Climatic Change and the Mediterranean

Environmental and societal impacts of climate change and sea level rise in the Mediterranean region

Volume 2

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6

Implications of Expected Climatic Changes for Malta

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ABSTRACT

The temperature and precipitation scenarios for the Malta region developed by the Climate Research Unit of the University of East Anglia suggest 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. A statistical analysis of past meteorological data for Malta indicates an existing trend towards increasing extremes of temperature; namely an increase in the maximum and a decrease in the minimum temperatures. The mean annual temperature is also apparently increasing. These data also suggest a trend towards lower total annual rainfall; an increase in the atmospheric pressure; an increase in the number of days with thunderstorms; and decreases in cloud cover and the number of hours of bright sunshine. These trends suggest that a process of desertification is already occurring in Malta, and that there is an increase in the suspended particle concentration including pollutants, in the atmosphere over the island.

The hydrological cycle will be significantly affected by global warming. In Malta, natural sources of freshwater account for about 37% of all potable water in the public supply and for 84% of all irrigation water. Global warming will affect the freshwater supply through changes to relative sea level, and through changes in rainfall and evapotranspiration. A eustatic rise in sea level of around 65 ± 35 cm by the year 2100 would adversely affect the existing extraction rates from Malta's principal aquifer and make

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. Since an increase in temperature with little change in the total rainfall is anticipated, evapotranspiration will increase, leading to an increase in aridity, and to soil degradation mainly due to salinization and alkalinization. The anticipated increase in temperature; a shift in precipitation patterns; a decrease in soil water availability; and a rise in sea level, will have negative impacts on agriculture, natural vegetation and associated fauna, favouring an increase in xerophilic, thermophilic and halophilic species. Such species are likely to be introduced ones, 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 more typical of deserts. This shift in vegetation pattern would be enhanced by soil erosion and increased soil salinity. Remedial action at a local level could include measures to prevent soil erosion by gradually changing to crops and trees that stabilize 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 might happen; 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, together with development of more sustainable use of fisheries resources. The present coastal, near-shore and freshwater ecosystems are threatened by a number of anthropogenic, 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 projections of future changes are to be accurate. Increased eutrophic conditions and increased water stratification are likely to occur under conditions of global change in certain localities already influenced by other non-climatic human activities. Non-linear biological responses to climatic changes are discussed and may prove to be quite significant but difficult to predict with the present state of knowledge.

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 depend largely on present and future land-use management practices.

Given the coastal topography, present drainage patterns and negligible tectonic movements in Malta, the predicted rise in sea level will have only a slight impact on settlement pattern. Some settlements along the coast and especially those in the main drainage basins will become more susceptible to periodic rainfall-induced flooding and anticipatory action will be needed to address the consequential economic and social disruption. Impacts on coastal settlements are expected as a result of tidal and storm surges rather than from permanent inundation.

A rise in sea level may cause sewage systems to flood, and new systems may have to be developed to reduce public health risks from such a hazard, including the increased risk of epidemics of enteric disorders such as typhoid fever. Salt water intrusion into aquifers will reduce the quantity and quality of potable water resources. Temperature rise and an increased frequency of extreme high temperatures, especially when combined with high humidity, will put some population groups such as the elderly and infants at risk from heat stress.

Diseases presently confined to the tropics may spread to higher latitudes, and tropical and sub-tropical vector borne diseases may become more widespread, partly because vector survival will increase 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, already seems to be on the increase, possibly as a result of recent increases in temperature and humidity.

Increased exposure to the sun when combined with possible ozone layer depletion may result in a further rise in the incidence of both melanomas and non-melanotic skin cancers. Exposure to increased ultraviolet (UV) radiation is expected to cause damage to the cornea and lens and an increased incidence of cataracts. The effect of UVB radiation on the human immune system is far less well understood, but it is a well accepted fact however, that UV, 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, employing 5.8% of the total working population. If the climate conditions of the Maltese Islands change, the tourist industry could suffer, causing 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, which would be adversely affected by the loss of sandy beaches and the reduction in potable water supply. The tourist industry, is by its very nature, fragile and susceptible to political, economic and social changes. 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 rain storms, which will probably increase along with the anticipated increase in autumn precipitation.

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. 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 a 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 that presents major scientific challenges spanning a wide range of disciplines. Changes in global climate between now and the middle of the 21st 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 the predictions, particularly with regard to the timing, magnitude and regional patterns of climatic change, as well as with 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.

In view of the importance of this issue, 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 organizations, launched, co-ordinated and financially supported a number of activities designed to contribute to an assessment of the potential impacts of climatic changes and to the identification of suitable policy options and response measures that may mitigate the negative consequences of the expected changes.

As part of these efforts, and in the framework of the activities of the Mediterranean Task Team, six site specific case studies were prepared, in the period from 1987 to 1989, covering: the deltas of the rivers Ebro, Rhone, Po and Nile; the Thermaikos Gulf; and the Ichkeul/Bizerte lakes. Since 1990, second-generation site specific case studies have been undertaken, covering: the Island of Rhodes; Kăstela Bay; the Syrian coast; Izmir Bay; Malta; and the islands of Cres and Lošinj. The present report represents the work of the Task Team asked to consider the potential implications of climate change for the island of Malta.

1.2 The Maltese Islands

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° 05′ and 35° 48′ 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 of 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 almost entirely composed 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; Greensand; and, Upper Coralline Limestone. Erosion of each of these rock types results in a different characteristic topography. Lower Coralline Limestone forms sheer cliffs that 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° 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 reflect: the chemistry of the parent rock material; their relatively young age; the low influence of the climate; and the dominant influence of human modification.

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 37% 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. There is no sharply defined plane of separation between the superficial fresh water and the saline water beneath. The equilibrium of this 'lens' is in state of flux depending on the fluctuations 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 and a series of gauging bore holes scattered all over the aquifer are used to monitor the lens and adjust pumping rates to minimize saline intrusion.

The climate of the Maltese Islands is typically Mediterranean, with a mild wet winter invariably followed by a long dry summer. 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. Rainfall records have been systematically maintained for over 100 years and annual rainfall is highly variable from year to year. Over the period 1854 to 1986 the extreme maxima and minima were 1011.3 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.

The average annual precipitation from 1961 to 1990 was 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, and around 6% of the total precipitation finds its way directly into the sea via this surface runoff. 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.

In spite of the limited area, the low habitat diversity, and the intensive human pressure on the natural environment, the islands support a diverse fauna, certain elements of which are of particular scientific importance. There are some: 1000 species of fresh water and terrestrial molluscs; more than 4000 species of insects; 1 amphibian; 9 terrestrial reptiles; 13 resident, 57 regularly visiting, and 112 migrant birds; and 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 vegetation communities are: maquis (scrub); garigue (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 garigue with scrub and trees (maquis and forest areas) collectively covering only about 4% of the island area.

The coast is particularly important ecologically since it supports habitat types that are rare elsewhere in the islands including sand dunes and saline marshlands. These localities are valuable as examples of their particular habitat and also, as they support specialized biota, which is itself rare and/or endemic. The coast includes type localities for some endemic species, and important nesting and migratory bird feeding sites.

The Maltese population is estimated at 358,623, giving an average population density of 1094 persons/km^2. At the last census in 1985 the enumerated population totalled 345,418, of whom, 319,736 resided in Malta, 25,682 in Gozo. This represents a rise of 12.6% over the previous 1967 census. The net emigration, after allowing for returned migrants is marginal and the natural growth rate of the Maltese population is about 0.6%/yr. 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 follows a recession in the early 1970s. The average annual rate for the 1973–1982 period was just under 9%, 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%. The GNP per capita reached US$ 5483 in 1991.

1.3 Methodology and assumptions used in the study

Observations and scientific analyses suggest that temperature is rising world-wide. 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 60 years between 1880 and 1940, a decrease of 0.2°C between 1940 and 1970 and 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.

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 Global Circulation Model (GCM) grid points. 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. Information from four models has been combined into a single scenario for each variable, according to the method described in Palutikof *et al.* (1992). 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.

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 rigorous 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. Palutikof *et al.* (1992) also presented 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

Table 6.1 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	–	–
University East Anglia Med		for each °C Global		
Rainfall		+3% winter –3% summer		
UNEP Task Teams				
Temperature		–	+1.5 to +3 °C	–
Sea level		–	+38 ± 14 cm	–
University 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.

change. The precipitation perturbations are given as the percentage change for each 1°C global annual change. The IPCC Report (Houghton *et al.*, 1990) suggests that for their business-as-usual scenario of emissions, the likely increase in global mean temperature by the year 2050 will 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, temperature and precipitation scenarios for Malta can be related directly to future global changes and the resultant operative scenarios for Malta are provided in Table 6.1.

Annual and seasonal scenarios for both temperature and precipitation change, produced for the Mediterranean region suggest that, in the case of temperature, greatest sensitivity will be in the mainland areas to the north-east. Temperature increases less than the global mean temperature change were indicated for the south-west 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 south-east, 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 Palutikof *et al.* (1992) who concluded that the confidence that can be placed in sub-grid-scale scenarios if precipitation is low.

The operative scenarios resulting from the procedures outlined above were used by the Task Team to evaluate the potential impacts of future changes on the Maltese Islands. This evaluation includes *inter alia*: consideration of the impacts of future climate change on the various sectors of the Maltese economy; the effects of an increase in temperature and a decrease in rainfall on agricultural production and water resources; the effect of temperature increase on tourism, on fishing and on the energy sector and electricity production; the effects of sea level rise on harbours, beaches and yacht marinas; and the effects of changed climate on the health of the local population. These assessments are based on available data concerning the present conditions and trends in each of the sectors considered and the resultant conclusions used to prepare recommendations for action by the appropriate authorities, in order that effective steps may be taken to mitigate the adverse effects of impending changes.

2 IDENTIFICATION AND ASSESSMENT OF THE POSSIBLE CONSEQUENCES OF CLIMATIC CHANGE

2.1 Past and present climate conditions

2.1.1 Analysis of past meteorological data for Malta

The Meteorological Office started taking 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 6.1

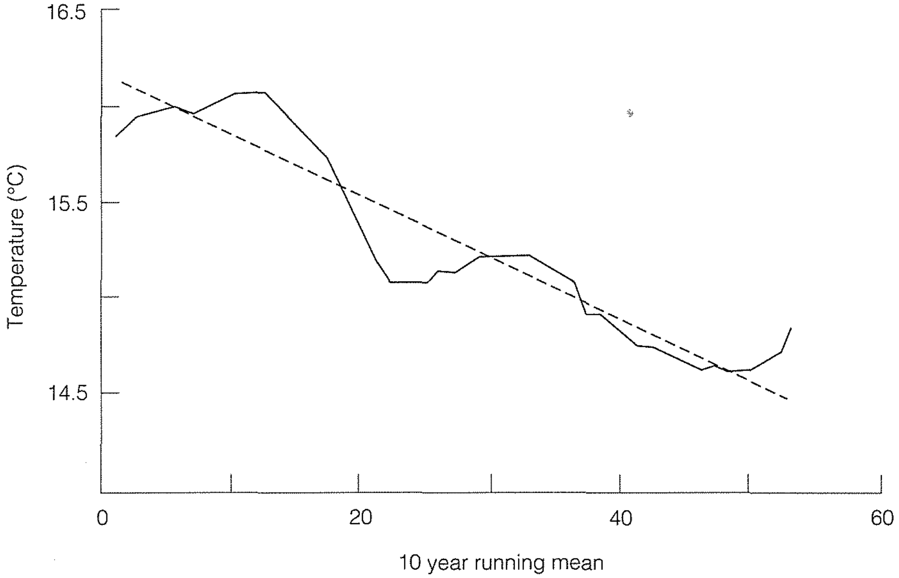

Fig. 6.1 Ten-year running mean, minimum annual temperature (°C) at Luqa, Malta over the period 1947 to 1988, combined with adjusted data from Valletta for the period 1927 to 1947.

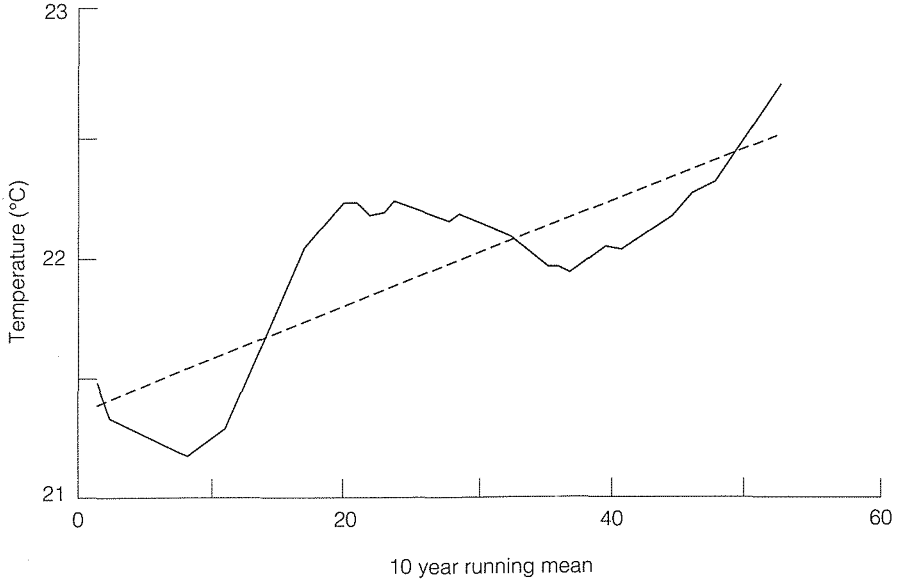

Fig. 6.2 Ten-year running mean, maximum annual temperature (°C) at Luqa, Malta over the period 1947 to 1988, combined with adjusted data from Valletta for the period 1927 to 1947.

and 6.2 present data from Luqa for the period 1947–1988 in the form of 10 year running means. A low-pass filter (the Binomial Coefficient method) was used to smooth out fluctuations in these data (Figs. 6.1 and 6.2) and in some of the rainfall data.

The data for maximum and minimum temperatures at Luqa and at 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 since Luqa is an inland and Valletta a coastal station. Regression equations were derived and the observations of Valletta maximum and minimum temperature (T_{max}, and T_{min},) amended by using the following regression equations:

$$\text{Luqa } T_{max} \text{ °C} = \{(\text{Valletta } T_{max} \text{ °C}) \times 1.0329\} - 0.1361$$
$$\text{Luqa } T_{min} \text{ °C} = \{(\text{Valletta } T_{min} \text{ °C}) \times 1.0395\} - 1.5322$$

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

Another series of graphs (Figs. 6.3 – 6.7) present data for temperatures recorded 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:

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

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

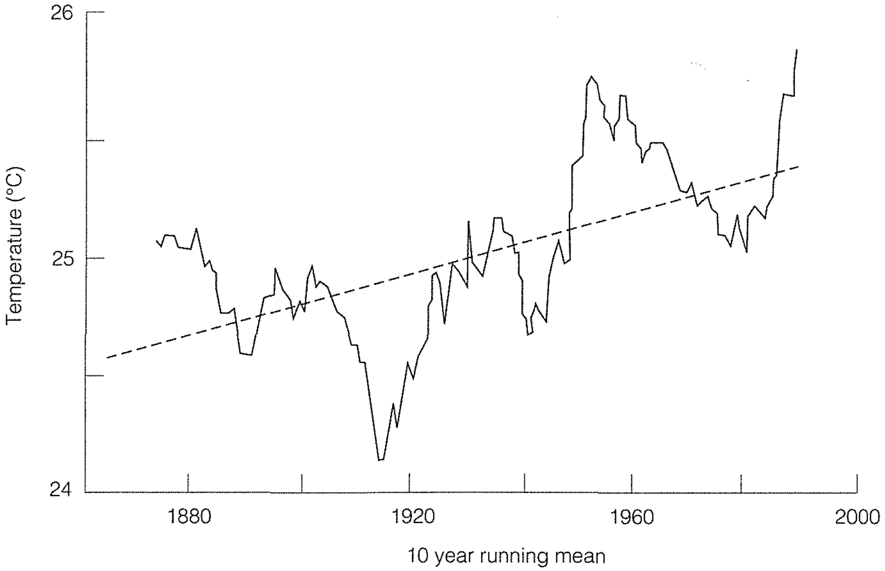

Fig. 6.3 Ten-year running mean summer temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988.

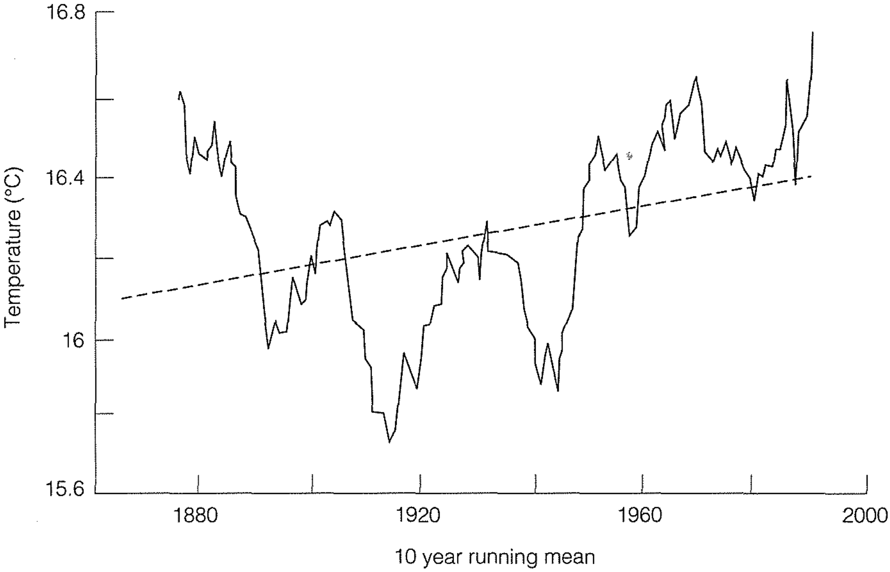

Fig. 6.4 Ten-year running mean spring temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988.

