygen we use is in ample supply and is continuously replaced through photosynthesis at the expense of carbon dioxide. Precipitation, acts to cleanse the atmosphere of undesirable gases and dust particles but some of these gases and particles dissolve in the cloud and rainwater, altering their chemical composition resulting in acid rain. Cleansing of the atmosphere is not always achieved before the gases and particles interact with sunlight, causing decreased visibility and increased atmospheric turbidity which reduces its transparency to visible radiation. It is now well recognised that the environment can be seriously and dangerously affected by increasing industrial production and individual consumption.

The atmosphere and the ocean interact at the sea surface through fluxes of momentum, heat and moisture across the air-sea interface. In addition the oceans play a key role in determining the earth's climate. Indeed any possibility of predicting the evolution of weather systems beyond a few weeks requires that ocean behaviour be taken into account.

When it is heated the ocean responds by storing some of the heat and by increased evaporation. Ocean surface waters are mixed, down to a depth of some metres by wind, thus heat is transported downwards in the water body and consequently the surface temperature rises much less than that of dry land under the same heating conditions. Evaporation of surface water has profound effects on the atmosphere and on climate. Water vapour released into the atmosphere increases the greenhouse effect and when it recondenses, sometimes far from where it evaporated, the resultant heating of the air is a major source of energy for atmospheric motion.

2.4.2. Analysis of past trends in atmospheric conditions

That the composition of the atmosphere around us is changing is now an accepted fact. The fact that such changes to atmospheric composition may also be affecting both the climate and the environment of Malta is to some extent borne out by the results of the analyses outlined in section 2.1 above.

Although measurements of the proportion of atmospheric constituents around Malta are not available because continuous monitoring of atmospheric composition has not been carried out, some plausible conclusions concerning changes may be deduced from an analysis of relevant, available, meteorological data. Data concerning cloud cover, relative humidity, atmospheric pressure and the number of hours of bright sunshine were analyzed and compared over the length of existing records in an attempt to elucidate what changes, if any, are occurring in the atmosphere around Malta. Ten year running means were calculated for all data in order to try and reduce the noise to signal ratio. Following this, regression analyses were carried out on the data to identify the presence or absence of trends in the selected parameters.

The hours of bright sunshine for the years 1947 to 1991 have been recorded regularly at Luqa by means of a Campbell-Stokes recorder. The mean annual total number of hours of bright sunshine for Luqa from 1947 to 1991 and from 1964 to 1991 were then used to derive the 10 year running means for different times of day and seasons of the year which are plotted in Figures 45 - 55. Plots for the period 1964 to 1991 were produced (Figures 45 - 51) in order to make direct comparisons with the more limited data set for relative humidity (see below).

An analysis of the annual total of bright sunshine hours shown in Figure 54 demonstrates a marked downward decline over the period of record. It is evident that this trend apparently contradicts the trend in cloud cover over the same period (Figures 55 - 59). Since cloud cover is decreasing, one might expect that the number of bright sunshine hours should be increasing, but on the contrary the reverse is apparently occurring. A factor other than changes in cloud cover must therefore be causing the decrease in number of bright sunshine hours.

The sunshine data were examined in more detail in terms of the daily pattern of bright sunshine hours. Running means were calculated for the total number of hours of bright sunshine:

- between dawn and 0900 local apparent time;

- between 0900 and 1500 local apparent time; and,

- between 1500 and dusk local apparent time.

and plotted against year. The three graphs (Figures 52 - 54) all have negative gradients of -2.98, -2.19 and -3.47 respectively. Whilst all three trends are significant that for the period 1500 onwards is greatest followed by that for the period up to 0900.

To find out whether the decrease in the number of bright sunshine hours was due to water vapour in the lower troposphere near the surface of the earth, the values of the relative humidity taken at 0600, 1200 and 1800 UTC were analyzed for each season of the year.

Relative humidity values for Luqa are available for the period 1951 to 1991. The plot of monthly average relative humidity for the period 1951-1991 shows a marked discontinuity between 1963 and 1964. This is due to the fact that the siting of the screen was changed to the present one in June 1963. Consequently, only the data from 1964 to 1991 were used to derive the graphs of relative humidity presented in Figures 61 - 65 which can be directly compared with the sunshine record plotted in Figures 45 to 51.

Figures 61 to 65 covering the period from 1964 to 1991, show significant downward trends in relative humidity during all hours of the day and particularly during spring, summer and autumn. This trend is most marked at 1200 and 1800 UTC during spring and summer. This would lead one to conclude that the decrease in the hours of bright sunshine is not due to an increase in the water vapour content in the atmosphere near the surface of the earth.

Cloud cover is observed every half hour at Luqa and is recorded in octas (eights). The values used to derive the 10 year moving means which are plotted in Figures 56 - 60 are based on the mean monthly values taken at Luqa for the period 1951 to 1991. Monthly mean values are derived from the three hourly synoptic observations carried out at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 UTC.

All the figures display a trend towards lower cloud cover during daylight hours; particularly between 0600 and 1500 UTC in winter; between 0600 and 1800 UTC in spring and autumn; and, between 0300 and 1800 UTC in summer.

2.4.3. Conclusions concerning future atmospheric conditions

A possible cause for these trends could be an increase in the density of suspended particles in the atmosphere which is significant enough to affect the transparency of the atmosphere, especially at low elevations of the sun. An increase in dust and smoke particles of a size comparable with, or larger than the wavelength of light could be scattering or reflecting, infra-red radiation from the sun as it passes through the earth's atmosphere. Such an increase in dust/smoke particles may be due to a number of factors including atmospheric pollution.

If pollution is indeed the cause of the observed trends then this would explain the fact that the trend is steepest for the afternoon following daytime working hours. The effect of pollution is also apparent during the period 0900 to 1500 local apparent time but it is not as marked as that when the sun's elevation is low, that is before 0900 and after 1500.

The results of these analyses lead one to conclude that an increase in atmospheric pressure (Figures 26, 27, and 65) reflecting an increase in anticyclonic conditions is leading to more low level temperature inversions. These inversions trap suspended particles including pollutants, in the lower troposphere. Such particles are not easily dispersed by the wind because of the slack pressure gradient associated with most anticyclonic situations. An increase in the turbidity of the atmosphere could therefore be one of the consequences of the change in the climate that is being experienced at our latitude.

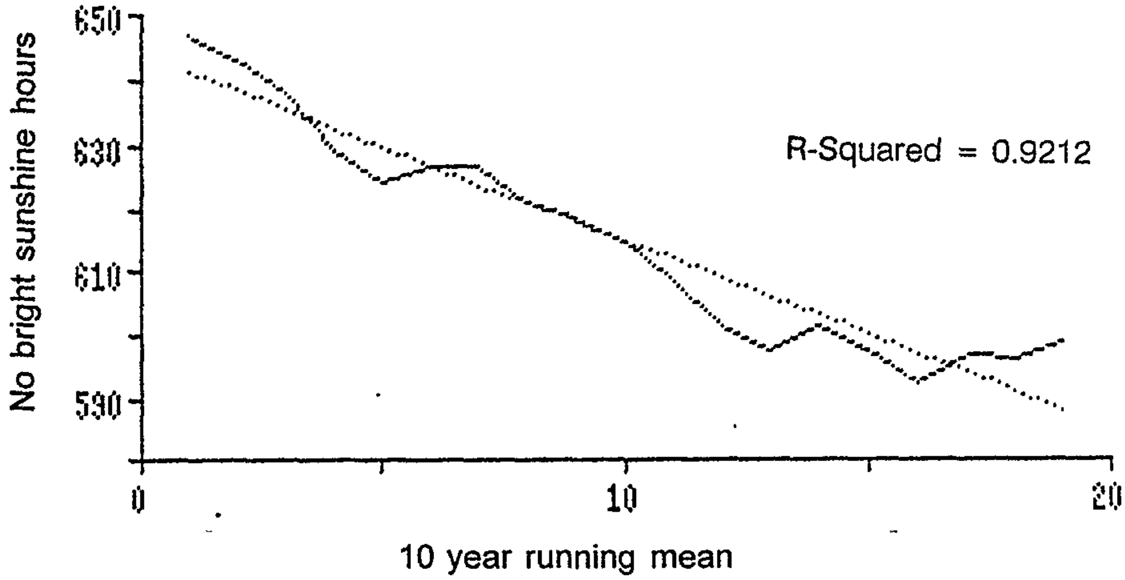

Figure 45 - Ten year running mean totals of bright sunshine hours
experienced between dawn and 0900 hours local time, over the period 1964 to 1991 at Luqa

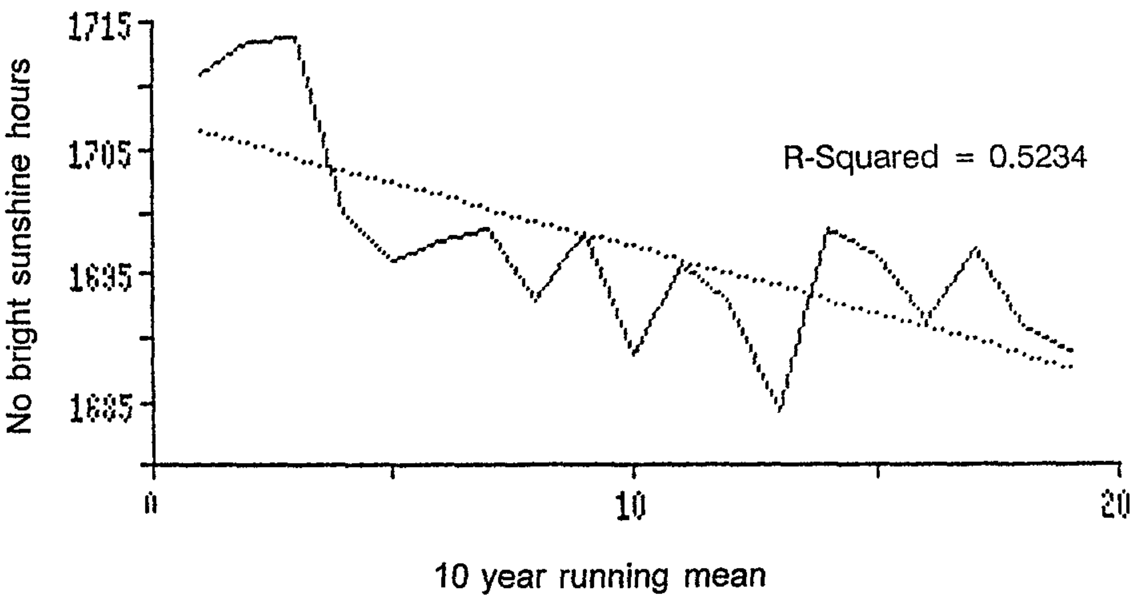

Figure 46 - Ten year running mean totals of bright sunshine hours
experienced between 0900 and 1500 hours local time, over the period 1964 to 1991 at Luqa

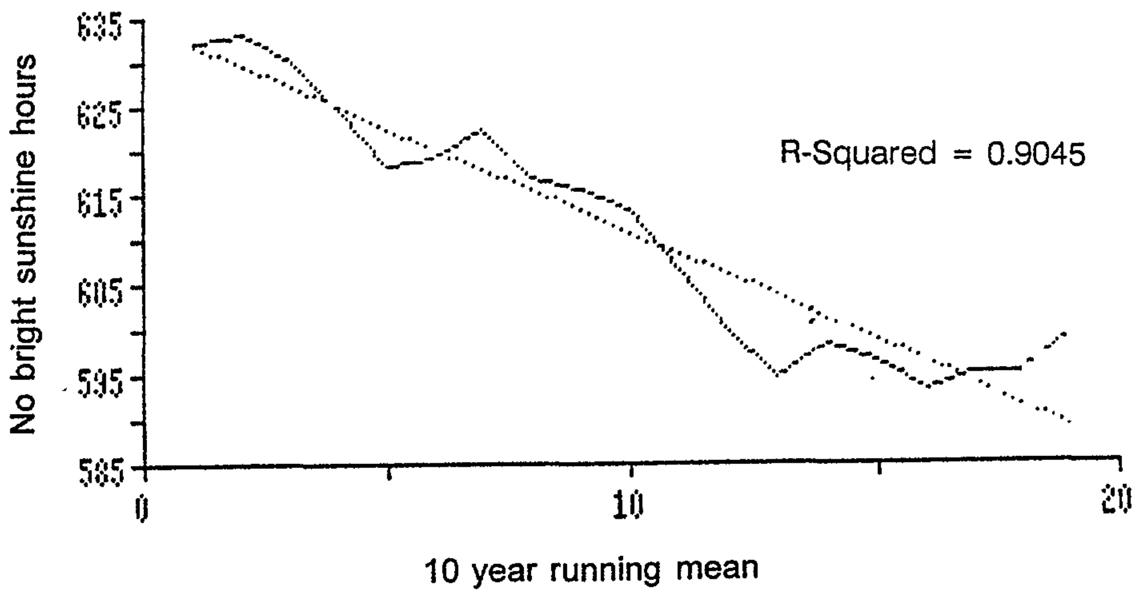

Figure 47 - Ten year running mean totals of bright sunshine hours experienced between 1500 hours and dusk, local time, over the period 1964 to 1991 at Luqa

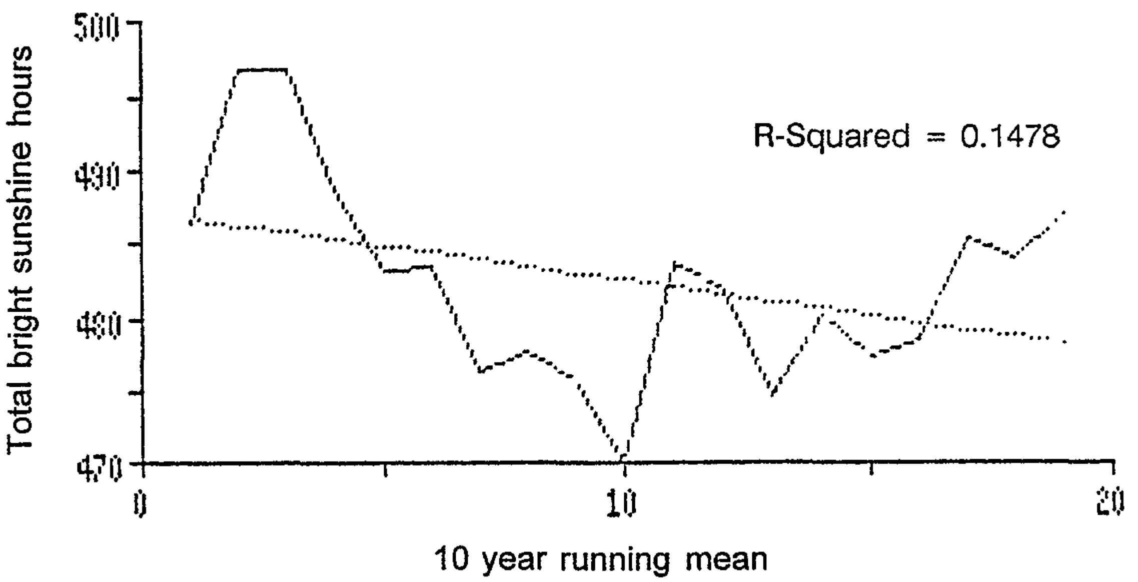

Figure 48 - Ten year running mean totals of bright sunshine hours experienced during winter, over the period 1964 to 1991 at Luqa

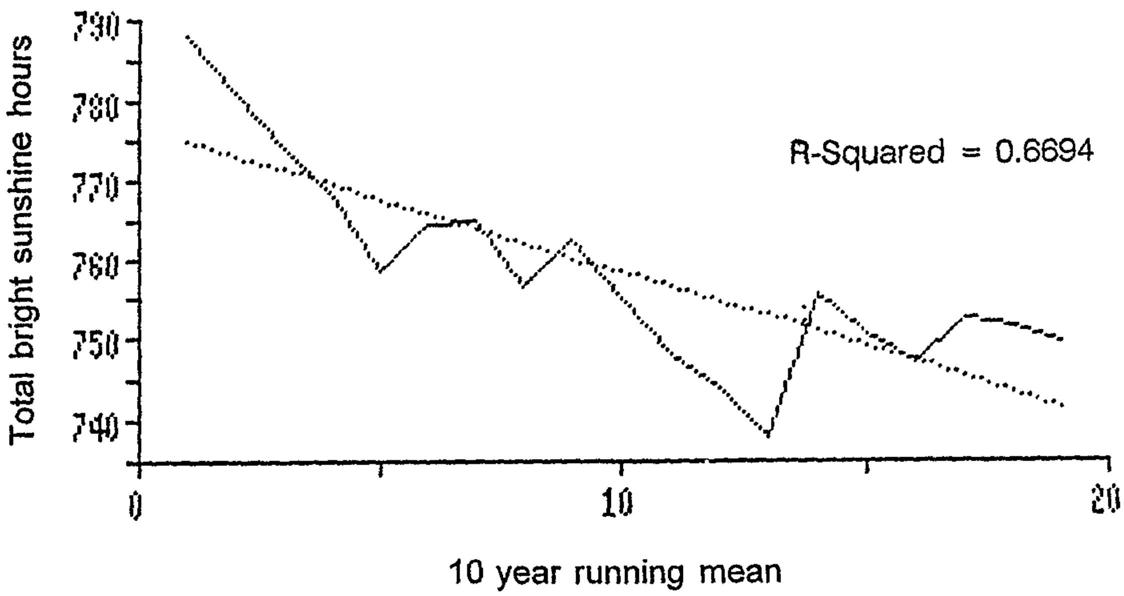

Figure 49 - Ten year running mean totals of bright sunshine hours experienced during spring, over the period 1964 to 1991 at Luqa

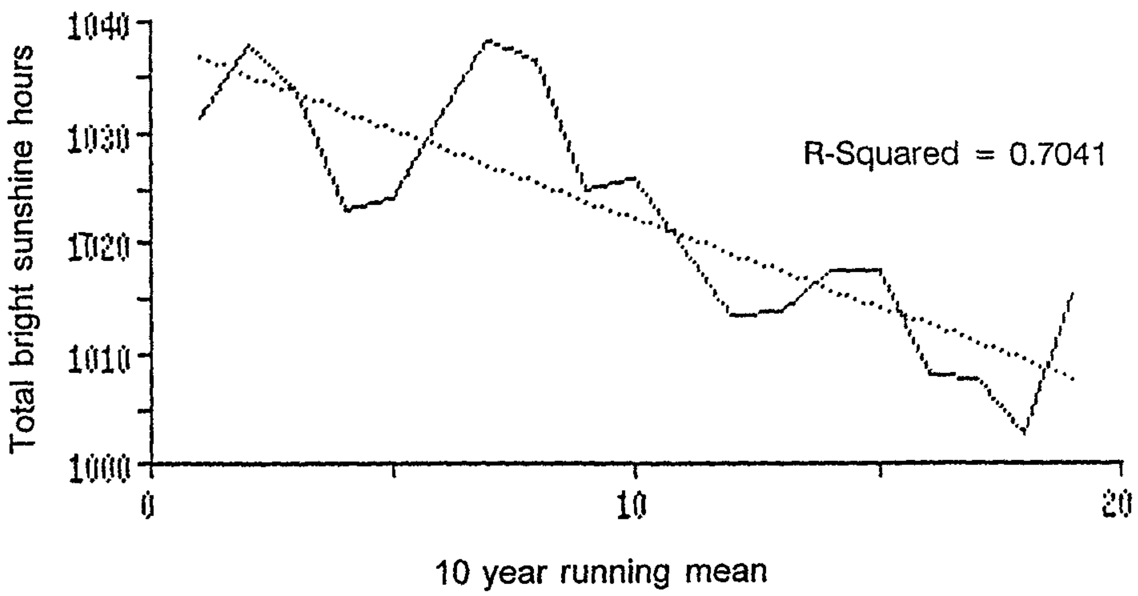

Figure 50 - Ten year running mean totals of bright sunshine hours experienced during summer, over the period 1964 to 1991 at Luqa

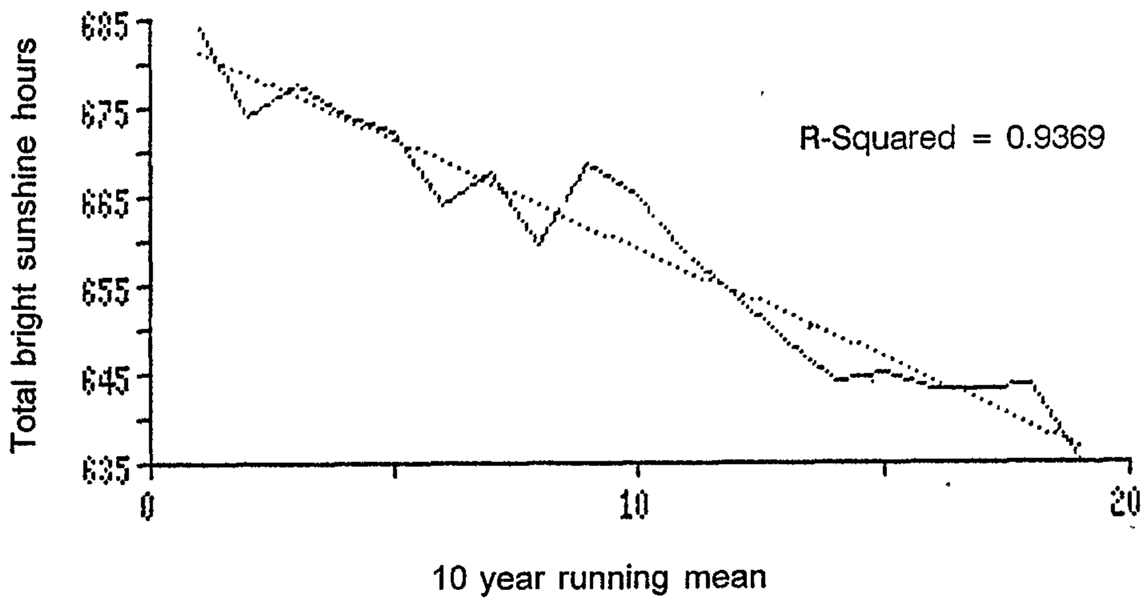

Figure 51 - Ten year running mean totals of bright sunshine hours experienced during autumn, over the period 1964 to 1991 at Luqa

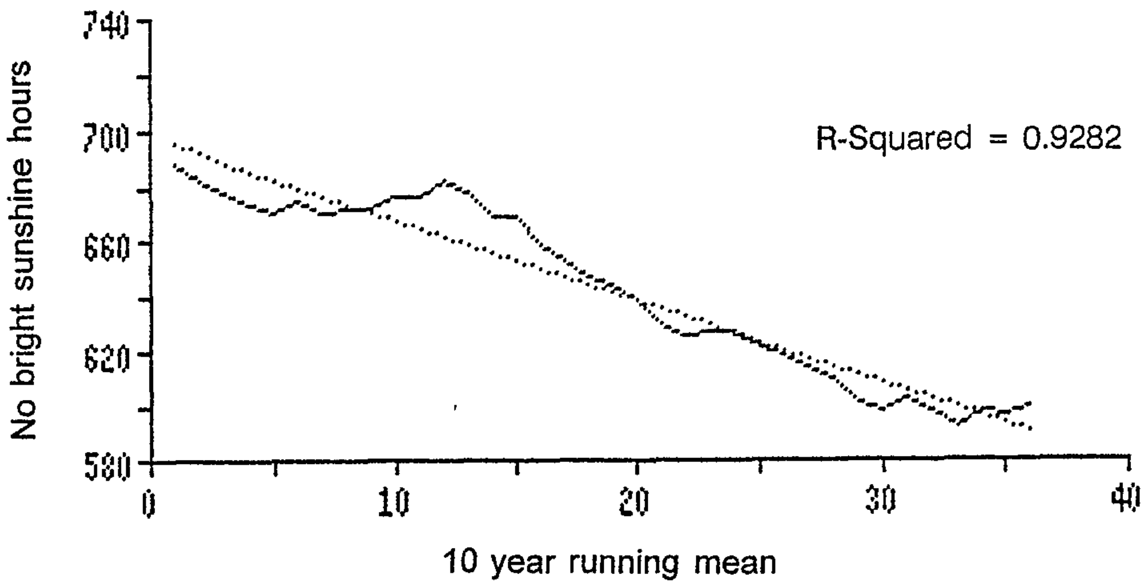

Figure 52 - Ten year running mean totals of bright sunshine hours experienced between dawn and 0900 hours local time, over the period 1947 to 1991 at Luqa

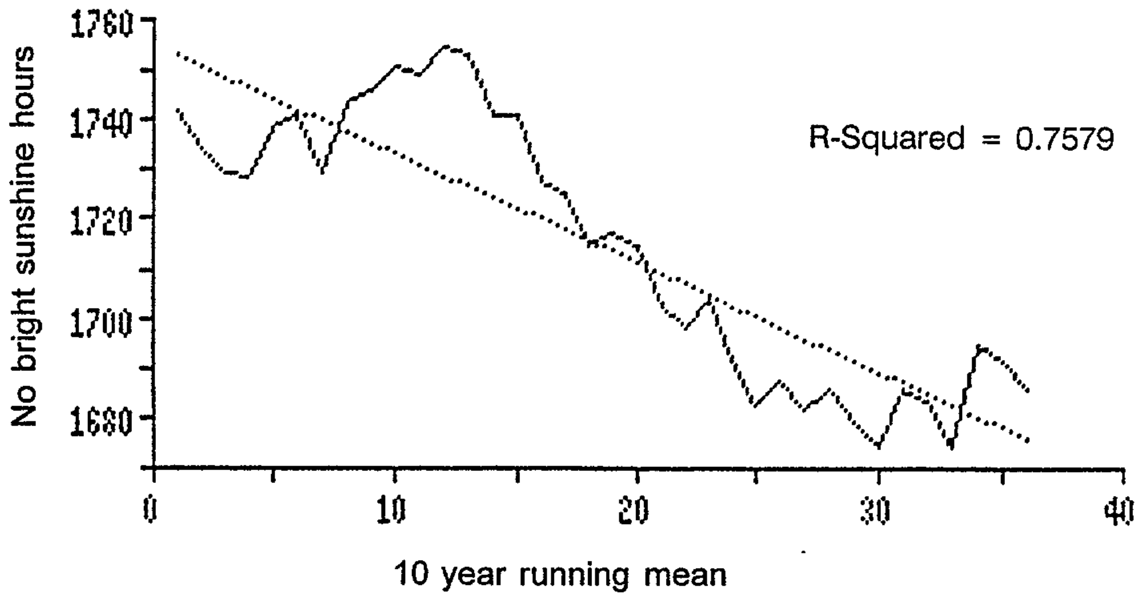

Figure 53 - Ten year running mean totals of bright sunshine hours experienced between 0900 and 1500 hours local time, over the period 1947 to 1991 at Luqa

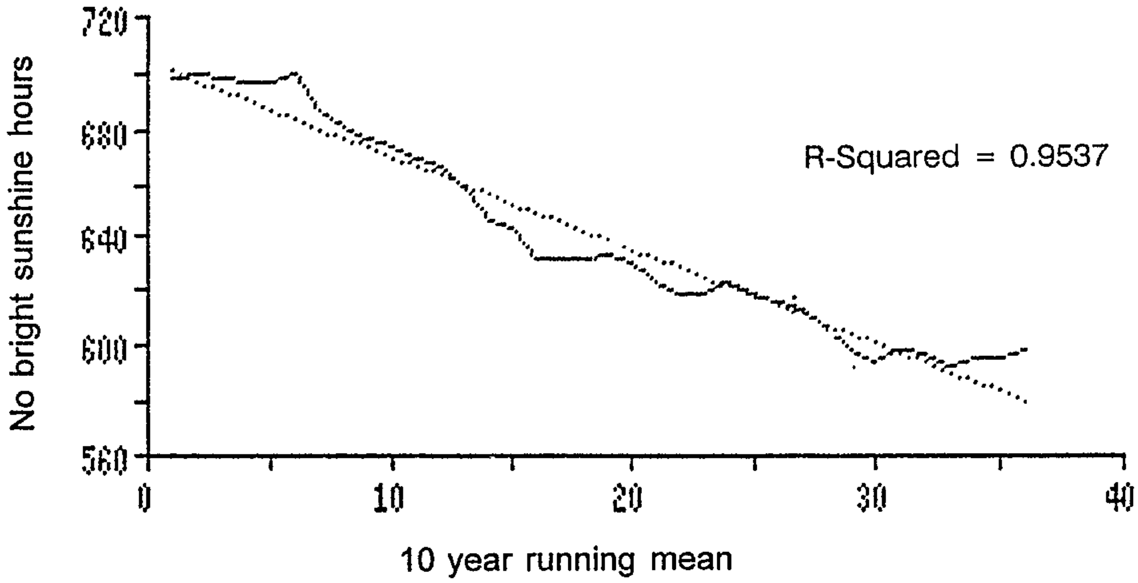

Figure 54 - Ten year running mean totals of bright sunshine hours experienced between 1500 hours and dusk local time, over the period 1947 to 1991 at Luqa

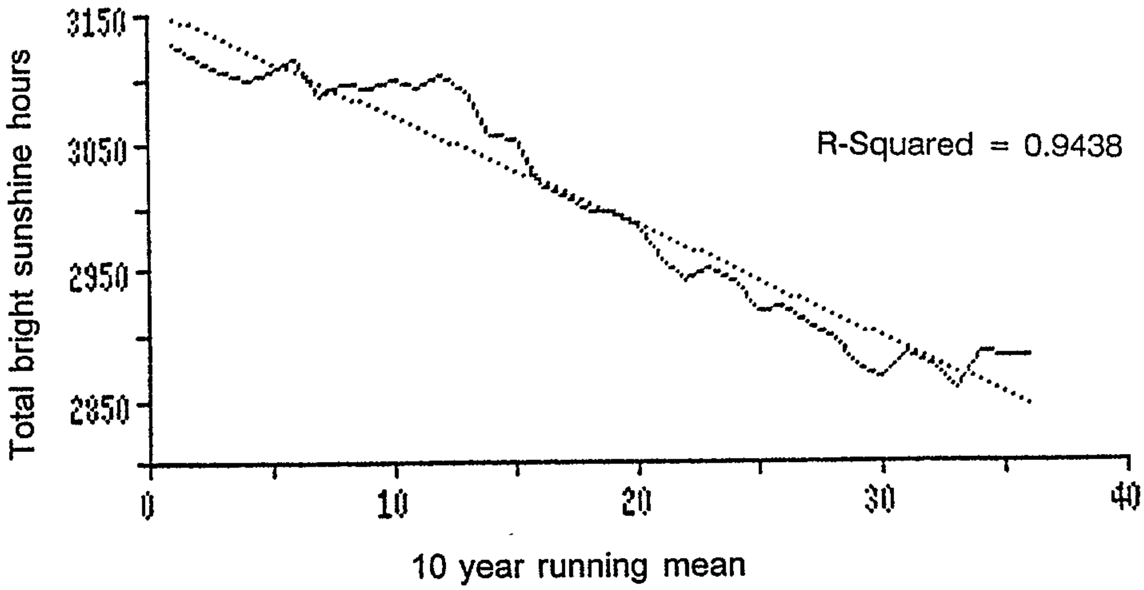

Figure 55 - Ten year running mean, annual total hours of bright sunshine hours experienced at Luqa, over the period 1964 to 1991

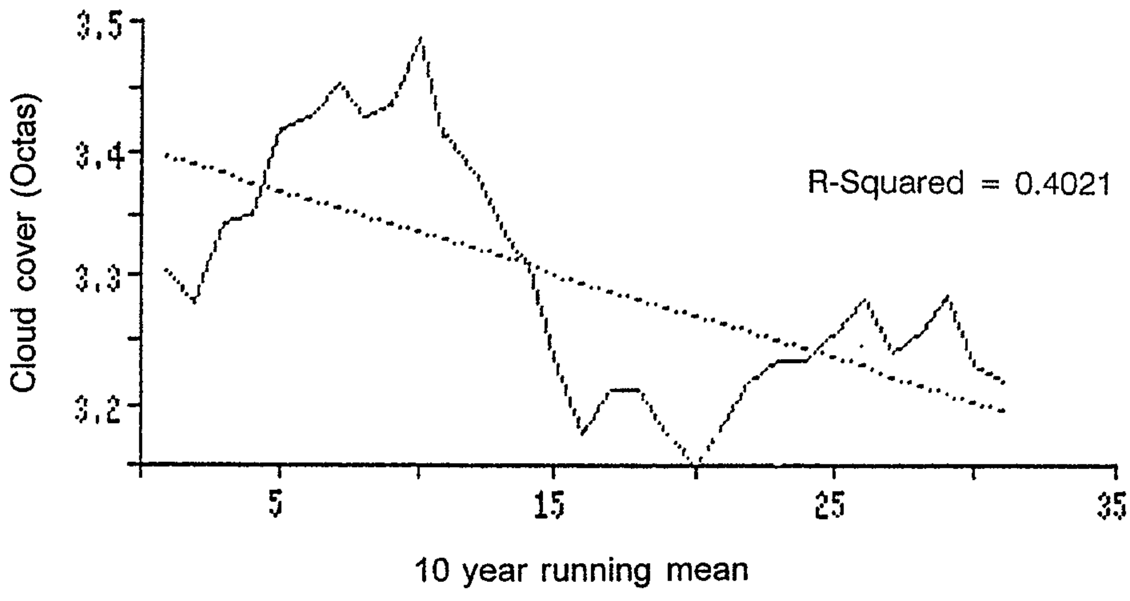

Figure 56 - Ten year running mean, cloud cover (octas) experienced at Luqa, over the period 1951 to 1990

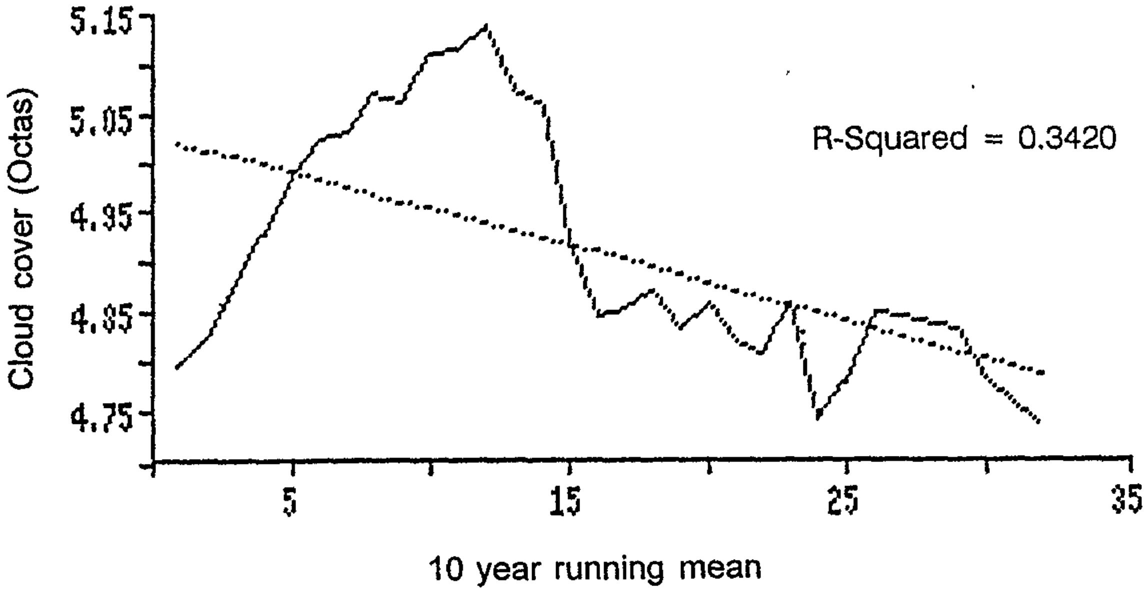

Figure 57 - Ten year running mean, winter cloud cover (octas) experienced at Luqa, over the period 1951 to 1990

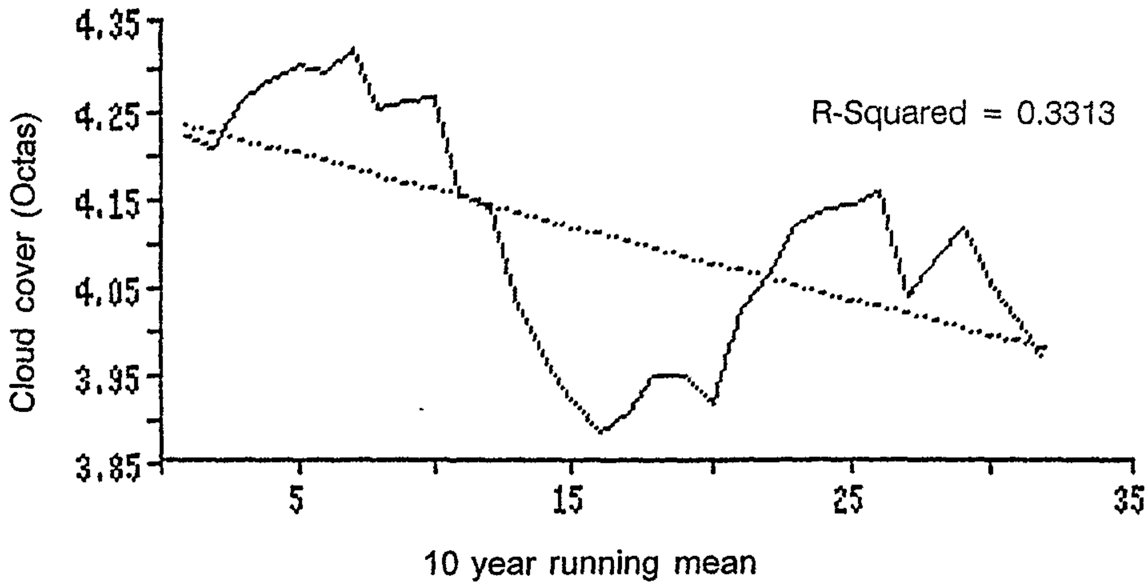

Figure 58 - Ten year running mean, spring cloud cover (octas) experienced at Luqa, over the period 1951 to 1990

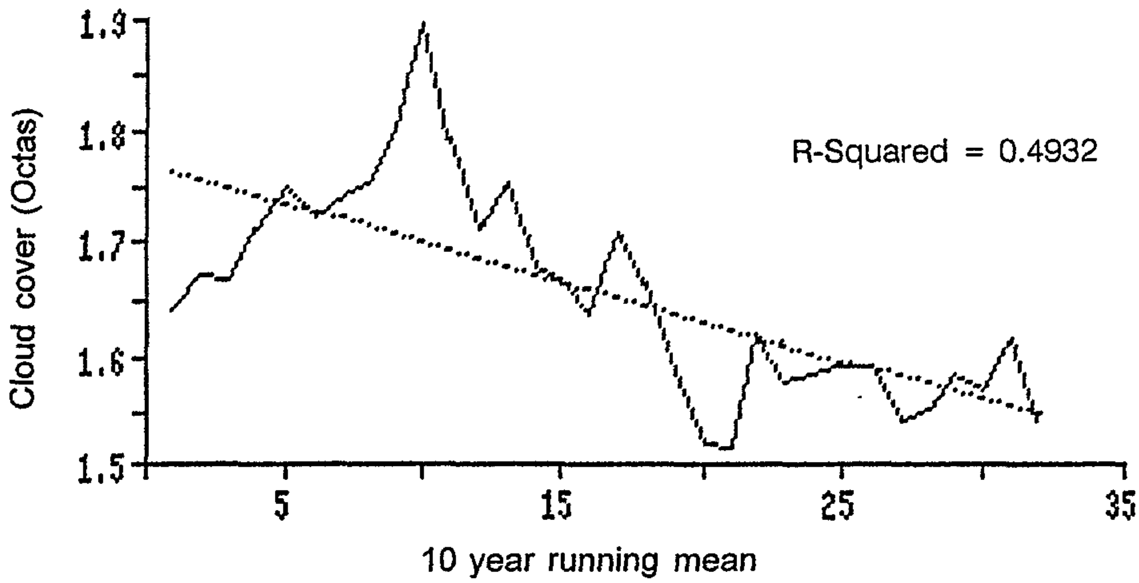

Figure 59 - Ten year running mean, summer cloud cover (octas) experienced at Luqa, over the period 1951 to 1990

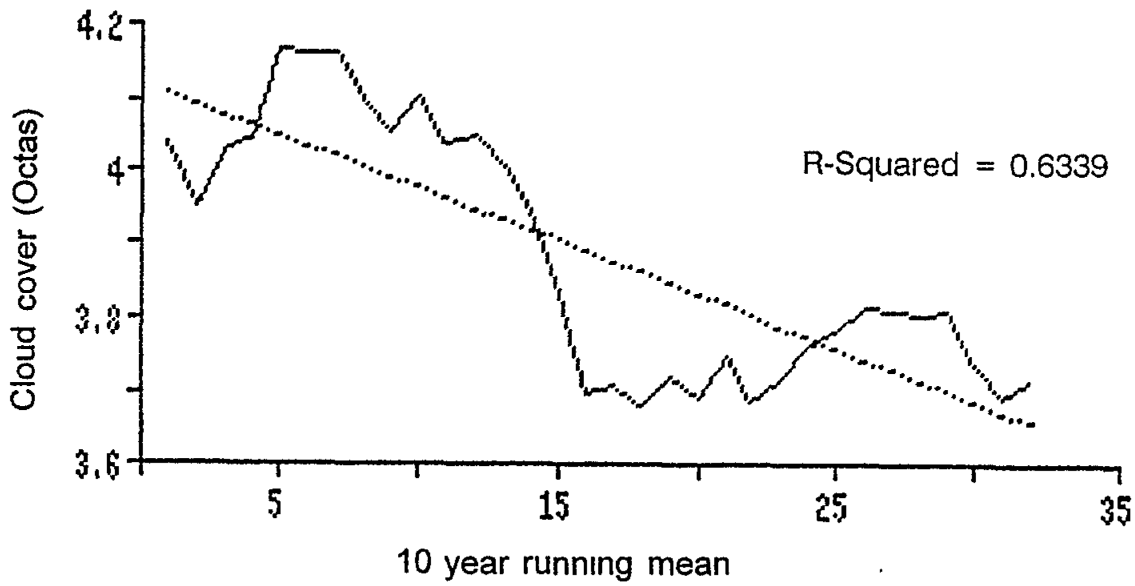

Figure 60 - Ten year running mean, autumn cloud cover (octas) experienced at Luqa, over the period 1951 to 1990

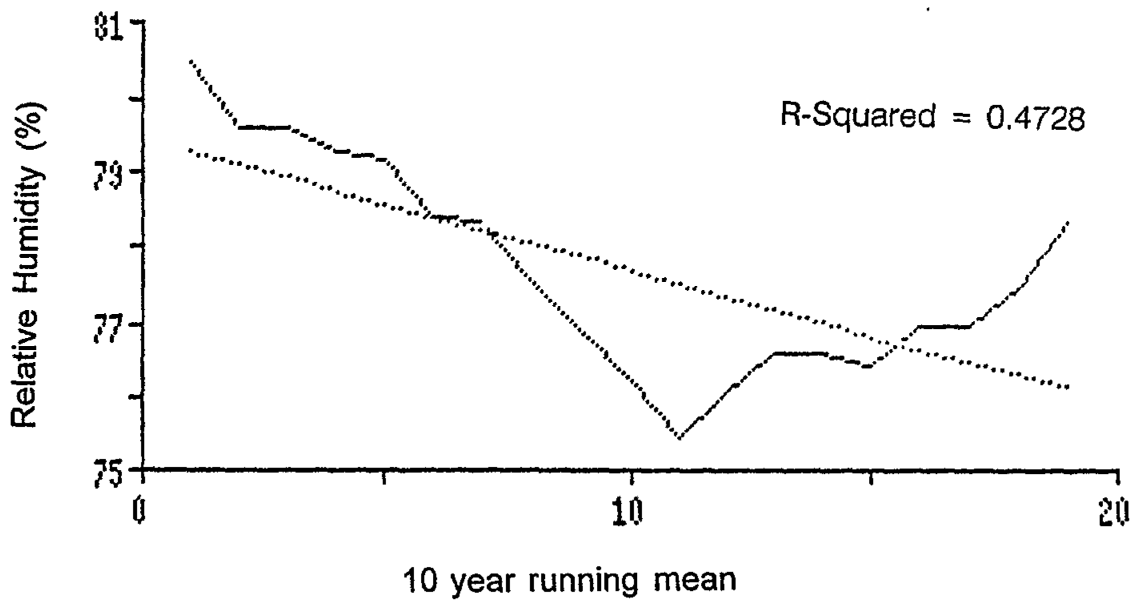

Figure 61 - Ten year running mean, winter relative humidity (%) experienced at Luqa, over the period 1964 to 1991

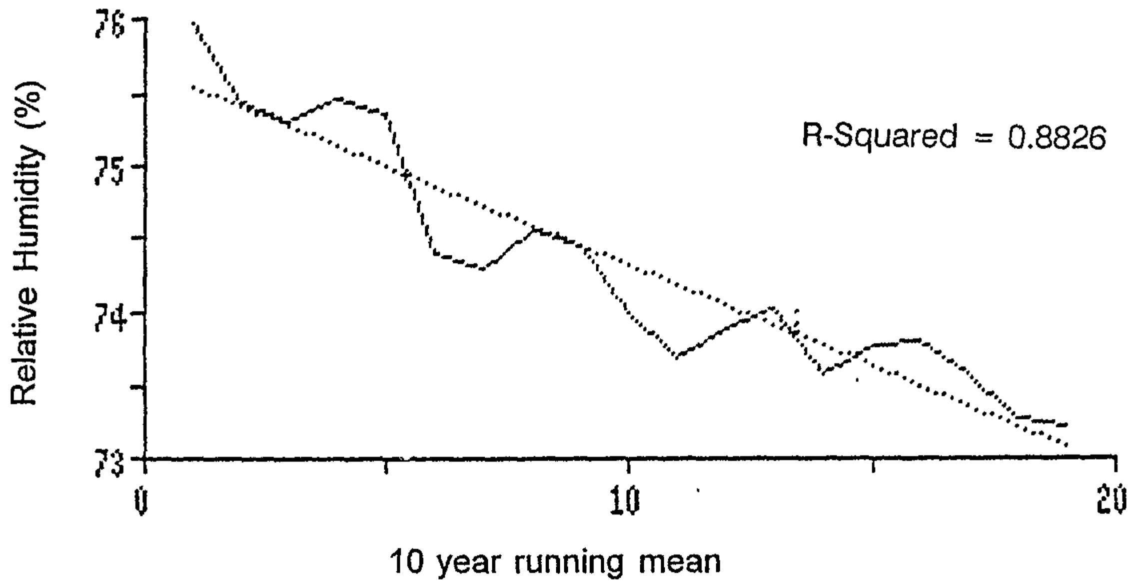

Figure 62 - Ten year running mean, spring relative humidity (%) experienced at Luqa, over the period 1964 to 1991

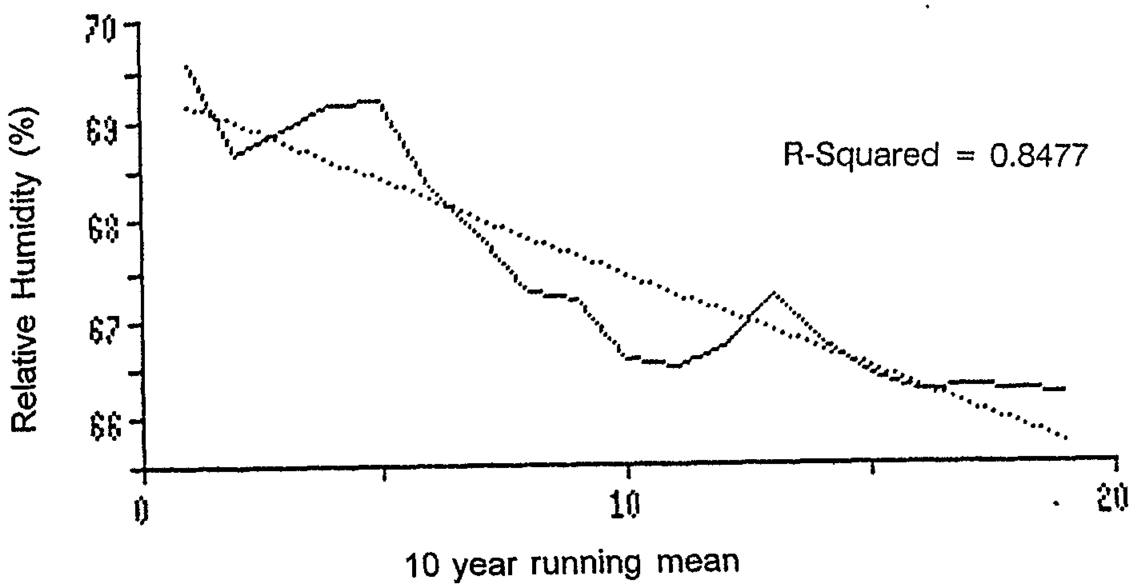

Figure 63 - Ten year running mean, summer relative humidity (%) experienced at Luqa, over the period 1964 to 1991

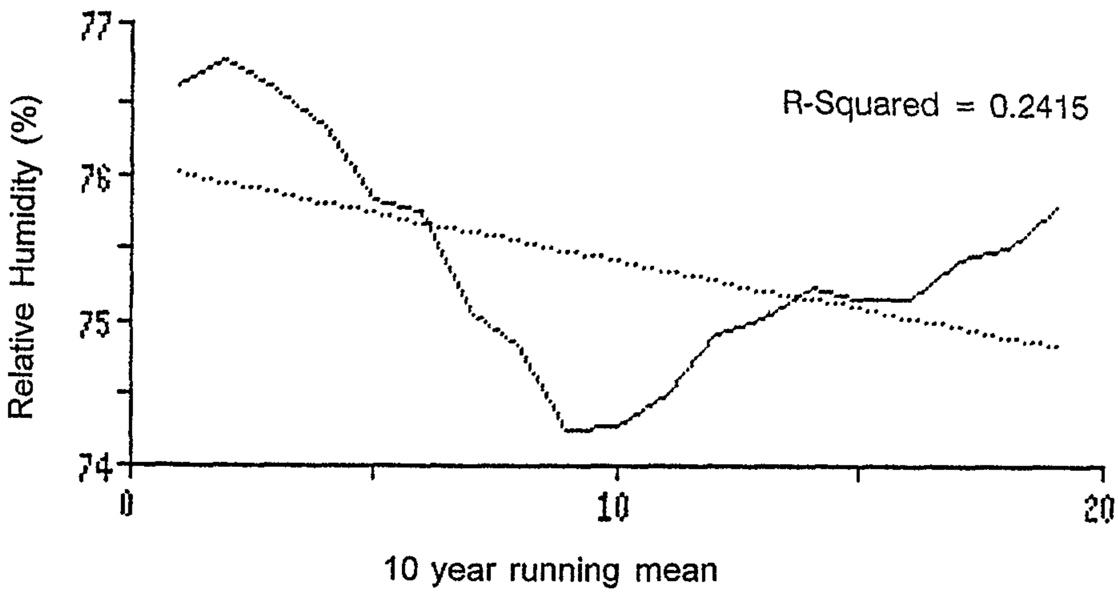

Figure 64 - Ten year running mean, autumn relative humidity (%) experienced at Luqa, over the period 1964 to 1991

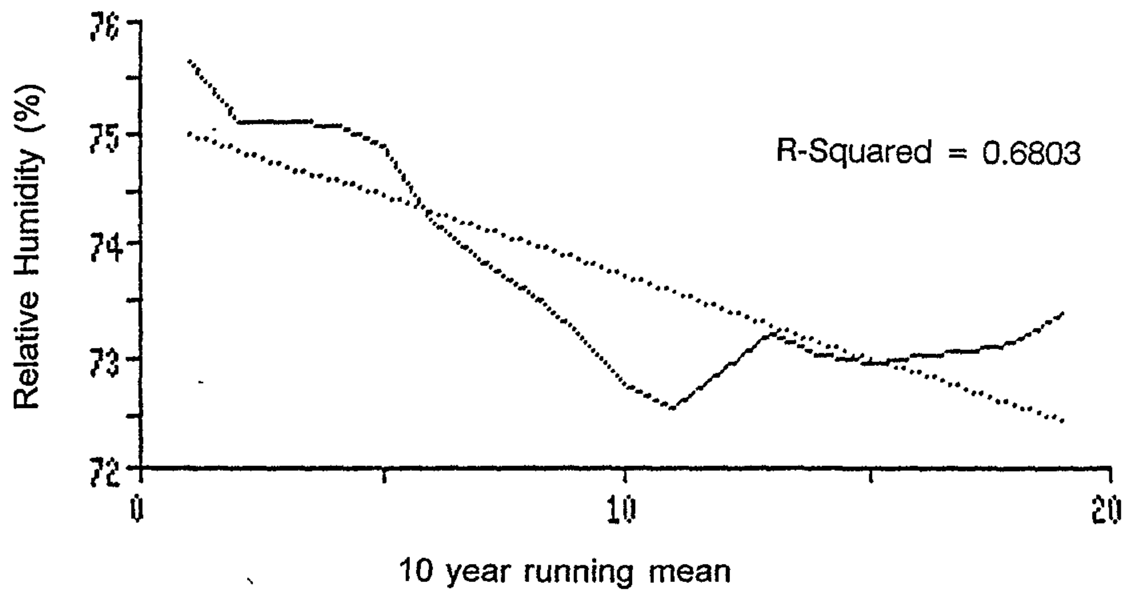

Figure 65 - Ten year annual running mean, relative humidity (%) experienced at Luqa, over the period 1964 to 1991

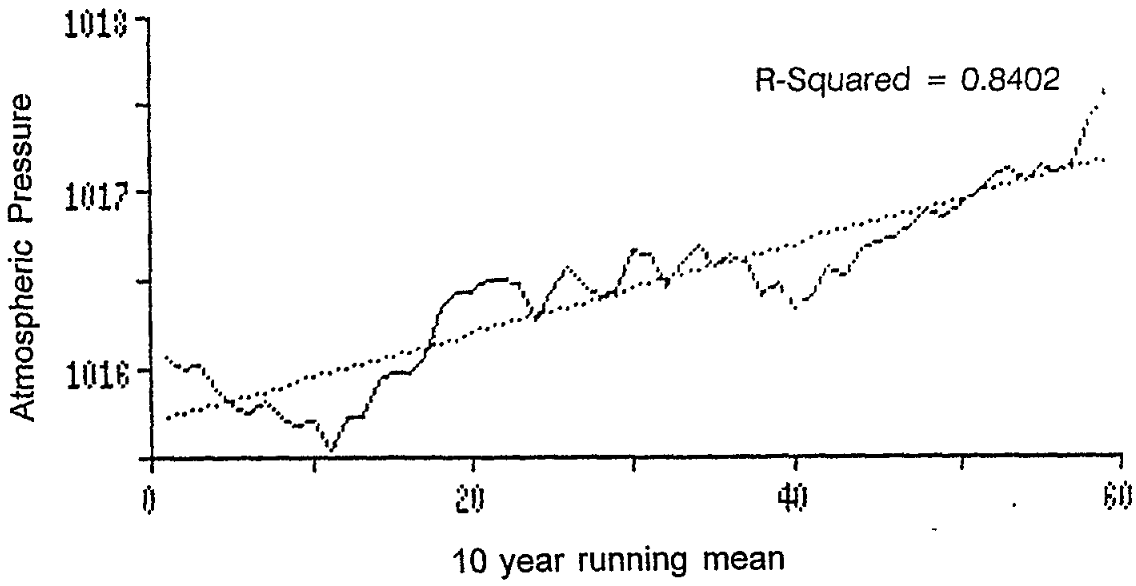

Figure 66 - Ten year annual running mean, atmospheric pressure (hPa) measured at Luqa over the period 1923 to 1990

2.5. Natural Ecosystems

2.5.1. Terrestrial ecosystems

2.5.1.1. The present terrestrial ecosystems of Malta

Lying in the centre of the Mediterranean and with the highest point being only 253 m, Malta's climate is typical of that of the Mediterranean coastal zone. Thus the year can be divided into a cool wet season lasting from about mid-September to mid-May and a warm dry season occupying the rest of the year. Temperatures are never extreme, the lowest being rarely less than 5 °C, although the minimum temperature in winter may occasionally go down to just below zero. The highest temperatures rarely exceed 35 °C although temperatures reaching up to the forties may be experienced for a few days. Mean annual rainfall is 513 mm but evapotranspiration reaches 942 mm (Chetcuti *et al.*, 1992) so that rainfall alone is insufficient to meet the islands' water needs. Thus there is a great dependence on water from the sea-level aquifer which is maintained by seepage of rainwater into the rock.

The Maltese Islands are composed entirely of Oligo-Miocene sedimentary rocks which are largely of marine biogenic origin and are highly calcareous thus giving rise to alkaline soils with a pH generally ranging from around 7.0 to 8.5. The small size of the islands coupled with their low altitude means that all parts are influenced by the sea and soils may be somewhat saline. The islands are also exposed to strong winds, especially north-easterlies which carry salt spray to the highest points. As a consequence the vegetation is subject to stress resulting from low water availability, high temperatures, high pH, soils with high calcium carbonate content, exposure to winds and salt. In addition the Maltese Islands, which were first settled by sophisticated immigrants equipped with an agricultural technology about 7000 years ago, have been subjected to heavy anthropogenic pressure which has exacerbated the natural sources of stress.

Malta's natural vegetation is basically a Mediterranean sclerophyll scrub. The natural climax is the evergreen wood, of Evergreen Oak, *Quercus ilex* and Aleppo pine, *Pinus halepensis*; practically all of which is now virtually destroyed although there have been attempts at reforestation. At an earlier stage of succession is the maquis with a profusion of small trees, large shrubs, lianes and large herbs. Native maquis was probably dominated by Sandarac, *Tetraclinis articulata*, now a very rare tree; species of *Pistacia* and *Rhamnus;* Myrtle, *Myrtus communis*, now also very rare; and, others. Present representatives of the Maltese maquis such as the Olive, *Olea europaea*; Carob, *Ceratonia siliqua*; Fig, *Ficus carica* and others are probably not native but were introduced in antiquity, because of their utility, and have become integrated with the natural vegetation. Exposed rocky sites are often characterized by a garrigue community dominated by a profusion of low shrubs such as Mediterranean Thyme, *Thymus capitatus;* Mediterranean Heather, *Erica multiflora*; Yellow Kidney-vetch, *Anthyllis hermanniae;* and, the endemic Maltese Spurge, *Euphorbia melitensis*.

The sites which are most subject to grazing and fires support steppic communities of various types dominated by grasses, geophytes (plants with underground storage organs), umbellifers, thistles and a profusion of annuals. The high degree of anthropogenic activity provides a profusion of disturbed habitats occupied by opportunistic species many of which are of adventive origin. Several of these adventives are the commonest of all "wild" plants including some of comparatively recent origin such as the South African Cape Sorrel, *Oxalis pes-caprae,* introduced at the beginning of the 19th century; and, Narrow-leaved Aster, *Aster subulatus*, which seems to have been introduced in the late 1930s. Malta's vascular flora includes about 1000 species of which around 700 are indigenous, the rest being more or less naturalized adventives. About twenty taxa are endemic (including two monotypic genera). Several of the more significant species are relics of the preglacial flora of the region.

The fauna is of course directly or indirectly dependent on the vegetation and the less vagrant component reflects the xeric nature of the islands. This is especially evident in the case of the land molluscs and reptiles characterized by genera such as *Trochoidea* and *Lampedusa* (most species of which are endemic) among the snails, and the endemic wall lizards, *Podarcis filfolensis* and its subspecies; geckos, *Hemidactylus turcicus* and *Tarentula mauritanica*; and, the introduced chamaeleon, *Chamaeleo chamaeleon*, among the reptiles. There are few species of mammals. With the possible exception of some bats, several of which are migrants, the only undoubted native species is an endemic subspecies of the Sicilian Shrew, *Crocidura sicula calypso* (Hutterer, 1991).

2.5.1.2. Consequences of climatic changes and sea level rise for terrestrial ecosystems

Available scenarios such as those developed by the University of East Anglia for Malta and the Mediterranean; and by IPCC for global conditions as well as the conclusions of Sestini *et al.* (1989) suggest a number of trends:

1. increase in temperature;
2. increase in sea level;
3. increase in autumn rainfall;
4. decrease in rainfall in other seasons;
5. decrease in water availability;
6. increase in soil salinity;
7. increased winds;
8. increased carbon dioxide levels plus other greenhouse gases; and
9. increased incident radiation (due to thinning of the ozone layer).

All of these changes are expected to have effects of varying intensity on the structure of terrestrial ecosystems.

Potentially the most far reaching change predicted by the various scenarios is a sea level rise of 1 metre by the year 2100. This will result in the gradual inundation of low lying coastal areas such that natural communities associated with these areas will move inland (Sestini *et al.*, 1989). However certain communities including existing saline marshlands and coastal dunes may be lost (see sections 2.5.3. and 2.5.4. below) although new marshlands and dunes may gradually form elsewhere. Vulnerable areas include the Pwales valley, Ramla Bay, Salini, Marsaxlokk harbour in Malta and the Ramla area in Gozo. Low-lying coastal sites are however, relatively few in number and the rise in sea level is not expected to be the major concern.

The most extreme scenarios for temperature change suggest an increase of up to 2.7 °C by 2050 and up to 4.5 °C by 2100. The effects of change in temperature will be accompanied by changes in water availability and for the purposes of this discussion it will be assumed that there will be a trend towards reduced water availability as well as a trend towards increased soil salinity.

An increase in temperature will negatively affect those species which are dependent on low temperatures for dormancy. Relatively few Mediterranean species need a cold treatment for dormancy but, recalling that current temperatures in Malta may reach minima which are slightly below freezing (Chetcuti *et al.*, 1992) such a potential impact should still be taken into consideration. Olive trees are known to require relatively cool winters as do most deciduous trees and shrubs such as poplars, willows, elms, ash and naturalized trees such as pecan nut, tree of heaven and mulberry. Most of the deciduous trees which are dependent on high water availability and low salinity are already on the decrease and this trend will worsen.

In contrast a temperature increase will favour species with a subtropical affinity. It is envisaged therefore that numerous xerophilic, subtropical plants which are presently in cultivation and well under control, because of their inability to compete in unmanaged environments, will become more competitive vis-a-vis the local species and will become naturalized. An increase in disturbed habitats will no doubt further favour invasion by such naturalised species. A considerable increase in thermophilic species such as the Tree Tobacco, *Nicotiana glauca* and the Castor Oil Tree, *Ricinus communis* is already observable. More seriously, a rise in temperature may favour the spread of pest organisms, especially insects and acarines which prey on, or parasitize indigenous species. A very serious threat is the increase (already under way) of the mite *Varroa jacobsoni* which parasitizes honey bees drastically reducing their numbers. Continuation of this trend would have very serious consequences for pollination since honey bees pollinate several plant species, including many of economic importance. If bee populations are decimated one may predict a shift in the pollination syndromes of the plant populations. One should always bear in mind that what affects the plants will also affect all the organisms dependent on them as well as the properties of the soil. Thus change in temperature will certainly affect the floristic and faunistic composition of our natural ecosystems although the effects of these changes on human quality of life is difficult to assess.

All projections point to a reduction in future water availability. This is a trend which has already started, practically since the Maltese Islands were first settled becoming acute in the last half century. The severity of the problem seems to be rising exponentially, due not to climate change but to the effects of human activities in reducing tree cover; enhancing soil erosion; and continuing bad agricultural practices; combined with an increase in population size, industrialization, and construction of asphalted roads. Coupled with the low rainfall, there is the loss of rainwater because much of this does not seep into the ground to contribute to the water tables but is lost to the sea. In fact we now depend to a greater extent on desalination for our water consumption needs but our consumption will continue growing due to increased industrialization, the tourist industry and natural population growth.

The overall effects of a decrease in water availability are already being felt. A comparison of the information contained in standard Maltese floras such as those of Sommier and Gatto (1915) and Borg (1927) with the current situation reveals a reduction in the number of species and abundance of plants characteristic of moist habitats. Several water dependent species have disappeared since the mid-seventies including the sedges *Cyperus distachyus, Isolepis cernua,* and *Cyperus fuscus* and Adder's tongue, *Ranunculus ophioglossifolius*. Several species now have more restricted distributions than in the past and are on the verge of local extinction including the willows, *Salix alba* and *Salix pedicellata*; Water Figwort, *Scrophularia auriculata*; Water Germander, *Teucrium fruticans*; and sedges such as *Carex hispida, Carex extensa* and *Schoenus nigricans*. Future trends would be towards the further restriction of water dependent species and an increase in xerophilic species, especially weedy types such as the American fleabanes, *Conyza bonariensis* and the recently recorded *Conyza albida*.

The overall decrease in water availability will tend to increase soil salinity so that the tendency will be to favour halophilic species such as several chenopods. In fact there is already a noticeable increase in weedy chenopods such as *Chenopodium album,* and *Chenopodium opulifolium* which are now very widespread but which were uncommon about fifty years ago. The increased salinity also means that strict glycophytes (salt-intolerant species) will be further restricted in their distribution. Overall there will be a floristic shift in favour of xerophilic, halophilic species most of which will probably be of adventive origin. A drier habitat is also expected to result in an increase in fires to the further detriment of terrestrial ecosystems This suggests that the prevalent flora will shift from one typical of Mediterranean coastal lowlands to one typical of deserts.

Although climate change scenarios do not predict an appreciable change in total annual rainfall, a change in the seasonal distribution is envisaged, with more rain concentrated in autumn and hardly any rain in the other seasons. Such concentration means that a higher proportion of the rain will be lost due to run-off, quite apart from the damage which heavy rains can cause. This may have several effects on the terrestrial ecosystems especially the loss of much of the water originating from torrential rains, since it will not have time to reach the water tables and, even more seriously, the physical damage which such concentrated rains will cause. Thus an increase in soil erosion with the consequent loss of plant and associated animal life may be expected. Thus change in rainfall pattern is bound to amplify the effects of general water shortage.

The sharper seasonal and diurnal changes in rainfall and temperature will also result in stronger winds and possibly a greater frequency in freak storms. This would affect the tree and shrub cover and thus subject the Maltese Islands to greater exposure These trends would further increase soil erosion.

It appears that the main agent of anthropogenic climate change is the gradual accumulation of carbon dioxide in the atmosphere. The increase in carbon dioxide itself would actually have a positive effect on development of some plant species since this would result in an increase in photosynthetic rates and hence greater productivity. This should however be seen in the context of the several incidental effects already discussed which will bring about adverse changes in the quality of the flora and associated fauna.

A consequence of carbon dioxide increase will probably be a lowering of the pH of the rain, which might affect the soil in various ways. Certain soil nutrients such as iron will be more readily available, but toxic heavy metals such as lead, a common pollutant in Maltese soils, will also become increasingly available. This would again cause shifts in floristic composition.

Other greenhouse gases, notably the CFCs attack the ozone layer resulting in increased levels of ultra-violet radiation the earths' surface. Such increased UV-B radiation may cause physical damage to sensitive organisms, including humans and possibly increase mutation rates.

2.5.2. Freshwater and marine ecosystems

2.5.2.1. The aquatic ecosystems of Malta

The Maltese Islands support a rich variety of natural habitats with a significant number of animal and plant species which live only on these islands (i.e. endemic species). The Malta Structure Plan (1990) refers to approximately 2000 species of plants, 50 species of fresh-water and terrestrial molluscs, and over 4250 species of animals. The rich variety of living communities is due to the insular nature of the archipelago as well as to its location at the intersection of ecologically distinct regions within the Mediterranean.

The local climate is Mediterranean-type, with a mean annual rain-fall of 530 mm, with 70% of this precipitation occurring during the period October-March. Summers are usually dry with maximum temperatures reaching 30 ° C in July-August. The purpose of this section is to discuss possible impacts of predicted climate changes on freshwater, coastal and marine ecosystems. The major features and characteristics of such ecosystems and habitats in their present state, will be outlined first. Then we will define the possible scenarios of local and regional climatic changes by the year 2050, being predicted on the currently available data and information. The last part will identify and evaluate the possible impacts of these scenarios on the ecosystems in question.