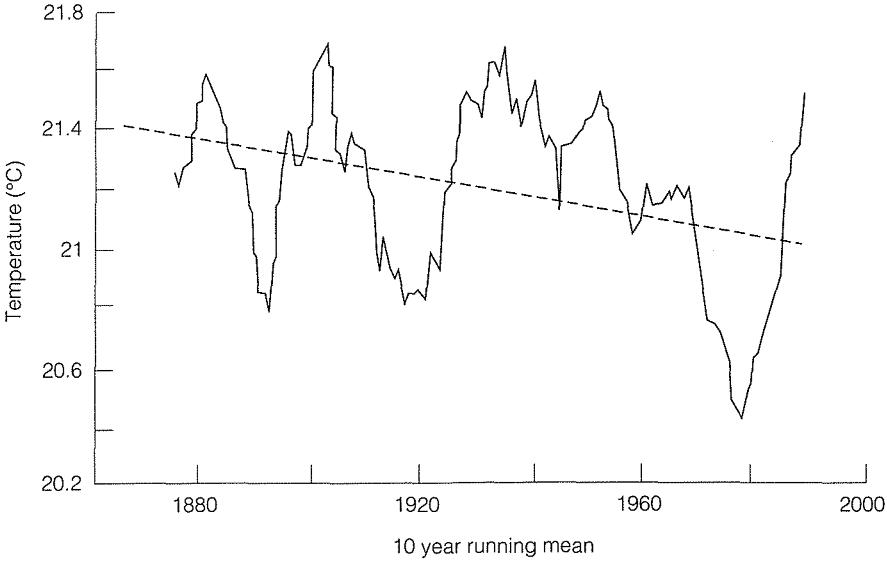

Fig. 6.5 Ten-year running mean autumn temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988.

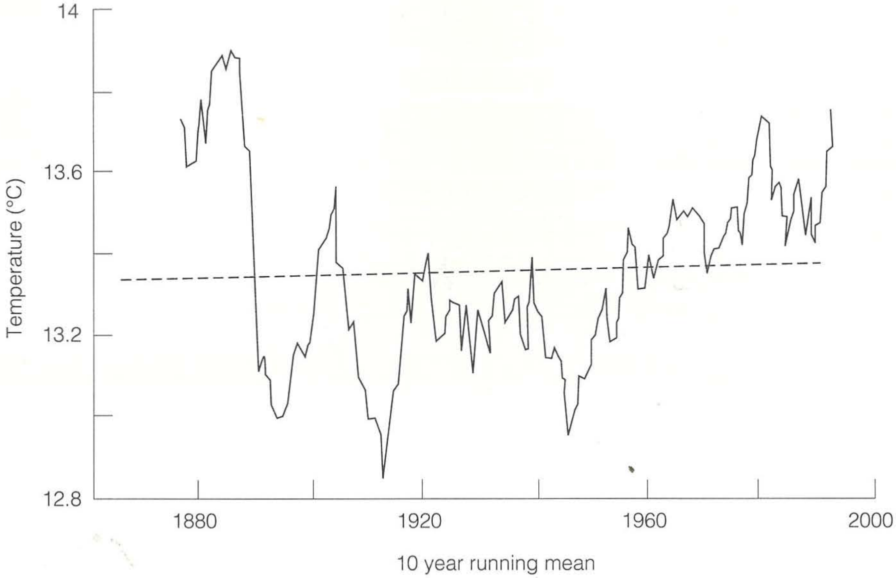

Fig. 6.6 Ten-year running mean winter temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988.

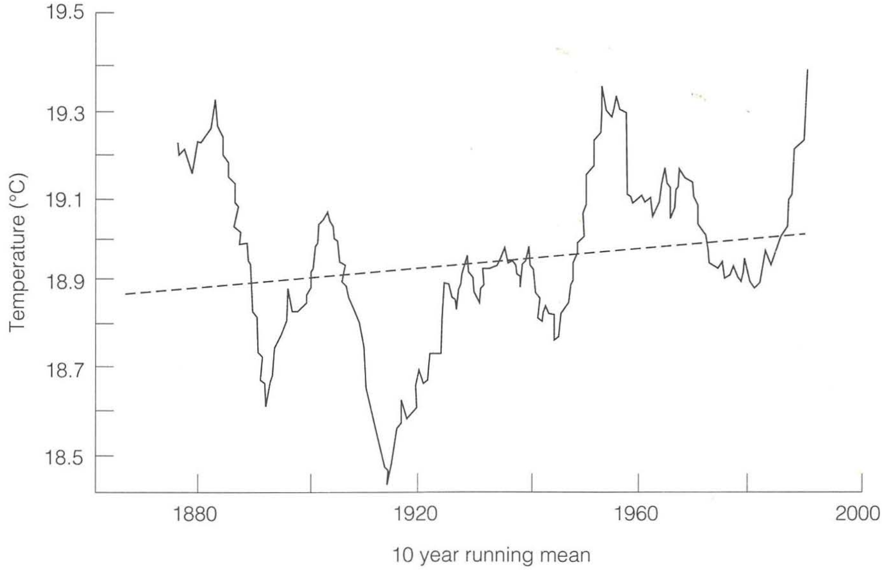

Fig. 6.7 Ten-year running mean annual temperature (°C) in Valletta, 1865 to 1953 combined with adjusted data from Luqa for the period 1954 to 1988.

Malta measurements of rainfall began in 1840. 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 wet season for the Valletta area has been calculated from August to July. For the period 1962 to 1988 the rainfall records of the Argotti Gardens in Floriana were used to update the records of Mitchell to 1988.

In the calculation of the 10 year running means for Luqa, calendar year totals have been used (Figs. 6.8 and 6.9). The 10 year running means for the days with precipitation equal to or greater than 2, 1, 0.1, 10 and 50 mm were also calculated on the basis of data from Luqa, covering the period 1951 to 1990. Similar records for Valletta are not available. A further series of graphs 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 (Figs. 6.8 and 6.9) or four seasons (Figs. 6.10–6.13) representing: spring, March, April and May; summer, June, July and August; autumn, September, October and November; and winter, December, January and February, respectively. The maximum rainfall recorded in a 24 hour period in each year from 1922 to 1990 is shown in Fig. 6.14. These observations, include those taken at Gwardamangia and at Valletta in addition to those from Luqa.

Atmospheric pressure readings taken by the Meteorological Office at Gwardamangia, Valletta and Luqa were all reduced to mean sea level by using standard procedures and the 10 year running mean is plotted in Fig. 6.15 for the period 1923 to 1990.

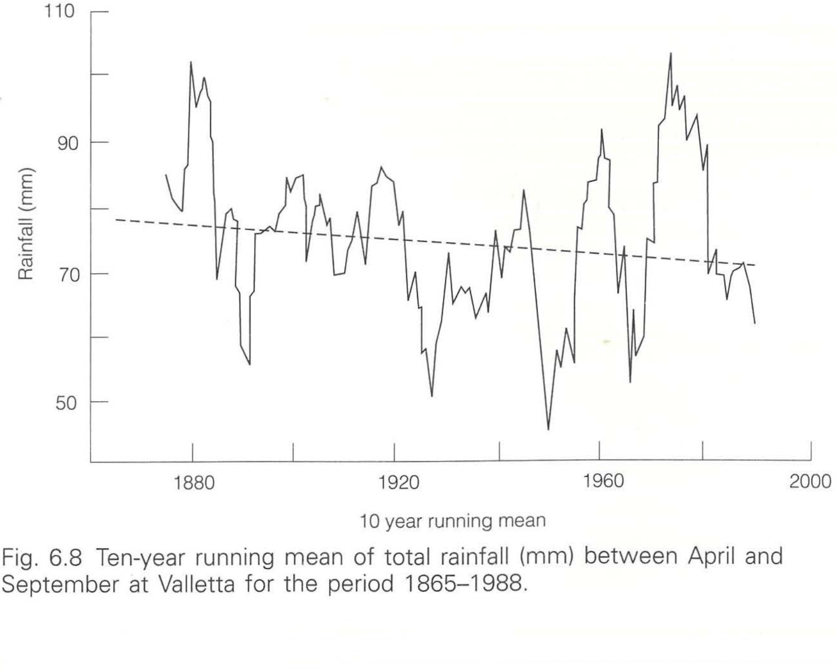

Fig. 6.8 Ten-year running mean of total rainfall (mm) between April and September at Valletta for the period 1865–1988.

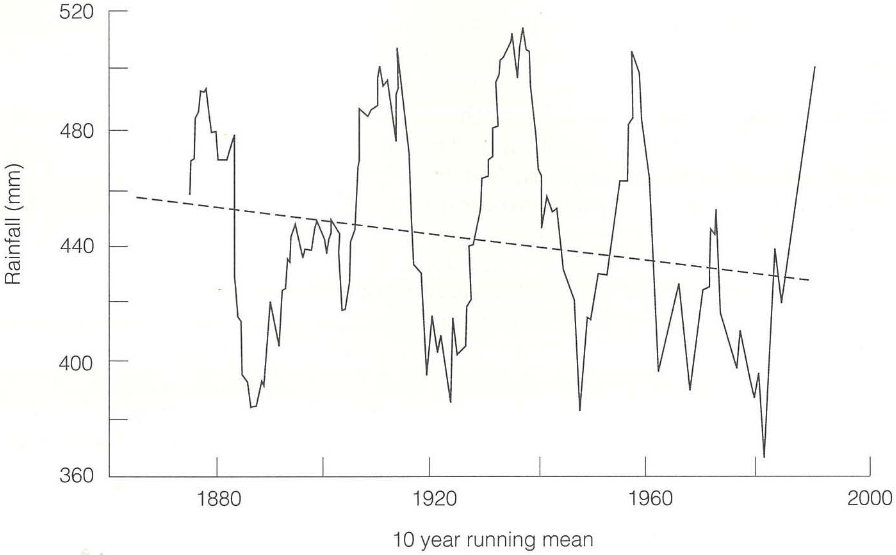

Fig. 6.9 Ten-year running mean of total rainfall (mm) between October and March at Valletta for the period 1865–1988.

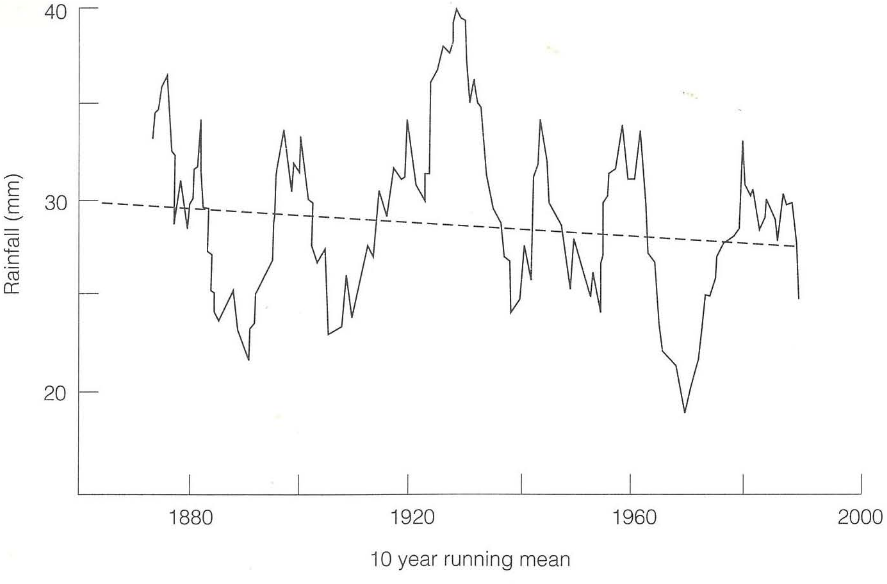

Fig. 6.10 Ten-year running mean of total spring (March, April and May) rainfall (mm) at Valletta for the period 1865–1988.

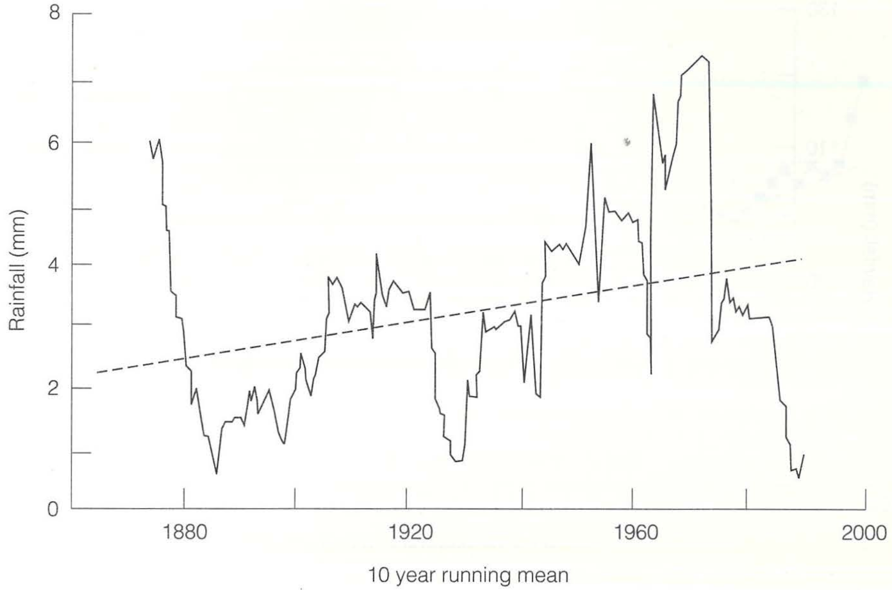

Fig. 6.11 Ten-year running mean of total summer (June, July and August) rainfall (mm) at Valletta for the period 1865–1988.

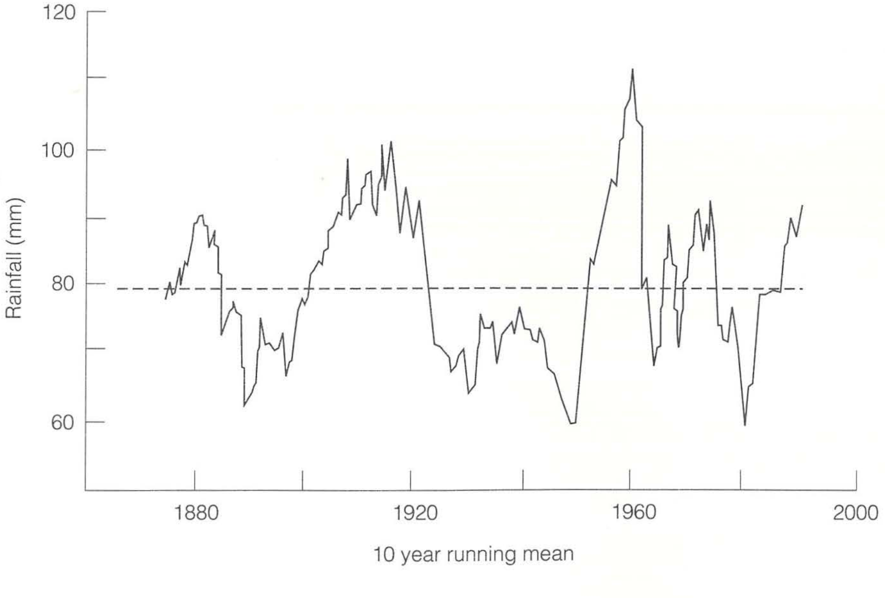

Fig. 6.12 Ten-year running mean of total autumn (September, October and November) rainfall (mm) at Valletta for the period 1865–1988.

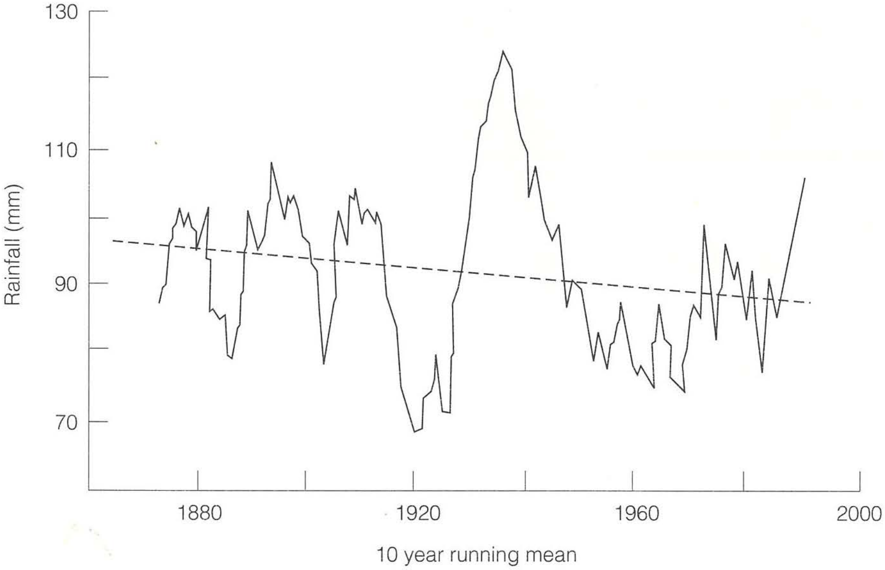

Fig. 6.13 Ten-year running mean of total winter (December, January and February) rainfall (mm) at Valletta for the period 1865–1988.