The Maltese Islands have a collective shoreline of about 190 km and a surface area of 316 square kilometres, of which, 5.2% is at 7.6 m or less, above the mean sea level. Rough estimates indicate that, approximately only 1.2% of the total land surface is 1 m or less above sea level. In fact, the islands' coastline is characterised by cliffs, clay slopes and boulder rocks (Figure 67). 50% of Malta's coasts and 74% of Gozo's coastline has been defined as inaccessible mainly due to physical features (Malta Structure Plan, 1990). This leads to the heavy pressures being exerted on the remaining lowlands for tourist, industrial and urban purposes.

Sandy beaches are few and constitute only 2% of the coastline. Nonetheless, these very restricted localities and the rest of the coastal lowlands support a number of habitats which are of unique ecological and scientific importance. These include: saline marsh lands, sand dunes and rocky gentle slopes. Our knowledge of such habitats is still limited though significant contributions have been made recently (Schembri *et al.*, 1987).

Man-induced pressures on coastal lowland habitats include: urban settlement and coastal development, land-based pollution, quarrying activities. Other pressure, which are only partially man-induced, include shoreline erosion. Spiteri (1990) has identified a number of sandy beaches presently undergoing shore-erosion, including: Mellieha Bay, St. George's Bay, Xlendi and Marsalforn. Pretty Bay (South of Malta) has experienced dramatic expansion of its sandy beaches due to changes in local water currents induced by modifications of coastline during the development of the Malta Freeport.

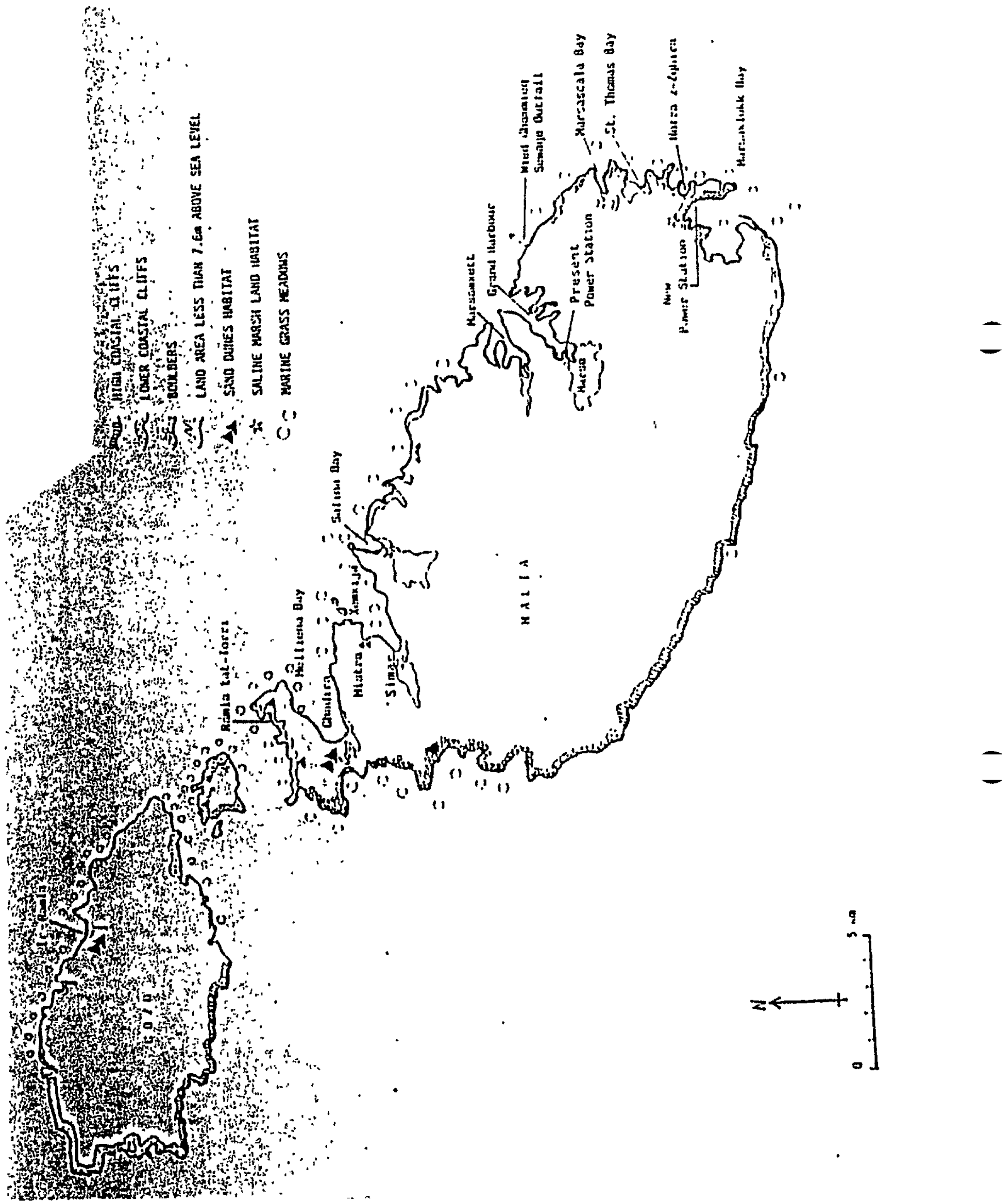

Figure 67 - Coastal Habitats of the Maltese Islands;
Adapted from the Malta Structure Plan (1990)

2.5.2.2. Near-shore marine waters

The sublittoral zone around the islands supports a diverse range of habitats including: steep drop-offs, boulder grounds, bare sand, mud and fine sands and sea grass meadows (Malta Structure Plan, 1990).

Seasonal sea surface temperature fluctuations range from 14° C during February-March to 28 ° C in August-September. Near-shore waters are generally oligotrophic with nutrient levels typically low. Nitrate levels in near-shore clean waters are generally below 2 $\mu g\ l^{-1}$, while phosphate levels are less than 0.2 $\mu g\ l^{-1}$. Near-shore waters such as harbours and semi-enclosed creeks exposed to effluents from urban areas, may occasionally show elevated nutrient levels, and moderately eutrophic conditions with nitrate reaching 45 $\mu g\ l^{-1}$ and phosphate 1.5 $\mu g\ l^{-1}$ in Marsamxett Harbour (Axiak *et al.*, 1992). Tidal range is minimal and generally overridden by other water movements. Surface currents generally set towards the south-east, although the local near-shore current regimes are characterised by significant variations and eddy currents. Water stratification is mostly due to thermal effects and is prominent during September, with temperature differences of approximately 5 ° C being recorded between surface and bottom waters. Salinity fluctuations may be quite significant especially during the autumn rain storms, when large quantities of suspended sediments are introduced into the marine environment.

Sea-grass meadows are relatively important ecosystems, both locally as well as regionally. *Posidonia oceania* meadows generally occupy open bottom areas which are not exposed to wide fluctuations in salinity and urban run-off. These form extensive areas of high productivity and support a rich community of animals, including economically important fish and molluscs. *Posidonia* meadows locally extend to relatively deep waters and the lower limits of growth around Malta are possibly one of the deepest recorded in the Mediterranean (E. Lanfranco, pers. comm.). This is because of the extremely clear waters and the consequent increased light availability at depth. Another sea-grass species of local importance is *Cymodocea nodosa* which is more tolerant of salinity fluctuations and therefore may be found inhabiting inshore waters, bays and creeks.

As in the case of the coastal lowlands, the near-shore marine communities are presently facing a number of man-induced pressures. These include land-based pollution, construction projects shoreline development and increased diving activities. Changes in the local and regional marine fauna and flora have also been observed due to a number of immigrant animal and plant species (Lessepsian migrants) colonizing the Mediterranean waters from the Indo-Pacific region through the Suez Canal. The immigrants are essentially warm-water species which for a number of reasons have established themselves in the Mediterranean. They include 41 fish species (Ben-Tuvia, 1985), some molluscs, as well as microplankton (Lakkis, 1990). This immigration into the Mediterranean region has been mostly limited to the eastern basin though a number of species (including molluscs) have also reached the western basin. A number of such migrants have been observed in Malta including the sea-grass *Halophila stipulacea* and a number of fish (E. Lanfranco, pers. comm.). *H. stipulacea* inserts itself in meadows of *Cymodocea* and it is possible that this will bring about changes in the associated fauna.

2.5.2.3. Freshwater habitats

There are no rivers on these islands and the number of permanent springs is very limited. Most freshwater habitats carry water during only part of the year and dry up during summer. Nonetheless, there are some freshwater habitats which though greatly restricted in geographic extent, manage to support a significant number of rare or endangered species as well as endemic flora and fauna. These localities include: the valleys in the Mtahleb area which support several species of freshwater snails and many rare plants; the valley system leading to Salina Bay on the NW of Malta, which includes Wied Qannotta, Wied Ghajn Rihana and Wied il-Ghasel; Bahrija Valley; Wied il-Luq at Buskett and the area known as Chadwich Lakes, being the drainage system for one of the largest freshwater catchment areas in Malta (Schembri *et al.*, 1987). In most of these localities, rain water forms temporary pools or streams which often support rich though geographically restricted freshwater communities. All of these freshwater habitats are threatened by competing land uses including: urbanisation, quarrying, or refuse dumping.

2.5.2.4. Climate change, sea level rise and aquatic ecosystems

The interaction and intimate association between the living components of an ecosystem and the physical environment, (including climate), is a basic concept in ecology. This interaction is two-way, in that climatic changes may be brought about by the living components of an ecosystem, and vice-versa. Certain living components of an ecosystem are however, less adaptable to climatic or environmental change than others, and it may be envisaged that rapid climatic changes on a time scale of a few decades, will have significant impacts on natural ecosystems.

Various General Circulatory Models predict a rise in global mean temperature in the range of 1.5 to 4 °C by the 21st Century due to the greenhouse effect. Such models cannot be used to predict with any certainty the magnitude of temperature changes at a regional or sub-regional level. However, according to sub-grid-scale climate change scenarios recently developed by the Climate Research Unit of the University of East Anglia (Guo *et al.*, 1992; Palutikof *et al.*, 1992), the local annual temperature change will be 0.8 to 0.9 °C per degree of global change, with the largest increase being found during summer. Predictions of the change in relative mean sea level are unreliable in the absence of data on local land subsidence (due to tectonic and other processes). In addition there is considerable uncertainty about how the predicted climatic changes will affect the water budget, precipitation rates and seasonal rainfall patterns. For the purpose of this assessment, two scenarios of local climate change by the year 2050 (Table 2) are considered: a Worst-Case Malta Scenario and a Mild-Case Malta Scenario.

In the Worst-Case Malta Scenario for the year 2050, we may expect an annual mean temperature rise of 2.7 °C with summer temperatures being significantly higher. Moreover, daily and seasonal temperature extremes may be more pronounced. A mean relative sea-level rise of approximately 52 cm will take place. There will be no change in the annual mean rates of rainfall, but there will be a significant change in the seasonal precipitation pattern, so that winter and spring may have lower rainfalls but autumn rainfall, and possibly the severity of the autumn rain storms, will increase.

In the Mild-Case Malta Scenario for the year 2050, the annual mean temperature will increase by 1.2 °C, with summer temperatures increasing by 1.4 °C. There will be a rise in the relative mean sea level of 14 cm. Rainfall annual rates and seasonal patterns will not be substantially changed.

2.5.2.5. Impacts on coastal lowlands

A rise in the mean relative sea-level of approximately 52 cm, is likely to cause inundation and shoreline recession in the following localities on the Malta mainland: Ramla tat-Torri and Gharmier Bay, Mellieha Bay, Xemxija Bay (is-Simar), Salina Bay, certain lowland localities from Ghalies Point to St. George's Bay, Marsaskala Bay, St. Thomas Bay and certain localities in Marsaxlokk Bay. The extent of inundation in each case will be determined by the presence of coastal roads and other man-made constructions, though increased frequencies of storm surges will also threaten a number of these coastal roads. Msida Creek and Marsa Creek will be less threatened by such storm surges or waves and more easily protected by the present man-made constructions.

Inland migration of sandy beaches will take place only in those cases where sedimentary flux and replenishment have not been reduced by inland construction (e.g. roads at the back of a beach) or where runoff due to changes in precipitation patterns does not occur. In other cases, coastal built-up areas and construction will prevent such inland movement of sandy beaches, leading to significant or complete loss of these areas. In spite of the very limited information available on the rates of local shoreline and beach erosion, there are indications that a number of sandy beaches are presently affected by erosion process (Spiteri, 1990).

Taking into account the fact that sandy beaches on these islands are few, and that they all take the form of small pockets fringed by rocky coastlines (which in most cases have man-made constructions on them) it may be assumed that one major impact of the predicted climatic changes on the local coastal environment will be the increased erosion and possible loss of coastal sandy beaches. Any reduction of sediment flowing out to sea, resulting from altered precipitation patterns, and the effects of reservoirs trapping sediments (e.g. retention basins to retain storm water as are being proposed in the Sewerage Master Plan for Malta and Gozo, (COWIconsult, 1992) may accelerate this coastal erosion. Sandy beaches are already threatened by a number of man-induced factors, and are likely to be negatively affected by the year 2050, even under the Mild-Case Malta Scenario of climate change.

As indicated above, Malta's coastal area supports a number of important habitats including sand dunes and saline marsh lands. At least four sites with well developed coastal sand dunes containing the full range of typical dune vegetation have been identified (Malta Structure Plan, 1990). These are at ir-Ramla tat-Torri, Ghadira, Ramla tal-Mixquqa (Golden Bay) on the Malta mainland and ir-Ramla dunes in Gozo. All these localities support a number of rare, threatened and/or endemic plants and animals and as such their loss will be highly significant to the overall biodiversity as well as to the scientific and cultural heritage of these islands. A number of saline marshlands including those at Ghadira, is-Simar (Xemxija) and Salina Bay are important bird nesting sites and their loss will reduce the ability of these islands to support resident and migrant bird life.

While increased ambient temperatures may lead to increased plant productivity in sand dune and salt marsh communities, increased intrusion of seawater brought about by a rise in sea level may reduce the number of species which are less tolerant to elevated salinities. Moreover, such habitats will be able to keep up with the general shoreline recession only if the rate of rise in sea level is slow; sediment inputs are sufficient to replenish the habitat substrate; and, only where the adjacent inland areas are free of man-made constructions such as roads, camp sites, and buildings.

Taking all these points into consideration, it may be assumed that climatic changes as predicted by the Worst-case Malta Scenario will negatively affect the local sand dunes and saline marshes, leading to a reduction in their area and in buffer zones which protect them from nearby habitats including urban areas. Further detailed considerations of the likely impact of climatic changes on one of the most important of such threatened site is provided in the following analysis. The extent of negative impact of climatic changes on such habitats will depend to a large extent on appropriate land-use management practices.

2.5.2.6. Impacts on the Ghadira Nature Reserve

The Ghadira Nature Reserve is located on the northeastern coast of Malta (Mellieha Bay) and encompasses the largest saline marshland on these islands. It occupies approximately 6 hectares of land and is separated from the sea by a road and a narrow sandy beach which are together approximately 100 m wide. Prior to 1980, this area was a typical saline marsh with water present in a central pool for most of the year; drying up only during the summer months. Since then, the central pool has been deepened and is now provided with rain water throughout the year.

This reserve is of unique scientific, educational and ecological importance. It is the first officially designated nature reserve in Malta and represents one of the few surviving migratory bird habitats in the Central Mediterranean, used by a number of migratory bird species as a temporary resting station on their migratory routes between Europe and Africa. It also forms a good over-wintering site for other bird species and in addition supports a number of rare or threatened plant and animal species. A number of detailed studies of this nature reserve have been recently published (Borg *et al.*, 1990).

During a one-year study undertaken in 1985-86, very high fluctuations in a number of physico-chemical parameters were reported, including salinity ranges from 7 up to 40 $^{o}/_{oo}$, with one particular station reaching a salinity of 70 $^{o}/_{oo}$ in September (Hili *et al.*, 1990). These salinity fluctuations were related both to precipitation as well as seepage of seawater through compacted beach sand and soil, which was most evident during the summer months. Oxygen levels were generally high though near-anoxic conditions were occasionally recorded during summer, immediately after a phytoplankton bloom. Such algal blooms were supported by elevated nutrient levels due to pollution from agricultural run off from the surrounding fields.

A rise in mean sea level of 52 cm will definitely increase the occurrence of seawater intrusions in the present marshland as well as result in more prolonged periods of elevated salinities, in the various parts of the central pool. Borg *et al.* (1990) have shown that the pool has a relatively low macrofaunal species diversity due to the wide fluctuations in salinity, temperature and oxygen levels. Prolonged elevated salinities, followed by sudden salinity drops during the autumn rain storms (which may become more pronounced, as a result of climate change), may lead to a further reduction in the range of animal and plant species which would be able to tolerate these environmental fluctuations.

Based on the available data, an attempt was made to model phytoplankton primary productivity as measured by chlorophyll a content in relation to other environmental parameters, through the use of multiple regression analysis. One regression model which could explain 45% of the variance of chlorophyll a, and which was found to be statistically significant at $P < 0.001$, indicated that primary productivity was mostly dependent on temperature, and on the levels of oxygen, phosphates and nitrites. This model indicated that with a rise of ambient temperature of 1 °C, and keeping all other parameters constant, there will be a 10.5% increase in phytoplankton primary productivity. This suggests that a rise in ambient temperature throughout the year may lead to an increase in algal productivity (both macro and micro algal blooms) and prolonged periods of low oxygen levels. This would further reduce or eliminate the populations of aquatic animals during the summer months.

Because of the relatively small dimensions of this nature reserve, fluctuations in some environmental parameters such as salinity, could be reduced through the controlled supply of fresh water from reservoirs. However, in the event of a more significant rise of up to 52 cm in the relative mean sea level, then it is envisaged that there will be an equally significant shoreline recession. Given the gentle slope of the Ghadira sandy beach, this shoreline recession may be roughly calculated to reach up to 65 m inland (assuming 1 m shoreline recession for each centimetre rise in sea level). This recession may be restricted by the existing coastal road, or alternatively the location of the road itself may have to be changed due to exposure to storm surges and waves. If this rise in sea level were to be slow (over a couple of centuries) then there would be a gradual landward migration of this salt marsh. However, if the sea-level rises at a rate greater than the ability of this wetland to keep pace, then it will be reduced in extent. If any landward migration is further blocked by land development such as extension of the present permanent camping site on the north side of the marsh, then there may be a complete loss of this habitat.

2.5.2.7. Impacts on near-shore marine ecosystems

The distribution and abundance of life in near-shore marine environments is affected by physico-chemical parameters such as salinity, temperature, nutrient levels, water turbidity, and bottom substrate types. Such environmental parameters are themselves influenced by land-based processes and activities. Moreover, the nature of these land-based interactions is highly complex making predictions of impact of climatic changes on processes such as freshwater run-off, sediment and nutrient inputs into coastal waters, quite difficult. Hence predicting changes to near-shore marine ecosystems is quite difficult. The limited baseline information available on near-shore marine life and on its responses to environmental fluctuations, further compounds the problems of prediction.

A rise in the mean sea level as well as in surface water temperatures, coupled with increased autumn rain storms, and a more prolonged dry season, are all bound to increase the range of fluctuations in a number of physico-chemical parameters in near-shore marine waters, especially in semi-enclosed bays. The magnitude of such changes is however difficult to predict at present. In the Worst-Case Malta Scenario, these changes may include: wider salinity fluctuations; increased water turbidity during the autumn and winter months; elevated nutrient levels; and more pronounced water stratification due to higher surface water temperatures. Such changes are bound to influence both primary productivity as well as the distribution of animal and plant life in shallow near-shore coastal waters. Localities which may be affected, include most of the northern and north-eastern coastal waters of the Malta mainland. A more detailed consideration of how climate changes may affect Marsamxett and Grand Harbour, is provided in the following section.

2.5.2.8. Impacts on Marsamxett and Grand Harbour

Data from a recent three-year field survey (1989-92) undertaken in Marsamxett and Grand Harbour and at a reference station, around 1 km off-shore from these harbours, (Axiak *et al.*, 1992) showed that water stratification was pronounced during the July-September period throughout the entire area investigated. The mean temperature difference between surface and bottom waters in Marsamxett was approximately 3 °C, while that in the reference station as well as over most of the Grand Harbour was 5 °C,. This pronounced water stratification in the Grand Harbour was related to the thermal emissions of the present power station into Marsa Creek. Under these conditions, the rate of replenishment of oxygen in bottom waters is reduced to the detriment of benthic organisms. A rise in ambient temperatures due to climatic changes is bound to make such water stratification along the northern and north-eastern coastal shallow waters much more pronounced and prolonged in time.

This study also illustrates the fact that at a local level non-climatic effects such as the thermal emissions from a power station may greatly influence the magnitude or even the direction of predicted changes in marine environmental parameters due to climate change. It is expected that within the next 5 years, a new power station will become operational in Marsaxlokk Bay (Delimara), which will discharge thermal emissions in the relatively shallow waters of Hofra iz-Zghira. A rise in ambient temperatures is bound to aggravate thermal stratification of the coastal waters at this locality as well as in the surrounding areas on the south-eastern coastline of Malta, to the detriment of the present extensive sea grass meadows.

This case study showed that while nutrient levels in the open waters of the reference station were generally low, those in the inland creeks were often quite high, leading to increased primary productivity and in some cases, to mild eutrophic conditions. While no significant algal blooms were recorded in these harbours during this study period, possibly due to their transient nature, and the frequency of the sampling programme; blooms have been recorded in the past, at least in Pieta Creek, Marsamxett (Fudge, 1977). Eutrophic conditions and possibly algal blooms may become more significant and frequent in these and other similar near-shore semi-enclosed localities such as Marsaxlokk Bay, under the climatic conditions of the Worst-Case Malta Scenario.

Levels of Chlorophyll A (as an index of primary productivity) were found to be mostly determined by phosphate levels and less so by temperature. Nonetheless, no significant regression model could be developed to describe primary productivity in the area in terms of the other environmental parameters. This may be due to the complex interacting forcing functions affecting algal productivity in inshore areas, as well as to the limited time frame over which the data were collected. It also illustrates the difficulty of predicting the nature and magnitude of impacts of climatic change on coastal primary productivity. It may be however tentatively stated that any increase in phosphate levels due to increased freshwater run off during the autumn months may lead to enhanced productivity as well as promoting algal blooms in this area. The present case study has also shown that dredging in these ports may lead to enhanced phosphate levels. Therefore, man-induced, non-climatic, changes may prove to be more important in determining water quality and productivity in inshore waters, than factors directly related to mild climatic changes.

As expected, salinities at the various inshore stations were found to be negatively correlated with precipitation over Marsamxett. This confirms that increased rates of precipitation during the autumn months will lead to greater salinity fluctuations in inshore waters, as well as to the introduction of greater sediment loads and enhanced turbidity, all of which may limit the range of sublittoral and benthic species in such environments.

2.5.2.9. Impacts on land-sea fluxes

During the autumn and winter rain storms, significantly increased turbidity at some coastal localities may be readily observed. This increased turbidity due to increased sediment inputs, may extend for up to 1 to 2 km offshore. These localities include coastal areas lined with clay slopes such as Xatt l-Ahmar (southern Gozo) and Gnejna Bay (eastern Malta). Any increased sediment inputs into the marine environment may be expected to lead to changes in off-shore bottom profiles, as well as to altered substrate types and therefore to changes in benthic communities.

Marine sea grass meadows are particularly sensitive to reduced water transparency and the upper limits of the extensive present meadows at these localities may be expected to retreat to greater depths as a result of significant sediment loads in these waters due to climatic change. On the other hand, a rise in water temperatures may be expected to favour such sea-grass meadows, particularly those of *Posidonia* whose reproduction is known to be highly sensitive to ambient temperature. The net effect of climatic changes on such communities is difficult to predict, especially since they are also highly sensitive to non-climatic anthropogenic activities such as coastal construction and land-based pollution.

Climatic changes may also produce alterations in the coastal water currents, thereby affecting sediment transport along the shoreline. Little information is as yet available as to how climatic changes in the Mediterranean may effect the circulation patterns at the regional level. Any prediction of the effects of such climatic changes on local current speed and direction is impossible, given the present state of knowledge.

Any significant alterations to the local hydrodynamic conditions will not only affect shoreline stability, bathymetry and coastal erosion, but will also (perhaps more significantly) affect the fate of pollutants in the coastal environment. For example, the siting of the present major submarine sewage outfall at Wied Ghammieq was largely based on the fact that the predominant south-easterly current flow would carry the pollutants away from a number of important bathing beaches on the northern areas of the mainland. Recent unpublished studies carried out by the present author have shown that the sewage plume emitted by this major outfall, affects coastal waters off Marsamxett and the Grand Harbour. Any significant changes, or increased variability in the current pattern along the north-eastern coast of Malta as a consequence of climatic changes may have implications on marine contamination and transport of pollutants in these areas. The siting of any additional marine sewage outfalls, as proposed by the present Sewerage Master Plan for Malta, must take such factors into consideration.

It is well known that one factor leading to contamination of coastal waters by sewage in a number of localities around Malta and Gozo, is the flooding of sewers by rain water during the autumn and winter months. Any increased occurrence of rain storms during these months will aggravate this problem although the implications for human health may be less significant since it will occur mostly outside the bathing period.

2.5.2.10. Impacts on animal and plant distributions

Temperature is known to be an important environmental factor which determines the zonation of animals and plants both at the local level as for example on a shoreline and at the global level as in latitudinal zonation of biomes. Therefore, it may be expected that any increase in ambient temperatures, coupled with wider salinity fluctuations, will affect shoreline zonation, though the extent of this impact is difficult to determine. On a regional level, one impact of increased water temperature in the Mediterranean may be the accelerated penetration of Lessepsian migrants from the Eastern to the Western basin, and possibly an increase in the rate at which some migrants enter the eastern Mediterranean from the Red Sea. An increased occurrence of these new species in the Malta area may therefore be expected. This may itself affect local communities in various ways which are difficult to define and predict.

A number of studies have indicated that living communities may often respond non-linearly to slight modifications in their environment (IOC, 1991). Examples of such non-linear responses include: bleaching and mass mortalities of corals in responses to elevated temperatures, and changes in planktonic communities in response to altered nutrient levels and water temperatures. One biological phenomenon which was recorded over a significant proportion of the Mediterranean, and which may be a further example of such non-linear biological responses to climatic fluctuations, is that of coastal and off-shore blooms and aggregations of the jelly fish, *Pelagia noctiluca* (Axiak and Civili, 1991). The impact of such jelly fish blooms proved to be significant on the epipelagic ecosystems as well as on man's activities including fishing and coastal tourism.

The most recent bloom period of *Pelagia* occurred during 1979-1984 and extended over most of the French coastline, Italy, the Adriatic, Malta and Greek waters. Goy (1984) suggested that this phenomenon was related to pluri-annual climatic and hydrological cycles. This author suggested that the years prior to the bloom period were characterized by a rainfall deficit and by anomalous high temperatures and atmospheric pressures particularly during May and June. The way in which the scenarios of climatic changes by 2050, will affect such natural cycles in the epipelagic zone of the Mediterranean in general, and of the local environment in particular, need to be studied in greater detail.

2.5.2.11. Impacts on freshwater ecosystems

As discussed above although the number of freshwater habitats on these islands is quite limited, they support a significant number of rare, endangered and endemic species. There has been an obvious reduction in such fresh water communities over the past two decades, as illustrated by a reduction in the associated flora of Bahrija, Wied Ghajn Rihana and Gnejna (E. Lanfranco, pers. comm.). This may be due to reduced water replenishment of the aquifers probably related to increased road cover, and thereby to a decrease in the number and output of permanent and temporary springs. Increased evapotranspiration and reduced fresh water inputs, will accelerate this reduction and degradation. Therefore, the Worst-Case Malta Scenario coupled with increased human interference with such habitats may lead to their complete loss by 2050 or 2100.

In addition, increased autumn/winter rain storms will lead to changes in the location of water courses as well as to increased disturbance of valley floors through the movement of rocks and boulders. These habitats are extremely sensitive to such rain storms. For example, the vegetation at the bottom of Wied Qirda has apparently not recovered from disturbance which occurred during a particularly heavy winter storm in 1979, and is still dominated by weed species, which are indicative of disturbed habitats (E. Lanfranco, pers. comm.). These considerations indicate that the local freshwater habitats and ecosystems are more sensitive to predicted climatic changes than are the marine ecosystems.

2.6. Managed Ecosystems

2.6.1. Agriculture and silviculture

2.6.1.1. Introduction to present practices

As noted elsewhere in this report (section 2.5.1.), the major factor causing stress on the natural vegetation of Malta is water shortage. Existing scenarios for the coming century, suggest that this problem will become increasingly acute. Malta's present agriculture is developed to address this problem. Where water is available, fruit trees and vines are cultivated, but the major crops are potatoes, broad beans, various cucurbits as well as wheat, barley and sulla (*Hedysarum coronarium*), the latter being used mainly as fodder especially on drier soils.

There is very little silviculture and although Malta used to have woods of Evergreen Oak, *Quercus ilex* and Aleppo Pine, *Pinus halepensis* until a few hundred years ago, these have been gradually destroyed. Buskett near Rabat is probably the best attempt at reafforestation which was undertaken by the knights of St.John. More recent attempts have been the establishment of groves at Mizieb and Marfa Ridge which have only been partially successful. Although Aleppo Pine has been used fairly widely in reafforestation little use has been made of the Evergreen Oak. Olives, *Olea europaea*, have been planted in a number of sites; but programmes in the sixties and seventies to make Malta green have featured foreign trees, mainly from Australia, such as the Blue Wattle, *Acacia cyanophylla;* eucalypts, mainly *Eucalyptus gomphocephala* and *E. camaldulensis* and She-oak *Casuarina equisetifolia*. This has been to the detriment of the local terrestrial environment and probably also to the water tables. Increased environmental awareness is now directing attempts at silviculture into more environmentally acceptable forms. Less than 1% of the Maltese Islands are wooded and 60% of the wooded areas are accounted for by Buskett, Mizieb and Marfa Ridge (Boffa *et al.*, in prep.).

2.6.1.2. Impacts of climatic change and sea level rise

The most drastic scenario predicts a sea level rise of up to 1 m by the year 2100 which may be expected to have a negative effect on low-lying agricultural areas such as the Pwales valley, one of Malta's prime agricultural areas. It is also expected that soil salinity will increase such that even those areas which are not inundated will require different management practices if they are to remain productive. The effect on current silviculture would probably be minor since the main afforested areas are on relatively high ground, although the low-lying Salini area (Kennedy Grove) may be expected to suffer.

Present trends and operative scenarios suggest that temperatures may rise by up to 2.7° C, by 2050 and up to 4.5° C by 2100. The impacts of temperature change are moderated by water availability and other factors, but scenarios suggest that there are trends towards increased water shortage, increased salinity and increased erosion. Crops which are dependent on high water availability will suffer and a shift to the use of more xerophilic crops will be required. On the positive side, it should be possible to use more thermophilic crops. Trees which require a cool winter for dormancy will suffer leading to a consequent reduction in deciduous tree crops such as stone fruits and in deciduous trees. A possible serious consequence of an increase in temperature would be the proliferation of pest organisms which may seriously affect agricultural yields. All these factors will require a shift in the type of crops and trees which can be used, favouring xerophilic and halophilic species.

Although mean annual rainfall is not expected to change, available scenarios suggest a trend towards the concentration of rainfall into the autumn period. If this prediction is correct it is probably the most harmful aspect of predicted climate change in so far as agriculture is concerned. Heavy rains will speed up soil erosion, and since much of the agricultural land is on sloping valley sides or in valley beds, the effect of torrential rains will probably be devastating. Sharp contrasts in diurnal temperatures will also cause strong winds, further increasing the rate of erosion.

In addition to the increase in soil erosion noted above, heavy autumnal rains will leach away nutrients, reducing plant cover which will in turn reduce the accumulation of organic nutrients. Increased atmospheric carbon dioxide levels will also increase the acidity of rainfall hence altering soil pH and trace mineral solubility and availability for plant growth.

2.6.2. Fisheries and aquaculture

2.6.2.1. Background to Maltese fisheries

Fisheries constitute one of Malta's more important industries and capture fisheries based on several methods of fishing are in widespread use (Burdon, 1956). Among the more important fish are pelagic species such as Mackerel, *Scomber scomber;* Bogue, *Boops boops*; and migratory fish such as Lampuki,*Coryphaena hippuris* and Swordfish, *Xiphias gladius*. Although forms of aquaculture have been practised at Il-Maghluq (Marsaskala) and il-Ballut (Marsaxlokk) (Bonello, 1992), it is only in the last few years that research and incentives have led to increased interest in this sector. The fish currently used are Sea Bass, *Dicentrarchus labrax* and Sea Bream, *Sparus aurata;* and research is also being carried out with Tilapia, *Oreochromis spilurus*. The industry is geared mainly to export and the range of impacts outlined above in relation to natural marine ecosystems may well be expected to impact this nascent development sector..

2.6.2.2. Impact of climate change

The increase in temperature of seawater will probably be less than the increase in air temperature but may nevertheless affect a variety of marine species including fish. Probably the most serious effect on Maltese fisheries would be through changes to migratory routes of staple fish, particularly Lampuki. The current migration route of this species carries them close to Malta, making Malta the main exploiter of this fish in the central Mediterranean.

The increase in temperature may favour the diffusion of warm water species migrating in from the Red Sea via the Suez Canal. Ben-Tuvia (1985) states that 41 fish species as well as other animals have become established in the Mediterranean by this method although it is difficult to assess the impact of these migrants on local fisheries. At best they would diversify catches, at worst they may actively compete with more desirable species. Inshore fish and cephalopods depend very much on the health of sea grass meadows (especially those of *Posidonia oceanica*).