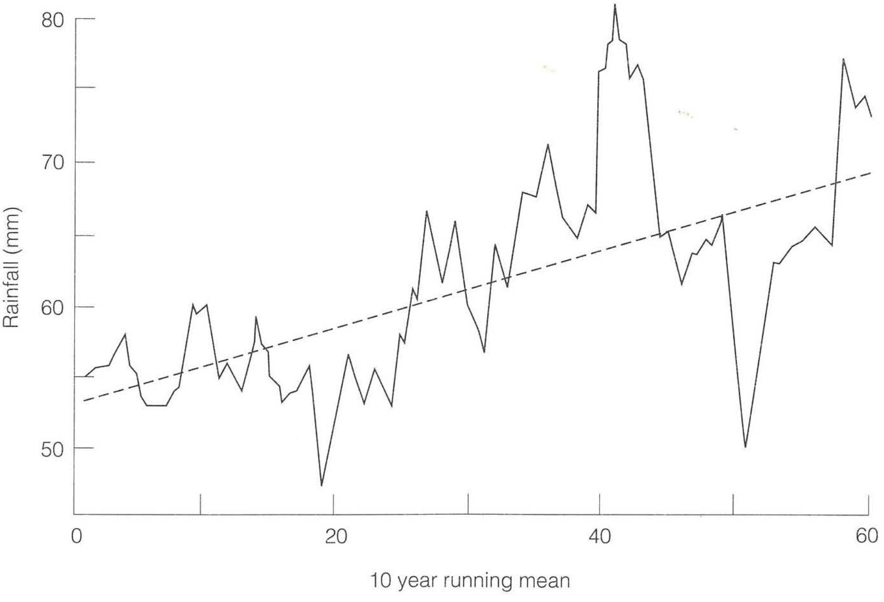

Fig. 6.14 Ten-year running mean of maximum 24 hour rainfall (mm) based on data from Gwardamangia, Valletta and Luqa for the period 1922 to 1990.

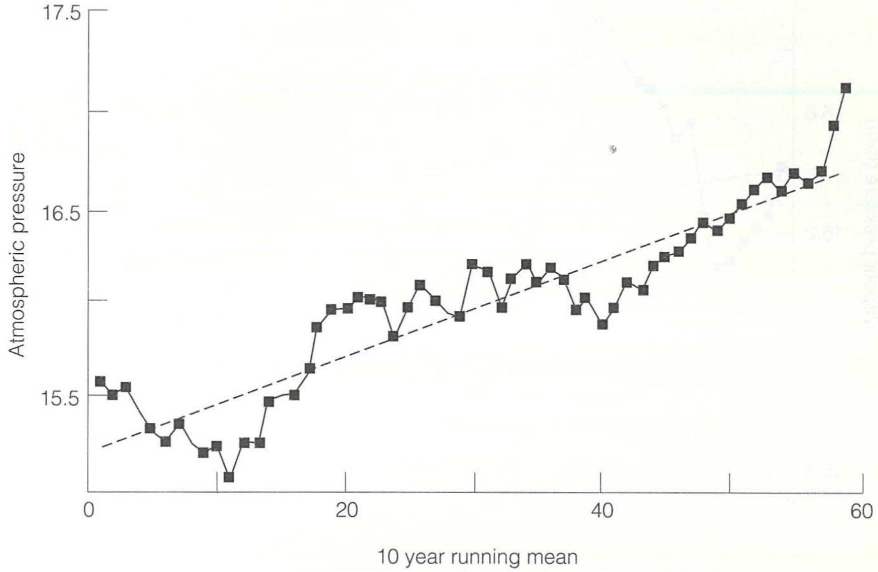

Fig. 6.15 Ten-year running mean of atmospheric pressure (adjusted to mean sea level) taken at Gwardamangia, Valletta and Luqa for the period 1923–1990.

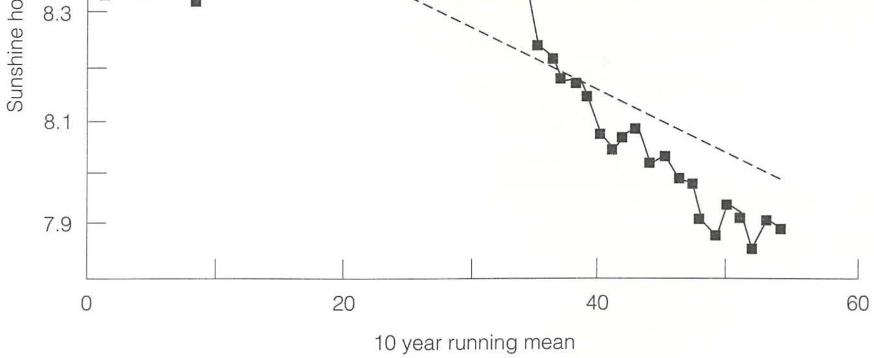

Fig. 6.16 Ten-year running mean of mean daily bright sunshine hours at Valletta, 1928–1946 and Luqa for the period 1947–1988.

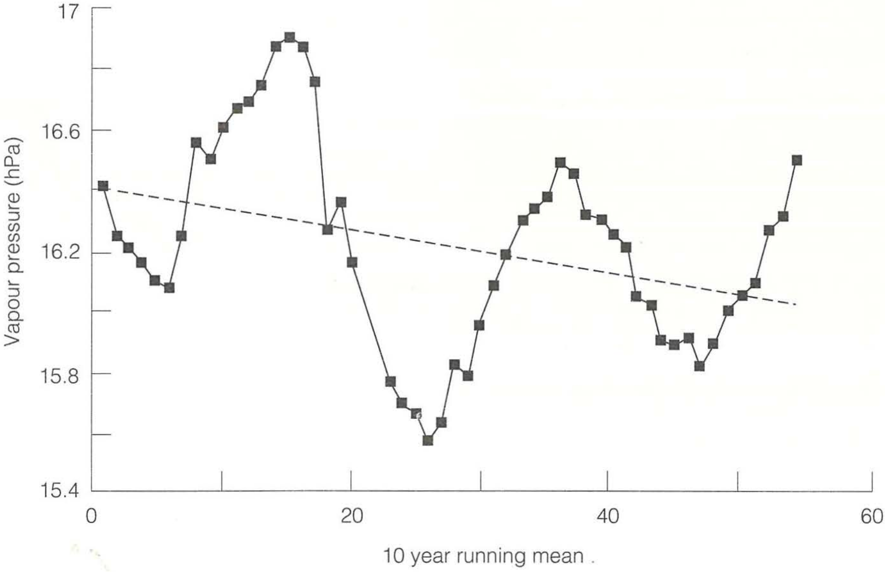

Fig. 6.17 Ten-year running mean of vapour pressure (hPa) based on mean monthly values derived from synoptic three-hourly observations at Valletta, 1929–1945 and Luqa for the period 1947–1990.

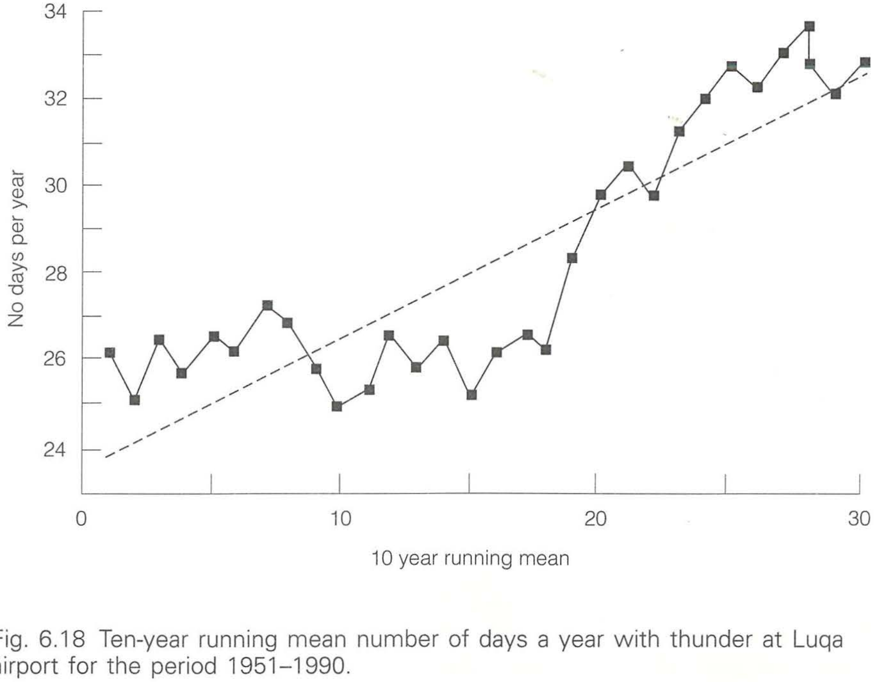

Fig. 6.18 Ten-year running mean number of days a year with thunder at Luqa airport for the period 1951–1990.

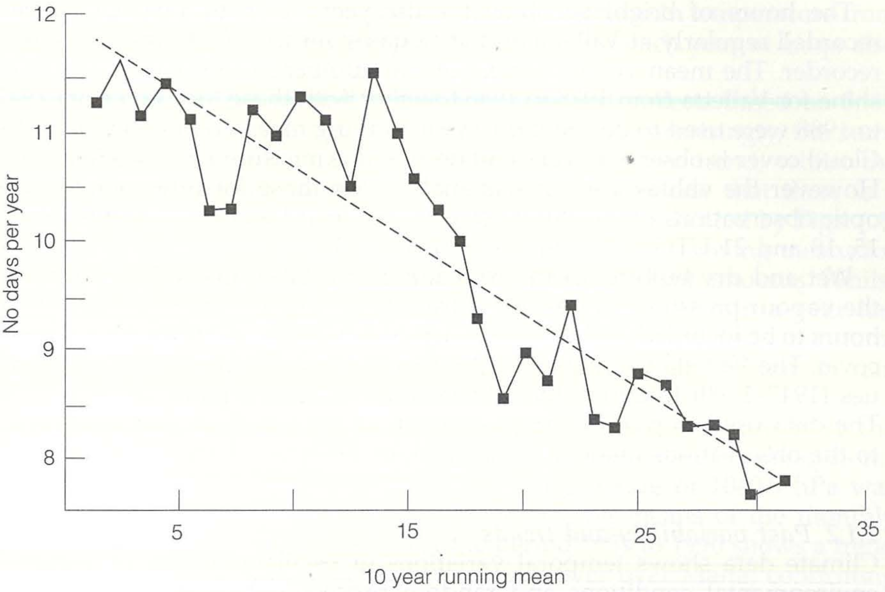

Fig. 6.19 Ten-year running mean of number of foggy days a year at Luqa airport for the period 1951–1990.

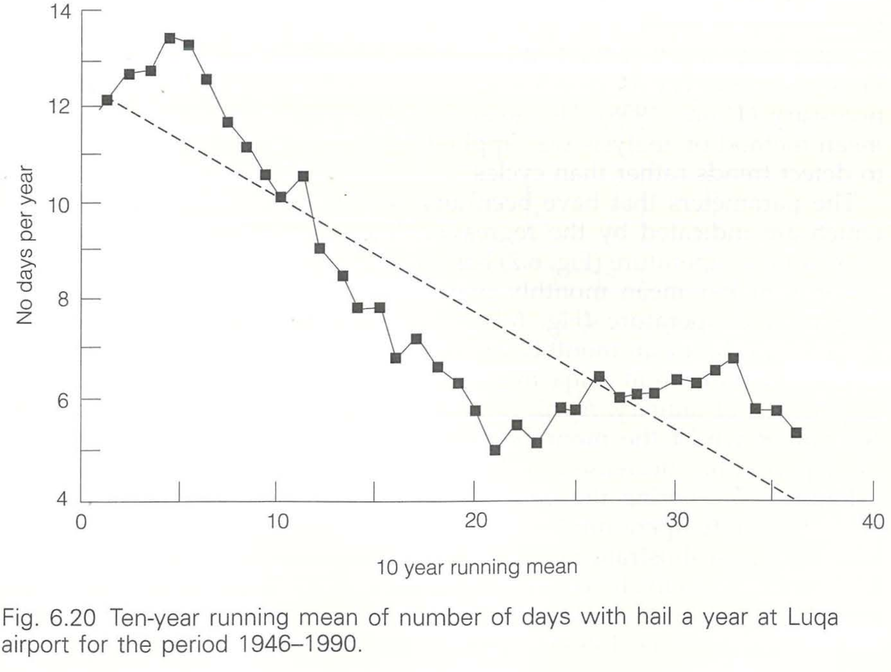

Fig. 6.20 Ten-year running mean of number of days with hail a year at Luqa airport for the period 1946–1990.

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. 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 Fig. 6.16. Cloud cover is observed every half hour and is measured in octas (eighths). However the values used in this analysis are those for three-hourly synoptic observations of the cloud amounts made at Luqa at 00, 03, 06, 09, 12, 15, 18 and 21 UTC (Co-ordinated Universal Time).

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 be included in the 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 Fig. 6.17. The data used to plot the graphs shown in Figs. 6.18, 19 and 20 all refer to the observations made at Luqa Airport during the period 1947 to 1990.

2.1.2 Past variability and trends

Climate data shows temporal variations or oscillations due to changing environmental conditions and random processes. Long-term trends are often hidden in the rather large inter-annual variations that 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 most common is the running or moving mean and the practice of using overlapping means may generate sine curves so that it is not clear whether the features of the smoothed curve are real or artefacts of 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.

The parameters that have been analysed show the existence of trends which are indicated by the regression lines plotted on each graph. The maximum temperature (Fig. 6.2) has a positive gradient, indicating a trend towards higher mean monthly maximum temperatures. In contrast, the minimum temperature (Fig. 6.1) 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.

Figure 6.7 covering the period 1865 to 1990 shows an increase in the annual mean temperature for Malta. Similar trends appear in Figs. 6.3, 6.4 and 6.6 which illustrate mean monthly temperatures in summer, spring, and winter respectively. This trend is most marked in summer. Surprisingly enough, the autumn curve (Fig. 6.5) 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 temperatures recorded each year at Luqa also show 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 Figs. 6.8, 6.9, 6.21 and 6.22. Also interesting are the Luqa 10 year moving means for the number of days with rain greater or equal to different amounts. 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 show a decreasing trend (Figs. 6.23 and 6.24).

Figure 6.15 indicates an increase in atmospheric pressure over the Maltese Islands, suggesting a trend towards an increase in anticyclonic conditions. The highest ever mean sea level pressure of 1040.9 hPa was recorded on 2 January 1992. The 10 year moving means of the monthly cloud amount in octas for Luqa over the period 1951 to 1990 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.

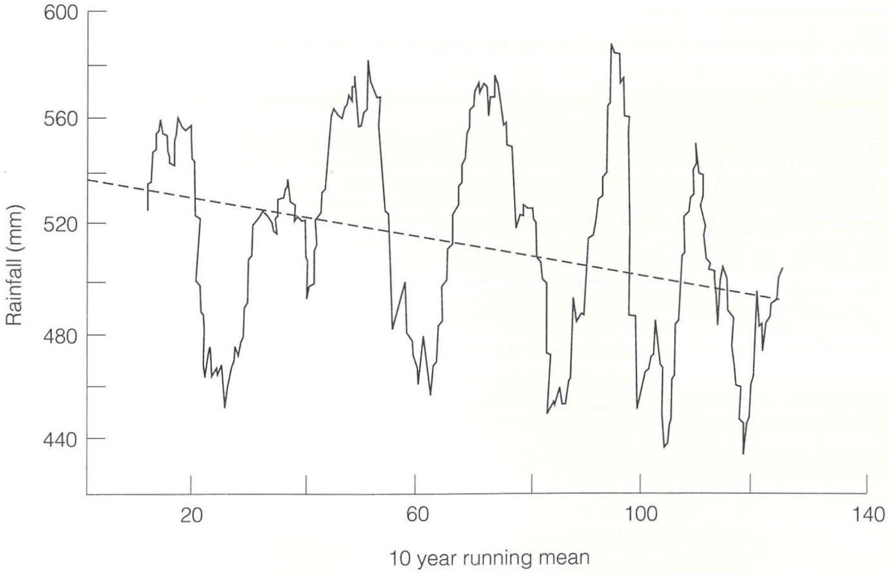

Fig. 6.21 Ten-year running mean, annual (12 months August to July) rainfall (mm) in Valletta for the period 1865 to 1988.

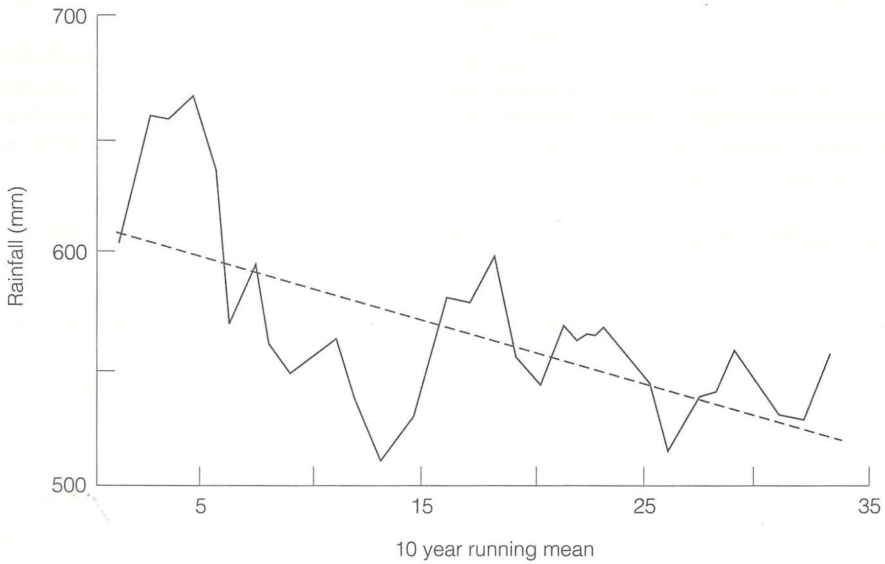

FIg. 6.22 Ten-year running mean annual (January to December) rainfall (mm) at Luqa for the period 1947 to 1988.

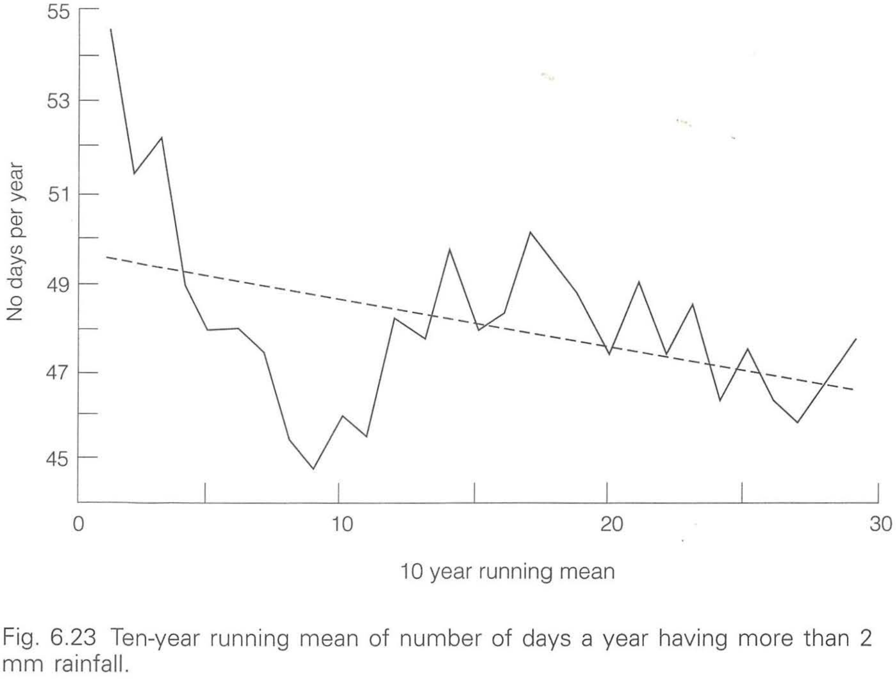

Fig. 6.23 Ten-year running mean of number of days a year having more than 2 mm rainfall.

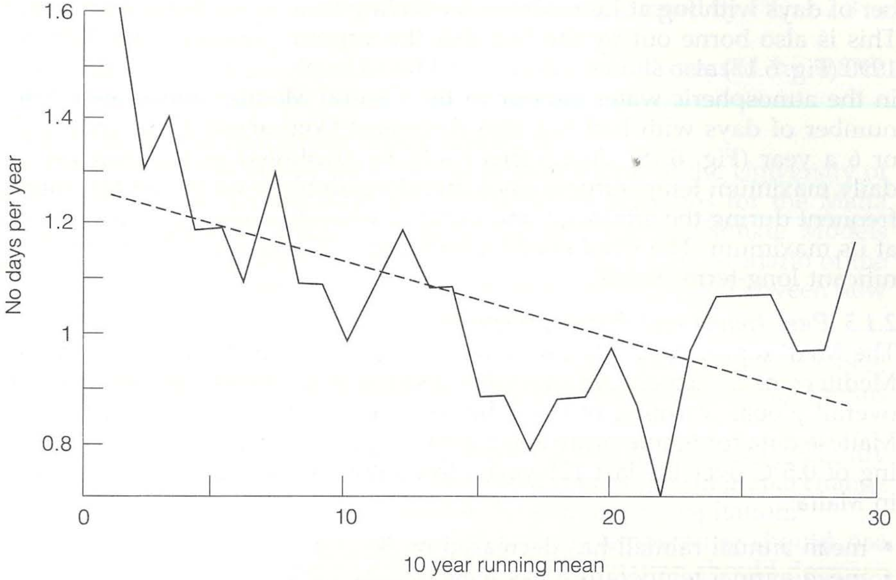

Fig. 6.24 Ten-year running mean of number of days a year having more than 50 mm rainfall.

Figure 6.16 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 findings 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. 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 (Fig. 6.15). The number of days with thunder shows an upward trend from about 25 to 32 per year (Fig. 6.18). 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 (Fig. 6.2). 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 Fig. 6.14, notwithstanding the fact that the absolute number of days with rain greater than 2 and 50 mm is decreasing (Figs. 6.23 and 6.24).

Two other interesting trends are shown in Figs. 6.19 and 6.20. 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 (Fig. 6.17) 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 (Fig. 6.18). 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 (Fig. 6.15) does not show any significant long-term trends.

2.1.3 Past trends and future prospects

The MAP 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 regional 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%; and
- October to March rainfall has decreased by 20 mm: –4.4%.

Over the last 70 years:

- 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%; and
- 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 has 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%; and
- the lowest temperature recorded each year has decreased by 0.8°C: –20.0%.

2.1.4 Conclusions concerning future scenarios

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 6.1; 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:

- annual temperature will increase by 0.8 to 0.9°C per degree of global change and there will be little if any change in the annual rainfall totals around Malta;
- 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 and no prediction could be made for the summer precipitation;
- the winter (December, January and February) temperature should rise by 0.9°C per degree of global change and precipitation should decrease by 9% per degree of global change;
- the spring (March, April and May) temperature should rise by 0.8°C per degree of global change and precipitation should decrease by 13% per degree of global change;
- the autumn (September, October and November) temperature should increase by 0.8°C per degree of global change and precipitation should increase by 14% per degree of global change.

The confidence that can be placed in these precipitation scenarios is low. The General Circulation Models (GCM) scenarios for precipitation are slightly different from those indicated by the sub-grid scenarios and suggest that for a 1°C 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.

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 necessarily reflect the expected increases in greenhouse gases and other forcing factors, for example 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 in Malta could be an increase in the density of suspended particles in the atmosphere, sufficient to reduce the transparency of the atmosphere, especially at low solar elevations and around the times of sunrise and 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 as it passes through the earth's atmosphere. The increase in dust and smoke particles may be due to a number of factors including atmospheric pollution.

The results of the analysis of the other meteorological parameters fit a more general 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 situations which, in turn, implies more low-level inversions. These inversions trap the atmospheric pollutants that 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.

2.2 Lithosphere

2.2.1 Geology

The Maltese Islands display a layered 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 south-west coast of the Islands, which probably is the cause of the slight regional dip to the north-east, as a result of which the oldest rock formations are exposed along the cliffs of the south-west coast.

The oldest exposed unit, the Lower Coralline Limestone, consists mainly 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 strata 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 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 12 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.

2.2.2 *Soil development*

There are five factors involved in the development of soil, and of these, three — parent material; climate; and time — are the most important factors influencing the soils of Malta. Topography, the fourth factor, is largely dependent on the first three, since landscape is determined by erosion and deposition related to the parent structure, processes and time. The fifth factor, biological influences, is dominated on Malta by man's activities, the effects of which are sometimes profound, producing modifications to the natural patterns.

Maltese soils are all rather young or immature since pedological processes are slow in calcareous soils where acidic drainage water is very limited in quantity. Certain soils, including the red brown clays of the Terra group, are believed to have been formed under the influence of past climate processes, which no longer occur. The present climatic regime has so far resulted in little change to the soil profile, thus these red brown clay soils can be considered, relict soils.

In the San Biagio series, very young, man-made, raw carbonate soils 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 have been developing over several hundred years.

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 dry springs, which also have a rainfall deficit. The variation in soils and vegetation, both natural and crops, between deep valleys, north-facing scarp slopes and the main open plateaux or south facing slopes are well marked. These differences result from differences in insolation, and thus surface temperature and evaporation. Soil profiles show virtually no difference between 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.

Past broad oscillations of climate have been responsible for the production of widely differing soil materials such as the 'red soil' (red brown Terra clays), stony calcareous debris and aeolian sands, which form the parent materials for the present soils. The present arid climate is not one under which leaching occurs and this 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 similar in chemical composition, and only moderately variable in physical characteristics. The massive, well jointed limestones have developed karst landscapes since they favour percolation and solution more than do the porous but less pervious, finer-textured limestones. In the karst areas, red brown terra clays have developed on almost completely decalcified limestone residues, but on other landscape types there has been less decalcification and the raw carbonate soils and xero-rendzinas are chemically very similar to the parent rock. Thus, the composition of trace minerals in the limestones from which they were originally weathered, 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.

Topography generally influences the development of the soil through: modifications to the micro-climate; variable conditions of drainage; and the influence on the 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 produces 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 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.

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 profound. Large areas of Malta, which have been covered by human habitation, factories, airfields and military installations, have had the soil bulldozed or covered up and the pattern of soils in agricultural areas has been considerably changed.

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 l-Iklin complex, which range from carbonate raw soils to Terra like soils, depending 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 that 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 giving rise to widespread changes in soil structure on a large scale.

Table 6.2 which is based on Kubiena's 1953 classification illustrates the small range of soils found in Malta and Gozo. There are no subaqueous soils, and only a small fraction of one percent of the soils are secondarily saline and thus classified as semiterrestrial. Some of the present soils such as Alcol, are developed on alluvial, semi-terrestrial soils, formed during an earlier climatic era.

2.2.3 *Soils and agricultural production*

The soils are important to Malta's economic welfare since agriculture is a major activity in the islands. According to the last agricultural census in

Table 6.2 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		
C. Terrestrial	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
	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				

1983, the agricultural workforce included 4500 full-time and 10,900 part-time farmers, together with 5000 full and part time labourers. There are around 12,200 agricultural holdings ranging in area from less than one to 10 ha, the majority being of small size. Of the 11,500 ha of arable land, 800 ha are irrigated, 200 are partially irrigated and the rest is dryland cultivation. 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 provides very fertile soils, which contribute to the agricultural productivity of the islands.

Through cultivation and irrigation man attempts to influence the disposition of water in favour of his crops, and by using fertilizers and herbicides or pesticides attempts to influence the chemistry and biology of the soil. A fertile soil is one that is in the optimum condition for the growth of crops, and this is dependent on a variety of physical, biological and chemical factors. A soil that 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 that appear to have poor structure are the heavy textured soils of the Xaghra series. In these soils 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 fertilizers; 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. The widespread use of rotary tillers is believed to decrease aeration through soil compaction. It is possible that an increase in soil CO_2 under enhanced greenhouse gas conditions would be beneficial in calcareous soils, reducing the pH to a level at which there is greater availability of nutrients, particularly phosphorus, which is deficient.

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. 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; satisfactory chemical data for calcareous soils are difficult to obtain and compare.

A few soils in Malta are affected by saline ground water; a limited number of plots are being irrigated with brackish water and some are also affected by saline spray. The result is an increasing soluble salt content in the lower part of the soil profile, but the concentration has not been great enough to cause noticeable effects on crops to date. The potential adverse effects of saline water can be avoided by making certain that through-drainage takes place from time to time, or by the occasional use of soluble calcium salts in irrigation water. These counter measures are difficult or impossible to undertake without proper drainage and soils with a high saline ground water table are probably untreatable.

2.2.4 *Possible consequences of climate change*

Water loss by evapotranspiration is a critical factor in determining both the overall water balance in Malta and the prospects of further developing irrigated agriculture. Theoretical, semi-empirical and empirical methods of estimating evapotranspiration under diverse climatic conditions and crop covers, 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 6.3 gives mean monthly values of PET computed according to the method suggested by Thornthwaite (1948).

Table 6.3 The present water balance of Malta

Month	Temperature (°C)	Rainfall (mm)	PET (mm)	Moisture		Real ET
				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

Under the temperature and rainfall scenarios for the Malta Region developed by the Climatic Research Unit of the University of East Anglia one would expect a further increase in the moisture deficit for the whole year. Soil formation involves a series of chemical reactions that 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. 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:

$$I \text{ (aridity Index)} = \frac{P_m \text{ (mean annual precipitation, mm)}}{T_m \text{ (mean annual temperature, °C)} + 10}$$

On the basis of this index, De Martonne described six climate regions from the perspective of aridity (Table 6.4). 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 no change in precipitation under conditions of 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. 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. The indices of aridity for different scenarios are presented in Table 6.5.

Table 6.4 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

Table 6.5 Aridity Index, and precipitation evaporation ratios for Malta under present and projected future climate scenarios

	Temperature		Rainfall		Index of Aridty	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	

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 6.5). This suggests a decrease in precipitation effectiveness will occur by the end of the next century. In relation to salinization and alkalinization, the FAO/UNEP consultation (1978) advised the use of the ratio P/PET (P = precipitation and 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 $(P/\mathrm{PET}) < 1$ 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 6.3) and the months of March and October have values close to 1. With the expected increase in temperature and a possible change in the rainfall amount, PET values are expected to increase in all months of the year thereby relegating March and October to the Moisture deficit category in Table 6.3. 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 in many physical, chemical and biological processes including the biological degradation and decomposition of organic matter. The humolytic index (HI) provides a means of evaluating this process under different temperature and moisture conditions. Using the 1961 to 1990 annual means for temperature and rainfall and a PET for the whole year of 947.6 mm, one derives a Humolytic Index of 4.9. With an increase in temperature of 2° to 3°; 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.

2.3 Hydrosphere

2.3.1 The hydrological cycle

The availability of natural water in any locality depends on the local hydrological cycle and 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. Despite the superficially arid appearance of the Maltese Islands, the local catchment characteristics are favourable for the storage of ground water. The generous supply of underground freshwater undoubtedly contributed to the early settlement of these islands. Natural freshwater resources now account for around 37% (45,500 m^3/day) 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) 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 and can be described in terms of the following basic components:

(i) Climate, which determines the distribution and availability of rainwater, the only significant source of water in the cycle;

(ii) A small percentage (6%) of the rainfall is lost directly to the sea as surface runoff. Geology, topography, urbanization and dams determine the extent of this runoff which contrary to public opinion is only of minor significance;

(iii) The rest of the rainfall percolates through the ground where it is partly retained by the soil. This soil 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;

(iv) 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. The characteristics of these natural underground stores of water are largely controlled by the local geology; and

(v) About half of the recharged water is extracted from the aquifers by local water development practices and half is 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 of small islands such as Malta, where the possibility of obtaining water from distant areas via rivers does not exist. 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 and an average annual precipitation of 553 mm has been recorded over this period. At present there are 128 recording stations scattered across Malta and seven stations in Gozo. The distribution of precipitation for the period 1950–1970 is shown in Fig. 6.25.

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

Structurally, Malta slopes gently to the east from the high western coast, to the sea along the eastern shores. This results in surface drainage channels 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 runoff losses to the sea. Only about 6% of the total precipita-

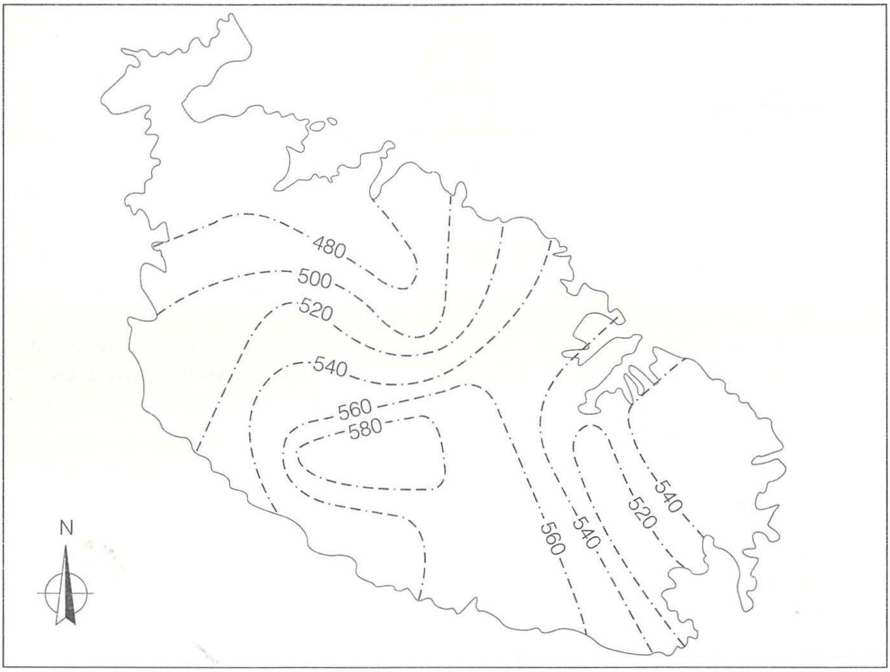

Fig. 6.25 Isohytal map of Malta (1950–1970).

tion, measured over many years by runoff recorders located at the exit points of major drainage areas such as Burmarrad, Msida and Marsa, finds its way into the sea. Most runoff occurs after heavy downpours when the 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 (Fig. 6.26). Open reservoirs have also been constructed along recently made roads to minimize runoff.