Sea grasses are already under threat from various anthropogenic factors such as pollution and trawling. An increase in sea surface temperature, is unlikely to have a direct negative effect since most sea grasses, including *Posidonia* are somewhat thermophilic. However, thermophilic algae and perhaps other sea grasses may actively compete with the native species resulting in changes in the composition of the fish community using the areas for nurseries. One migrant sea grass, *Halophila stipulacea* has already become established in some parts of the Mediterranean, including Malta. This, however, is unlikely to pose a threat to *Posidonia* since it is established in a different niche which is not sensitive from the fisheries point of view. Greater concern has been caused by the recent rapid establishment of the green seaweed *Caulerpa taxifolia* off the Mediterranean coasts of France. Like most species of *Caulerpa* this is somewhat thermophilic and it may also compete actively with *Posidonia*. Another possible threat to fisheries is the spread of pathogens which may affect fish populations.

Climatic change impacts on aquaculture will probably be more manageable, the main negative impact in this case would probably be the proliferation of pathogens. On the other hand, an increase in temperature is expected to increase the fish's metabolic rate possibly resulting in increased growth rates and production. Nevertheless with increased temperature, oxygen availability decreases, a factor which might affect fish bred in tanks.

2.7. Energy and Industry

2.7.1. Introduction

The energy supply and consumption patterns and the associated carbon dioxide emissions for Malta are reviewed. This analysis is based principally on data covering the period 1st October, 1987 to 30th September, 1988. Procedures leading to the more prudent use of resources as well as to future protection of the environment are discussed. It is generally accepted that human energy consumption accounts for 75% of greenhouse gas emissions and that CO_2 alone is the single largest determinant of the climate change problem (Table 8).

TABLE 8

Sources and nature of greenhouse gas emissions

75 %	Energy generation and consumption
25 %	Miscellaneous human activities: agriculture, industry, etc.
25 %	Carbon monoxide, ozone, methane, chlorofluorocarbons, oxides of nitrogen and others
75 %	CO_2

Much has been written about the causes of climate change and it is well established that anthropogenic CO_2 emissions released into the atmosphere during energy conversion processes are the major cause of the climate change phenomenon. Between 1958 and 1984 CO_2 concentrations in the atmosphere increased by 90% reaching a concentration of 20-25% above the level of pre-industrial times. The ability of the natural environment including, forests and the oceans to absorb this increase in CO_2 in the atmosphere, is not yet clear.

Reducing CO_2 emissions associated primarily with energy related human activities is considered an important response strategy to mitigate climate change. This section presents an energy overview for Malta and outlines possible future impacts which a changing climate may have on energy related activity in the country. Changes in the climate are expected to have an effect on energy demand in terms of the provision of electric lighting, space heating and space cooling.

2.7.2. Primary energy use in Malta

Throughout this section, the energy consumption on the island of Gozo is included in the figures for Malta. During the year 1987-1988, 841,793 Tonnes of coal equivalent (Tce) of primary fuels were used in Malta (Tables 9 and 10). Fuel, oil and coal are consumed primarily in the electric power generating station and a relatively small percentage is used for sea water distillation. Jet Al is used as aviation fuel, whereas petrol is employed mainly for private vehicles in the domestic sector. Diesel fuel and gas oil are used in all sectors: the data in Table 9 include sales to vessels calling at Malta. "Light" fuel oil tends to be demanded primarily by the commercial and industrial sectors, and liquefied petroleum gas (1pg) mainly by the domestic market (Figure 68). Kerosene is used in the domestic sector and as a diesel fuel supplement by omnibus owners.

TABLE 9

Fuel consumption by type and sector; CO_2 and SO_2 emissions by sector

FUEL CONSUMPTION				% EMISSIONS	
Type	**%**	**Sector**	**%**	**CO_2**	**SO_2**
Coal	25	Domestic	24	25	29
Fuel oil	40	Commercial	22	22	34
Petrol	9	Industrial	25	23	34
Diesel	10	Transport	29	30	3
Gas	3				
Kerosene and Jet A1	13				

TABLE 10

Fuel consumption and greenhouse gas emissions for Malta during the year 1st October 1987 to 31st September 1988
Gas emission values are based on factors provided by EneMalta Corporation

ANNUAL FUEL CONSUMPTION				GREENHOUSE GAS EMISSIONS			
				CO_2		SO_2	
Type	Tonnes	Tonnes Coal equivalent	%	Total Tonnes	%	Total Tonnes	%
Fuel oil	211936	307307	37	663360	36.0	12716	73.0
Coal	216411	216411	25	497745	27.0	3030	17.4
Jet A1	59609	87625	11	190748	10.3	179	1.0
Diesel	60087	86525	10	189274	10.0	240	1.4
Petrol	53819	77499	9	169530	9.0	108	0.6
Thin fuel oil	17032	25037	3	54502	3.0	1021	6.0
Gas	14507	22340	3	46422	2.5	43	0.3
Kerosene	12959	19049	2	41469	2.2	52	0.3

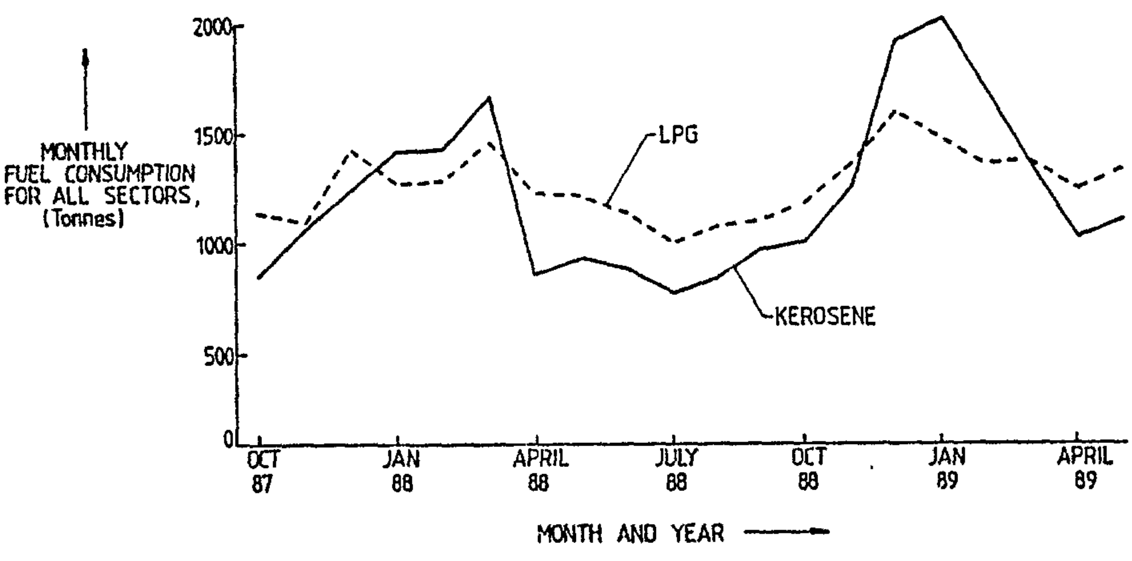

Figure 68 - Seasonal trends in liquid petroleum gas and kerosene consumption in all sectors

2.7.3. Energy conversion

Electricity is the most convenient form of delivered energy available. The industrial, commercial and domestic sectors in Malta employ electricity as their main energy source. Until recently, electricity was generated at a single power station, the output capability of which has been increased progressively to the present level of 260 MW. A new power station is under construction and will eventually replace this existing station. The distribution of electricity is via a two-tier transmission system at 33 and 11 kV with the service supplies at 240V, 50 Hz single-phase and 415V, 50Hz three-phase.

Even when there is adequate demand for electricity at the charged tariff, full output generation from thermal power plants is not realised anywhere in the world and in Malta, the average electricity plant load factor is only approximately 40%. The crude oil crises of the 1970s encouraged the use of coal as an alternate fuel for electricity generation and hence during the 1980s, boiler plant, with dual oil or coal-firing, was installed at the power station. The production of ash, as a residue of the coal-burning process, however has led to disposal problems. Environmentally-sustainable uses for this "waste" could include its use as a constituent in road repair and as a building material.

Electricity consumption has grown, on average, by about 8.5% per year recently in Malta (Figure 69), leading to a power demand of 190 MW during the winter of 1988. There are about 160 000 registered consumers connected to the national power grid, for a total population of ~345 000 and a stock of ~130 000 buildings. The average annual consumption *per capita* for electricity and primary fuels are approximately 3000 kWh and 2.4 Tce respectively.

Annual CO_2 emissions *per capita*:

electricity - ~3.5 T
other fuels - ~2.0 T

Continuing economic development appears likely to result in a sustained high growth rate for electrical power over at least the next decade.

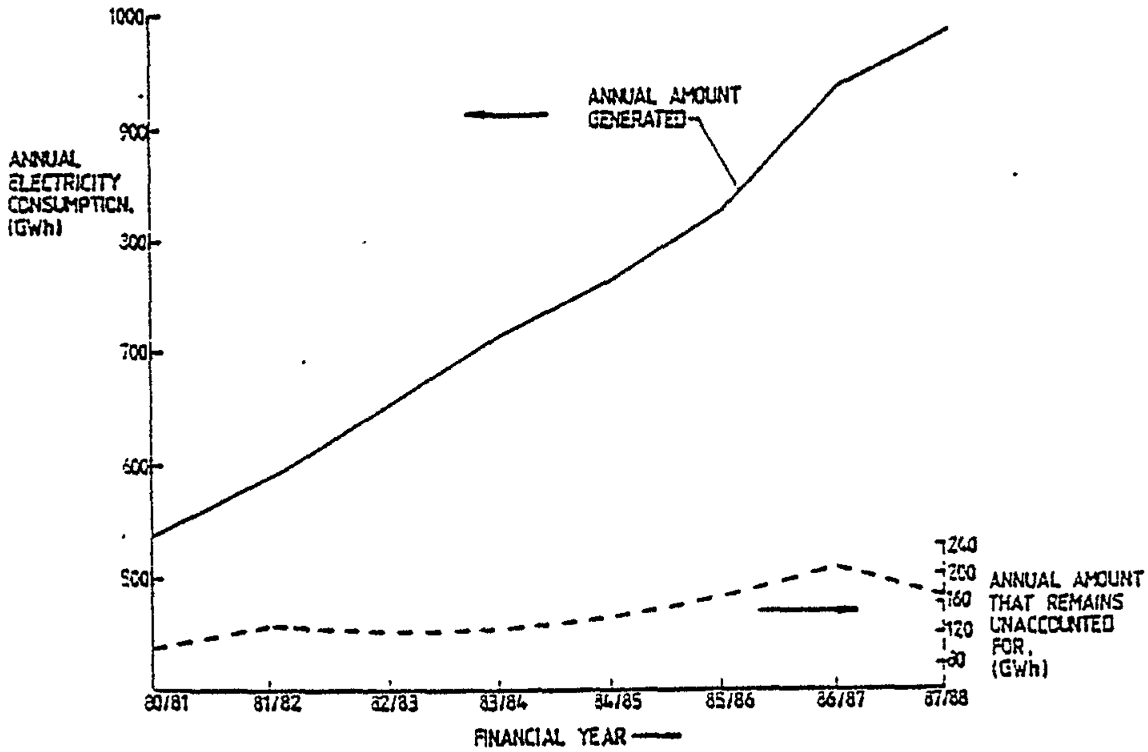

Figure 69 - Annual electricity generation in Malta, 1980 - 1988

Conversion efficiencies exceeding 30% can be achieved with conventionally fired thermal power stations (Table 11). With fluidised-bed combustors and integrated combined-cycle power plants, this efficiency can be greater than 36%. The use of two, multi-stage fluidised beds for burning those combustible components of domestic, commercial and industrial refuse which are not easily recycled should be considered for the new power station. Each bed would probably incorporate a reciprocating grate to facilitate the removal of ash and other non-combustible residues. Burning the refuse in this manner would make a positive contribution to reducing the greenhouse effect, since it would obviate the need for refuse burial and its subsequent decay to produce methane. By using these new technologies, more complete combustion can result and hence CO_2 emissions will be reduced.

TABLE 11

Mean Efficiencies of Thermal Power Stations in 1980 (2-4)

COUNTRY	THERMAL EFFICIENCY (%)
Federal Republic of Germany	38.6
Netherlands	38.6
USSR	37.5
Italy	37.3
Japan	36.3
Indonesia	35.3
France	35.1
Hong-Kong	34.5
UK	34.1
USA	32.5
Malaysia	30.0
Iran	27.5
Sri Lanka	26.2
India	25.9

2.7.4. Electricity generation

During the year from 1st October, 1987 to 30th September, 1988, 307 307 Tce of fuel oil and 215 691 tonnes of coal were imported into Malta and used to generate 309.93 GWh of electricity. Thus, 522 998 Tce of the 841 793 Tce or 62 % of imported fuel is used in electricity generation in the country.

Electricity generation accounts for 63% of CO_2 emissions and 90% of the SO_2 emissions in the country. Improving the generating efficiency would reduce these figures appreciably. This can be achieved by improving "house keeping" standards at the power station and by introducing a time-of-use tariff structure, thereby displacing demand peaks. It is estimated that these measures could increase the generating efficiency up to 30% and as a result, CO_2 emissions would be reduced by 820 514 T (29%).

During the year 1987/88, electricity was generated at the rate of 1.74 MWh/Tce. Assuming a mean calorific value for coal of 29.6 MJ/kg, then the average generating efficiency throughout the year was:

$$(1.74 \times 3.6 \times 10(3) \times 10(2)) / (20.6 \times 10(3))\% = 21.2\%.$$

Thus approximately 79% of the imported primary fuel used in the power station served no useful purpose - the "wild" heat being lost as pollution, e.g. via the exhaust combustion gases, such as CO_2, through the flue to the environment. Thus, due to inefficiencies in the power station, 49% of all fuel imported into Malta, served no useful purpose, whilst simultaneously contributing to global warming. Considering the lack of energy efficiency in a number of sectors, future increases in energy demand by the end user could be offset by increasing efficiency of energy conversion and elimination of waste.

From the economic point of view, energy conversion could be considered an energy source in itself. Experience elsewhere has shown that it is more cost effective to increase energy supply by resorting to energy conservation measures rather than by investing in additional generating plant.

2.7.5. Financial and loss considerations

It is believed that 909.93 - 735.13 = 174.8 GWh (i.e. 19%) of the electricity leaving the power station was not accounted for, primarily due to: line losses, resulting from inadequacies in the transmission and distribution systems; inaccurate metering; and, pilferage (Table 12). During the previous year, the corresponding figure was 23% (Table 13). Such financial losses must be reduced through reduction in leakages and more accurate measurement of the electricity used by each individual customer, thus allowing identification of exactly where the losses are occurring. The authority to disconnect such an essential service from an individual customer, in the event of theft being revealed, should not be given to a monopoly utility without restraint. Restraints must strike a balance between the consumer's justifiable need to remain connected to the service and the state's interests in being paid for the supply.

TABLE 12

Electricity purchases and equivalent CO_2 emissions by sector

SECTOR	ELECTRICITY PURCHASED		PROPORTION OF TOTAL FUEL IMPORTS	TONNES CO_2 EMITTED
	GWh	%		
Domestic	233.03	31.7	20	297346
Commercial	224.79	30.5	19	286832
Industrial	277.31	37.8	23	353847
TOTAL	735.13	100	62	938025

TABLE 13

Power generation and consumption by sector in Malta for the period 1980 to 1989

Year	GWh Gener-ated	Consumption as a % of power generated						
		Power station	Industrial	Commercial	Domestic	Public	Sundries	Lost unac-counted
1980-81	538	5.9	20.9	25.5	25.9	2.0	0.2	19.6
1981-82	588	6.0	23.2	22.1	23 0	1.9	0.2	23.6
1982-83	652	6.5	27.1	20.9	25.1	1.7	0.1	18.6
1983-84	715	5.6	26.2	21.5	27.7	1.5	0.1	17.4
1984-85	767	6.3	25.8	21.8	26.1	1.5	0.1	18.4
1985-86	826	6.2	24.9	22.4	24.5	1.5	0.2	20.3
1986-87	933	7.2	25.9	19.8	22.5	1.6	0.2	22.8
1987-88	993	8.3	27.9	20.8	24.4	1.6	0.2	17.6
1988-89	1095	8.1	27.9	19.4	24.4	1.7	0.2	18.5

2.7.6. Electricity consumption by sector

A breakdown of electricity consumption by sector is presented in Table 13 while end user costs are given in Table 14. Figure 70 indicates the trends in annual growth in electricity consumption. Details of energy consumption by sector for the year 1st October, 1987 to 30th September, 1988 are also provided in Table 10. It should be noted that Transportation accounts for 29% of all primary fuel consumption in Malta.

TABLE 14

End user costs in Maltese pounds (LM) by sector for the calendar year 1988 (It should be noted that unit costs for commercial premises greatly exceed such costs for domestic customers)

SECTOR	CONSUMPTION		END USER COSTS	
	GWh	% of total	106 LM	% of total
Domestic	272.15	36	6.66	30
Commercial	194.84	27	7.34	33
Industrial	279.5	37	8.13	37
TOTAL	746.49	100	22.13	100

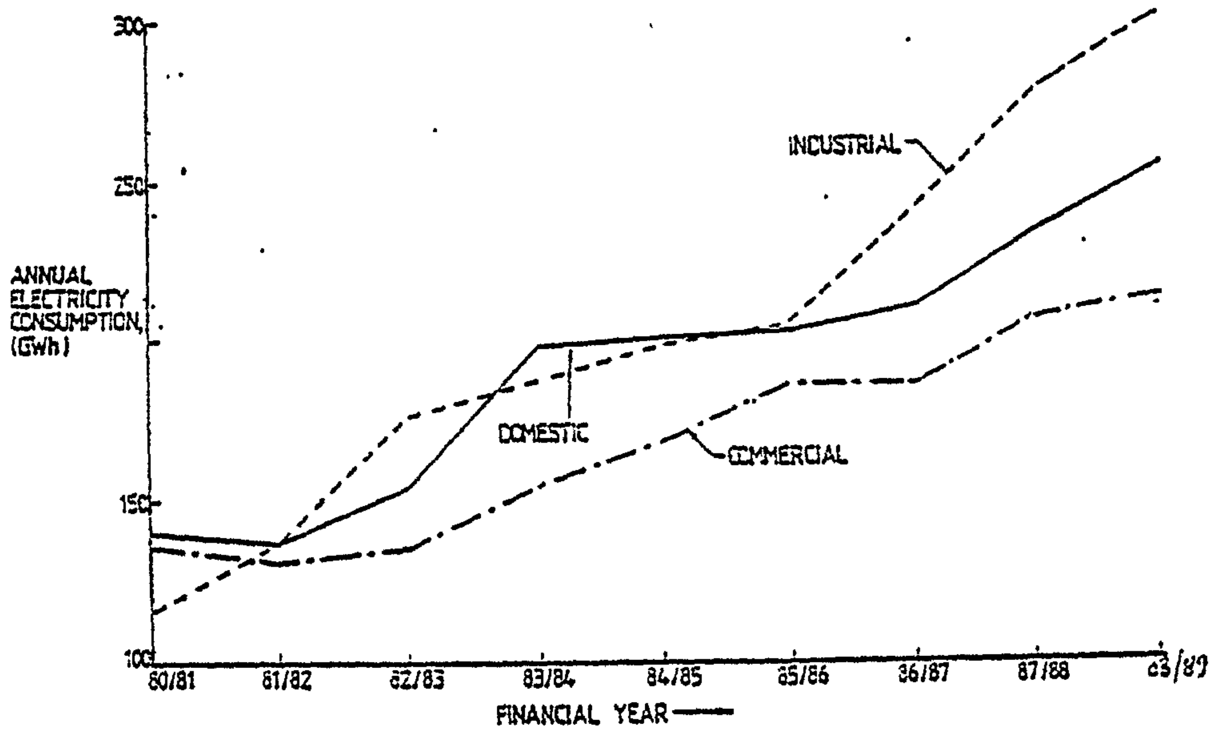

Figure 70 - Growth in annual electricity consumption by sector from 1980 to 1989

Electricity consumption in domestic buildings accounts for 24.4 % of the total fuel imports to Malta (Table 15). In combination with consumption in commercial buildings, this accounts for 46.4% (= 390 000 Tce) of the primary fuel imports to Malta. In addition around 5% of the electricity consumed in industrial premises is used in environmental control either in heating or cooling. This figure is likely to grow because of the increasing use of air-conditioning plants in factories. Thus buildings comprise the largest single consumer of energy, and over 80% of this energy, for heating, cooling, lighting and operating appliances is in the form of electricity. The base-load requirement imposed on the power station occurs during the summer and the peak demand, which is generally underestimated occurs during the winter (Figure 71). The pattern of electricity consumption is therefore largely determined by the external ambient temperature. The second peak in demand occurs in midsummer and may be attributed to air conditioning load. This peak is increasing from one year to the next. During the period October, 1987 to September, 1988, the built environment accounted for 956,174 tonnes (51.6% of the Maltese total) of CO_2 emissions and 11,790 (67.8%) tonnes of SO_2 emissions.

TABLE 15

Energy used in domestic buildings in Malta by source

ENERGY SOURCE	% OF TOTAL FUEL IMPORTS
Electricity	20.0
Liquid petroleum gas	2.4
Kerosene	2.0
TOTAL	24.4 (=205400 Tce)

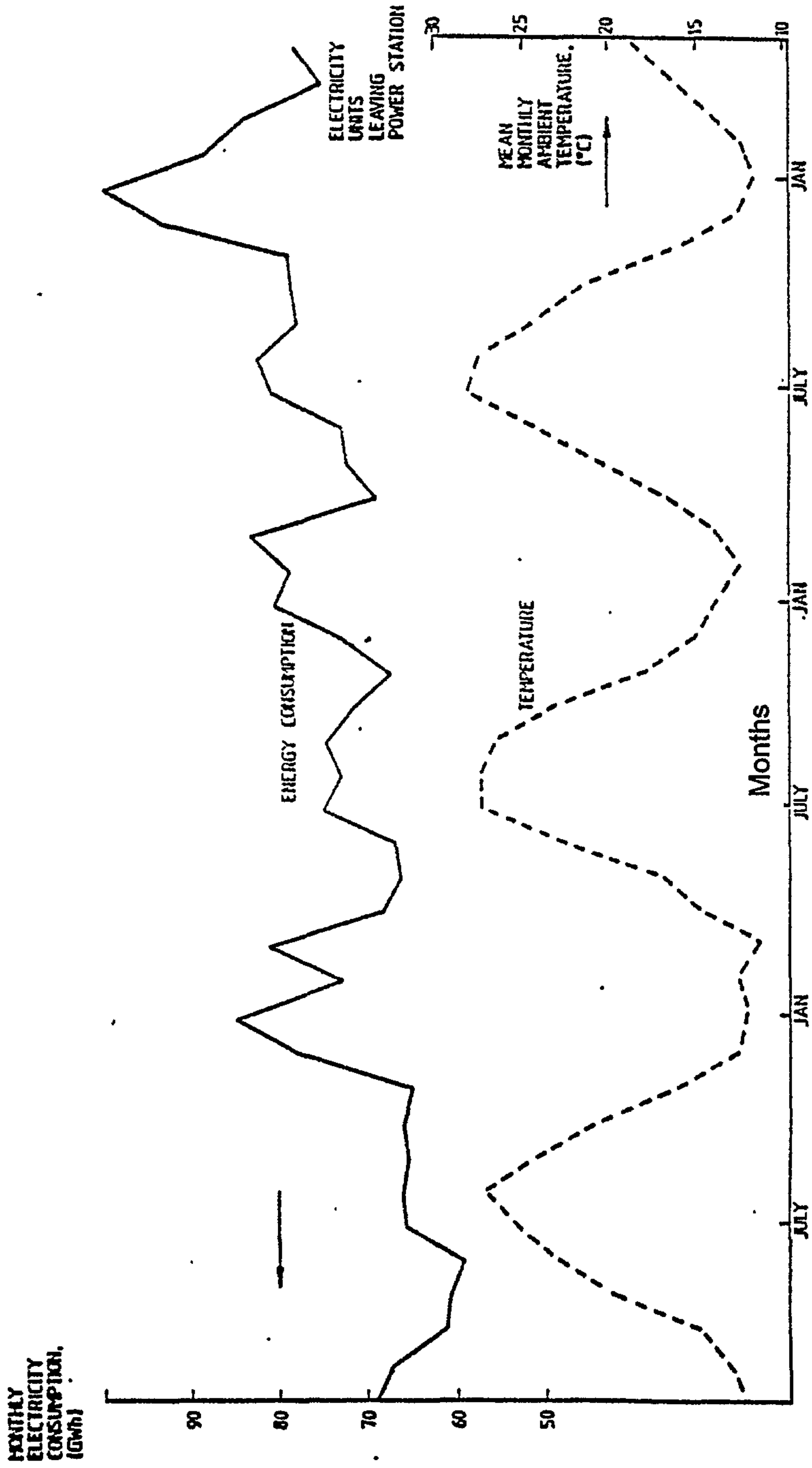

Figure 71 - Relationship between monthly trends in total electricity consumption and mean monthly air temperature over the period 1986 to 1989

The heating and cooling demand in a building as well as the need for electric lighting can be reduced by taking the necessary measures during the architectural design stage. The use of energy efficient appliances and lighting will further reduce electricity consumption and electricity demand delaying the necessity to invest in additional generating capacity.

Meteorological records for the past seventy years suggest that there has been a decrease in the number of bright sunshine hours in Malta. Generally speaking, this would result in a decrease in available natural daylight and hence would suggest that the use of artificial electric light should have increased. If this trend continues further use of electricity for artificial lighting might be expected.

More than half of Malta's daily drinking water supply, amounting to nearly 12 million gallons, is produced by reverse osmosis desalination of sea water. The production of potable water by this method accounted for 11% of electricity consumption in 1988 (Table 16).

TABLE 16

Electricity consumption (GWh), CO_2 emissions and cost (10^6 US$) of drinking water production through reverse osmosis desalination, 1987 to 1991

PLANT	1987	1988	1989	1990	1991	TOTAL
Tigne	8.15	25.14	31.98	34.48	37.73	137.48
Cirkewwa	-	0.26	10.17	20.79	36.14	67.37
Ghar Lapsi	51.27	51.02	52.00	52.49	51.62	258.40
Marsa	1.21	0.83	0.87	1.44	1.54	5.89
Marsa add*	2.57	1.76	1.85	3.06	-	9.25
Pembroke	-	-	-	-	9.49	9.49
Malta Total	63.21	79.01	96.88	112.27	136.52	487.89
Gozo	0.90	2.34	1.99	1.63	1.13	7.99
Country Total	64.11	81.35	98.87	113.90	137.65	495.88
CO_2 emissions	81800	103800	126200	145300	175700	632700
Cost (10^6 US$)	5.76	7.32	8.91	10.26	12.39	44.64

2.7.7. Energy intensity

The relationship between GDP and electricity consumption provides a clear indication of the energy intensity of the country's economic activity. Energy intensity, expressed in GWh 10^{-6} LM (Gigawatt hours per million Maltese liri) is presented in Figures 72 and 73. In Figure 72, total electricity consumption in all sectors is plotted while Figure 73 illustrates industrial consumption. The trend in both instances is similar. For the four year period between 1983 and 1987, electricity intensity per unit of GDP increased annually and this upward trend is unlikely to level off for years to come.

Until recently, industrial growth was considered to be necessarily accompanied by a corresponding increase in energy consumption. Over the past two decades however the energy intensity in OECD countries has declined by 3% *per annum*.

2.7.8. Renewable energy resources

The necessity to incorporate more renewable energy sources into the world energy structure was recommended by the Brundtland Commission (The World Commission on Environment and Development, 1987). The displacement of fossil fuels by renewable energy sources, particularly biomass and hydropower could reduce substantially future CO_2 emissions. In Malta, there exists a good potential for the use of solar energy, particularly in those applications where low to medium grade source of heat is required. The possibilities of harnessing wind energy on a large scale are more restricted, although wind energy is widely used for water pumping in agriculture.

Solar energy flow can be regarded as a very large energy resource which in principle can supply all the energy needs of mankind. The amount of solar energy incident on the Maltese Islands in one year is five hundred times greater than the annual electricity consumption. However, a solar thermal electricity generating plant working at 20% efficiency would require 10% of the available land area to supply this quantity of energy. Passive solar energy use in buildings whereby a building's orientation, window sizing and fabric are designed in order to optimise the use of solar energy for space heating, cooling, lighting and ventilation can considerably reduce the energy demands of new buildings. The built environment is the single most energy intensive sector in Malta and hence alterations to building design and practices could provide an energy conservation mechanism in the long-term .

The decreasing trend in the number of bright sunshine hours in Malta amounting to 3.1% over the past seventy years could however restrict the future application of solar energy in those instances where direct solar radiation is required. An economic and technically viable application of solar energy is for water heating. The widespread use of solar water heating systems in the domestic sector could reduce Malta's annual energy bill by up to 3%. In the event that available solar radiation is reduced, the economic feasibility of this application is less attractive.

2.7.9. Implications of expected climatic changes for energy use

During the winter, the predicted average temperature increase should reduce the need to provide artificial heat, thereby conserving energy. Considering the low thermal performance of the building stock in Malta; and the fact that only certain areas are heated in most buildings and then only intermittently, it might be expected that, an increase in ambient temperature would lead to more thermally comfortable building interiors, rather than to a saving of energy. Malta weather records also indicate a drop in the extreme low temperatures over the past seventy years suggesting that energy consumption may be increased to cope with these extremes.

While the above conclusion may be valid for domestic buildings, in the commercial and industrial sectors, the internal heat gains are much higher, due to the use of computers and machinery. Consequently an ambient temperature increase may generate a cooling load to be satisfied by increasing ventilation and possibly the extension of the air conditioning season.

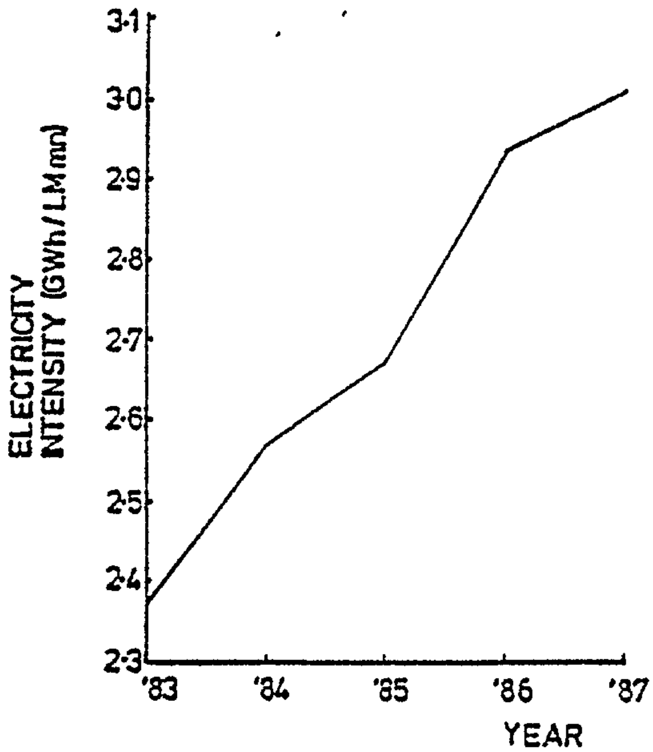

Figure 72 - Changes in Energy Intensity (GWh/10 ^{6} LM) for all sectors over the period 1983 to 1987

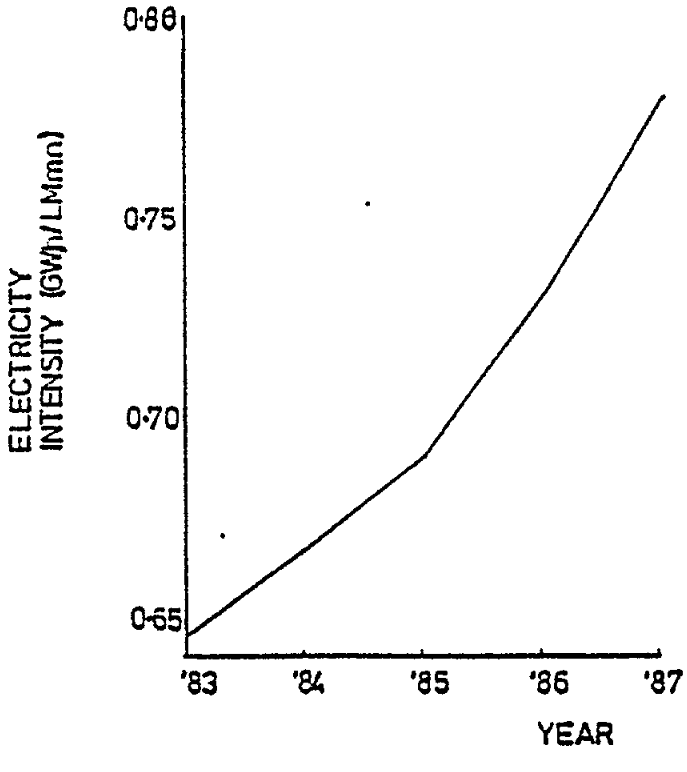

Figure 73 - Changes in Energy Intensity (GWh/10 ^{6} LM) in the industrial sector over the period 1983 to 1987

Whatever the outcome, the introduction of thermal insulation to the building envelope reduces both the heating demand in winter as well as the cooling demand in summer. It should also be borne in mind that people not buildings consume energy and that the sensation of thermal comfort is a subjective matter. It would therefore be incorrect to conclude outright that a change in the ambient air temperature will be reflected in a directly related change in energy consumption.

In conclusion, it seems that the anticipated changes to the climate in Malta could increase the use of electric lighting, increase the demand for mechanical air conditioning and reduce the extent to which renewable energies could be utilised.

2.8. Tourism

2.8.1. Introduction

Since time immemorial tourism in the Mediterranean has played an important role in the economic and social development of the littoral countries of the region. Estimates have shown that the resident population in the Mediterranean of about 130 million people is doubled during the peak summer months.

By the end of the 1980s, over 120 million tourists had visited the countries of the Mediterranean, which is about 36% of world tourists. By the year 2025, if the present trends continue, there will be between 35 million and 52 million additional tourists visiting the Mediterranean region over the three-month summer tourist peak between June and August. The estimated total number of tourists by 2025 will be around 400 million in the Mediterranean.

Statistical data show that tourism contributes an average of 6.5% to the Gross Domestic Product in these countries. In addition to generating employment, tourism is also in some instances the major source of foreign exchange earnings. Such earnings are used to pay for: the cost of imported goods and services used by tourists; some of the costs of capital investment in tourist amenities, including hotels and transport facilities; payments to foreign travel agents; royalties; and, promotion of Malta as a tourist destination overseas.

At the same time, an increase in the number of tourists is accompanied by strain on the infrastructure of a country including increased water consumption and increased volumes of sewage requiring disposal. These trends necessitate improvement and further development of coastal management systems in the country concerned.

The rise in the 1980s in the number of tourists visiting the Mediterranean has been matched by a rise in global temperatures. The last decade has recorded six of the eight warmest years ever, while 1990 was the warmest year on record.

Climate change will also put pressure on the local population. With a progressive warming of the planet, more water will evaporate with the result that freshwater, particularly drinking water, may become scarcer. Indeed, at the Second World Climate Conference (Jager and Ferguson, 1991), meteorologists from the Mediterranean region reported that drought was now seriously threatening water supplies that are so essential for a healthy tourist industry It is obvious that any adverse climatic changes are likely to adversely affect current patterns of tourism which are dependent upon particular climatic conditions. The majority of tourists visiting the Mediterranean arrive in search of sunshine and warm seas. The Mediterranean is dotted with holiday resorts of all kinds. If climate change were to destroy the interest value of national parks, or blight resorts through excessive heat or over-frequent storms, then the tourist infrastructure would have to be relocated and disadvantaged resorts would suffer.

2.8.2. Tourism in Malta

Tourism in Malta has for many years been one of the Islands' most important economic activities. Tourist arrivals in 1990 reached 871,776 while in 1991 the figure rose to 895,036 (Table 17, Figure 74). In 1990 earnings from tourism totalled about 157 million Maltese Liras, (US$ 518 million) representing about 25.1% of exports in goods and services. In 1991, earnings from tourism rose to Maltese Liras 175.3 million (US$ 578 million).

The projection for total arrivals by 1994, is set to reach the one million target with maximum total future arrivals ceasing to rise at around 1.2 million tourists a year. The population of Malta is 359,455 or about one third of the current number of tourists visiting the islands. It is clear that the tremendous pressure on the local population as a result of this influx has to be compensated for by financial rewards.

The heavy demands being created by tourists on the Maltese economy are evident from the level of full-time direct employment in hotels, complexes and catering establishments which at the end of September 1991 stood around 7,609 or 5.8% of the total gainfully occupied population. This percentage would be considerably higher if the figure were to include employment in tourism-related services.

While efforts are being undertaken to extend the distribution of visitors throughout the year, seasonal patterns (Figure 75) show that the peak summer months of July, August and September continue to attract the majority of tourists (Tables 18 and 19). The proportion of arrivals during this quarter, totals nearly 50% of total annual arrivals.

TABLE 17

Tourist arrivals (thousands) in Malta by country of origin

	1985	1986	1987	1988	1989	1990	1991
UK	256.5	329.4	446.7	476.6	492.9	450.0	458.5
Germany	57.0	59.7	70.2	77.6	91.7	130.2	136.4
Italy	43.8	36.5	43.5	50.7	53.2	64.0	64.0
Libya	43.3	23.1	44.4	37.1	31.2	36.1	46.8
France	24.4	25.5	27.9	23.9	27.7	34.4	33.8
Scandinavia	20.0	23.2	22.5	22.5	23.3	29.4	17.9
Netherlands	7.9	9.2	16 1	17.8	17.3	22.2	23.6
Belgium	2.9	30.0	4.5	6.2	8.6	10.0	10.0
Switzerland	9.9	11.5	14.2	14.0	13.9	14.4	17.0
Austria	4.8	5.7	4.6	5.1	7.9	12.1	14.1
USA	6.8	5.2	7.1	87.3	9.8	9.9	8.8
Other	40.4	42.1	44 1	43.4	50.7	58.9	63.9
TOTAL	517.9	574.2	745.9	783.8	828.3	871.8	895.0

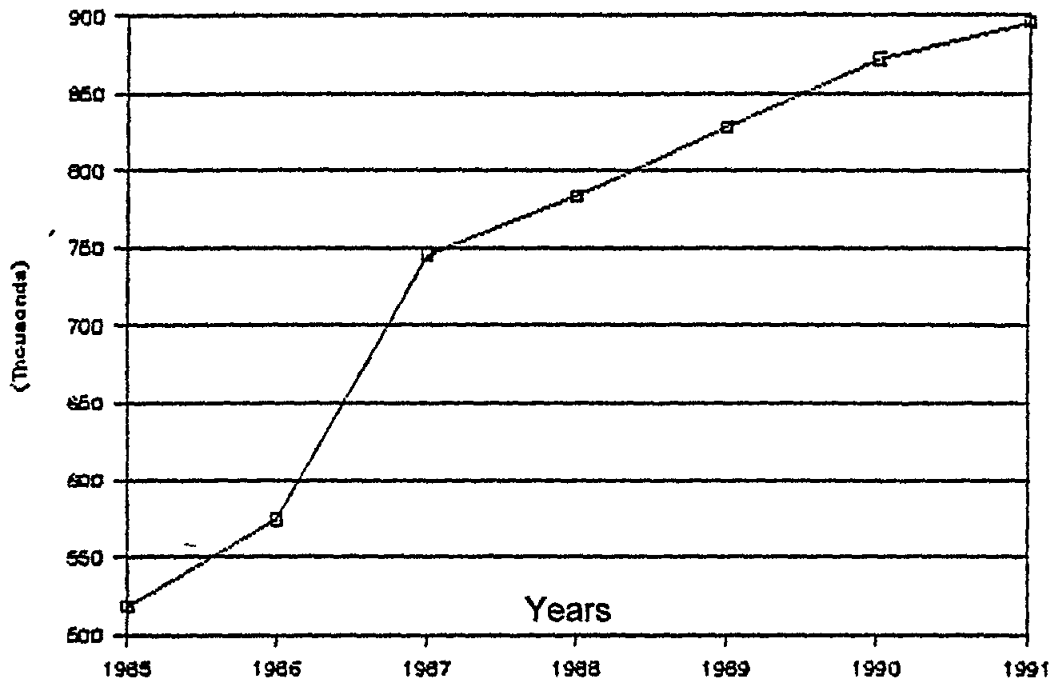

Figure 74 - Annual growth in tourist arrivals (thousands) in Malta, 1985 to 1991

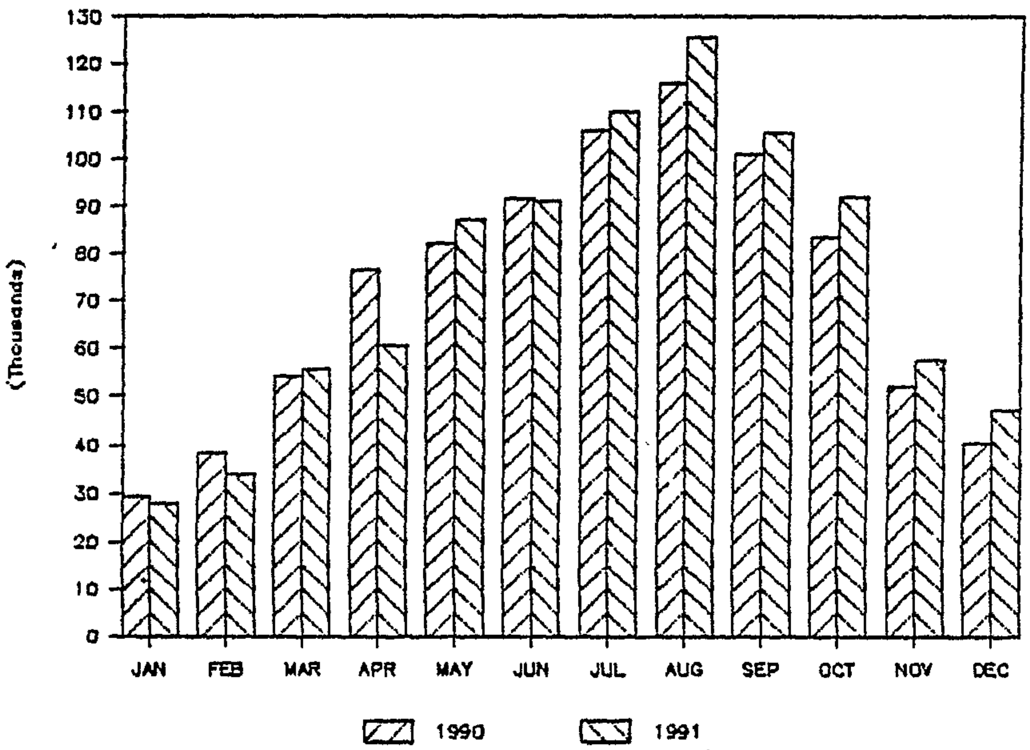

Figure 75 - Seasonal pattern of tourist arrivals in Malta during 1990 and 1991

TABLE 18

Monthly distribution of tourist arrivals (thousands) in Malta

	1985	1986	1987	1988	1989	1990	1991
January	15.3	17.6	20.4	24.0	28.6	29.2	28.0
February	20.3	21.5	25.4	31.5	35.5	38.4	34.0
March	32.0	37.5	36.6	47.6	57.4	54.0	55.5
April	35.0	32.0	52.9	52.4	58.8	76.8	60.6
May	45.8	54.8	75.0	76.5	83.9	82.3	87.3
June	49.9	55.7	82.0	84.4	87.2	91.5	90.9
July	65.6	72.4	99.7	105.2	104.3	106.0	110.1
August	83.1	89.0	110.4	106.4	110.2	116.1	125.7
September	63.5	69.6	90.7	94.6	94.7	101.3	105.8
October	52.6	61.3	76.1	78.6	80.7	83.6	92.0
November	27.7	33.3	39.4	45.6	50.3	52.1	57.6
December	26.9	29.3	37.0	37.0	36.7	40.5	47.3
TOTAL	517.9	574.2	745.9	783.8	828.3	871.8	895.0

TABLE 19

Seasonal pattern of tourist arrivals in Malta

	1987	1988	1989	1990	1991
Winter Nov. Dec Jan. Feb.	122332	138095	151012	160132	166973
	16.4%	17.6%	18.2%	18.4%	18.7%
Shoulder Mar. Apr. May. Jun. Oct.	322661	339539	368033	388256	386370
	43.3	43.3	44.4	44.5	43.2
Summer Jul. Aug. Sept.	300950	306212	309266	323388	341693
	40.3	39.1	37.3	37.1	38.2
TOTAL	745943	783846	828311	871776	895036
	100%	100%	100%	100%	100%

The sun, sea and sand continue to be the main images and attractions for tourists visiting Malta, even though efforts are being made to diversify these images to include the cultural and historical assets of the Maltese Islands. Malta has often been referred to as "the island of sunshine" and therefore the sun-seekers who flee from Northern Europe's cold and often damp weather, find in Malta the perfect refuge. Some 85% of the tourists that visit Malta come from the countries of the European Community.

2.8.3. Impacts of climatic changes

The impacts of climate change on the Maltese Islands can be encapsulated in the message delivered by the Prime Minister of Malta on the occasion of the 1991 WMO World Meteorological Day, who stated that:

> " ... the very temperature of our people is a reflection of our climate, which has influenced our lives. Atmospheric warming, rainfall deficiency and sea-level rise will dramatically affect our small island and life therein. Water resources and agriculture are two important resources that are already strained. Malta already spends 30% of our energy bill transforming seawater into drinking water. Tourism, which is one of the island's major foreign-currency earners employing thousands, would suffer if the heat becomes intolerable. Already we find that warm summers in the north of Europe - Malta's main market - affect the number of incoming tourists."

It is of no surprise that tourism could be adversely affected by changes in the Maltese climate since tourism is climate sensitive in general. In addition the tourist industry is fragile being susceptible to political, economic and social upheavals. The possibility of a change in climate adds another element of uncertainty in a small society like that of Malta. If the mild and warm climatic conditions in Malta are replaced by biting winds, fog, snow, excessive heat or over-frequent storms, the tourist industry will suffer and with it a substantial part of the Maltese population.

An important aspect mentioned by the Prime Minister of Malta relates to the rise in temperature in the countries that are providing the bulk of tourists to Malta, particularly those coming from Austria (1.58%). France (3.78%), the Netherlands (2.64%), Switzerland (1.90%) and the Scandinavian countries (2.7%). An increase in temperature will have an adverse impact of the number of tourists visiting Malta in that these 'Northern' tourists will think twice before visiting the 'Island in the South'. The Commonwealth Group of Experts on Climatic Change has noted that the greatest warming is likely to occur in winter at high latitude (60-90 degrees), especially in the Northern hemisphere (Holdgate *et al.*, 1989). With an average one degree increase in temperature in the United Kingdom, the extremely hot, dry year of 1976 would no longer be considered a rare event and hence one reason for UK tourists visiting Malta would be removed.

A further concern, in terms of an adverse impact on tourism is the health hazard resulting from increased penetration of harmful UV radiation. Already, in other parts of the world, public service campaigns are warning of the dangers of sunbathing. As the ozone gets thinner, people may have to cover up year-round to avoid risks of damage to the eyes and skin.

Climate change and sea-level rise may have significant and mixed impacts on such site-dependent infrastructure supporting coastal tourism and the recreation industry. In the case of infrastructure development directed towards the tourist industry, climate change could render non-functional the buildings along sections of resort coastlines. In Malta, the length of accessible coastline which is dominated by tourism is 84% on mainland Malta and 74% on Gozo and Comino. These percentages show in no uncertain manner the magnitude of the impact which climate change could have on Malta's tourist coastal areas and hence on the economy of the country.

Residential buildings which have increased in numbers over the last decade along the coast will also suffer if there is an increase of winds and storms, making it unpleasant and difficult to enjoy the cool sea-breeze which frequently blows near the Maltese seashore. Sandy beaches which are thronged by tourists who visit Malta, could also be endangered by sea-level rise. Because of the geological nature of the coastline there are a few sandy beaches in Malta and as discussed above a rise in the mean relative sea-level of approximately 50 cm, is likely to cause inundation and shoreline recession in a number of localities on the Malta mainland. Spiteri (1990), states that:

> "there are indications that a number of sandy beaches are presently affected by erosion process".

Climate change would accelerate this process.

A change in climate, particularly a rise in temperature would increase water and electricity consumption. The use of more water in hotels and holiday complexes will necessitate an increase in the production of drinking water which in turn increases the demand for greater electricity supply. It has been calculated that a luxury hotel consumes around 600 litres of fresh water per guest per night. This water demand can lead to lower ground water levels. Furthermore, higher evaporation rates as a result of temperature rise will increase the aridity of the Mediterranean region which will in turn cause the freshwater aquifers to be replenished more slowly. All these factors could create serious problems of water shortage.

Increased demands on electricity supplies will result from the demand for additional cooling systems in hotels and holiday complexes, not only during the summer months but also during other months of the year. This would in turn bring about a rise in the hotel accommodation rates and other related services.

A rise in temperature could possibly affect those hotels and tourist complexes that are situated inland since tourists might prefer to stay near the shore where sea breezes would ameliorate the higher temperatures. This would result in changes to the distribution of tourists on the island causing economic hardship in disadvantaged areas.

2.9. Transport and Services

2.9.1. Introduction

In the report 'Climate Change - Meeting the Challenge' prepared by a Commonwealth Group of Experts (Holdgate *et al.*, 1989), it is stated that:

> "transport is likely to be affected both by the direct impact of climate events (flooding, fog, ice or snow) and by demands for enhanced economy in the use of fossil fuels which could augment pressures for more efficient systems and for public transport at the expense of energy-demanding, low-occupancy private vehicles."

This conclusion is also reached by the Intergovernmental Panel on Climate Change Impact Assessment Report (Tegart *et al.*, 1990) which states that:

> "an increase in temperature can be expected to reduce sea and river ice and snowfall, affecting shipping, air travel, highway and rail transport" and "some elements of transport are likely to be significantly affected by public policies or consumer actions designed to restrain emissions of Greenhouse Gases".

At the same time, the IPCC Report points out that:

> "the studies concerning the likely implications of climate change for transport are quite restricted in geographic scope, being limited largely to three countries: Canada, the United Kingdom and the United States. It is uncertain how these studies in three high latitude Northern Hemisphere nations are representative of likely transport impacts on the globe as a whole".

The conclusions which can be deduced concerning the impacts of climate change on transport in the Maltese Islands may therefore be limited.

2.9.2. The transport systems in Malta

In Malta, because of its small land area, no railway exists and there are no inland waterways or rivers. As a result, transport on the islands of Malta depends entirely on roads although a ferry service connects the two islands of Malta and Gozo. A ferry service has also been introduced around the Grand Harbour area.

Being an island country in the middle of the Mediterranean, Malta is dependent on sea and air links with the outside world. Sea and air transport are the backbone of the local economy particularly in relation to: the tourist industry; the import of goods and commodities; and, the export of manufactured products. Ship repair and ship building are two other important sectors which depend on maritime transport. Transport and communications-related activities account for about 6 per cent of the Gross Domestic Product.

The European Community is the main trading partner of Malta, accounting for 78 per cent of overseas trade and being the principal source of Maltese imports and market for exports. More use is being made of the TIR transport and together with the shipping lines serving Malta, these facilities offer Maltese businessmen the opportunities of increased foreign trade.

Another important sector that depends on sea transport is the container terminal run by Malta Freeport Corporation which is fast securing the role of a major distribution centre in the Mediterranean from where important markets can be reached.

2.9.2.1. Road transport

Road traffic is greatly on the increase as a result of a substantial increase in the number of cars (Table 20). Car ownership in Malta has risen sharply, averaging an annual growth of 7 % per annum between 1981 and 1991. The number of cars per 1000 inhabitants is about 346 compared with 550 in the USA; between 200 and 400 in Western Europe; 9 in Africa; 2 in India; and only 0.4 in China.

Transportation accounts for 29 % of all primary fuel consumption in Malta. The combustion of oil-based fuels such as petrol and diesel causes the emission of gases, primarily carbon dioxide, oxides of nitrogen, hydrocarbons and carbon monoxide. Two of these gases, carbon dioxide and nitrous oxide, are greenhouse gases and so have a direct effect on climate change. These emissions are a significant proportion of all emissions from the commercial and industrial sectors. Studies have shown that 30% of CO_2 emissions in Malta come from transport while those from the commercial and industrial sectors amount to 45%.

In the light of concerns over global warming and environmental pollution, the Government of Malta is taking steps to restrain emissions of greenhouse gases including those from transport. One direct measure that has been taken to reduce the levels of potential greenhouse gases is the introduction of lead-free petrol for motor vehicles. Owners of motor vehicles are also being encouraged to make sure that their petrol-driven cars are equipped with three-way catalytic converters which remove oxides of nitrogen, hydrocarbons and carbon monoxide from the exhaust gases. These steps are also in line with Malta's application to join the European Community where three-way catalytic converters became compulsory for all cars from early 1990.

No studies exist on the likely impacts of climate change on roads in countries similar to Malta, where local transport is entirely based on road transport. The total length of public roads in Malta in 1989 was about 1553 kilometres of which 1433 kilometres were paved or asphalted. Since then a vast programme of road improvement has been undertaken. The importance of road communication in Malta therefore cannot be over-emphasized. Road transport is affected by heavy rainfall when roads are often flooded. According to the scenarios developed by the Climatic Research Unit of the University of East Anglia (Palutikof, 1992), there will be no appreciable change in total precipitation before 2025, although the incidence of autumn heavy rains may increase. Lowered rainfall at other times of the year could result in fewer potholes and reduced flooding frequency.

An increase in temperature would necessitate a considerable financial output to upgrade the public transport which currently is not equipped with air-conditioning. The majority of buses have been on the road for a number of years and therefore it will prove difficult to install air-conditioning systems. Such buses will therefore have to be replaced with new ones that are energy efficient and less polluting. It should be noted that when second hand buses were imported from the U.K. they were found to be unsuitable due to their size and the prevailing climate.

2.9.2.2. Maritime transport

The IPCC Impact Assessment Report states that:

"there is little data or analysis concerning the potential impacts of climate change and associated sea-level rise on ocean shipping and on sea ports".

Being an island country, Malta utilizes its maritime potential as much as it is technically and financially possible. Vessels of the company Sea Malta Ltd. navigate the Mediterranean and adjoining seas, while its ports offer safe-haven to numerous vessels, transhipment facilities, yachting centres and most importantly dockyard facilities which are the major employer in Malta.

Ferry services between the two major islands of Malta and Gozo are used all year round for transport of commuters (workers and tourists) and for inter-island movement of consumer goods.

Climate change could have a negative impact on the maritime sector, in particular if there is an increase in the frequency or strength of storms and winds which have in the past caused cancellation of the ferry services between Malta and Gozo. In the past strong winds and waves have damaged breakwaters and wharfs around Malta and increased frequency of such events could result in increased maintenance costs. However, according to the data discussed above the number of days each year with gusts greater than 34 knots shows a downward trend from 54 to about 35. This trend, together with the new ship-building technology provides a favourable outlook for maritime transport in and around Malta.

At the same time, wind speed data show no significant long-term trends hence wind generated waves will continue to damage the sheltered harbours and caves that protect fishing and leisure boats. The building of breakwaters would therefore have to be continued.

2.9.2.3. Air transport

The situation in regard to air transport is similar to that of the maritime sector. Climate change might in fact give a boost to the air service sector in Malta.

Air Malta, the Maltese air carrier, is an important communication link with major capitals of Europe. Air Malta's operations have scheduled services to 22 major airports and regular charter flights from several more. In view of its small fleet, Air Malta's aircraft have one of the highest utilization rates in Europe. In addition, a helicopter air-link service is maintained between Malta and Gozo for six months every year. Already this service, introduced in 1990, increased its passenger load by 38% in 1991, a trend which could further improve with a positive climate change

Technological advances have made it possible for aircraft to fly in temperatures as low as -65 ° C and in winds as strong as 400 knots. Furthermore, technological improvements are minimizing fog and low cloud visibility problems. From an analysis of climate trends in Malta, the outlook for air transport is good since there are already trends towards a decrease in the amount of cloud cover; an increase in anticyclonic conditions; a decrease in the number of days with fog; a decrease in the number of days with gusts >34 knots. If these trends continue under changed climatic conditions this will have a positive influence on air transport.

Helicopter operations may on the other hand, face problems particularly during take-off if conditions of high temperature and low barometric pressure become more prevalent. According to existing data the maximum temperature has increased by 1.0°C or 4.7% over the last 70 years. Over the last 40 to 45 years, the highest temperature recorded each year has increased by 2.8%. In contrast, atmospheric pressure is showing an upward trend. In fact, over the last 70 years or so, atmospheric pressure in Malta has increased by 11.5 hPa or 10%, which may hinder aircraft performance, particularly during take-off.

A negative aspect that might influence air flights is the increase of the number of days with thunder, which shows an upward trend from about 25 to 32 per year. Since thunderstorms are on the whole more frequent during the afternoon and evening, aircraft may be faced with turbulent weather during these periods. Since a number of flights are scheduled in the afternoon and evening a shift in their timing would have to be made. In addition an increase in hazy conditions due to suspended particles in the air is apparently occurring which may also adversely affect air transport operations.

TABLE 20

Increases in numbers of vehicles in Malta, 1981 to 1991

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Private cars	69973	76409	73448	77419	79712	82580	86298	949095	107005	115327	124483
Hire cars	4800	3421	2772	2921	2547	3018	3206	3542	3638	4285	4750
Buses	297	57	138	611	645	646	636	697	674	583	583
Commercial	17288	17665	16037	16757	17524	17178	16579	18597	18889	21521	24170
Motorcycles	10988	11880	12019	9301	9587	9405	9146	8406	8122	8359	8482
Other	1184	1070	838	1089	1195	1370	1285	1491	1784	1914	2142
TOTAL	104530	110502	105252	108098	111210	114197	117150	126828	140112	151990	164610

2.10. Health and Sanitation

2.10.1. Introduction

The effects of climate on health were already appreciated and commented upon centuries ago. Climate may not only influence somatic conditions but it is also well known that it may affect mood as well. As early as the twelfth century, the Jewish physician, Rabbi Moshe ben Maimon (Maimonides) born in Cordoba, and court physician to Saladin, was already well aware of the negative effects which certain climatic factors had on such respiratory conditions as bronchial asthma. In 1190, this 'prince of physicians' wrote a treatise on asthma, in arabic; 'Makalah Pi Alrabo' for the benefit of Saladin's son Alfadhel, who was an asthmatic. Amongst other measures, Miamonides recommended a change from the humid air of Alexandria to the dry heat of Cairo (Rosner, 1973).

Malta, because of its favourable climate, has often in the past been considered an ideal place of residence for invalids; especially those suffering from chronic respiratory disorders (Domeier, 1810; Sankey 1893). Man, by tampering with his immediate environment, has frequently affected negatively his own health (Ellul-Micallef and Al Ali, 1984).

2.10.2. Effects of temperature rise

Possible adverse health effects resulting from atmospheric changes could occur in Malta as a consequence of both the greenhouse effect (Broecker, 1987; Cicerone 1988) and the depletion of the ozone layer (Molina and Rowland, 1974; Farman *et al.*, 1985). Changes in the global atmosphere may occur sooner than some scientists have predicted as a result of man's industrial activities over the centuries and the scant regard he has paid to the effects of his activities on the environment. It is obvious that the magnitude of such changes is a function of: the size of the world population, which is still increasing at an alarming rate; the increasing demand for energy; and, of forest clearance by burning, for cultivation. The reality of climatic changes resulting from these activities is now generally accepted. What is still at issue is the rate at which such changes will occur. The uncertainty concerning the rate of change appears to be largely related to: the ability of the oceans to absorb carbon dioxide; the effect of increased cloud cover; the destabilising effects of increasing water vapour; and, the melting of polar ice-caps. The latter may result in alteration to the course of ocean currents and in the elevation of sea levels. Sea-level rise is one of the most disturbing potential consequences of global warming. Estimates suggest that a rise of about 1 metre will occur, by the end of the next century. However, even the 30 cm rise predicted to occur by the middle of the next century will bring about social and economic problems in low lying areas (Meier, 1990).

A local mean sea-level rise of about 50 cm would result in inundation and shore-line recession in a number of localities in Malta, which together may damage public sewage systems. New systems will have to be developed to protect public health against possible flooding of such drainage systems. The danger of epidemics of typhoid fever as well as of other enteric disorders has to be kept in mind. There will also be increased intrusion of salt water resulting in the spoilage of ground water aquifers. The negative impacts resulting from depletion or loss of readily available, good and safe drinking water on human health in the islands hardly needs emphasizing.

The majority of models predict an increase in global mean surface temperature of between 1.5 and 4.5 °C by the middle of the next century. This rise in temperature will have an enormous impact on global ecosystems seriously affecting world food production. The worst-case scenario for Malta (Table 2) suggests a mean summer temperature rise of 3.5 °C and an increased frequency of extreme high temperatures. These changes, combined with spells of high humidity, will put particular population groups at risk from heat stress. It is already well known that the number of deaths during heat waves are especially high amongst the elderly, and infants below 1 year are also at risk since they are known to dehydrate very quickly.

Diseases which have so far been confined to the tropics may spread to higher latitudes as global temperatures rise. Insect-borne diseases may well become more widespread, either because the vector will be able to survive better at higher latitudes or because parasites may be able to complete their life-cycle more easily. Temperature increases will lengthen the breeding season and survival rates of a number of insect vectors, including species of *Anopheles* mosquito and as a consequence malaria may reappear in Europe (Grant, 1988).

Leishmaniasis is a zoonotic, endemic infection, involving dogs in the Mediterranean littoral. Its prevalence in dogs varies between 4 to 10% in Malta and the disease is spread to man through the bites of female sandflies of the genus *Phlebotomus*. The disease mainly affects children and the condition which has been well controlled in the recent past, seems to be on the increase once again (Figure 76). An increase in temperature and humidity may well result in increased breeding rates of phlebotomines and an increased incidence of leishmaniasis.

2.10.3. Effects of ozone depletion

Observations from satellite and ground-based instruments appear to indicate that between 1979 and 1990 there have been statistically significant losses of ozone at mid- and high altitudes in the lower stratosphere (WMO/UNEP, 1991). Anthropogenic emissions of chlorofluorocarbons (CFCs) and other

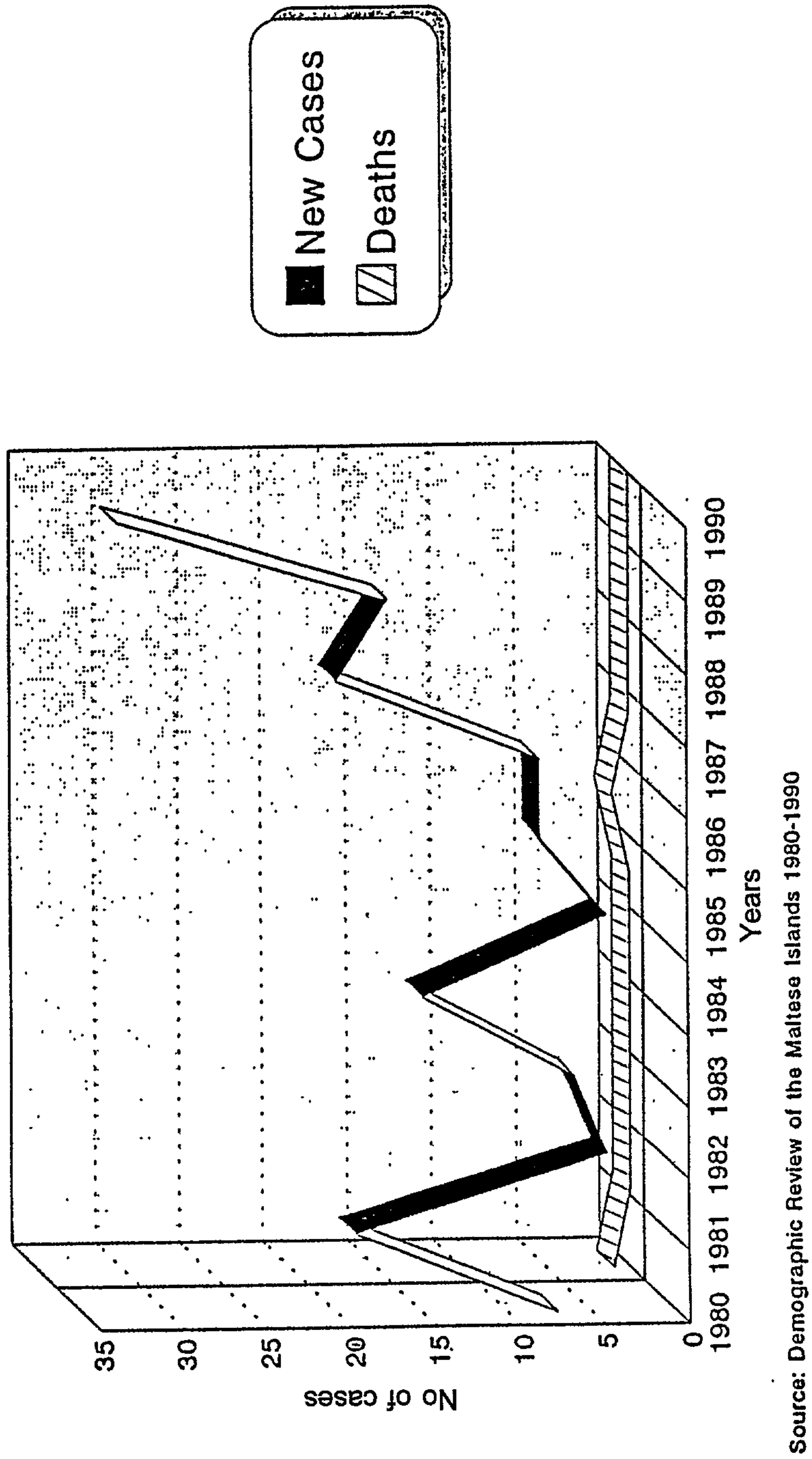

Figure 76 - Incidence of Leishmaniasis in Malta, 1980 to 1990

halocarbons are thought to be largely responsible for the observed ozone depletions (Molina and Rowland, 1974). Such a loss of stratospheric ozone means that there may be an increased incidence of harmful ultraviolet radiation (UV-B 290-320 mm) at the earth's surface. On a regional scale, the issue is not so clear cut, since factors such as tropospheric ozone (Bruhl and Crutzen, 1989), sulphate particles (Liu *et al.*, 1991) and even cloudiness (Crutzen, 1992) may produce an opposite effect. Until an integrated global network of monitoring stations for ultraviolet radiation is set up, it will not be possible to measure the increases in UV radiation directly (Crutzen, 1992). Only recently has it been possible to estimate in a theoretical manner the intensification of UV-B radiation over the globe due to the measured losses of ozone between the years 1979-1989 (Madronich, 1992).

The greatest relative ozone losses have occurred over the Antarctic, and therefore well away from human centres of population. The annual average depletion has been calculated to be around 3 % and these calculations are based on data derived from the satellite-borne Total Ozone Mapping System (TOMS) which integrates the ozone concentrations over the entire depth of the atmosphere (Stolarski *et al.*, 1991). In the northern hemisphere, the disquieting news is that limited losses of ozone, but as yet no hole, have also been detected over the Arctic. Reductions in ozone that cannot easily be explained by transport processes seem to have taken place in the Arctic stratosphere during the winter of 1990 (Hoffman and Deshler, 1990). The decreases in ozone mixing ratio reported so far do not dramatically affect total ozone, but if a full-blown ozone hole does occur in the arctic as well, it may move south to affect densely populated areas of Europe including Malta (Kerr, 1992).

The precise relationship between UV-B intensity near the ground and the amount of ozone in the stratosphere and troposphere is still the subject of debate. The potential impacts of increased UV-B radiation arising from ozone depletion appear to be all negative. Effects on terrestrial vegetation as well as on marine organisms are likely to result in reduced food supplies, since UV-B radiation reduces a both terrestrial plant's and phytoplankton productivity with dramatic negative consequences for natural ecosystems.