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

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 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 islands 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

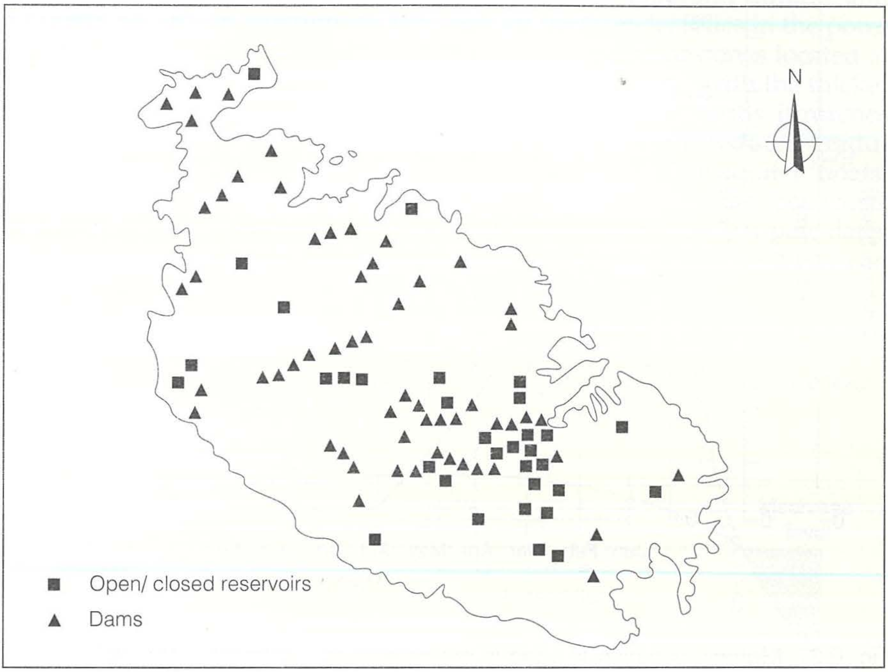

Fig. 6.26 Location of storm water dams and reservoirs on the island of Malta.

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 where rainwater enters the ground directly, 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. The temperature ranges from 6°C in winter to 32°C in summer, whereas the daily sunshine hours range from 5.1 hours in December/January to 12.6 hours in July (Fig. 6.27).

2.3.2 *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 (Fig. 6.28).

The perched aquifer is contained in the porous Upper Coralline Limestone, which lies directly above the impervious Blue Clay. It is also

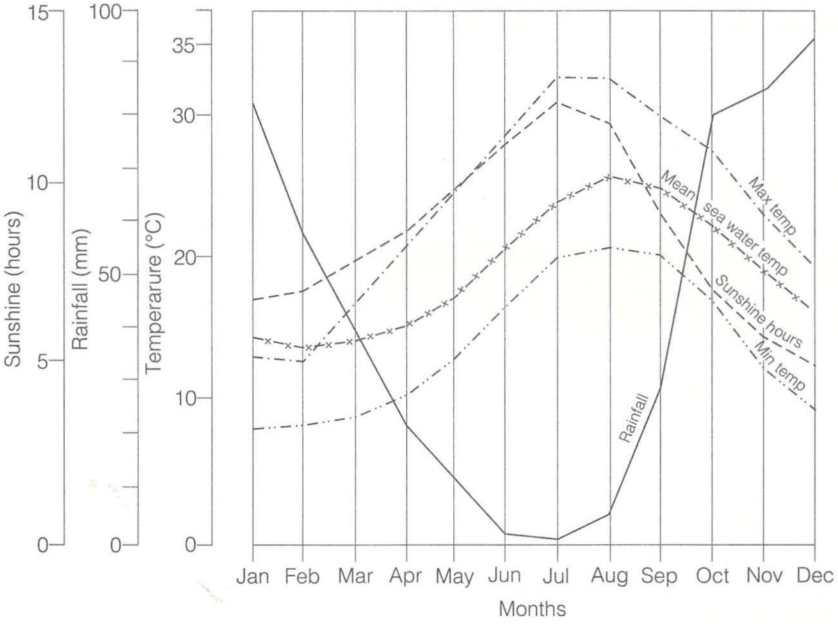

Fig. 6.27 Monthly variation in various meteorological parameters for Malta.

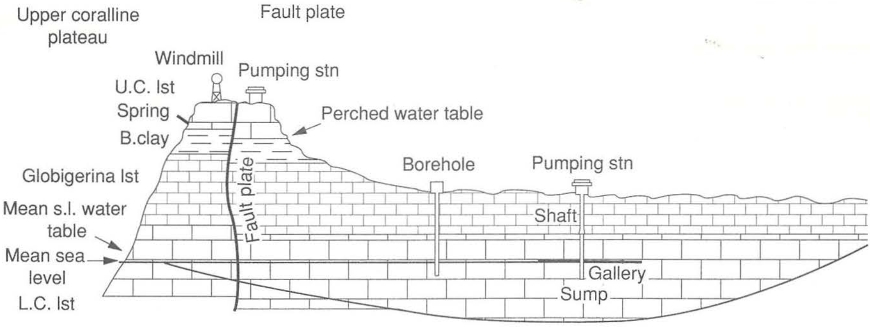

Fig. 6.28 Section across Malta showing the perched and the mean sea level aquifers.

sometimes found in the permeable Greensand, which is located in some areas at the base of the Upper Coralline Limestone.

The mean sea level aquifer is by far the most important aquifer and accounts for 98% of all groundwater used 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 about 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 (Fig. 6.29).

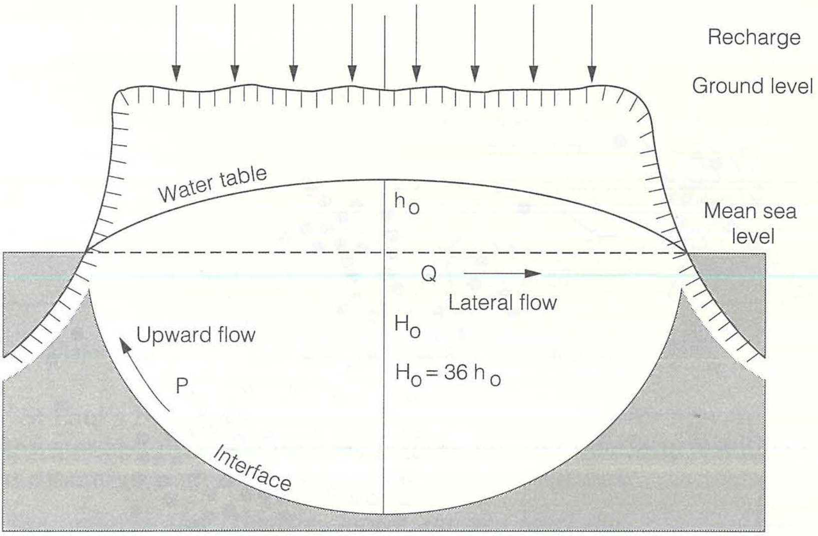

Fig. 6.29 Schematic cross-section of a mean sea level aquifer.

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 Lines Fault. 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.

2.3.3 *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 water 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). Extraction is achieved by means of a system of 36 km of underground galleries located at about sea level together with a complex network of around 100 boreholes spread across the island (Fig. 6.30). 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.

Fig. 6.30 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) for drinking water supply which is extracted from 4.2 km 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

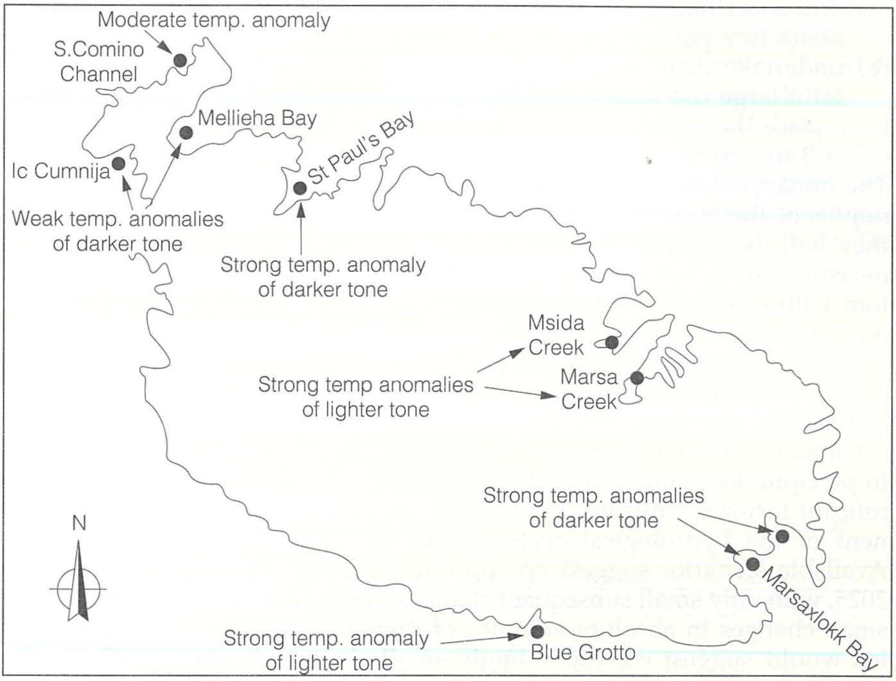

Fig. 6.31 Major subsurface discharge points around the coast of Malta.

ir-Rih, St Paul's Bay, Mistra and Mellieha Bay (Fig. 6.31). An upward flow of freshwater also occurs at the freshwater–saltwater interface, resulting in coastal discharge from the aquifer via submarine springs.

2.3.4 The impacts of a climatic change and sea level rise

Global warming will affect the hydrology of Malta in two ways, first 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 given the uncertainties inherent in the scenarios of future precipitation.

Sea level rise will have impacts on the main sea level aquifer in Malta and this is of major concern since it has considerable implications for the development of water resources on the island. The most important impact will result in the majority of the 40 km of galleries in Malta being at a level that is no longer optimal for the extraction of potable groundwater. Saline water intrusion will become more prevalent, and a rise of 1 m would reduce production by as much as 40%. The major economic benefit derived from extracting groundwater via galleries compared with other methods would therefore be lost. At present, 50% of all ground water extraction is from such galleries, hence the magnitude of this problem is large. To compensate for this loss three solutions could be applied:

(a) drill more boreholes at an estimated capital cost of about 0.6 million Malta Lira per hole at present prices;
(b) undertake structural alterations to the galleries; the cost is prohibitive for a large rise in sea level;
(c) replace the lost production by desalinated water at an estimated cost of 3 to 5 million Malta Lira per year.

The impact on groundwater boreholes will be less profound. The effective depths of the boreholes within the aquifer would be increased and hence they will extend into the lower, saline portion of the aquifer. Corrective measures are relatively simple and cheap, consisting of plugging the bottom with cement. Production rates could remain relatively unaffected by this correction.

The impact of a 1 m rise in sea level on the catchment area is negligible and this will not effect the volume of precipitation that is available for groundwater recharge.

Climate change impacts will influence the hydrological cycle via changes in precipitation, radiation, temperature, humidity and wind. The most significant factor is precipitation and the impacts of changes to this component of the hydrological cycle would have the greatest overall effect. Available scenarios suggest no appreciable change in precipitation before 2025, with only small subsequent changes in total annual precipitation. The small changes in absolute volumes of rainfall suggested by these scenarios would suggest correspondingly small changes in the runoff, evapotranspiration and recharge components of the cycle.

2.4 Atmosphere

2.4.1 Analysis of past trends in atmospheric conditions

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. 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 clouds and rainwater, altering their chemical composition and 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.

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. Although measurements of the proportion of atmospheric constituents around Malta are not available because continuous atmospheric monitoring has not been undertaken, 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 analysed and compared over the length of existing records in an attempt to elucidate what changes, if any, are occurring in the atmosphere around Malta.

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 were used to derive the 10 year running means for different times of day and seasons of the year, which are plotted in Figs. 6.32 – 6.39. The annual total of bright sunshine hours shown in Fig. 6.39 demonstrates a

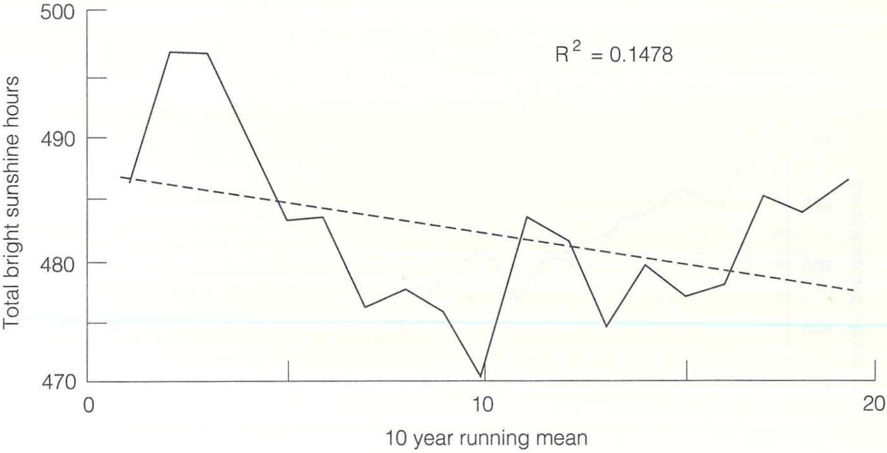

Fig. 6.32 Ten-year running mean total of bright sunshine hours experienced during winter over the period 1964 to 1991 at Luqa.

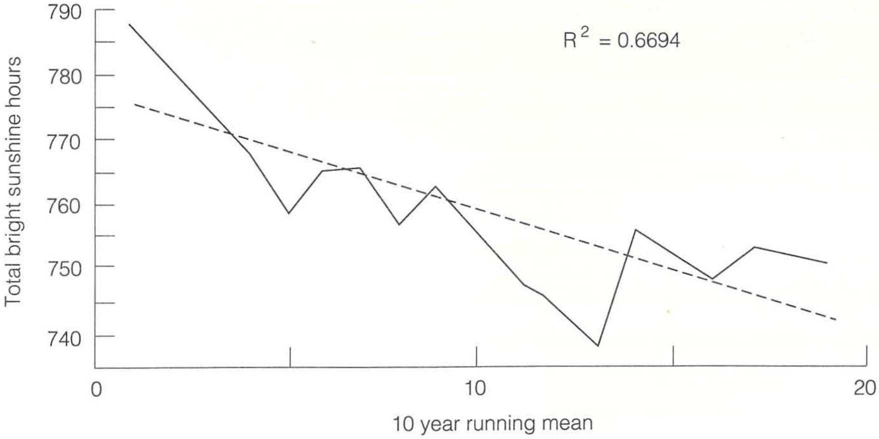

Fig. 6.33 Ten-year running mean total of bright sunshine hours experienced during spring over the period 1964 to 1991 at Luqa.

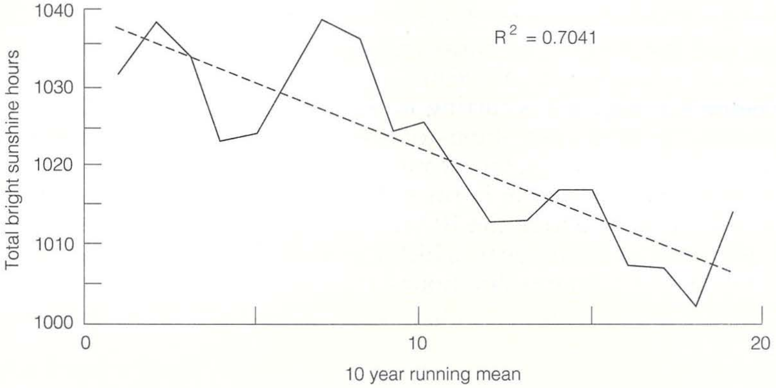

Fig. 6.34 Ten-year running mean total of bright sunshine hours experienced during summer, over the period 1964 to 1991 at Luqa.

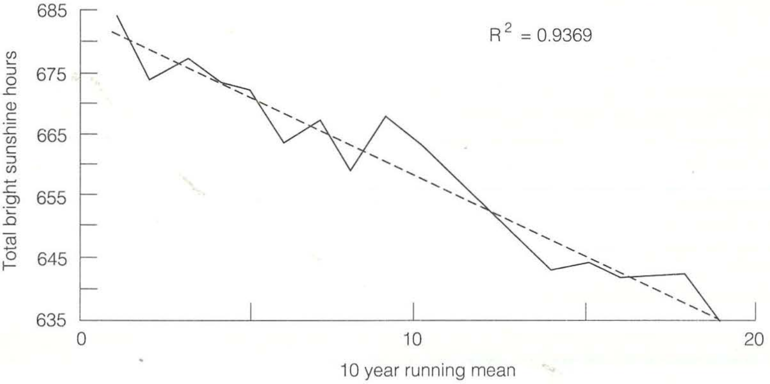

Fig. 6.35 Ten-year running mean total of bright sunshine hours experienced during autumn over the period 1964 to 1991 at Luqa.

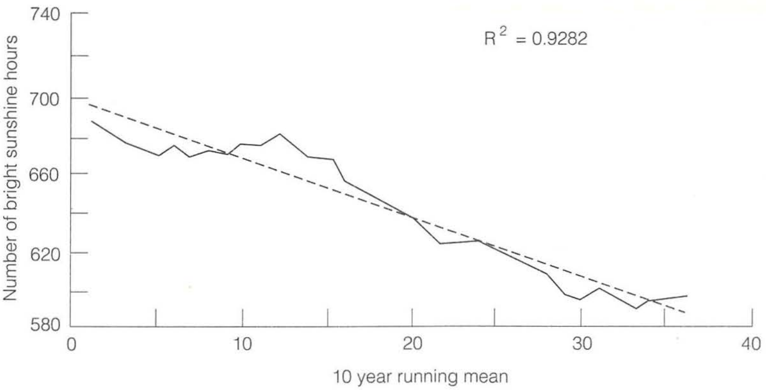

Fig 6.36 Ten-year running mean total of bright sunshine hours experienced between dawn and 0900 hours local time over the period 1947 to 1991 at Luqa.