Much has been written about the potential direct impact upon human health resulting from increased UV-B radiation. The lack of data on doses of UV-B radiation received, not just in Malta , but worldwide, prevents the quantitative analysis along sound epidemiological lines, of the effects on human health of increased UV-B radiation. It is only comparatively recently that the dangers associated with prolonged over-exposure to sunlight have been appreciated by the average man in the street. Increased UV-B radiation is likely to result in a higher incidence of skin malignancies, of eye damage and immunological disturbances.

Exposure to UV light appears to be closely linked to the aetiology of non-melanoma skin cancer (Russell Jones, 1987; Mackie *et al.*, 1987, Mackie and Rycroft, 1988; Urbach, 1989; Crosby, 1990). It has recently been predicted that an ozone depletion of 1 % will result in an increase in the incidence of basal cell carcinomas of 1.6-2.1 % and of squamous cell carcinoma of 1.3-1.7 % (Moan *et al.*, 1989). Unfortunately non-melanoma skin cancer is very infrequently recorded in cancer registers worldwide. At least, the serious public health implications of these malignancies, particularly in terms of morbidity and expense, are being appreciated. Increased recreational sun exposure, when combined with possible ozone layer depletion is a growing cause for concern. An increasing incidence of skin cancer, resulting from this exposure, has been reported in Europe (Henriksen *et al.*, 1990; Staehelin *et al.*, 1990) in North America (Urbach, 1989) as well as in Australia and New Zealand (Giles *et al.*, 1988; McKenzie and Elwood, 1990). Figure 77 shows the incidence of skin cancer in Malta over the past 12 years.

The relationship between UV exposure and melanoma, the other form of cutaneous malignancy, is far more complex (Loggie and Eddy, 1988; Lee, 1989). Of the four clinicopathological types of this skin malignancy, only lentigo maligna melanoma appears to be directly related to cumulative UV exposure, but the other types of melanoma may also, in some ways, be affected by UV light. There seems to be a consistent inverse relationship between the incidence of melanoma and latitude. Accurate predictions are difficult to establish, but it seems reasonable to suggest that further rises in melanoma incidence will be among the first biological effects seen with ozone depletion. Empirically derived relationships between

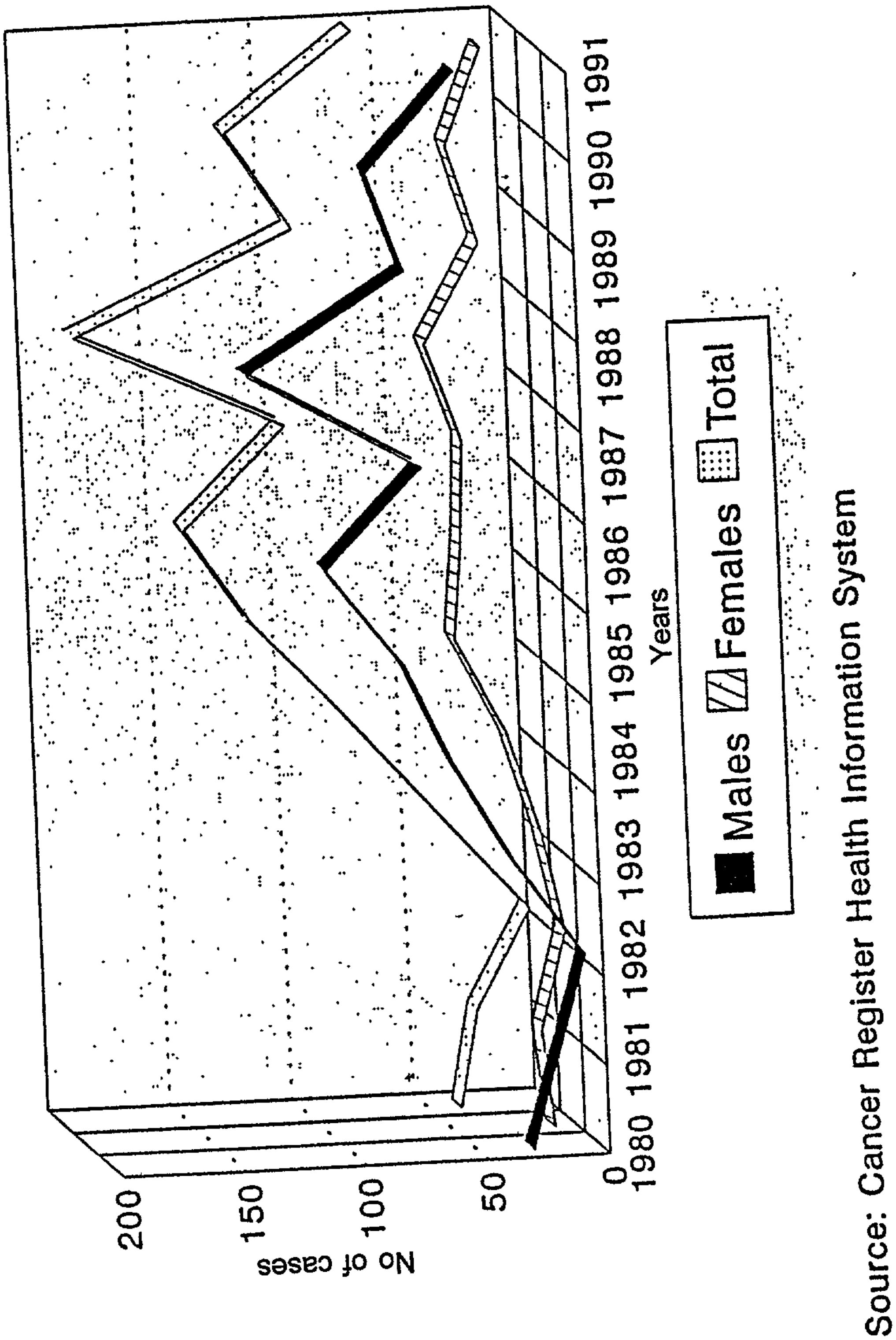

Figure 77 - Incidence of notified cases of skin cancer in Malta, 1980 to 1991

UV-B exposure and the incidence of cutaneous melanoma predict that a 1 per cent depletion of ozone will result in an increase of 1-2 per cent in melanoma incidence (Longstreth, 1988).

Most of the available evidence suggests that nucleic acids (DNA) are the primary targets for UV radiation. The principal epidermal DNA photo-products are pyrimidine dimers such as thymine dimers. An action spectrum for the frequency of pyrimidine dimer formation induced in the DNA of human skin per unit dose of UV incident on the skin surface has been recently determined (Freeman *et al.*, 1989). The peak of this action spectrum is near 300 nm and decreases rapidly at both longer and shorter wavelengths. It appears that chronic exposure to UV irradiation and a high total cumulative dose may be less deleterious than are periodic bursts of large amounts of sun exposure (Ross and Carter, 1989). This would appear to be of particular relevance to fair-skinned tourists visiting Malta during the summer months.

Exposure to increased ultraviolet radiation will be expected to cause a higher incidence of cases of impaired vision as a result of damage inflicted to the cornea and the lens. Studies carried out by UNEP and WHO *have estimated that for every 1 % decrease in stratospheric ozone, there will be an increase* of between 0.3 and 0.6 % in cataracts. Ozone changes of the order predicted would be expected to have a negligible effect on the amounts of solar radiation reaching the retina (Charman, 1990).

A far less well understood phenomenon is the effect of UV-B radiation on the human immune system. In experimental animals, exposure to UV-B radiation is known to produce selective alterations of immune function, mainly in the form of suppression of normal immune responses (Morison, 1989). This immune suppression may be important in the development of non-melanoma skin cancer; may influence *the development and course of infectious disease and possibly protects against autoimmune disorders.* The evidence that such immune suppression occurs in humans is less compelling and somewhat incomplete. However, it is a well accepted fact that UV- light, possibly through DNA damage, is an important precipitating factor in the autoimmune condition, systemic lupus erythematosus.

2.10.4. Conclusions

A new awareness of man's fundamental reliance on the integrity of the world's ecosystems and the need for a change in his way of life and his use of energy resources is now a matter of some urgency. Man's interaction with his environment may otherwise lead to changing patterns of disease. The costs in terms of human suffering are likely to be considerable. To quote Seneca, 'Animum debes mutare non caeleum'.

2.11. Population and Settlement Pattern

2.11.1. Introduction

Whereas the predictions of precipitation patterns remain as yet uncertain, the consequences of global warming for sea-level rise are more predictable. According to IPCC-Working Group I, a global sea-level rise in the range of 30 to 100 cm will take place by the year 2100 under conditions of a "Business as usual" scenario for the use of fossil fuels. The best estimate is 65 cm. This rise is mainly attributed to thermal expansion of the upper ocean layer and to melting of land based glaciers and small ice caps. This rise will continue, albeit to a lesser extent, even if preventive measures to limit man's contribution to global warming are effectively applied now under IPCC's scenarios "B" and "C". In addition to the values of global mean sea-level rise, local land subsidence can contribute to a further rise which could be significant in some tectonically or geomorphologically active areas.

The most obvious impact of a sea-level rise is the loss of land through inundation and shoreline regression. Sea-level rise also adversely affects drainage systems, making them more vulnerable to flooding as gravitational gradients are reduced. These factors have a direct impact on population patterns as present settlement is adjusted existing conditions of availability and land use which may change under future scenarios of climate change.

The Coastal Zone Management Subgroup of IPCC has examined the physical and institutional strategies needed to combat potential hazards threatening population and settlement patterns arising from sea-level rise. The Subgroup recognized three categories of remedial action: retreat, accommodation and protection.

Retreat: this strategy involves the abandonment of land following seawater invasion.

Accommodation: this implies the continued use of land under new living and economic conditions including the use of emergency flooding shelters, elevated structures on piles and adjustment to an aquatic economic practice.

Protection: this involves the erection of hard structures such as dikes and the implementation of dewatering schemes.

Malta, as a whole, is not particularly vulnerable to sea-level rise on account of its favourable topography, good drainage and negligible land movement. A rise in sea-level by 65 ± 35 cm would have no impact whatsoever on the population growth and only very little impact on settlement patterns. Some dense settlements along the coast and particularly along the principal drainage channels would be affected to some extent. Some level of anticipatory action would be needed to cope with any consequential economic and social disruption.

Malta is located on the extensive Pelagian Platform of the North African Plate. It therefore falls outside the orogenic belt of the Tunisian Atlas - Sicilian Overthrust Belt and tectonic movements are consequently relatively small being characterized by extensional faulting.

This faulting is closely linked to the structural adjustment of the Platform to the relative movements of Africa and Europe from the Triassic, about 220 million years ago, to present times. One result of this adjustment is the dissection of the Platform by the Pantelleria-Malta rift system in the Plio-Quaternary, about 2 million years ago. Movement along one of the faults in this system, the Malghaq fault in the south of Malta, resulted in the uplift of the island above sea-level and produced the present day gentle NE structural dip.

On the basis of seismic evidence of drowned shorelines off Malta (Figure 78), the sea-level rise in Malta over the past 18,000 years has averaged about 140 m. This is of the same order of magnitude as the global average rise since the last glaciation and would indicate that in spite of the presence of slickensides along the face of the Malghaq fault, there has been little, if any, absolute vertical movement of the land during this period. The impact of land movement on sea-level rise in Malta can therefore be ignored.

2.11.2. Impact on population

Population growth in Malta, as in other countries, is likely to remain heavily dependent on prevailing socio-economic factors. It has been growing at an average annual rate of about 0.9% over the past ten years and in 1991 the population was 358,600. If this rate of growth is maintained, the population by 2100 would be approximately double that of today. Although the nexus between some of the socio-economic factors and climate can be strong it is unlikely that any socio-economic change arising from a climate change will have an impact on the population growth rate. Even the most obvious economic impact; namely that of a loss of land accompanying the expected sea-level rise; is insignificant. Although the demand for urban space will become more and more acute as population grows, it will not be affected in any practical terms by the loss of 1 % of the total land area.

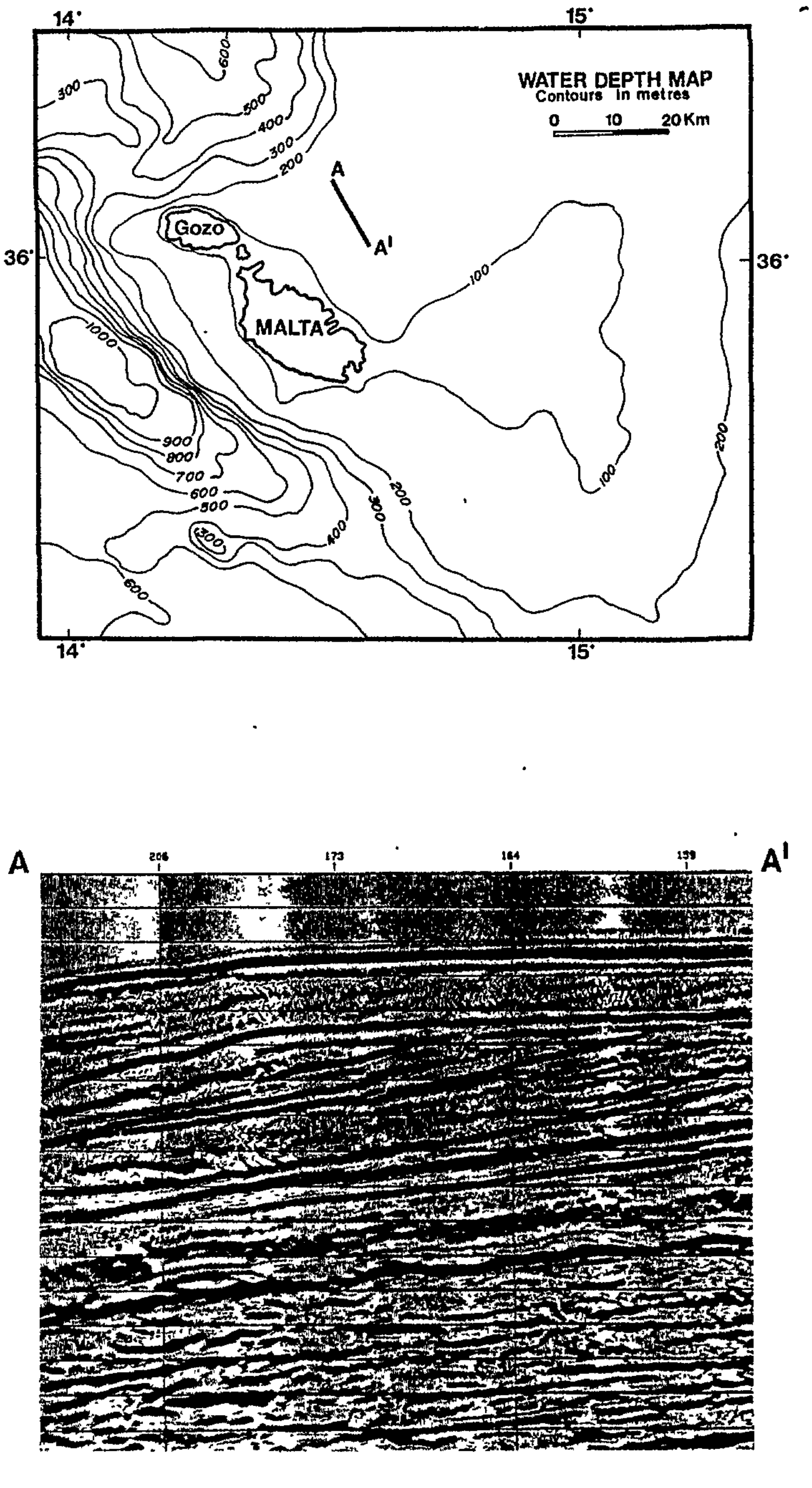

Figure 78 - Seismic evidence of sea-level lowstand of the last glaciation at about 140 m.
The lower portion of the figure is the seismic section along the section located in the upper half

2.11.3. Implications of climate change and sea level rise on settlement pattern

2.11.3.1. *Coastal settlements*

The land-use and demographic pattern in Malta shows that geology was a key factor in determining the spatial distribution of urban and rural areas (Figure 79). Most villages are congregated around outcrops of available building stone, the Lower Globigerina Limestone, whereas arable land is concentrated on outcrops of formations which easily weather to a fertile soil, the Blue Clay and Middle Globigerina Limestone. The difficulty of erecting structures on these soft formations contributed to the absence of settlements on these outcrops.

Settlements along the coast were primarily limited to port areas like Valletta, Senglea, Victoriosa and Cospicua but later extended to other, primarily recreational areas, such as Sliema. This settlement, which today constitutes Malta's most densely populated area, originally started as a summer residence for city dwellers. Recreational settlements along other coastal areas spread in recent years to B'Bugia in the south and Bugibba and St.Paul's Bay in the north of the Island.

In spite of this recent tendency towards coastal settlement, the topography of the Island is relatively rugged with only a few low-lying coastal areas. Here, settlement is discouraged by the presence of thick deposits of alluvium and silt which favour agricultural use of the land (Burmarrad, Marsa, Pwales and Mellieha Valleys).

On the basis of topographic maps of the Island which are available with a contour interval of 25 feet (8 m); and assuming a sea-level rise of 65 cm; and a negligible land movement by the year 2100; then the 1 m contour can be considered as a good marker for assessing the extent of inundation of the Island. Interpolation of the 1 m contour onto maps of the built-up area would suggest that disruption of social activity arising from sea-level rise would be small and limited to: the Strand-Pieta-Msida-Marsa sea-fronts (Figure 81); Marsascala; Marsaxlokk; and, parts of B'Bugia (Figure 80). Assuming a uniform population density, a total population of about 20,000 may be affected by sea-water invasion following tidal and storm surges along these coasts. This represents 7% of the total population of the Island, by no means a significant figure when one considers that these areas have already reached maximum population growth.

Of the three remedial actions that may be employed to combat sea-water inundation, elevating the coastal risk areas by means of back-filling would represent the easiest and most cost effective protective measure.

2.11.3.2. Low-lying settlements along drainage systems

Malta is divided into two main morphologic units by the Victoria Lines Fault. North of this fault the Island is broken up into a number of horsts and grabens by less pronounced faults. Drainage is parallel to the general strike of these horsts with a few intermittent streams flowing into the bays to the NE. An exception to this pattern is the major drainage line which has an origin near Rabat in the southern unit and crosses into the northern unit with an outflow at Salina.

The only populated area found in a drainage line of this morphological unit is at Burmarrad (Figure 81) where flooding, which is already a problem, will get worse as drainage gradients are reduced with a rise in sea-level.

The second unit lies south of the Victoria Fault. The eastern half of this unit has the Globigerina Limestone as the prevailing outcrop forming a gently rolling landscape. This outcrop provides the building stone in Malta and has undoubtedly contributed to the dense settlement in this part of the Island. Three main drainage systems are found here, one converging into Valletta Harbour, one flowing into Msida Creek and the other into Marsaxlokk Bay.

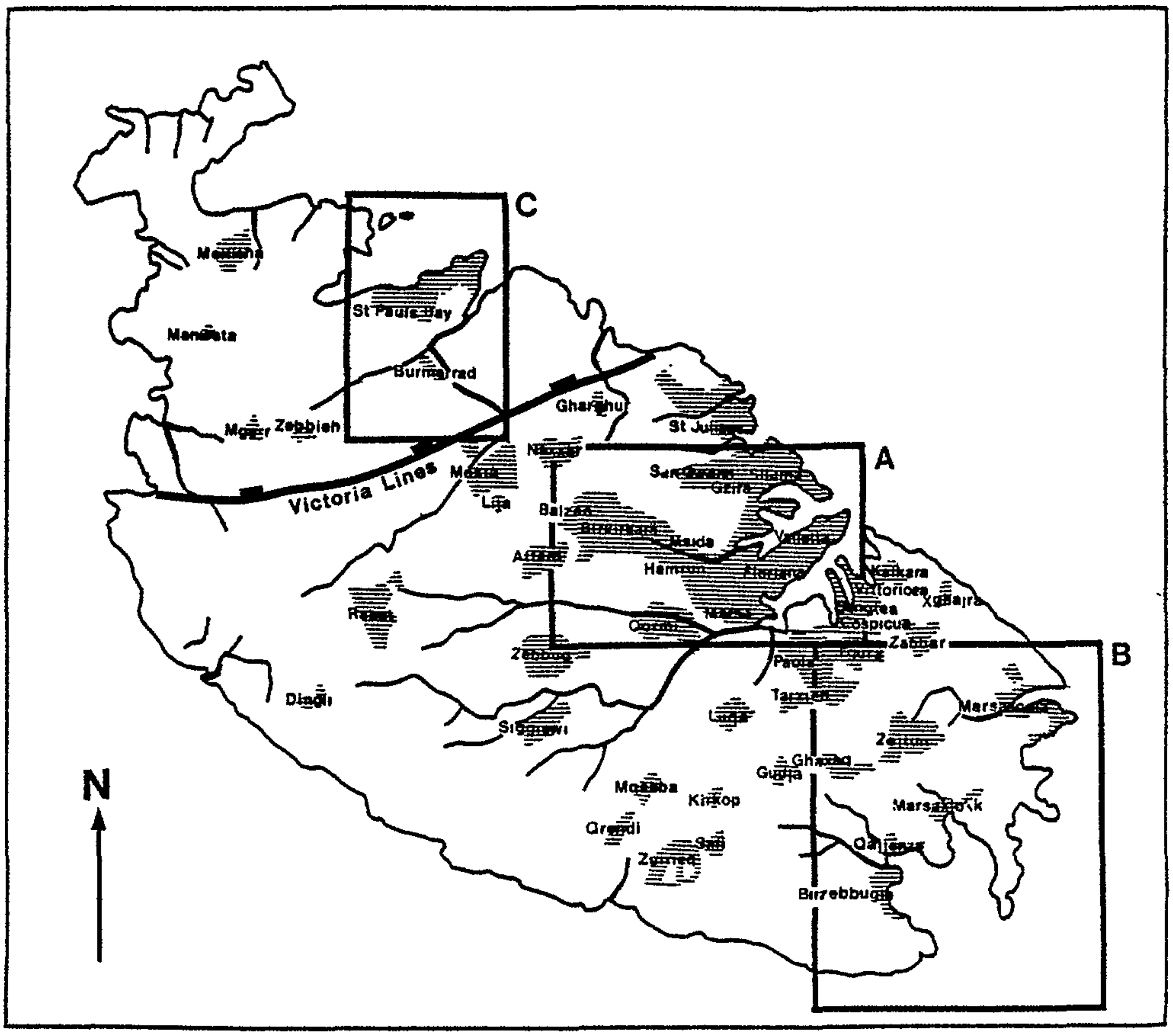

Figure 79 - Distribution of settlements and drainage systems

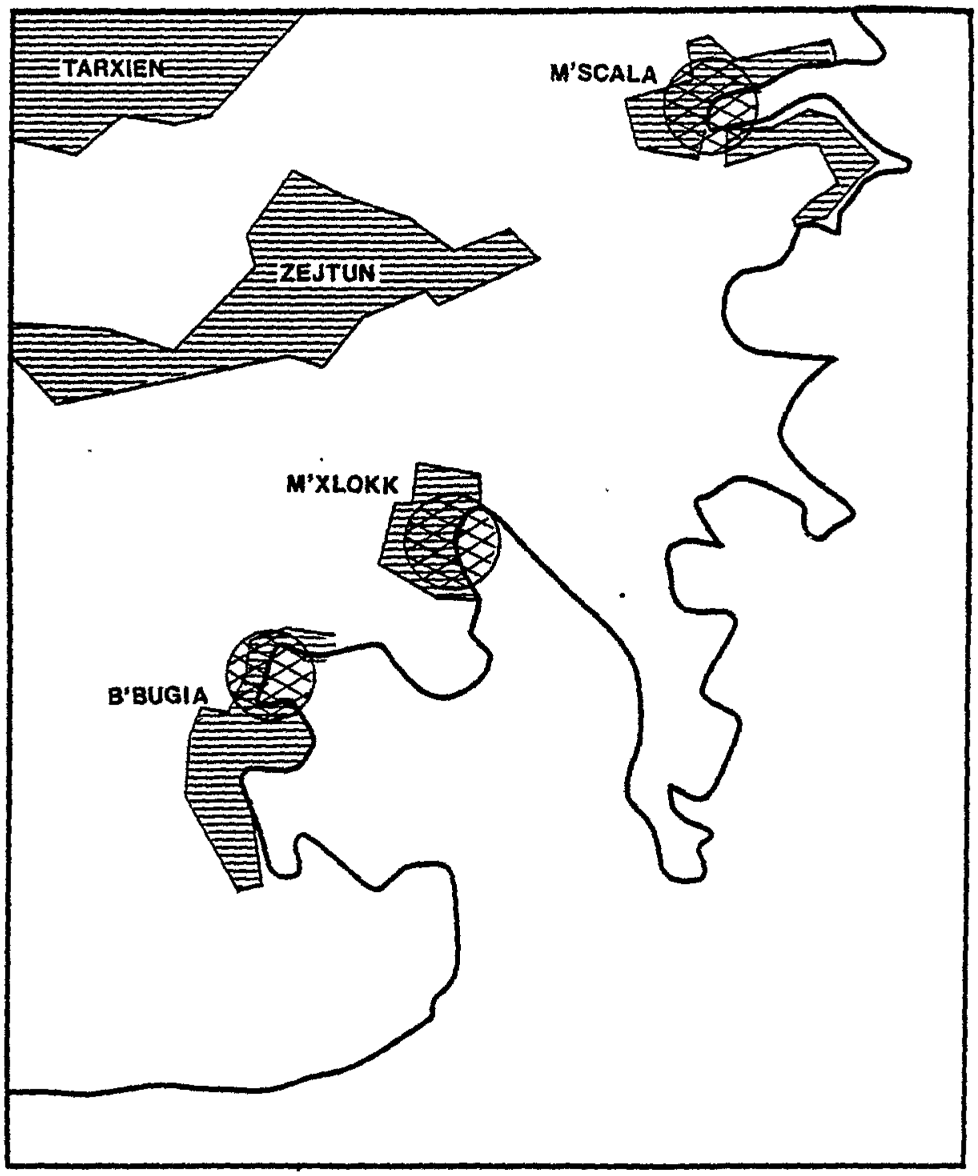

Figure 80 - Low lying coastal areas as Marsascala, Marsaxlokk and B'Bugia

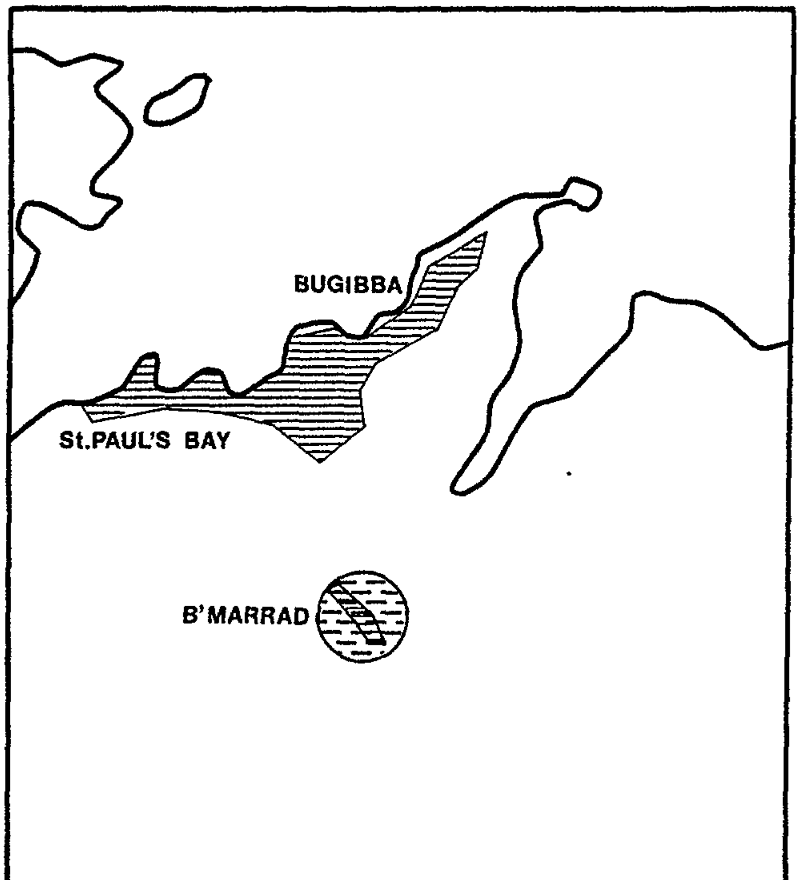

Figure 81 - Low lying drainage area at Burmarrad

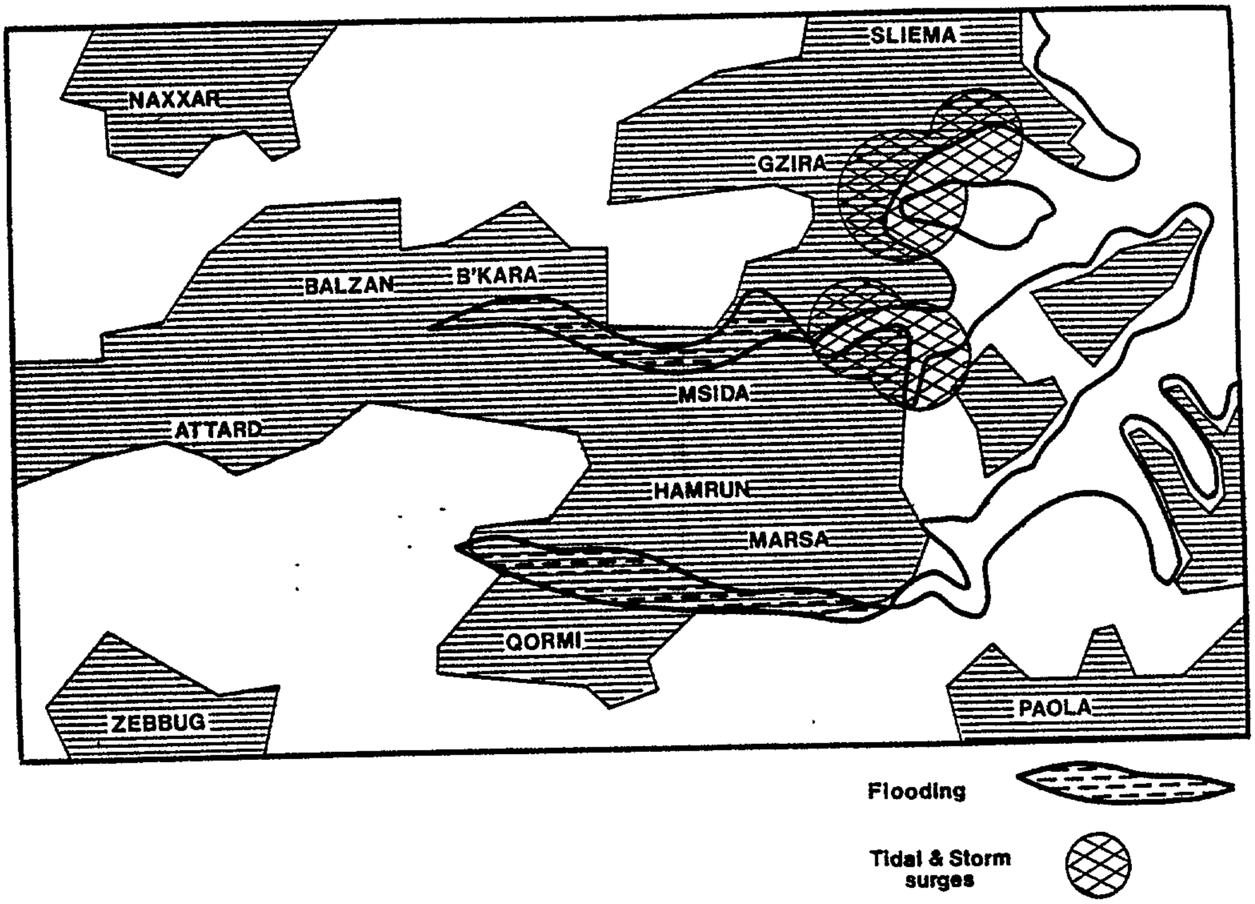

Figure 82 - Low lying drainage areas at B'Kara, Msida, Qormi and Marsa and low lying coastal areas along Strand-Pieta-Msida-Marsa seafronts

Some densely populated areas are found along all three major drainage systems of the second unit. In particular we find the low-lying parts of B'Kara, Msida, Qormi and Marsa (Figure 82) located along these drainage lines which are already prone to flooding after heavy downpours. Further reduction in the gradients of these systems will inevitably make these urban areas far more susceptible to flooding.

2.11.4. Conclusions

A global mean eustatic rise of 65 ± 35 cm by the year 2100 would have no impact on the population growth and very little impact on settlement patterns in Malta. Disruptions of settlements are more likely to result from temporary tidal and storm surges along the coasts and flooding of drainage systems during heavy rainfall rather than from permanent inundation.

3. SYNTHESIS OF FINDINGS

3.1. Present Situation

3.1.1. The physical environment

The Climate of the Maltese Islands is typically Mediterranean with hot dry summers, warm and showery autumns and short cool winters. Frost and snow are unknown, and rain falls for very short periods averaging about 553 mm over the year. The average temperature between November and April is 14.1 °C that between May and October is 23.0 °C. The hottest period is from mid-July to mid-September but the heat is tempered by cool sea breezes. The analysis of data for this study indicates that over the last 125 years there has been a decrease in the mean annual rainfall, evident in all seasons except in summer. The mean annual temperature has shown an increase which is also evident in all seasons except autumn. Over the last 70 years, the maximum temperature has increased by one degree celsius whilst the minimum temperature has decreased by 1.5 °C. Over the last 40 to 45 years, the number of days with thunder-storms has shown an increase of over 30% whilst the number of days with fog and with hail have decreased significantly.

This study also indicates that over the last 44 years, the number of hours of bright sunshine has decreased by about 11%. Cloud over Malta has also decreased and the relative humidity shows a downward trend in all seasons. Over the last 70 years, atmospheric pressure has increased by 1.5 hpa; a 10% increase. Suspended particles, including pollutants, could therefore be increasing over the Central Mediterranean.