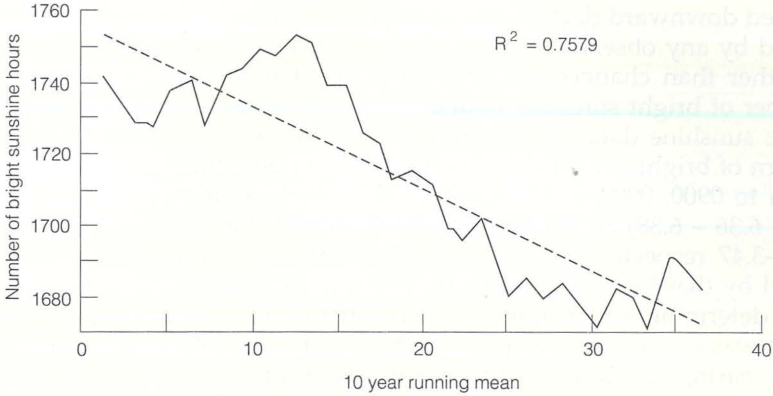

Fig. 6.37 Ten-year running mean total of bright sunshine hours experienced between 0900 and 1500 hours local time over the period 1947 to 1991 at Luqa.

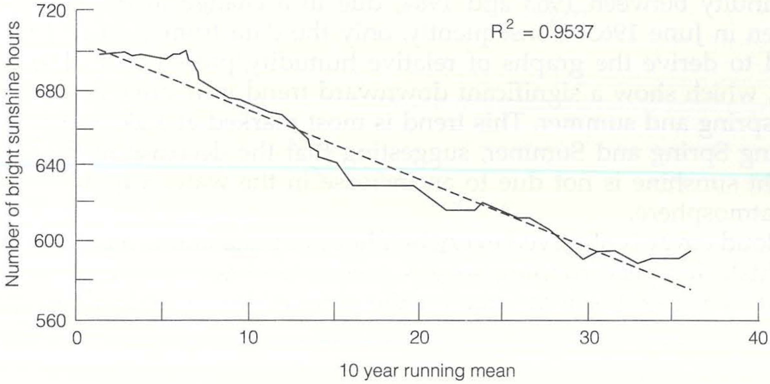

Fig. 6.38 Ten-year running mean total of bright sunshine hours experienced between 1500 hours and dusk local time over the period 1947 to 1991 at Luqa.

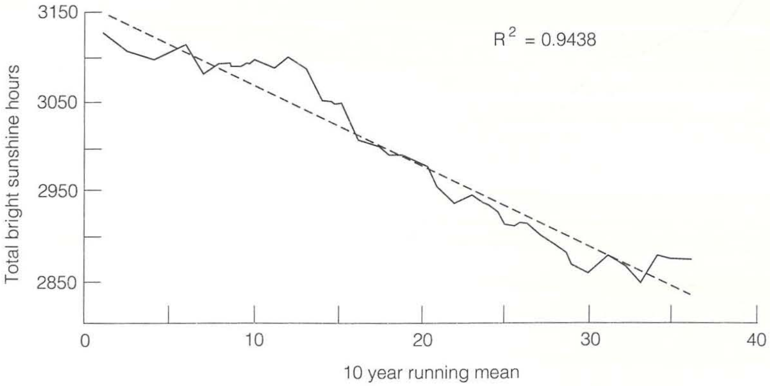

Fig. 6.39 Ten-year running mean annual total hours of bright sunshine hours experienced at Luqa over the period 1964 to 1991.

marked downward decline over the period of record. This trend is not paralleled by any observable trend in cloud cover, suggesting that some factor other than changes in cloud cover must 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 for three periods during the day namely: dawn to 0900; 0900 to 1500; and 1500 to dusk. While the three data sets (Figs. 6.36 – 6.38) all display significant negative gradients of –2.98, –2.19 and –3.47 respectively, that for the period 1500 onwards is greatest followed by that for the period from dawn to 0900.

To determine 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 were analysed 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, due to a change in the siting of the screen in June 1963. Consequently, only the data from 1964 to 1991 were used to derive the graphs of relative humidity presented in Figs. 6.40 – 6.44, which show a significant downward trend in relative humidity during spring and summer. This trend is most marked at 1200 and 1800 UTC during Spring and Summer, suggesting that the decrease in the hours of bright sunshine is not due to an increase in the water vapour content of the atmosphere.

Cloud cover is observed every half hour at Luqa and is recorded in octas (eights). Ten-year running means were calculated based on the mean monthly values taken at Luqa for the period 1951 to 1991. Monthly mean

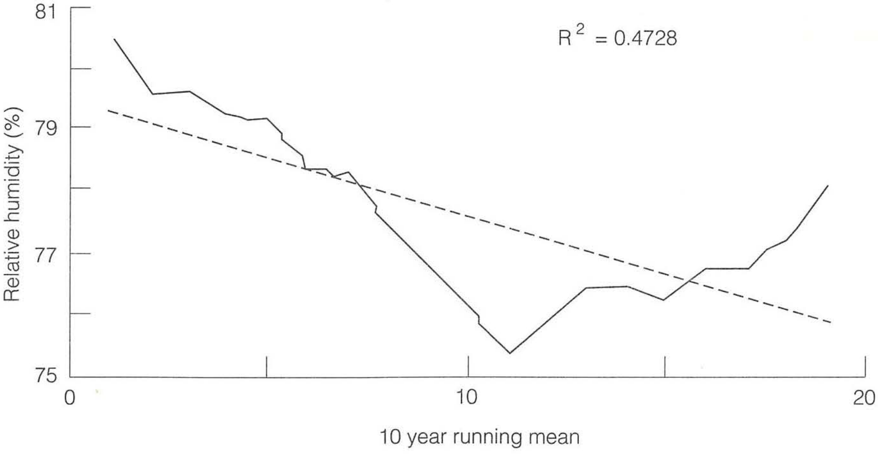

Fig. 6.40 Ten-year running mean winter relative humidity (%) experienced at Luqa over the period 1964 to 1991.

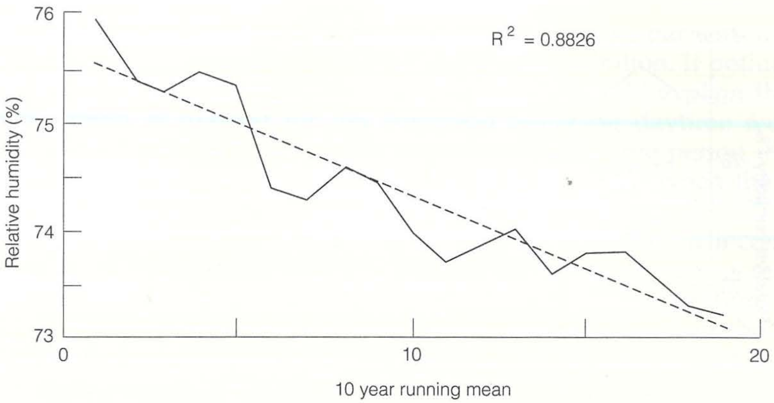

Fig. 6.41 Ten-year running mean spring relative humidity (%) experienced at Luqa over the period 1964 to 1991.

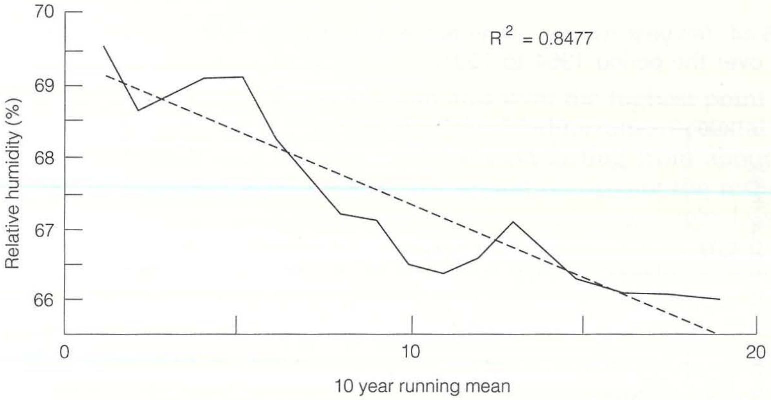

Fig. 6.42 Ten-year running mean summer relative humidity (%) experienced at Luqa over the period 1964 to 1991.

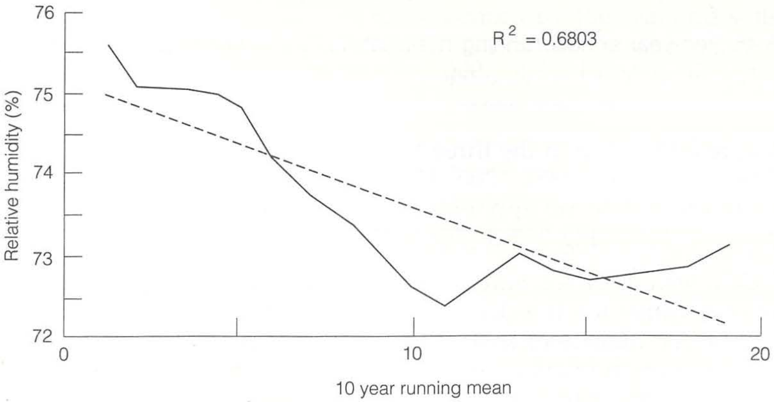

Fig. 6.43 Ten-year annual running-mean relative humidity (%) experienced at Luqa over the period 1964 to 1991.

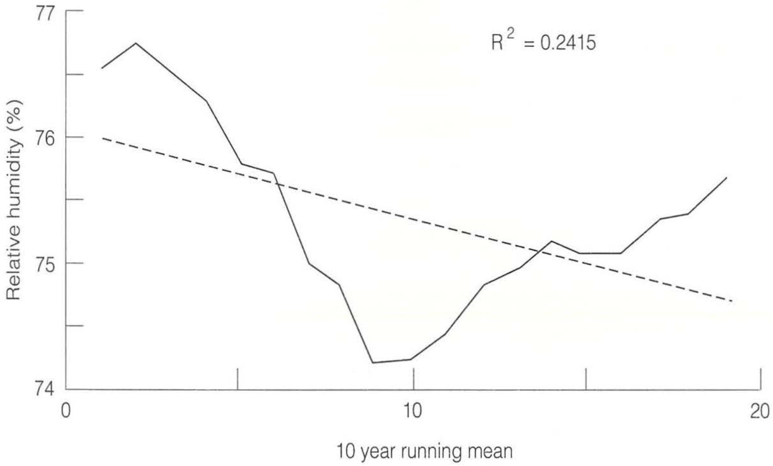

Fig. 6.44 Ten-year running mean autumn relative humidity (%) experienced at Luqa over the period 1964 to 1991.

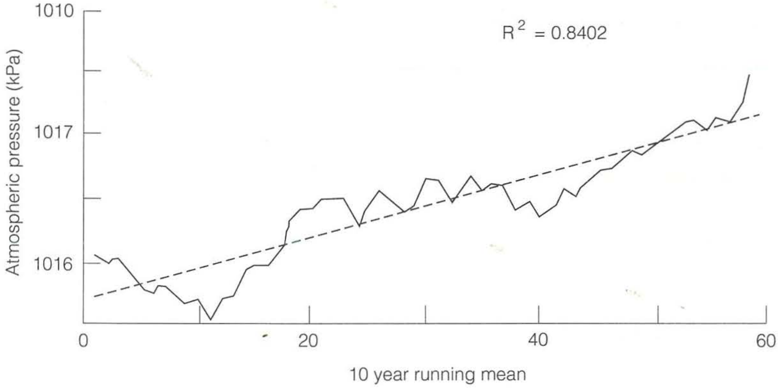

Fig. 6.45 Ten-year annual running mean atmosphere pressure (hPa) measured at Luqa over the period 1923 to 1990.

values are derived from the three-hourly synoptic observations carried out at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 UTC. No significant trends in these data are apparent. In contrast, mean atmospheric pressure displays an increasing trend (Fig. 6.45).

2.4.2 Conclusions concerning future atmospheric conditions

A possible cause for the decrease in bright sunshine hours 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 infrared 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 (Figs. 6.26, 6.27, and 6.45) reflecting an increase in anticyclonic conditions, is leading to more low-level temperature inversions, which 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. A further increase in the turbidity of the atmosphere could therefore be one consequence of climatic change in Malta.

2.5 Natural Ecosystems

2.5.1 Terrestrial ecosystems

Lying in the centre of the Mediterranean and with the highest point being only 253 m, Malta's climate is typical of the Mediterranean coastal zone. The year can be divided into a cool wet season lasting from about mid-September to mid-May with 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).

The Maltese Islands are composed entirely of Oligo-Miocene sedimentary rocks that 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, high calcium carbonate content of the soils, 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 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. The maquis, with a profusion of small trees, large shrubs, lianes and large herbs represents an earlier stage of succession. 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 a few other species are probably not native but were introduced in antiquity. Exposed rocky sites are often characterized by a garigue 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 that are subject to heavy grazing and fires support steppe 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 most common 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 20 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 chameleon, *Chamaeleo chamaeleon,* among the reptiles. There are 21 species of mammals, of which, 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).

2.5.2 *Freshwater and marine ecosystems*

The Maltese Islands have a collective shoreline of about 190 km and a surface area of 316 km^2, of which 5.2% is at 7.6 m or less, above the mean sea level. Rough estimates indicate that approximately 1.2% of the total land surface is 1 m or less above sea level. In fact, the islands' coastline is characterized by cliffs, clay slopes and boulder rocks (Fig. 6.46). 50% of Malta's coasts and 74% of Gozo's coastline has been defined as inaccessible mainly due to physical features (Structure Plan for the Maltese Islands, 1990). This results in heavy pressures being exerted on the lower lying shores for tourist, industrial and urban use.

Sandy beaches are few and constitute only 2% of the coastline. Nevertheless, these very restricted localities and the rest of the coastal lowlands support a number of habitats that are of unique ecological and scientific importance. These include: saline marsh lands, sand dunes and

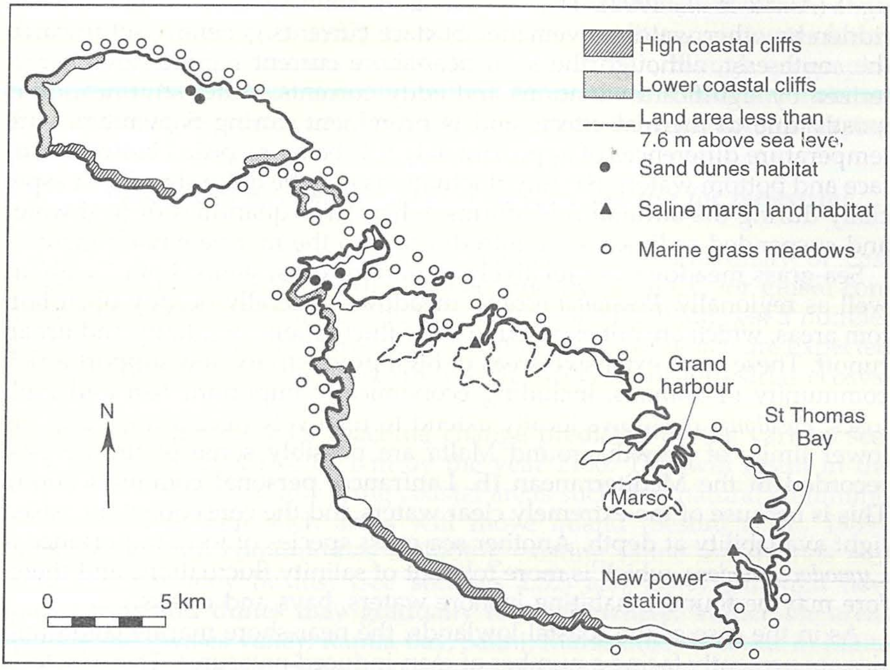

Fig. 6.46 Coastal habitats of the Maltese islands (adapted from the Structure Plan for the Maltese Islands, 1990).

rocky gentle slopes. Our knowledge of such habitats is still limited, although 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 and quarrying activities. Other pressures, which are 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 to the coastline during the development of the Malta Freeport.

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 (Structure Plan for the Maltese Islands, 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 μg/l, while phosphate levels are less than 0.2 μg/l. Near-shore waters including harbours such as Marsamxett 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 μg/l and phosphate 1.5

µg/l (Axiak *et al.*, 1992). The 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 characterized 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 freshwater and 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 runoff. 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 some of the deepest recorded in the Mediterranean (E. Lanfranco, personal communication). 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 that have established themselves in the Mediterranean, and 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, although a number of species (including molluscs) have also reached the western basin. A number of such migrants has been observed in Malta including the sea-grass *Halophila stipulacea* and a number of fish (E. Lanfranco, personal communication.). *H. stipulacea* inserts itself in meadows of *Cymodocea* and it is possible that this will bring about changes in the associated fauna.

There are no rivers on the 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. Nevertheless, there are some freshwater habitats which, though greatly restricted in geographic extent, 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: urbanization, quarrying or refuse dumping.

2.5.3 Consequences of climate change 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 the IPCC for global conditions, as well as the conclusions of Sestini *et al.* (1989) suggest a number of changes in various meteorological parameters, all of which 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 m by the year 2100. This will result in the gradual inundation of low lying coastal areas such that natural communities associated with such 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) 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 in Malta.

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 that 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 that 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 are 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-à-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 decline, one may predict a shift in the pollination patterns of the plant populations. Thus, a change in temperature will have direct and indirect affects on the floral and faunal composition of natural ecosystems, although the impacts on humans of these changes is difficult to assess.

All projections point to a reduction in future water availability. 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 poor agricultural practices; combined with an increase in population size, industrialization, and construction of asphalted roads. These changes reduce aquifer recharge rates and enhance runoff.

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-1970s 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. 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 50 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 climatic 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. Such concentration means that a higher proportion of the rain will be lost due to runoff, quite apart from the damage that 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, and the physical damage that such heavy rains will cause. An increase in soil erosion with the consequent loss of plant and associated animal life may be expected. The sharper seasonal and diurnal changes in rainfall and temperature will also be accompanied by stronger winds and possibly a greater frequency of storms, affecting tree and shrub cover.

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 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 adverse effects noted above, which will change the composition 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.

2.5.4 Consequences of climatic change and sea level rise for 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.

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 occurring 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 and hence runoff patterns.