The hydrological cycle of the Maltese Islands accounts for the availability of about 37% of all potable water in the public supply and for 84% of all irrigation water. Climate determines the distribution and availability of rainwater which is the only significant source of water in the cycle. Geology, topography, urbanization and hydraulic structures determine the extent of run-off, which contrary to public opinion is only of minor significance (6%). The rest of the rainfall infiltrates into the ground where it is partly retained by the soil. The retained water is eventually lost to the atmosphere by evaporation from the soil surface and by transpiration from the vegetation. This evapotranspiration loss, which amounts to around 70% of the total precipitation, is largely determined by the nature of the soil, vegetation and climatic factors such as humidity, wind, temperature and radiation. The water that manages to pass the root-zone (24%) percolates through the fissures and fractures in the rock formations until it reaches the aquifers as recharge water. The characteristics of these natural underground freshwater reserves are largely controlled by the water development practice and what is left is ultimately returned to the sea by natural subsurface discharge along the coast.

The Maltese Islands are composed entirely of Oligo-Miocene sedimentary rocks of marine biogenic origin. These are highly calcareous thus giving rise to more or less alkaline soils. Due to the small size and low altitude of the islands, sea spray can reach practically all parts of the islands so that soils have a tendency to be more or less saline.

There are five factors involved in the development of soil and probably three are fundamental in the production of the soils of Malta. These are the nature of the parent material, climate and time. Topography, the fourth factor is largely dependent on the first three since landscape is moulded by erosion and deposition related to the parent structure, environmental processes and time. The fifth factor, biological influences, is presently dominated by human activities. The effects of natural biological influences are secondary, producing modifications to the existing patterns.

3.1.2. The biological environment

Malta's vascular flora consists of around 1000 species, of which some twenty are endemic, about 700 are indigenous and the rest more or less naturalized aliens. The Islands have been under heavy anthropogenic pressure since their settlement about 7000 years ago. This has resulted in deforestation leading to soil erosion and increased aridity. This pressure had been rising exponentially during the past century leading to the current situation of extreme water shortage.

The chief problem of all plant life in the Maltese Islands is the water shortage. Malta has short cool winters with enough rainfall for agriculture in most years, but leaving insufficient reserve in the soil, to combat the rainfall deficit during the dry season. Total evapotranspiration losses are equivalent to around 70% of the annual rainfall. The De Martonne aridity index for Malta is 19.4 putting the Maltese Islands in the semi-arid category.

Maltese agriculture is geared to cope with severe shortage of water. In the more fertile areas, fruit trees and vines are cultivated. But the main crops are potatoes, broad beans and various cucurbits as well as sulla, wheat and barley which are mainly cultivated as fodder crops. Native woods of evergreen oak and Aleppo pine have been destroyed several hundred years ago but there have been some more or less successful attempts at reforestation. Less than 1% of the Maltese Islands are wooded however and 60% of the wooded areas are confined to the areas of Buskett, Mizieb and Marfa Ridge.

Though geographically small, the Maltese Islands support a wide range of habitats. The coastal lowlands have very few sandy beaches, but support a number of sand dunes and saline marsh habitats, all of which are however in a state of regression. The near-shore marine communities are likewise, quite diverse, with sea grass meadows representing the most locally productive and biodiverse areas.

There are no rivers and permanent fresh water springs are few. Most freshwater habitats carry water during only part of the year and are highly restricted geographically. Nonetheless, such habitats support a significant number of rare, endemic and endangered animal and plant species.

As a result of one of the highest human population densities in the region, combined with rapid urban, industrial and tourist development over the past 30 years, most marine and fresh-water habitats are threatened by a number of man-induced non-climatic environmental pressures. Coastal land development and shore-line construction are leading to significant loss of specialized habitats, which often support rare and endemic species. Land-based pollution, as well as habitat interference by divers and destructive fishing and specimen collection are also threatening such marine communities. Freshwater communities are being degraded at a rapid rate, possibly due to reduced water replenishment of the aquifers resulting from rapid urbanisation.

Fishing is one of Malta's most vital industries. The most important fish for local consumption are the migratory lampuki and swordfish and pelagic species such as mackerel and bogue. Aquaculture has only recently become a profitable industry and is geared mainly towards export. Sea bass, sea bream and Tilapia are the main species currently used.

3.1.3. The human environment

Population growth in Malta is heavily dependent on prevailing socio-economic factors. The population has been growing at an average rate of about 0.9% over the past ten years and in 1991 it stood at 358,600. It is expected to double by the year 2100. The geography of land-use and demographic pattern shows that geology was a key factor in determining the spatial distribution of urban and rural areas. Most villages are congregated around outcrops of building stone, whereas arable land is concentrated on outcrops of formations which easily weather to a fertile soil. Settlements along the coast were primarily limited to port areas but later extended to other coasts for recreational purposes. In spite of the attraction of coastal settlements, the topography of the Island is relatively rugged providing only a few low-lying coastal areas suitable for settlement.

Populated areas found in drainage basins where flooding is already a problem are few, but include some very densely populated towns.

Malta's mild climate has always made it an ideal place of residence for invalids. High temperatures in summer however, especially when combined with spells of high humidity put certain population groups at risk from heat stress. During heat waves there is a rise in the number of deaths amongst senior citizens and an increase in dehydration cases amongst infants.

Malta's favourable climate also attracts a large number of tourists which visit the island all year round. Tourism contributes an average of 6.5% to the Gross National Product in Mediterranean countries. Tourism not only generates employment but is also, in some instances, the major source of foreign exchange earnings. In Malta, tourism is one of the Islands' most important economic activities. Tourist arrivals in 1991 rose to 895,036 with the projection of one million tourists by 1994. In 1991 earnings from tourism rose to Maltese Liri 175.3 million or about U.S.$578 million. About 5.8% of the total gainfully occupied population in Malta is engaged in full-time direct employment in the tourist industry. Tourist arrivals peak in the summer months of July, August, and September with nearly half of the annual visitors coming during this period. Some 86% of the tourists that visit Malta come from the countries of the European Community.

As a state with an economy in transition, electricity generation in the Maltese islands has increased by 9% per annum in recent years. Continuing economic development appears likely to sustain the high growth rate in electrical power generation for at least the next decade. All Malta's energy needs are imported in the form of coal, oil and gas. Nearly two thirds of the fuel imported is converted into electricity which is the most widely used form of delivered energy. The built environment is the largest energy consuming sector and accounts for half of Malta's energy bill. Industry, transport and water production are the other heavy energy consumers. Immediate increases in energy demand by the end user could be offset by improving the efficiency of energy conversion and by eliminating waste. In the case of electricity conservation, each unit saved results in at least a two fold reduction in carbon dioxide emissions due to energy conversion inefficiencies.

Industry is predominantly of a light nature characterised by the manufacture of textiles and electronic components. There exists a foundry and a ship repair yard which is world renowned.

Transport in the Maltese Islands depends on road communications although a ferry service is used to connect the three islands of Malta, Gozo and Comino. Malta, as an island in the Mediterranean, also depends on sea and air links which are the backbone of the Maltese economy, particularly in relation to tourism, the import of goods and the exports of manufactured products. Ship repair and ship building are two other important sectors which depend on maritime communications. Malta utilizes its maritime potential as far as is technically and financially possible. Its ports offer safe haven to numerous vessels, transhipment facilities, yachting centres and most importantly dockyard facilities. Transport and communications related activities account for about 6% of the Gross Domestic Product with the European Community being the main trading partner at around 78%.

Car ownership in Malta has risen sharply, with an average annual growth of 7 per cent per annum in the last ten years. The number of cars per 1000 habitants is about 346. Transportation accounts for 29% of all primary fuel consumption and studies have shown that 30% of the carbon dioxide emissions come from road transport compared to 45% from the commercial and industrial sectors. With a view to reducing the levels of potential greenhouse gases, lead-free petrol was introduced in 1990 while new owners of motor-vehicles are being encouraged to make sure that their cars are equipped with three-way catalytic converters.

The Maltese air carrier, Air Malta, is an important communication link with major capitals of Europe with schedule services to 22 major airports and regular charter flights. Air Malta's aircraft have one of the highest utilization rates in Europe. A helicopter air-link service is maintained between Malta and Gozo for six months of the year.

Whilst this study has reviewed the current situation concerning those areas likely to be influenced by predicted climatic changes a lack of data has often made it rather difficult to quantitatively assess the potential impacts of such change. Nevertheless it was possible to identify and estimate the nature of the impacts which predicted climate changes are likely to have on the Maltese Islands.

3.2. Major Expected Changes and their Impacts

No major impacts due to climate change are expected to occur by the year 2030. It is likely that Malta will face bigger environmental problems during the intervening period as a consequence of intensive land use and rudimentary coastal zone management. The major changes which are predicted as a result of a change in the climatic conditions of the islands are detailed below.

3.2.1. Changes in climate

The scenarios of climate change for Malta developed by the Climatic Research Unit of the University of East Anglia suggest that:

By the year 2030:

- the mean annual temperature should increase by 1.4 - 1.6 °C;
- sea level should rise by 18 cm + 12 cm;
- the mean annual rainfall should show no change over present values;
- the mean winter (December, January, February) rainfall should decrease by 16.2 % compared to present values;
- the mean spring (March, April, May) rainfall should decrease by 27 to 21.6% compared to present day values; and
- the mean summer (September, October, November) rainfall should increase by 25.2 % when related to present values.

By the Year 2050:

- the mean annual temperature should increase by 1.8 - 2.0 °C;
- sea level is expected to rise by 38 cm = 14 cm;
- the mean annual rainfall should show no change compared to present values;
- the mean winter rainfall should decrease by 20.3% compared to present day values;
- the mean spring rainfall should decrease by between 33.8 and 27% compared to present day values;
- the mean summer rainfall should remain unchanged; and
- the mean autumn rainfall should increase by 31% compared to present day values;

By the year 2100:

- the mean annual temperature should increase by 1.8 - 2.0 °C;
- sea level is expected to rise by 65 +/- 35 cm;
- the mean annual rainfall should show no change compared to present values;
- the mean winter rainfall should decrease by 31.5% compared to present day values;
- the mean spring rainfall should decrease by between 52.5 and 42% compared to present day values;
- the mean summer rainfall should remain unchanged; and
- the mean autumn rainfall should increase by 49% compared to present day values.

3.2.2. Implications of changes in temperature

The existing trend towards higher mean temperatures during the day and lower mean temperatures during the night are typical of desert regions. If this trend continues it would lead to a process of desertification which may already be in progress.

Elevated temperatures may increase plant productivity which however may be less significant or even reversed, due to other relatively rapid environmental changes such as increased salinity and water stress. An increase in temperature is expected to favour the naturalisation of thermophilous weeds.

Migration patterns of fish such as lampuki may be altered as a result of changes in current patterns and marine productivity. Thermophilic fish may enter via the Suez Canal. These impacts are however difficult to estimate; at worst immigrant species may compete with more desirable species and at best it may diversify catches. Immigrant seaweeds may actively compete with the valuable *Posidonia oceanica* meadows on which most of Maltas' fisheries depend. An increase in temperature may have positive effects on aquaculture by increasing productivity.

Heat waves may have negative effects on public health, particularly amongst infants and senior citizens. Higher temperatures may lead to the spread of vector borne diseases, pathogens and pests.

Warmer winters in the Northern Hemisphere, Malta's main tourist market would negatively affect the tourist industry. Warmer temperatures would lead to a greater demand for potable water, already an acute problem on the Islands. A growth in the beverage industry is also to be expected.

Higher temperatures are expected to increase the electricity demand in summer for mechanical space cooling, which is already widespread. In winter, temperature increases may not necessarily reduce the need for space heating as thermally more comfortable interiors become affordable. Factory production costs are expected to rise as air-conditioned interiors become more common.

3.2.3. Implications of changes in precipitation patterns

No appreciable change in total precipitation is expected before 2025 and only a little is forecast for the later part of the next century. Of serious concern however is the possibility that most of the annual rainfall will be concentrated in the autumn with a corresponding decrease in winter and spring. As a consequence the incidence of freak storms and torrential rains is expected to increase.

This may have a number of impacts:

- more rainwater would be lost to the sea instead of infiltrating to the water table; this would lead to soil erosion, whilst a decrease in winter and spring rainfall may lead to a higher incidence of soil salinity and soil aridity to the detriment of managed and natural ecosystems;

- increased autumn rains would increase water turbidity and negatively affect near-shore vegetation and ecosystems especially sea grass meadows; the likely changes in volumes of flow, transport and environmental fate of land-based pollutants in the near shore marine environment are difficult to quantify;

- increased sediment inputs during heavy rain storms may lead to changes in off-shore bottom profiles and to altered substrate types and therefore to changes in the benthic communities, and also may increase the resultant disturbances and habitat alterations in valley-bottom communities;

- an increase in evapotranspiration and reduced fresh water inputs will accelerate reduction and degradation of the limited fresh water habitats and communities in these islands;

- violent storms and heavy precipitation would cause flooding in major traffic arteries, hinder transport by air and sea and damage sheltered harbours, yacht marinas and coves protecting fishing boats; such conditions would also have a detrimental effect on beaches and tourist infrastructure; and,

- the predicted changes in precipitation would worsen the problem of water availability, particularly during the summer months, if rainfall decreases in winter and spring.

3.2.4. Implications of sea level rise

According to IPCC Working Group 1, a global sea-level rise in of 65 +/-35 cm will take place by the year 2100 under a "Business as usual" scenario of fossil fuel consumption. This rise is mainly attributed to thermal expansion of the upper ocean layer and to the melting of land based glaciers and small ice caps. This rise would continue albeit to a lesser extent, even if preventive measures to limit man's contribution to global warming are effectively applied under IPCC's scenarios 'B' and 'C'.

In addition to this rise in mean global sea-level, the local land subsidence contributes to a further relative rise which could be significant in some areas. This will not be the case in the tectonically and geomorphologically stable islands of Malta. The potential consequences of a rise in global mean sea level are:

- sea water intrusion into the aquifers located at sea-level and particularly in the case of the main aquifer in Malta where the majority of the 40 Km of galleries will no longer be operational for the safe extraction of groundwater; a rise of 1 metre would result in reduced production by 40% in order to maintain a safe extraction ratio; 50% of all ground water is presently derived from such galleries and this would increase pressure on water resources and the need for production of potable water from reverse osmosis sea water desalination plants, thereby increasing energy consumption; the impact of sea level rise on ground water boreholes is less serious;

- sea-level rise will reduce the efficiency of drainage systems due to reduced gradients and lowered falls; sewage systems would become a health hazard to the general public, increasing the danger of epidemics such as typhoid fever and other enteric disorders;

- sea-level rise would lead to inundation and shore line recession;

- although a rise in sea-level by 65+/-35 cm would have no impact whatsoever on the population growth, settlements along the coast and the principal drainage channels would be affected by increased severity and frequency of flooding;

- assuming a uniform population density, a total population of about 20,000 (7% of the total population) may be affected by sea-water flooding and intrusion following tidal and storm surges along the coasts; and,

- sandy beaches and other low lying, popular tourist resorts would be negatively affected, as would important low-lying agricultural areas such as Pwales. Increased saline water intrusion may reduce the number of species supported in certain ecologically important localities such as the Ghadira Nature Reserve.

4. RECOMMENDATIONS FOR ACTION

4.1. Preventive Policies and Measures

4.1.1. General preventive policies and measures

(1) There is the need for a local or national structure plan which takes into consideration the possible impacts of climate change on the Maltese Islands so as to ensure that any future developments (including land use) are in line with the preventive and adaptive measures required to mitigate the predicted climatic change impacts.

(2) Seek through UNEP to obtain and implement a Central Mediterranean limited area climate model and to maintain links with international organizations and networks for scientific and technical assistance.

(3) Set up a monitoring station for atmospheric constituents, to assess the presence of greenhouse gases and also to monitor U.V. radiation at ground level.

(4) Assess, through further research, the vulnerability of humans, livestock and crops to a future increase in pests and pathogens as well as to the consequences of climate change and to adopt and implement appropriate response strategies. Maintain careful records of the incidence of both melanomas and non-melanotic skin cancer and cataracts.

(5) Formulate an Energy Plan which would:

- ensure rational energy use and determine strategies for reducing harmful gas emissions;

- analyse the sectoral demand and consumption trends with the aim of reducing present and future energy supplies by determining the right fuel mix;

- introduce building energy regulations whereby the building sector, would eliminate energy waste and make new buildings more energy efficient, thus not only reducing green-house gas emissions but also favourably influencing the balance of payments;

- introduce incentives, through taxes and levies in relation to energy consumption in industry;

- undertake a feasibility study to consider *inter alia*: subsidizing energy efficient light bulbs through the generating company, which at present have a low market penetration because of their relative expense; introducing energy labelling of household appliances to enable the purchaser to base his choice on running cost as well as the capital outlay, this would benefit the purchaser in terms of lower electricity bills and at the same time reduce greenhouse gas emissions at the generating end;

- carbon dioxide emissions can also be reduced by resorting to renewable energy appliances including production of hot water by solar energy which has been tried and tested in other countries with a similar climate to that of the Maltese Islands; use of domestic solar water heaters in Malta would reduce the country's energy bill by not less than 3%, and make economic sense since their life expectancy is in the region of twenty years and the amortisation period is normally less than three years;

- encourage the use of electricity during low demand night periods thus leading to more efficient use of the generating plant and hence savings of energy; electricity generation accounts for almost two-thirds of Malts's energy bill and the existing tariff structure is not related to the time of use, consequently electricity demand peaks during the day and drops at night; and,

- control emissions from motor vehicles; encourage the consumption of lead-free petrol and the installation of three way catalytic converter in motor vehicles; initiate further studies on the possible effects of climatic changes on transport particularly in the maritime sector.

(6) Initiate more detailed studies on the impact of climate change on the tourist industry in the Maltese Islands and in the Mediterranean in general. Technical and financial assistance may be sought from the Global Environment Facility (G.E.F.) of the UNDP/UNEP/World Bank; the European Bank for Reconstruction and Development; the World Meteorological Organization and the World Tourism Organization.

(7) Measures to protect freshwater and marine ecosystems from the impacts of climate change must be evaluated in the context of other non-climatic sources of disturbance otherwise the exercise of impact evaluation and mitigation will be futile and irrelevant. Improve the reliability of climate change impact predictions on climate change by focusing on a comprehensive risk assessment at the local and regional levels. This will enable a periodic re-assessment e.g. every one or two years period, depending on the rate of new developments in predictive models of the likely impacts of climatic changes on ecosystems.

(8) Implement comprehensive spatial zone management over the next decade and in the context of the Malta Structure Plan, with revisions based on the availability of new information. Within this spatial management programme there is an urgent need to identify sites which may be expected to be highly sensitive to climatic and non-climatic effects and then to designate appropriate buffer zones around them in which human activities and development will be highly restricted. This comprehensive spatial management programme must be based on the availability of base line information on ecosystems and their natural environment. Such baseline information is at best incomplete and in some cases, completely lacking. There is urgent need to develop fully the local potentials in marine sciences especially physical\chemical and biological oceanography. This requires a substantial commitment of funds and other resources, if the required baseline information is to be made available in time for wise management of the land and marine territory of the Islands.

(9) Establish and enforce fishing quotas to ensure sustainable use of resources. Control all sources of marine pollution, already seriously damaging marine resources. Educate fishermen and farmers on the preventive and adaptive measures required as a result of the impacts of climatic change on Maltese fisheries and agriculture. Invest in agricultural research and in fisheries research, keeping up the pace in aquacultural research. Take measures for the protection and monitoring of sea grass meadows.

4.1.2. Preventive policies and measures relating to changes in precipitation.

(1) Attempt to achieve more reliable estimates of future changes in the precipitation around Malta as more accurate global and regional climate models become available.

(2) Protect soils from increased surface runoff due to the probability of an increase in freak storms and torrential rains. Improvement of existing water catchment areas and reservoirs and provision for new ones to meet with the expected increase in rainfall intensity.

(3) Increase use of sea water in industrial and domestic systems wherever freshwater in not essential. Maintenance of existing rubble walls to prevent soil erosion.

4.1.3. Preventive policies and measures relating to sea level rise

(1) Assess the extent and nature of damage which a predicted rise in sea level of 65+/-35 cm would have on settlements along the coast and principal drainage lines and take appropriate actions to minimise disruption which would have both economic and social consequences.

(2) Expansion of settlements in low lying risk areas should be stopped. Anticipatory regulations, economic incentives and compensation should be introduced to shift settlements from critical areas, such as parts of Msida, to safety with the least disruption.

(3) Malta as coastal state should implement a comprehensive coastal/drainage zone management policy by the year 2000. The policy should include the precise identification of all coastal/drainage areas at risk and their subdivision into habit- able, industrial and agricultural areas, and consider the effects of sea-level use on coastal structures such as quays, docks, breakwaters and yacht marinas.

(4) Improve principal drainage systems in B'Kara - Msida, Qormi, Marsa and Burmarrad by means of adequate culverts.

(5) Implement measures to rectify the base of the galleries to a new optimal level to protect them from sea-water intrusion as a result of sea-level rise.

(6) Evaluate sewage systems in the light of the predictions on sea-level rise.

(7) Initiate a detailed study on the impact of sea level rise and the change in local climate, on the local aquifers. This study should be quantified and based on the mathematical hydrological models calibrated for Malta. The study should also include economic aspects attributed to any changes in availability of water from the aquifers. It is further recommended that measures of water conservation should be fully implemented.

4.2 Adaptive Policies and Measures

4.2.1. Policies and measures relating to temperature change

(1) Examine the possibility of introducing green tarmac instead of black to lower the road surface temperatures during the hot summer months.

(2) Take appropriate measures to adapt to higher temperatures, ensuring the availability of properly air-conditioned wards and homes for both geriatric and paediatric patients.

(3) Hotels and holiday complexes should be adequately provided with air-conditioning systems to meet with higher temperatures.

4.2.2. Policies and measures relating to changes in precipitation.

(1) Install a Doppler Weather Radar to provide advance warning of heavy rains, squalls, wind shear and other parameters.

(2) Encourage research in dry climate technology and introduce more drought resistant crops and trees which would consume less water without loss in productivity. Establish gene banks to protect endangered species.

(3) Plant suitable trees and other plants to reduce soil erosion. Improve irrigation methods including more widespread use of drip irrigation.

(4) As winter and spring precipitation may decrease and hence the problem of water availability may arise, provision must be made for a regular water supply especially during the peak season in summer.

4.2.3. Policies and measures related to sea level rise

(1) Emergency plans should be formulated and put in force to adequately cope with any eventual flooding, even if temporary.

(2) To maintain a safe extraction ratio, water production from all aquifers located at sea level must be reduced by 40%.

(3) Improve drainage systems in main traffic arteries .

(4) Carry out regular maintenance of existing breakwaters and initiate studies to consider the need to build new protective structures in harbours and coves around the islands in the light of the findings on the impacts caused by sea level rise. Any local development plans such as the Major Sewage Plan for Malta may need to take into consideration the likely consequences of climatic as well as non-climatic effects on local ecosystems.

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APPENDIX

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ANNEX

TEMPERATURE AND PRECIPITATION SCENARIOS FOR THE MALTA REGION

Report to the UNEP Co-ordinating Unit for the Mediterranean Action Plan

January 1992

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TEMPERATURE AND PRECIPITATION SCENARIOS FOR THE MALTA REGION

Report to the UNEP Co-ordinating Unit for the Mediterranean Action Plan

(in alphabetical order)
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January 1992

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SUMMARY

We have applied the methods developed by Kim et al. (1984) and Wigley et al. (1989) to the problem of constructing sub-grid-scale climate change scenarios for the area surrounding Malta. Regression equations were developed to predict station temperature and precipitation anomalies from regionally-averaged climate anomalies. We proceeded to substitute GCM perturbed-run minus control-run values of temperature and precipitation in the regression equations to obtain a prediction of the change due to the greenhouse effect at each station. The results were scaled by the equilibrium temperature of each of the four GCMs and an average for the four models obtained. The procedure was repeated for every station in the data set, and the results contoured to produce a scenario for the Malta region.

Annual and seasonal scenarios for both temperature and precipitation change were produced. For temperature, the annual change around Malta should be slightly less than the global change (around 0.8-0.9°C per degree global change). At the seasonal level, the largest increase is found in summer, when the temperature should rise slightly more than the global change. In the other three seasons the temperature response is less than the global mean change. The lowest value for the Malta region is in spring (0.8°C per degree global change).

The scenarios for precipitation are much more difficult to evaluate. This is particularly the case as we have been unable to generate a sub-grid-scale scenario for the summer perturbation. The available scenarios indicate that there will be no change in precipitation at the annual level. Winter and spring are shown to have lower precipitation, whereas in autumn rainfall should increase.

We have attempted to evaluate conditions in summer by examining the composite GCM scenarios presented in the Final Report. These indicate that there will be little if any change in summer rainfall around Malta due to the enhanced greenhouse effect. However, for the other seasons and for the year as a whole the composite GCM scenarios are not compatible with the sub-grid-scale scenarios. The problems associated with the construction of regional scenarios of precipitation change associated with the enhanced greenhouse effect are discussed at length in the Final Report for the UNEP Mediterranean Project. The confidence that we can place in these scenarios of precipitation is low.

1. THE USE OF GCMS IN REGIONAL SCENARIO DEVELOPMENT

It is generally accepted that the results from General Circulation Models (GCMs) offer the best potential for the development of regional climate scenarios. They are the only source of detailed information on future climates which can extrapolate beyond the limit of conditions which have occurred in the past.

GCMs are complex, computer-based, models of the atmospheric circulation which have been developed by climatologists from numerical meteorological forecasting models. The standard approach is to run the model with a nominal "pre-industrial" atmospheric CO_2 concentration (the control run) and then to rerun the model with doubled (or sometimes quadrupled) CO_2 (the perturbed run). In both, the models are allowed to reach equilibrium before the results are recorded. This type of model application is therefore known as an equilibrium response prediction.

The fact that the GCMs are run in equilibrium mode must in itself be regarded as a potential source of inaccuracy in model predictions. It can be argued that the predicted regional patterns of climate change will differ from those that will occur in a real, transient response world. This is because equilibrium results ignore important oceanic processes, not least ocean current changes, differential thermal inertia effects between different parts of the oceans and between land and ocean, and changes in the oceanic thermohaline circulation. Transient response predictions, where the CO_2 concentration increases gradually through the perturbed run and where the oceans are modelled using ocean GCMs, and which therefore should provide a more realistic estimate, are becoming available. However, the complexity of the problem in relation to present-day computing capability casts doubt on the reliability of the results, and this is likely to remain the case over the next decade. The present study restricts itself, therefore, to the use of results from equilibrium GCM experiments.

The results from four GCMs developed for climate studies are used in this report. These four are from the following research institutions:

UK Meteorological Office (UKMO)
Goddard Institute of Space Studies (GISS)
Geophysical Fluid Dynamics Laboratory (GFDL)
Oregon State University (OSU)

The models vary in the way in which they handle the physical equations describing atmospheric behaviour. UKMO, GISS and OSU solve these in grid-point form whereas GFDL uses a spectral method. All models have a realistic land/ocean distribution and orography (within the constraints of model resolution); all have predicted sea ice and snow; clouds are calculated in each atmospheric layer in all models.

One problem with the application of GCMs to the study of climate impacts is the coarse resolution of the model grid. The grid scale of the four models listed above ranges from 4° latitude x 5° longitude (OSU) to 7.83° latitude x 10° longitude (GISS). GCMs, therefore, have a spatial resolution of several hundreds of kilometres, which is inadequate for many regional climate change studies, especially in areas of high relief. We present here a set of high resolution scenarios for the north-eastern Mediterranean, based on the statistical relationship between grid-point GCM data and observations from surface meteorological stations.

2. CONSTRUCTION OF SUB-GRID-SCALE SCENARIOS

Kim et al. (1984) looked at the statistical relationship between local and large-scale regionally-averaged values of two meteorological variables: temperature and precipitation. They then used these relationships, developed using principal component analysis techniques, to look at the response of local temperature and precipitation to the predicted change at GCM grid points. The area of study was Oregon State. Although the paper contains certain statistical flaws, the underlying idea of relating local and large-scale data statistically is sound. The method of Kim et al. has been extended and refined by Wigley et al. (1990) and by Wilks (1989).

The methods of Kim et al. and Wigley et al. have been modified for application in the Mediterranean region. In the model validation exercise carried out for the Mediterranean Project (see Final Report) it was established that no single GCM can be identified as being always the best at simulating current climate. This being the case, there is little merit in presenting scenarios based on only one model. Presentation of scenarios for each of the four models avoids the issue, since the task of deciding which model is 'best', and/or of synthesizing the information to obtain a best estimate, is left to the impact analyst. We have therefore combined the information from the four models into a single scenario for each variable, according to the method described below.

The problem with presenting the scenarios in this form is that the results may be biassed by the different equilibrium responses of the individual models. The global warming due to $2xCO_2$ for the four GCMs ranges between 2.8°C for the OSU model and 5.2°C for the UKMO model run. We would therefore expect that the warming indicated by the UKMO GCM for the Mediterranean Basin will be greater than that suggested by the OSU model, even though the sensitivity of the region to climate change when compared to the global sensitivity might be the same. The individual model perturbations have therefore been standardized by the equilibrium (global annual) temperature change for that model, prior to the calculation of the four-model average.

We required a generalized computer program that would be applicable throughout this geographically complex area, and could be used with meteorological records of variable length and density. After investigating a number of approaches to the problem, we adopted the procedure summarized below:

1. Data sets of monthly mean temperature and total precipitation have been compiled for the area surrounding the Mediterranean Basin. Stations used in this study of the Malta region are listed in Appendix 1. Where possible, each record should be complete for the period 1951-88. Any station with a record length less than 20 years in the period 1951-88 for over six months out of twelve was immediately discarded.

2. Then, for every valid station, the temperature and precipitation anomalies from the long-term (1951-88) mean were calculated. For this part of the work, which is the first step in the construction of the regression equations (the calibration stage), only the data for 1951-80 were used. The 1981-88 data were retained to test the performance of the regression models (the verification stage, see Final Report). For the calculation of the temperature anomaly At_{ij}, the simple difference was used:

$$At_{ij} = t_{ij} - T_j$$

where t_{ij} is the mean temperature of month j in year i, and T_j is the long-term mean for month j. The precipitation anomaly Ap_{ij} was expressed as a ratio of the long-term mean:

$$Ap_{ij} = (p_{ij} - P_j)/P_j$$

where p_{ij} is the monthly total precipitation in month j of year i, and P_j is the long-term mean for that month. If P_j is less than 1mm, then this equation is modified to:

$$Ap_{ij} = (p_{ij} - P_j)/1.0$$

3. The individual station anomalies are used to calculate regionally-averaged anomalies. The procedures described from here to the end of Point 6 are station-specific, and must be repeated for each station in the data set.

   A 5° latitude x 5° longitude square is centred over the station for which regression equations are to be developed (the predicted station). All the stations which fall within this square are used to calculate the regional averages. If the number of stations is less than three, for temperature, or four, for precipitation, the procedure is halted. For temperature, the anomalies from all stations in the 5° x 5° square are averaged month-by-month to produce an area-average time series. For precipitation, the substantial degree of spatial variability makes it advisable to area-weight the station anomalies before calculating the regional mean for each month. To do this, the 5° x 5° region is divided into 20 x 20 smaller squares. The precipitation anomaly value assigned to a particular square is that of the station nearest to it (with the restriction that the distance separating a square from its nearest station should be no greater than 1° - where the distance is greater the square is ignored). The area average is then the mean of the values in the 400 (or fewer, if any fail the minimum distance criterion) squares. This method is similar to the standard Thiessen polygon method.

4. Regression analyses were performed using station temperature and precipitation anomalies as the predictands. These analyses were carried out on an annual and seasonal basis: winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October and November). By considering the monthly values as separate observations within each season, we were able to extend the number of observations and so preserve a high number of degrees of freedom. The predictor variables are the regionally-averaged anomalies of temperature and precipitation.

5. In order to determine the perturbation due to the greenhouse effect at each station, the results from GCMs were employed. It is assumed that a GCM grid-point temperature or precipitation value is equivalent to a regionally-averaged value derived from observational data. For each of the four GCMs (GFDL, GISS, OSU and UKMO), the perturbed run and control run grid-point temperature (t) and precipitation (p) values are interpolated to the station position. Then, we obtain, for temperature:

$$Atm_i = t_i(2 \times CO_2) - t_i(1 \times CO_2)$$

where Atm is the perturbation due to CO_2 or the 'temperature anomaly' for model i and, for precipitation:

$$Ptm_i = [p_i(2 \times CO_2) - p_i(1 \times CO_2)] \times 100/p_i(1 \times CO_2)$$

where Ptm is the standardized perturbation due to CO_2 or the 'precipitation anomaly'.

The values for Atm and Ptm for each GCM are then substituted in the regression equations to obtain a prediction for the station perturbation of temperature (°C) and precipitation (%) due to CO_2.

6. The predicted change in temperature and precipitation for each model is divided by the equilibrium (global mean) temperature change for that model. The results are then averaged across the four models to obtain a composite value.

7. The procedures from Points 3 to 6 is repeated for each station throughout the Mediterranean. The results can then be plotted and contoured to obtain a map of the expected patterns of temperature and precipitation change due to the greenhouse effect.

In order to arrive at this procedure, a rigorous investigation of the validity of the method has been carried out. In particular, we have looked at:

- the use of other predictor variables in the regression equations
- performance and verification of the regression equations
- autocorrelation in the data
- multicollinearity in the predictor variables

These aspects are discussed in detail in the Final Report.

3. CLIMATE CHANGE SCENARIOS FOR THE MALTA REGION

The sub-grid-scale scenarios, constructed according to the method outline in Section 2, are shown in Figs. 1-5. The temperature perturbations are presented as the model average change, in degrees Celsius, per °C global annual change. The precipitation perturbations are shown as the percentage change for each 1°C global annual change. This procedure is described in greater detail, and the approach justified, in Section 2.

The problem with expressing the scenarios in this form is then to scale the values up (or down) in relation to some realistic estimate of the temperature perturbation to be expected from the greenhouse effect. The IPCC Report (Houghton et al., 1990) provides one such family of estimates. For their Business-as-Usual scenario of emissions, the likely increase of global mean temperature by the year 2050 is predicted to be about 1°C above the present level. By the end of next century, the increase is estimated at 3°C above present-day. On this basis, the temperature and precipitation scenarios for the Malta region presented in this report can be related directly to changes between now and the year 2050.

The scenarios for changes at the annual level are presented in Fig. 1. For the whole of the area, the temperature response is indicated to be less than the global mean change i.e. less than 1°C. Around Malta itself, the change is in the region 0.8-0.9°C per degree global change. The precipitation scenarios indicate that, at the annual level, there will be little if any change in rainfall amounts around Malta.

The seasonal maps are presented in Figs. 2-5. In all seasons the temperature change around Malta is close to the global value (i.e. 1°C per degree global change). The greatest change is seen in summer (the months of June, July and August, shown in Fig. 4). In this season, temperatures should rise by slightly more than the global increase. In the other three seasons, the temperature change around Malta is less than the global response. However, it never falls below 0.8°C per degree global change.

Precipitation maps are only presented for three seasons: winter (Fig. 2), spring (Fig. 3) and autumn (Fig. 4). No prediction could be made by this method for the summer season because the correlations between the regionally-averaged climate predictors and the station precipitation time series fall below the cut-off value of 0.7 (see Section 4.2.3 of the Final Report for a full explanation). A reduction in precipitation is indicated for the winter season around Malta, of around 9% per degree global change (Fig. 2). Spring precipitation (Fig. 3) also shows a decline, by between 12 and 15% per degree global change. Lower rainfall in these two seasons is offset by a substantial increase in the autumn, of around 14% per degree global change.

Two problems arose in the construction of the sub-grid-scale scenarios for Malta:

1. We were not able to use data from the Maltese meteorological station, Luqa Airport, in the scenario construction. As noted in Section 2, the method requires that there should be at least three stations, for temperature, and four stations, for precipitation, in a 5° x 5° square surrounding the station for which the regression equations are to be developed. Luqa Airport fails to meet this criterion. Although the size of the square could be enlarged to encompass the necessary number

of stations for the calculation of regionally-averaged climate time series, this would throw doubt on the validity of the results. The scenarios presented here were generated by interpolating the results from stations with the requisite number of surrounding stations over the Malta region.

2. No precipitation scenario for Malta in the summer season could be constructed by the method used here. This means that the scenario of annual changes in precipitation is in fact representative of only nine months of the year.

In order to partially overcome the problem created by the lack of a summer rainfall scenario, we can use the results from the composite GCM scenarios presented in Chapter 3 of the Final Report. These scenarios are constructed by first mapping the output from the four GCMs onto a common grid, size 5° latitude by 10° longitude. A standardized precipitation change for each grid point is then calculated, expressed as the percentage change per °C global-mean warming. By interpolating between the grid points, maps were presented in the Final Report for the whole Mediterranean Basin. We have extracted from these maps the relevant values for the Malta region, and these are shown in Table 1.

It can be seen that the predictions from the composite GCM scenarios for precipitation change are slightly different from those indicated by the sub-grid-scale scenarios. This is not surprising in view of the low degree of confidence associated with regional precipitation scenarios. At the annual level, a slight increase in precipitation is suggested, which is reflected in higher precipitation in the spring and autumn seasons. Winter and summer are shown to have no change in their precipitation amounts.

Table 1 Precipitation changes over Malta, as predicted by composite GCM scenarios (% per °C global temperature increase)

Annual	1% increase
Winter	No change
Spring	1% increase
Summer	No change
Autumn	3% increase

Fig. 1 Regional climate scenarios for the Malta region: annual. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.

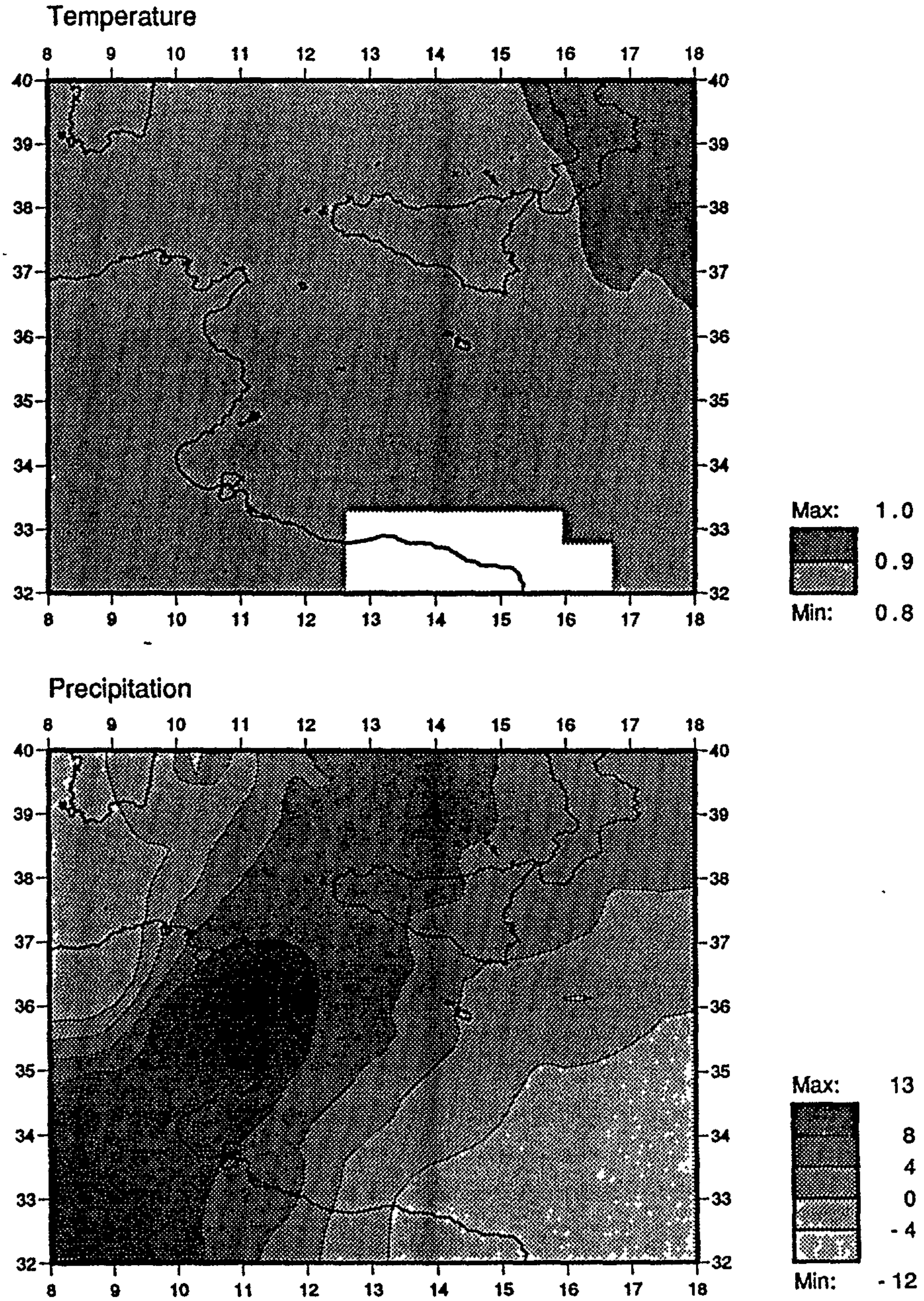


Fig. 2 Regional climate scenarios for the Malta region: winter. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.

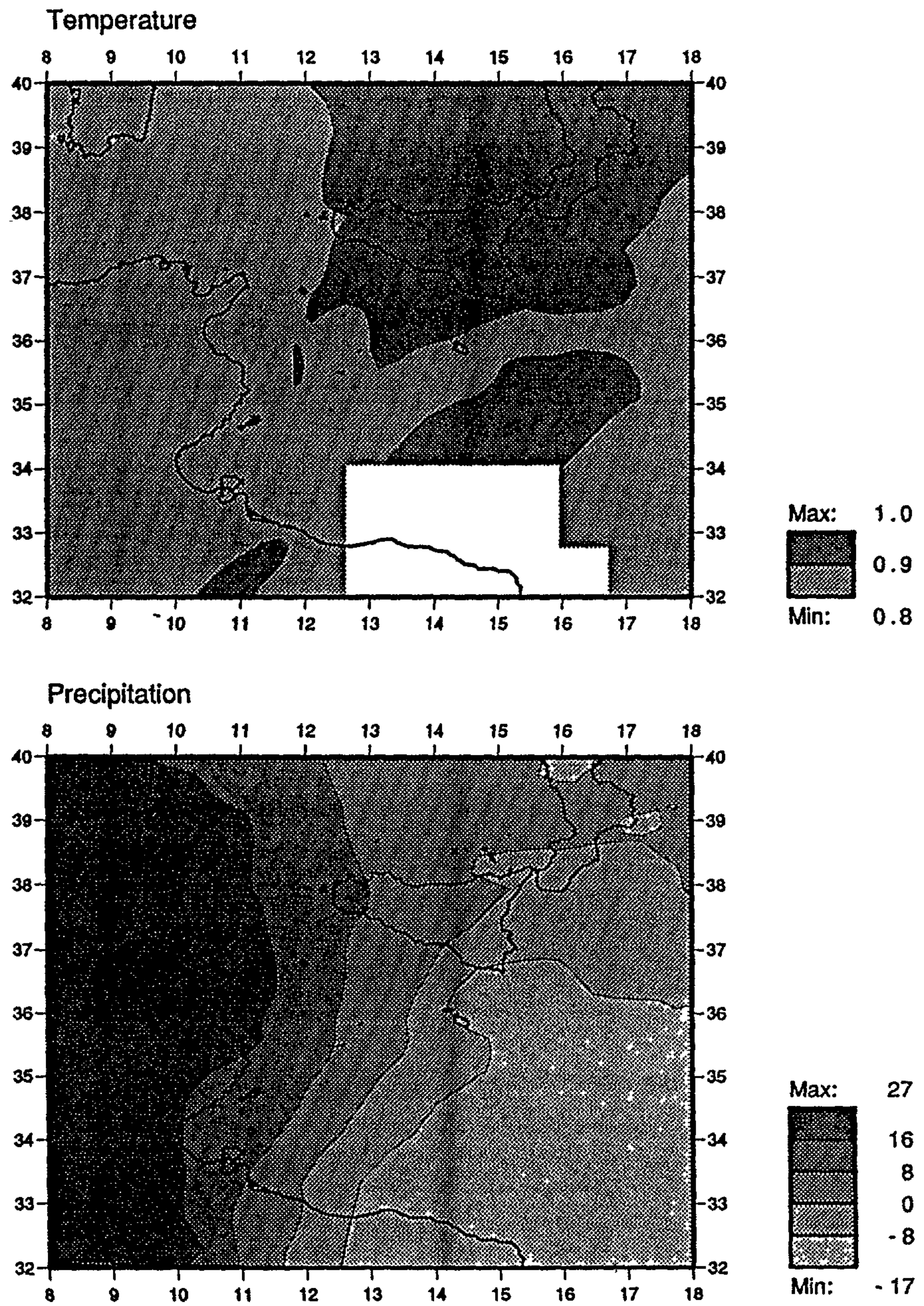
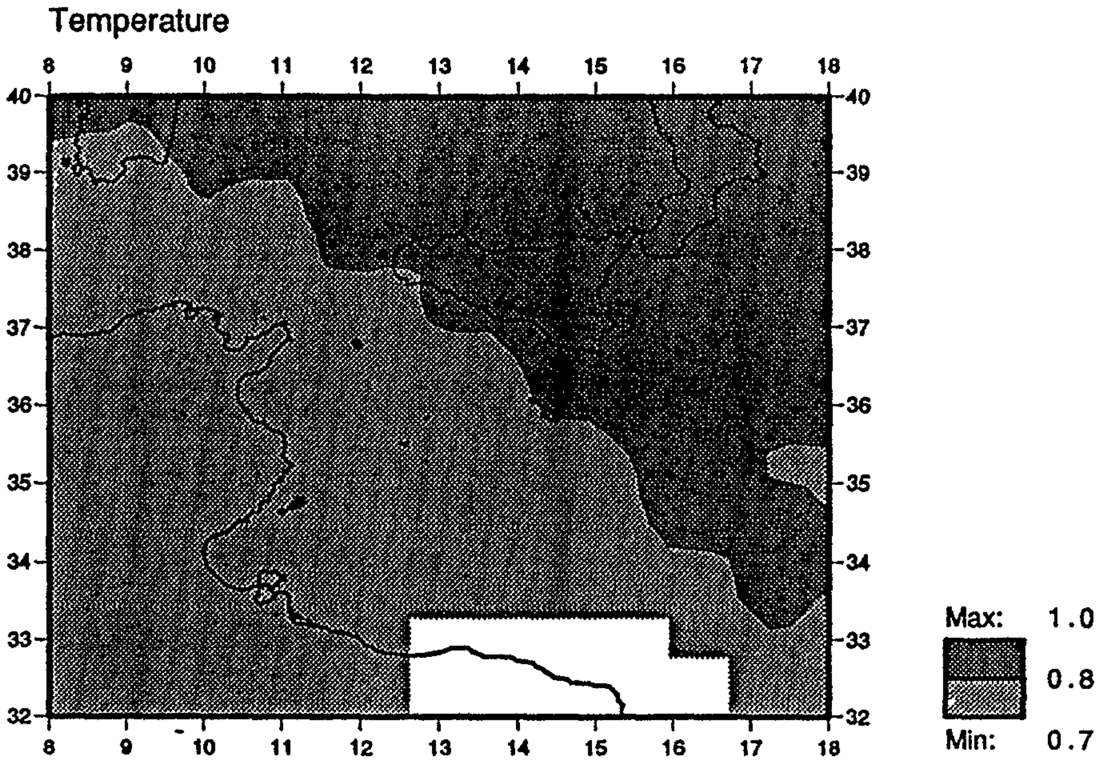


Fig. 3 Regional climate scenarios for the Malta region: spring.
Temperature in units of °C per degree global change;
precipitation in units of % per degree global change.



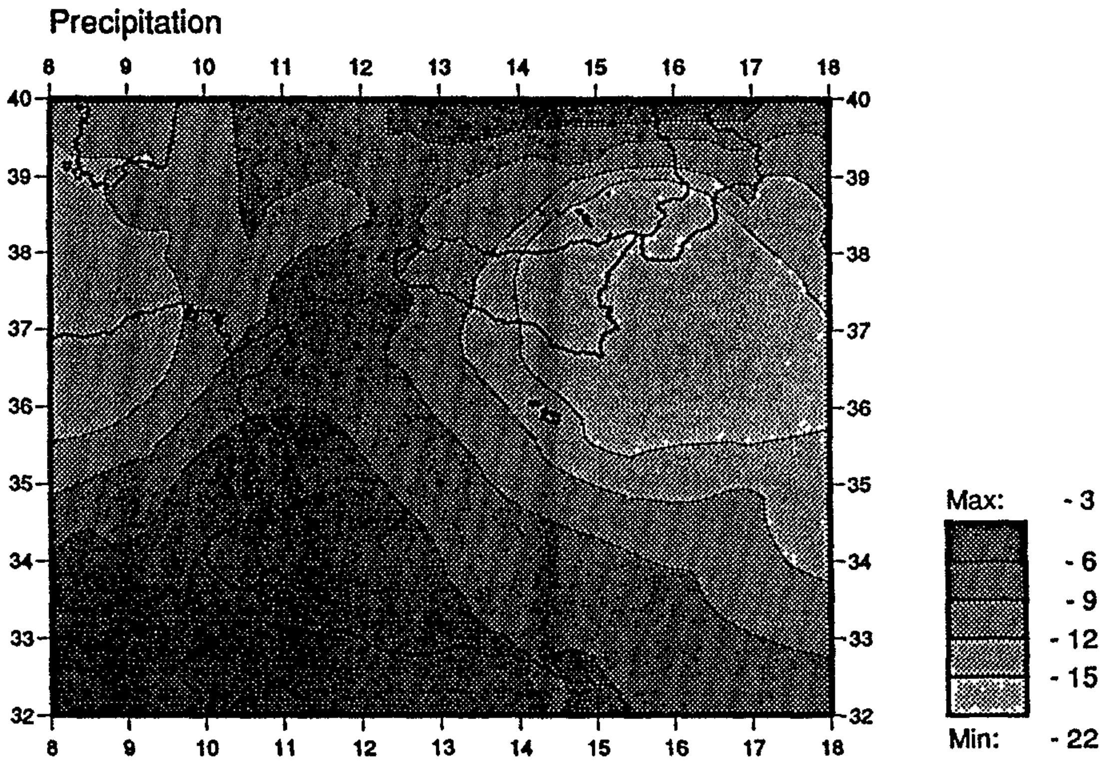
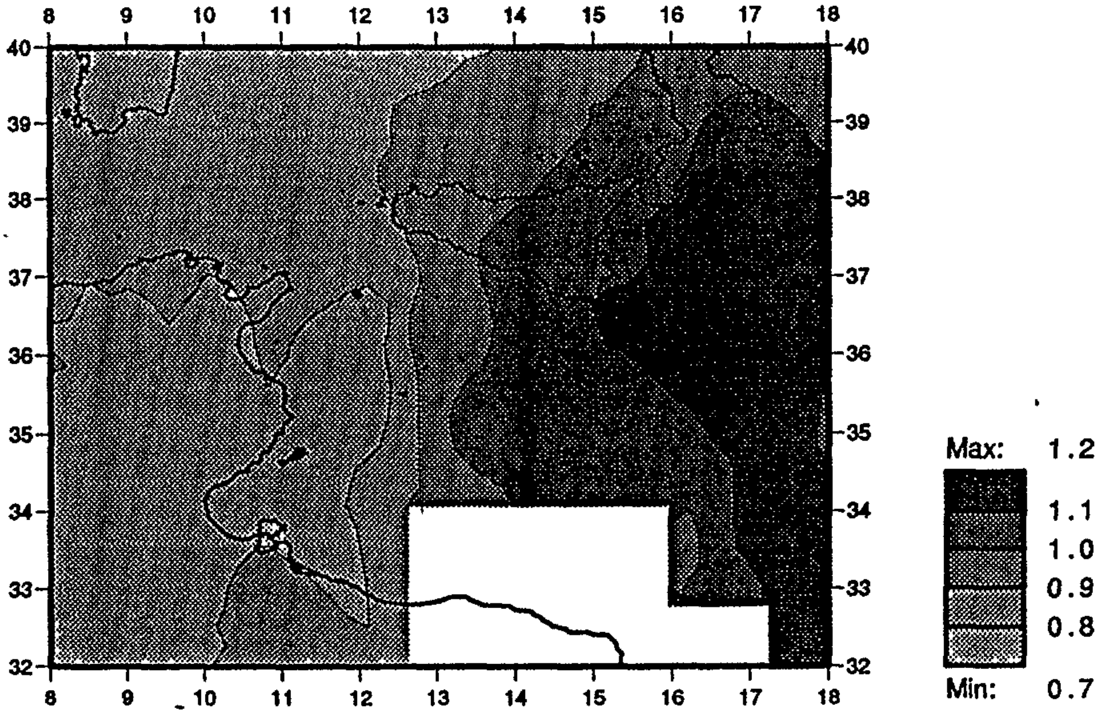


Fig. 4 Regional climate scenarios for the Malta region: summer. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.

Temperature



Precipitation

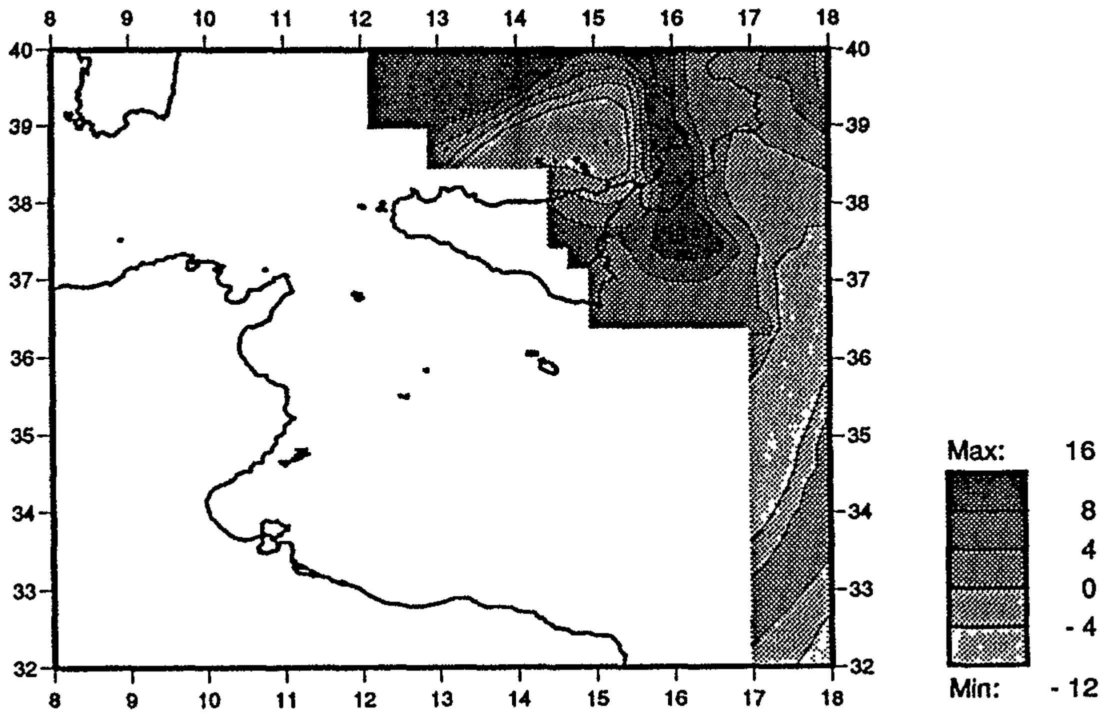
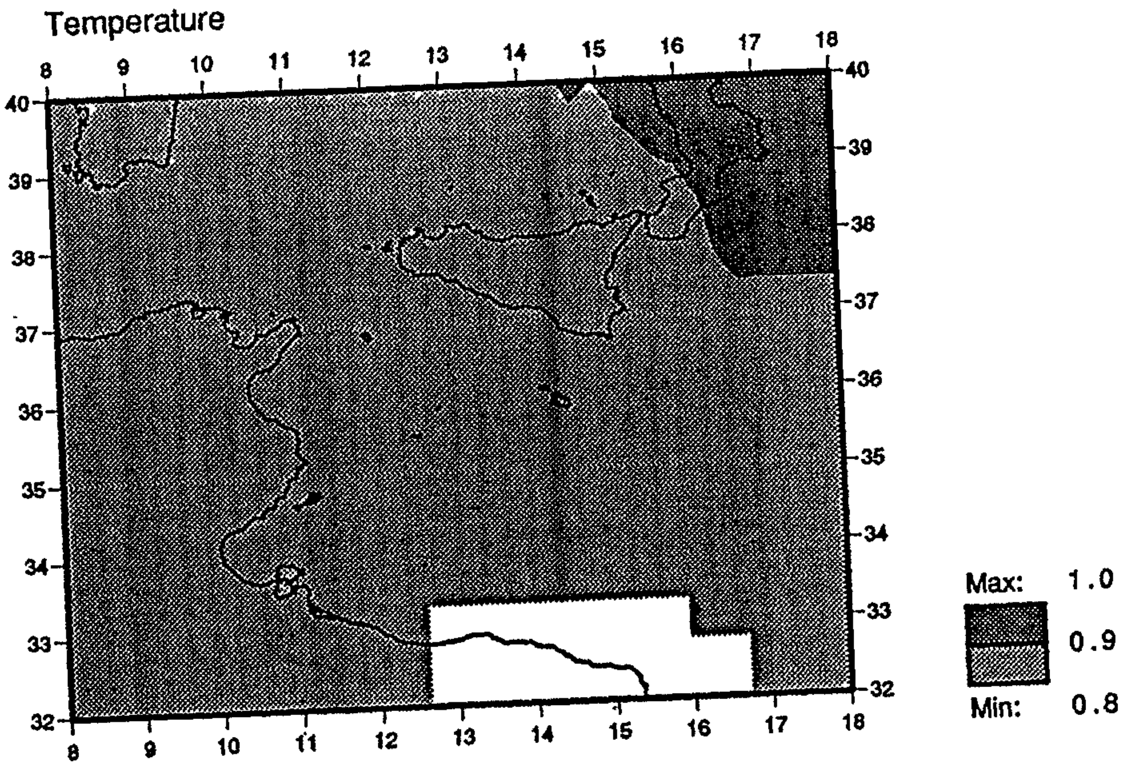
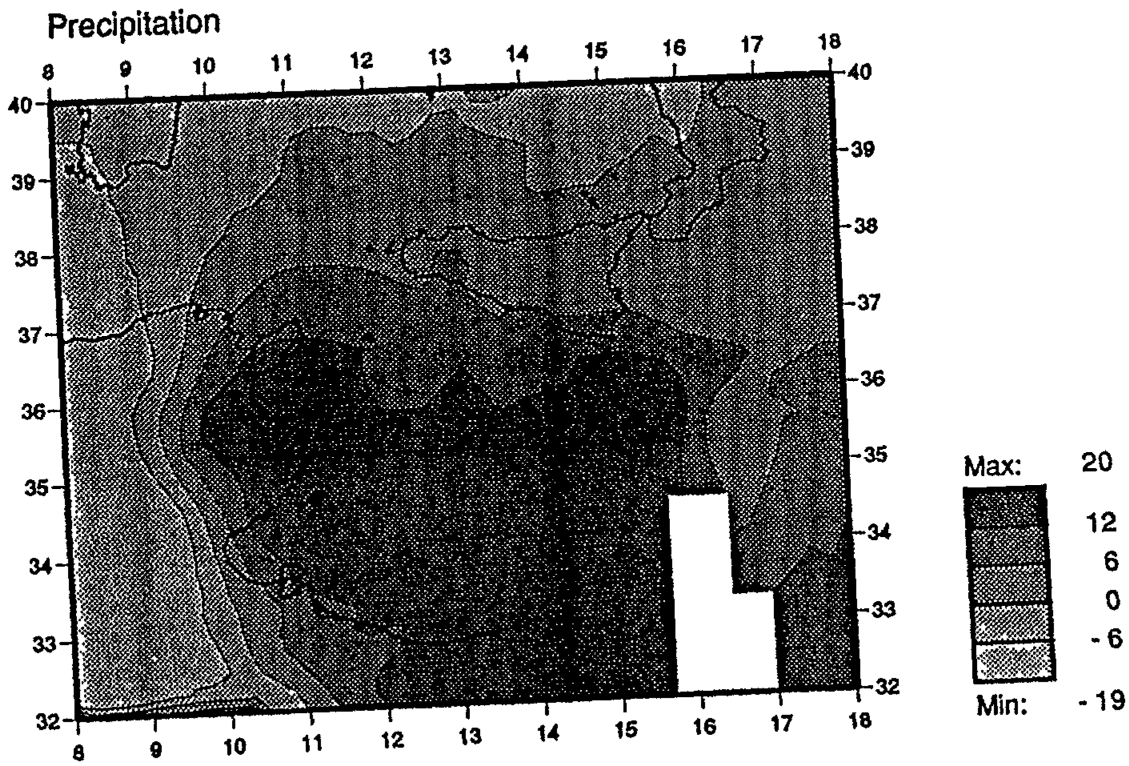


Fig. 5 Regional climate scenarios for the Malta region: autumn. Temperature in units of °C per degree global change; precipitation in units of % per degree global change.





4. CONCLUSIONS

We have applied the methods developed by Kim et al. (1984) and Wigley et al. (1989) to the problem of constructing sub-grid-scale climate change scenarios for the Malta region. Regression equations were developed to predict station temperature and precipitation anomalies from regionally-averaged climate anomalies. We proceeded to substitute GCM perturbed-run minus control-run values of temperature and precipitation in the regression equations to obtain a prediction of the change due to the greenhouse effect at each station. The results were scaled by the equilibrium temperature of each of the four GCMs and an average for the four models obtained. The procedure was repeated for every station in the data set, and the results contoured to produce a scenario.

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APPENDIX 1

STATIONS AVAILABLE FOR USE IN SCENARIO CONSTRUCTION FOR THE MALTA REGION

Note that not all these stations will necessarily be used in the final scenario construction. They must first fulfill the criteria for acceptance laid down in Section 2 of this report, and in the Final Report.

ALBANIA

Station	E	N	HT	PRN	TEM	P%	T%
1. SHKODRA	19.5	42.1	43	1951-1970	1951-1970	100	100
2. TIRANA	19.8	41.3	89	1951-1970	1951-1970	100	100
3. VLORA	19.5	40.5	1	1951-1970	1951-1970	100	100

ALGERIA

Station	E	N	HT	PRN	TEM	P%	T%
4. SKIKDA	7.0	36.9	9	1967-1989	1966-1986	52	76
5. ANNABA	7.8	36.8	4	1963-1989	1963-1986	62	94
6. BEJAIA	5.0	36.8	22	1969-1989	1969-1974	38	81
7. CONSTANTINE	6.6	36.3	704	1951-1989	1967-1986	75	100
8. BISKRA	5.7	34.8	81	1951-1989	1951-1986	65	88
9. TOUGGOURT	6.0	33.1	85	1951-1989	-	37	0
10. OUED	6.9	33.3	63	1951-1989	-	62	0
11. OUARGLA	5.4	31.9	141	1951-1972	1963-1971	95	87
12. BATNA	6.3	35.6	n/a	1972-1986	1972-1986	100	100

FRANCE

Station	E	N	HT	PRN	TEM	P%	T%
13. AJACCIO	8.8	41.9	5	1951-1989	1951-1988	99	100
14. BASTIA	9.4	42.7	n/a	1961-1985	1961-1985	100	100

GREECE

Station	E	N	HT	PRN	TEM	P%	T%
15. KERKYRA	19.9	39.6	2	1951-1989	1951-1988	96	96
16. YANENA	20.7	39.6	n/a	1956-1987	-	100	0
17. ZAKYNTHOS	20.9	37.8	8	1951-1982	1951-1982	79	79

ITALY

Station	E	N	HT	PRN	TEM	P%	T%
18. PESCARA	14.2	42.4	9	1961-1989	1961-1980	97	100
19. ROME	12.2	41.8	2	1951-1989	1951-1988	98	99
20. NAPOLI	14.3	40.9	88	1961-1987	1961-1987	99	99
21. BRINDISI	18.0	40.7	15	1961-1989	1961-1980	98	100
22. MARINA	16.9	40.4	12	1967-1989	1967-1980	96	95
23. MESSINA	15.6	38.2	51	1961-1989	1961-1980	98	100
24. TRAPANI	12.5	37.9	79	1961-1989	1961-1980	98	100
25. CATANIA	15.1	37.5	65	1961-1987	1961-1987	98	99
26. ALGHERO	8.3	40.6	23	1961-1989	1961-1985	79	99

27. CAGLIARI	9.1	39.3	18	1951-1989	1951-1988	98	99
28. AVEZZANO	13.6	42.0	n/a	1951-1970	-	100	0
29. GROSSETO	11.1	42.8	5	1961-1985	1961-1985	99	100
30. CAMPOBASSO	14.7	41.6	793	1961-1985	1961-1985	99	99
31. BARI	16.8	41.1	34	-	1961-1985	0	99
32. POTENZA	15.8	40.6	823	1961-1985	1961-1973	99	96
33. CROTONE	17.1	39.0	155	-	1961-1985	0	99
34. PALERMO	13.1	38.2	21	-	1961-1985	0	99

LIBYA

Station	E	N	HT	PRN	TEM	P%	T%
35. NALUT	11.0	31.9	620	1951-1988	1954-1960	98	94
36. BENI-WALID	14.0	31.8	n/a	1951-1989	1951-1960	67	92
37. MIZDA	13.0	31.5	n/a	1951-1988	1951-1960	95	92
38. ZUARA	12.1	32.9	3	1951-1988	1954-1988	98	70
39. GHARIAN	13.0	32.2	n/a	1951-1988	1951-1960	96	94
40. HOMS	14.2	32.6	n/a	1951-1989	1951-1960	92	94
41. TRIPOLI	13.2	32.7	84	1951-1989	1951-1988	90	91
42. MISURATA	15.1	32.4	6	1951-1988	1954-1988	100	93
43. TUMMINA	15.1	32.2	n/a	1951-1989	1951-1960	36	94
44. SIRTE	16.6	31.2	22	1951-1988	1954-1988	98	65
45. BENINA	20.3	32.1	132	1951-1989	1951-1988	85	88
46. BENGHAZI	20.0	32.1	10	1951-1973	1985-1988	100	100
47. AGEDABIA	20.2	30.7	n/a	1951-1988	1954-1988	99	60
48. HON	16.0	29.1	261	1954-1988	1954-1988	94	75
49. GHADAMES	9.5	30.1	n/a	1951-1988	1969-1988	91	96

MALTA

Station	E	N	HT	PRN	TEM	P%	T%
50. LUQA	14.5	35.9	80	1951-1989	1951-1988	96	99

TUNISIA

Station	E	N	HT	PRN	TEM	P%	T%
51. TUNIS	10.2	36.8	3	1951-1988	1951-1988	100	97
52. JENDOUBA	8.8	36.5	143	1951-1988	1964-1974	100	95
53. KAIROUAN	10.1	35.7	60	1951-1988	1964-1974	100	95
54. GAFSA	8.8	34.4	313	1951-1988	1964-1974	100	93
55. SFAX	10.7	34.7	21	1951-1988	-	100	0
56. GABES	10.1	33.9	4	1951-1988	1951-1974	100	95
57. DJERBA	10.6	33.8	0	1951-1988	-	100	0
58. MEDENINE	10.3	33.3	117	1951-1972	-	100	0
59. AIN-DRAHAM	8.7	36.8	739	1951-1988	-	100	0

YUGOSLAVIA

Station	E	N	HT	PRN	TEM	P%	T%
60. ULCINJ	19.2	41.9	30	1951-1980	1951-1980	100	100
61. TITOGRAD	19.3	42.4	33	1951-1989	1951-1988	97	98

E - latitude

N - longitude
HT - height above sea level (m)
PRN - length of precipitation record
TEM - length of temperature record
P% - percentage of precipitation record present
T% - percentage of temperature record present