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 (Fig. 6.46). The extent of inundation in each case will be determined by the presence of coastal roads and other man-made constructions, although 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 processes (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 anthropogenic factors, and are likely to be negatively affected by the year 2050, even under the scenarios of lowest climatic change.

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 (Structure Plan for the Maltese Islands, 1990). These are at 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 habitat for 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 that 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 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 the extreme climatic changes suggested by the scenarios for 2050 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 sites are 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.

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, personal communication). 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, and the extreme changes suggested under the 2050 scenario coupled with increased human interference could lead to the complete loss of such habitats by 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 the disturbance that occurred during a particularly heavy winter storm in 1979, and is still dominated by weed species that are indicative of disturbed habitats (E. Lanfranco, personal communication). These considerations indicate that the local freshwater habitats and ecosystems are more sensitive to predicted climatic changes than are the marine ecosystems.

2.5.5 *Impacts on the Ghadira Nature Reserve*

The Ghadira Nature Reserve is located on the north-eastern coast of Malta (Mellieha Bay) and encompasses the largest saline marshland on these islands. It occupies approximately 6 ha 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 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 recently been 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‰ , with one particular station reaching a salinity of 70 ‰ 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 although 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 runoff 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 resulting 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 that 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 that 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.

2.5.6 *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 the impact of climatic changes on processes such as freshwater runoff, sediment and nutrient inputs into coastal waters, quite difficult. The limited baseline information available on near-shore marine life and on its responses to environmental fluctuations, further compounds the problems of impact assessment and 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. Under the extremes suggested for the 2050 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 that may be affected, include most of the northern and north-eastern coastal waters of the Malta mainland.

2.5.7 *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 offshore 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 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 will enhance 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.

The results of this study show 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 the 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 nearshore semi-enclosed localities such as Marsaxlokk Bay, under changed climatic conditions.

Levels of chlorophyll A (as an index of primary productivity) were found to be mostly determined by phosphate levels and less so by temperature. 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 tentatively concluded, however that any increase in phosphate levels due to increased freshwater runoff during the autumn months may lead to enhanced productivity as well as promoting algal blooms in this area. The present study has also demonstrated that dredging in these ports leads 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, thus 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.

2.5.8 Impacts on land–sea fluxes

During the autumn and winter rain storms, significant turbidity plumes may be observed at some coastal localities extending up to 1 to 2 km offshore, and resulting from increased sediment inputs. Such 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 offshore 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 presently extensive meadows at these localities may be expected to retreat offshore due to significantly increased sediment loads in these waters. In contrast, 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, given their high sensistivity to non-climatic anthropogenic activities such as coastal construction and land-based pollution.

Climatic changes may also produce alterations in coastal currents, thereby affecting sediment transport along the shoreline. Little information is as yet available as to how climatic changes in the Mediterranean may affect 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. 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 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.

2.5.9 *Impacts on animal and plant distributions*

Temperature is known to be an important factor that determines the zonation and distribution of animals and plants both at the local level, as for example on a shoreline, and at the global level as in the latitudinal distribution of biomes. It may be expected that any increase in ambient temperatures, coupled with wider salinity fluctuations, will affect shoreline zonation, although 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 that has been 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 offshore 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.

2.6 Managed ecosystems

2.6.1 Agriculture and sylviculture

As noted earlier (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 and, where water is available, fruit trees and vines are cultivated, together with major crops of potatoes, broad beans, and various cucurbits as well as wheat, barley and sulla (*Hedysarum coronarium*), the latter being grown mainly as fodder on drier soils.

There is very little sylviculture 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 that 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 1960s and 1970s 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 sylviculture into more environmentally acceptable forms. Less than 1% of the Maltese Islands are wooded and the woodland areas of Buskett, Mizieb and Marfa Ridge encompass 60% of the total (Boffa *et al.*, in preparation).

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 that are not inundated will require different management practices if they are to remain productive. The effect on current sylviculture 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 that 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 that require a cool winter for dormancy will suffer leading to a consequent reduction in deciduous tree crops such as stone fruits. 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 that 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 out 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

Fisheries constitute one of Malta's more important industries, and capture fisheries based on several methods of fishing are widespread (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.

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) stated 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 that 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 use and generation

2.7.1 Introduction

The energy supply and consumption patterns and the associated carbon dioxide emissions for Malta are reviewed on the basis of data covering the period 1 October 1987 to 30 September 1988. The energy consumption on the island of Gozo is included in the figures for Malta. 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; that CO_2 alone is the single largest determinant of the climate change problem; and that anthropogenic CO_2 emissions released into the atmosphere during energy conversion are a major cause of the enhanced levels of atmospheric CO_2. Between 1958 and 1984, CO_2 concentrations in the atmosphere reached concentrations 20–25% above the level of pre-industrial times.

Reducing CO_2 emissions associated 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 that 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 cooling.

2.7.2 Primary energy use in Malta

During the year 1987–1988, 841,793 tonnes of coal equivalent (Tce) of primary fuels were used in Malta (Tables 6.6 and 6.7). 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 A1 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 6.6 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 (LPG) mainly by the domestic market, which

Table 6.6 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 6.7 Fuel consumption and greenhouse gas emissions for Malta during the year 1 October 1987 to 31 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	%	Total	%
Fuel oil	211,936	307,307	37	663,360	36.0	12,716	73.0
Coal	216,411	216,411	25	497,745	27.0	3,030	17.4
Jet A1	59,609	87,625	11	190,748	10.3	179	1.0
Diesel	60,087	86,525	10	189,274	10.0	240	1.4
Petrol	53,819	77,499	9	169,530	9.0	108	0.6
Thin fuel oil	17,032	25,037	3	54,502	3.0	1,021	6.0
Gas	14,507	22,340	3	46,422	2.5	43	0.3
Kerosene	12,959	19,049	2	41,469	2.2	52	0.3

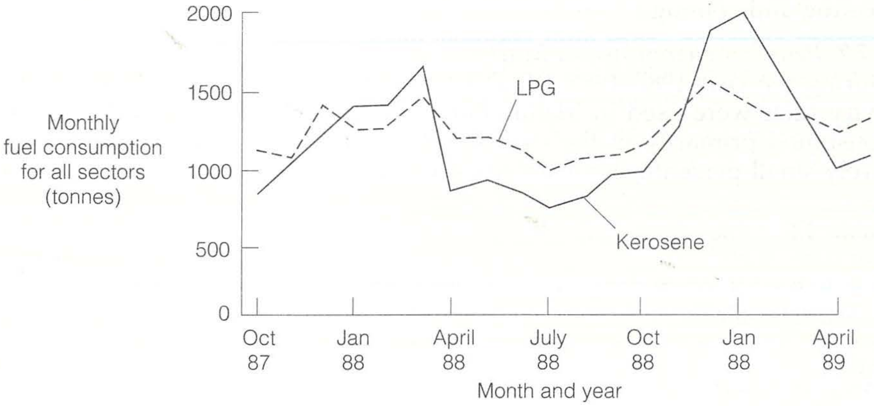

Fig. 6.47 Seasonal trends in liquid petroleum gas and kerosene consumption in all sectors.

demonstrates a seasonal demand (Fig. 6.47). Kerosene is used in the domestic sector and as a diesel fuel supplement by omnibus owners.

2.7.3 *Electricity generation*

Electricity is the most convenient available form of delivered energy and 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 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

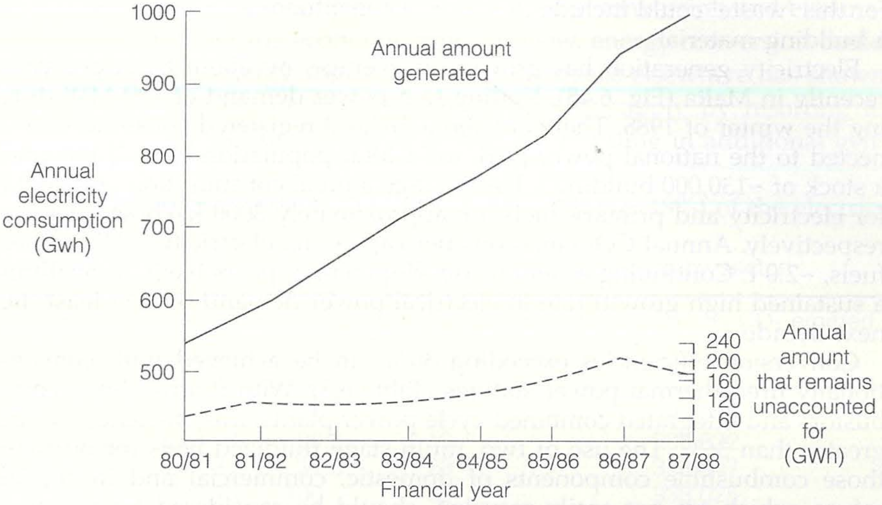

Fig. 6.48 Annual electricity generation in Malta, 1980–1988.

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, 50 Hz three-phase.

Even when there is adequate demand for electricity at the charged tariff, full output generation from thermal power plants is not realized anywhere in the world, and in Malta the average electricity plant load factor is 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

Table 6.8 Mean efficiencies of thermal power stations in 1980

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

for this 'waste' could include its use as a constituent in road repair and as a building material.

Electricity generation has grown, on average, by about 8.5% per year recently in Malta (Fig. 6.48), 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 are: electricity, ~3.5 t; other fuels, ~2.0 t. Continuing economic development appears likely to result in a sustained high growth rate in electrical power demand over at least the next decade.

Conversion efficiencies exceeding 30% can be achieved with conventionally fired thermal power stations (Table 6.8). With fluidized-bed combustors and integrated combined-cycle power plants, this efficiency can be greater than 36%. The use of two, multi-stage fluidized 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.

During the year from 1 October 1987 to 30 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, serves 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.

It is believed that 909.93 – 735.13 = 174.8 GWh (i.e. 19%) of the electric-

Table 6.9 Electricity purchases and equivalent CO_2 emissions by sector

Sector	Electricity purchased		Proportion of total	Tonnes CO_2 emitted
	GWh	%	fuel imports	
Domestic	233.03	31.7	20	297,346
Commercial	224.79	30.5	19	286,832
Industrial	277.31	37.8	23	353,847
Total	735.13	100	62	938,025

Table 6.10 Power generation and consumption by sector in Malta for the period 1980 to 1989

Year	GWh Generated	Consumption as a % of power generated						
		Power station	Industrial	Commercial	Domestic	Public	Sundries	Lost unaccounted
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

Table 6.11 End user costs in Maltese Liras (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	10^6 LM	% of total
Domestic	272.15	36	6.66	30
Commercial	194.84	27	7.34	33
Industrial	279.50	37	8.13	37
Total	746.49	100	22.13	100

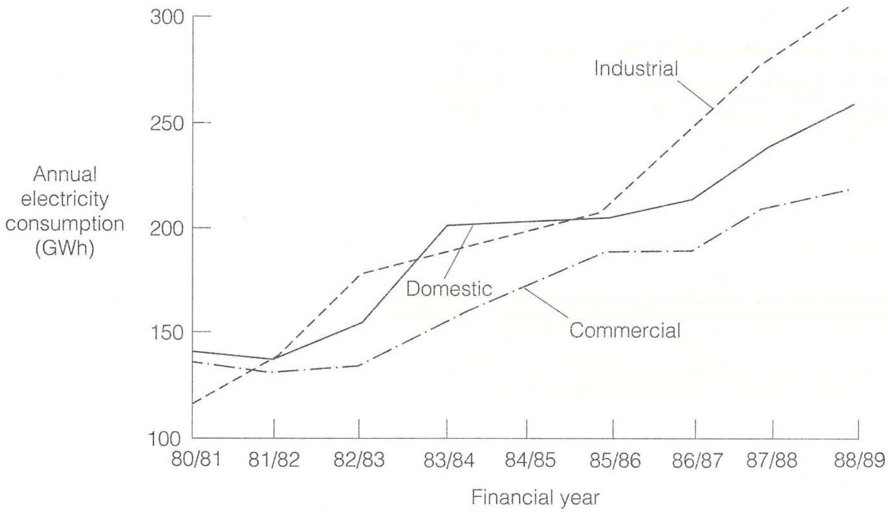

Fig. 6.49 Growth in annual electricity consumption by sector from 1980 to 1989.

ity 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 6.9). During the previous year, the corresponding figure was 23% (Table 6.10). 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.

2.7.4 Electricity consumption

A breakdown of electricity consumption by sector is presented in Table 6.10 while end user costs are given in Table 6.11 and Fig. 6.49 indicates the trends in annual growth in electricity consumption. Details of energy consumption by sector for the year 1 October, 1987 to 30 September, 1988 are also provided in Table 6.10. It should be noted that transportation accounts

Table 6.12 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 (=205,400 Tce)

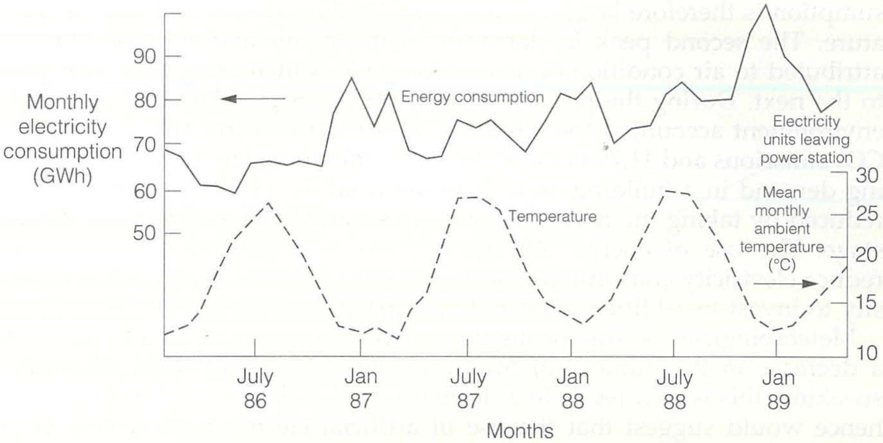

Fig. 6.50 Relationship between monthly trends in total electricity consumption and mean monthly air temperature over the period 1986 to 1989.

for 29% of all primary fuel consumption in Malta.

Electricity consumption in domestic buildings accounts for 24.4% of the total fuel imports to Malta (Tables 6.10 and 6.12). 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 (Fig. 6.50). The pattern of electricity con-

Table 6.13 Electricity consumption (GWh), CO_2 emissions (tonnes) 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	81,800	103,800	126,200	145,300	175,700	632,700
Cost (10^6 US$)	5.76	7.32	8.91	10.26	12.39	44.64

sumption 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 t (67.8%) of SO_2 emissions. 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 70 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 6.13).

2.7.5 Energy intensity and renewable energy resources

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 liras) is presented in Fig. 6.51 and 6.52. In Fig. 6.51, total electricity consumption in all sectors is plotted while Fig. 6.52 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.

The necessity to incorporate more renewable energy sources into the world energy structure was recommended by the Brundtland Commission. 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 a 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

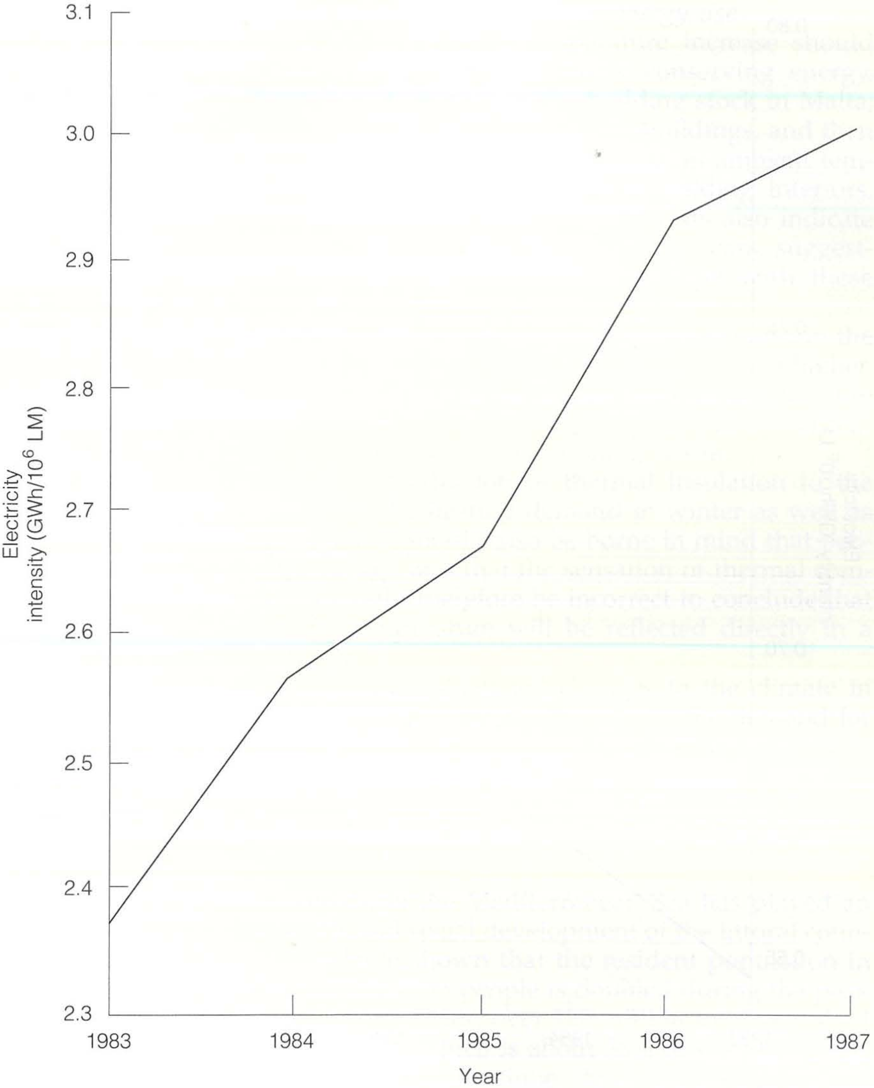

Fig. 6.51 Changes in energy intensity (GWh/10^6 LM) for all sectors over the period 1983 to 1987.

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 optimize 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.

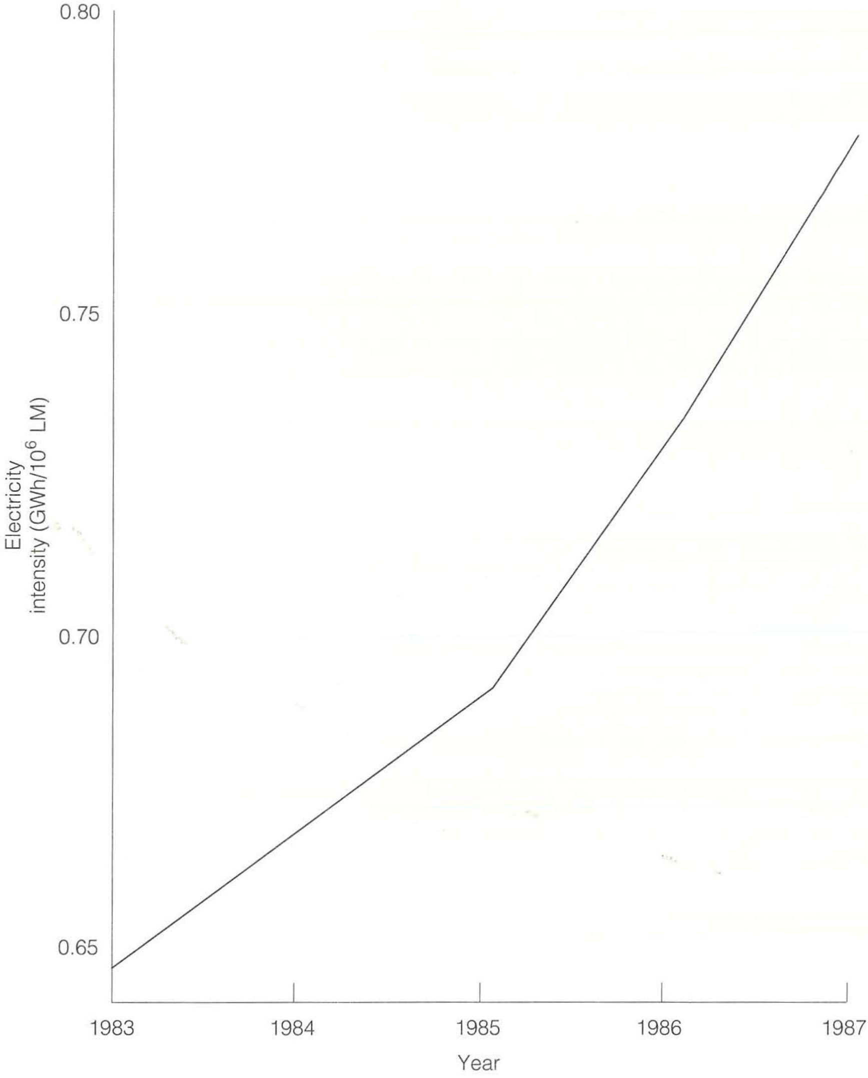

Fig. 6.52 Changes in energy intensity (GWh/10^6 LM) in the industrial sector over the period 1983 to 1987.

The decreasing trend in the number of bright sunshine hours in Malta, amounting to 3.1% over the past 70 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 demand by up to 3%. In the event that available solar radiation is reduced, the economic feasibility of this application is less attractive.

2.7.6 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. Maltese weather records also indicate a drop in the extreme low temperatures over the past 70 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 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.

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 that a change in the ambient air temperature will be reflected directly in a 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 utilized.

2.8 Tourism

2.8.1 Tourism in Malta

Since time immemorial, tourism in the Mediterranean Sea 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 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, 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 tourist destinations abroad.

Table 6.14 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

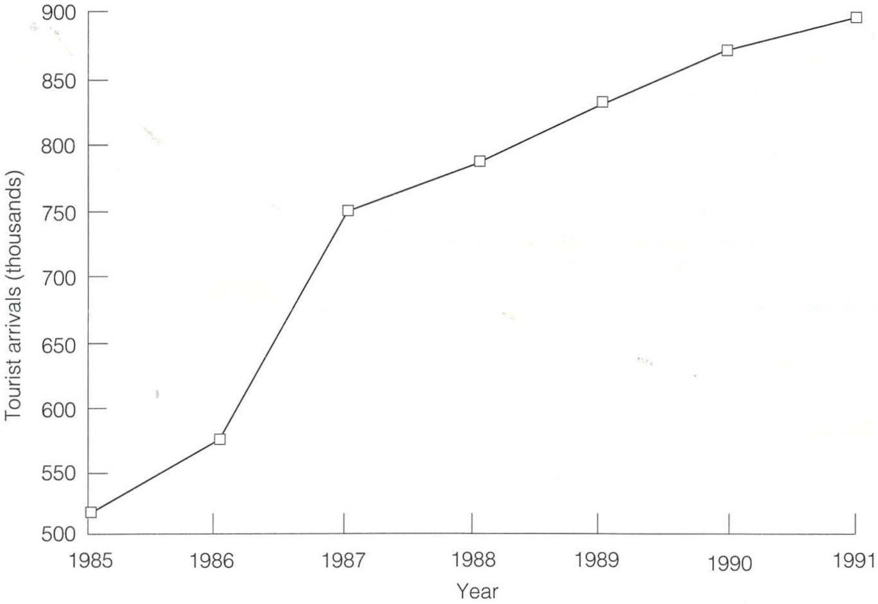

Fig. 6.53 Annual growth in tourist arrivals (thousands) in Malta, 1985 to 1991.

At the same time, an increase in the number of tourists is accompanied by a 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.

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 that 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.

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 6.14, Fig. 6.53). 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 Malta. The impacts of tourism on the Maltese economy are evident from the level of full-time direct employment in hotels,

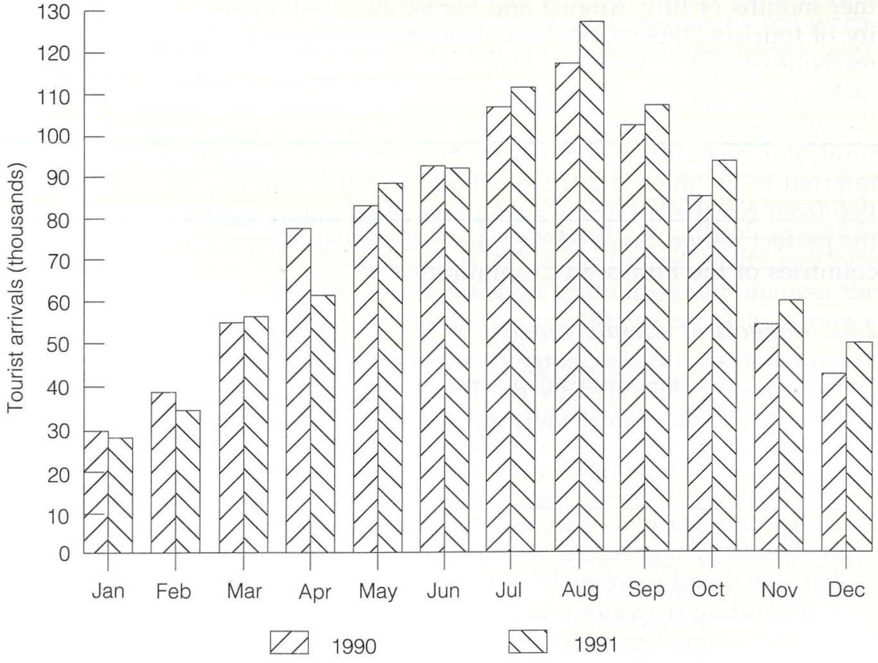

Fig. 6.54 Seasonal pattern of tourist arrivals in Malta during 1990 and 1991.

Table 6.15 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

complexes and catering establishments which, at the end of September 1991, stood around 7609 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 (Fig. 6.54) show that the peak summer months of July, August and September continue to attract the majority of tourists (Table 6.15). The proportion of arrivals during this quarter, totals nearly 50% of total annual arrivals. 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.

2.8.2 Impacts of climate change

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.

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 change such that the possibility of a change in climate adds another element of uncertainty to planning future developments. If the mild and warm climatic conditions in Malta are replaced by excessive heat or over-frequent storms, the tourist industry will suffer and with it a substantial part of the Maltese population.

A further important consideration mentioned by the Prime Minister 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 may have an adverse impact of the number of tourists visiting Malta, in that 'Northern' tourists may find the warm climates at home a disincentive to visit 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°), especially in the Northern hemisphere (Holdgate *et al.*, 1989). With an average 1° 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 the site-dependent infrastructure supporting coastal tourism and recreation. 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 that 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 that climate change could have on Malta's tourist coastal areas and hence on the economy of the country.

Residential buildings along the coast, which have increased in number over the last decade will also suffer if there is an increase of winds and storms. Sandy beaches that are thronged by tourists visiting Malta, could also be endangered by sea level rise. Spiteri (1990), stated that 'there are indications that a number of sandy beaches are presently affected by erosion process' and 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

The report 'Climate Change — Meeting the Challenge' prepared by a Commonwealth Group of Experts (Holdgate *et al.*, 1989), notes 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', a conclusion also reached by the Intergovernmental Panel on Climate Change (IPCC) Impact Assessment Report (Tegart *et al.*, 1990). The IPCC Report also 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'. As a consequence, the conclusions that can be deduced concerning the impacts of climate change on transport in the Maltese Islands are somewhat limited.

In Malta, because of its small land area, there is no railway and there are no inland waterways or rivers. As a result, transport on land depends entirely on roads, while a ferry service connects the two islands of Malta and Gozo. 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 that depend on maritime transport. Transport and communications-related activities account for about 6% of the Gross Domestic Product.

The European Community is the main trading partner of Malta, accounting for 78% 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

Table 6.1 Numbers of vehicles in Malta, 1981 to 1991

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Private cars	69,973	76,409	73,448	77,419	79,712	82,580	86,298	949,095	107,005	115,327	124,483
Hire cars	4,800	3,421	2,772	2,921	2,547	3,018	3,206	3,542	3,638	4,285	4,750
Buses	297	57	138	611	645	646	636	697	674	583	583
Commercial	17,288	17,665	16,037	16,757	17,524	17,178	16,579	18,597	18,889	21,521	24,170
Motorcycles	10,988	11,880	12,019	9,301	9,587	9,405	9,146	8,406	8,122	8,359	8,482
Other	1,184	1,070	838	1,089	1,195	1,370	1,285	1,491	1,784	1,914	2,142
Total	104,530	110,502	105,252	108,098	111,210	114,197	117,150	126,828	140,112	151,990	164,610

offer Maltese businessmen the opportunities of increased foreign trade. Another important sector that depends on maritime 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 *Road transport*

Road traffic is greatly on the increase as a result of a substantial increase in the number of cars (Table 6.16). 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. Owners of motor vehicles are 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 new 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 km of which 1433 km were paved or asphalted, since when a programme of road improvement has been undertaken, reflecting the importance of road communication. 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 *et al.*, 1992), there will be no appreciable change in total precipitation, 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 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 it will prove difficult to install air-conditioning systems, necessitating their replacement with new models that are energy efficient and less polluting.

2.9.3 *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, transshipment 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 the increased frequency of such events could result in increased maintenance costs. However, the data discussed above suggest that 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 coves that protect fishing and leisure boats. The building of breakwaters would therefore have to be continued.

2.9.4 *Air transport*

The situation in regard to air transport is similar to that for the maritime sector. Air Malta, the Maltese air carrier, is an important communication link with major capitals of Europe and has 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 service, introduced in 1990, is maintained between Malta and Gozo for six months every year.

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; and 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 in 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.

2.10 Health and sanitation

2.10.1 Effects of climatic change and sea level rise

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 12th 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 as 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 negatively affected his own health (Ellul-Micallef and Al Ali, 1984). 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) and 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 may also damage public sewage systems. New systems will have to be developed to protect public health against possible flooding of such drainage systems increasing the risk of epidemics of typhoid fever and other enteric disorders. There will also be increased intrusion of salt water into the sea level aquifer resulting in negative impacts on drinking water quality and quantity and hence potentially on human health.

The extreme conditions suggested by the 2050 scenario for Malta (Table 6.1) suggests a mean summer temperature rise of 3.5° C and an increased

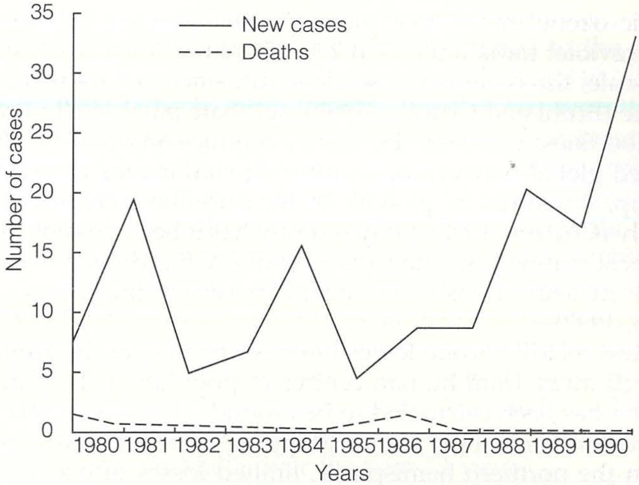

Fig. 6.55 Incidence of Leishmaniasis in Malta, 1980 to 1990. (*Source*: Demographic Review of the Maltese Islands 1980–1990.)

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 is especially high amongst the elderly, and infants below 1 year are also at risk since they are known to dehydrate very quickly.

Diseases that 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 vectors 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 (Fig. 6.55). An increase in temperature and humidity may well result in increased breeding rates of phlebotomines and an increased incidence of leishmaniasis.

2.10.2 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 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 nm) 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%, based on data derived from the satellite-borne Total Ozone Mapping System (TOMS) (Stolarski *et al.*, 1991). In the northern hemisphere, 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. The decreases in ozone mixing rates reported so far do not dramatically affect total ozone, but if an ozone hole does develop in the Arctic, it may affect densely populated areas of Europe including Malta (Kerr, 1992).

The potential impacts of increased UV B radiation appear to be all negative. Effects on terrestrial vegetation as well as on marine organisms are likely to result in reduced primary production, since UV B radiation reduces both terrestrial plant and phytoplankton productivity. Although much has been written about the potential direct impact upon human health, a lack of data on doses of UV B radiation received, not just in Malta, but worldwide, prevents a quantitative analysis along sound epidemiological lines, of the effects on human health of increased exposure to UV B. It is thought likely that a higher incidence of skin malignancies, of eye

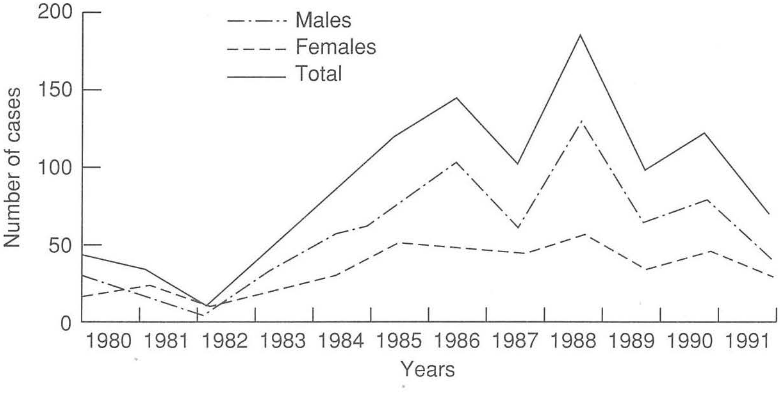

Fig. 6.56 Incidence of notified cases of skin cancer in Malta, 1980 to 1991. (*Source*: Cancer Register Health Information System.)

damage and immunological disturbances could occur.

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 world-wide. The serious public health implications of these malignancies, particularly in terms of morbidity and expense, are however now appreciated. Increased recreational sun exposure, when combined with possible ozone layer depletion, is a growing cause for concern. An increasing incidence of skin cancer 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). Fig. 6.56 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. 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 UV B exposure and the incidence of cutaneous melanoma predict that a 1% depletion of ozone will result in an increase of 1–2% 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 photoproducts 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 recently been 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 nonmelanoma skin cancer; may influence the development and course of infectious disease, and may possibly protect 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*.

2.11 Population and settlement pattern

2.11.1 Introduction

The Maltese Islands, consist of Malta itself, Gozo, Comino and the smaller islets like Comminetto and Filfla. The total area of the islands is 316 km^2 of which Malta itself occupies 245.728 km^2; Gozo 67.078 km^2 and Comino 2.784 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: 1301 per km^2 on the main island and 382 per km^2 on Gozo. On the main island about 30% of the population is classified as rural while in Gozo, the whole population is considered rural. Malta has very few natural resources. Tourism, small scale industries and dockyard facilities are new developments that have been undertaken to strengthen its 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 and animal food and, also increase exports such as strawberries, out-of-season vegetables, flowers, seed and cuttings.

Whereas the predictions of precipitation patterns remain as yet uncertain, the consequences of global warming for sea level rise are more predictable.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 the present settlement is adjusted to 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 sea water 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 (Fig. 6.57), 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 movements in terms of accentuating the global mean sea level rise can therefore be ignored.

2.11.2 Impacts 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

Table 6.17 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

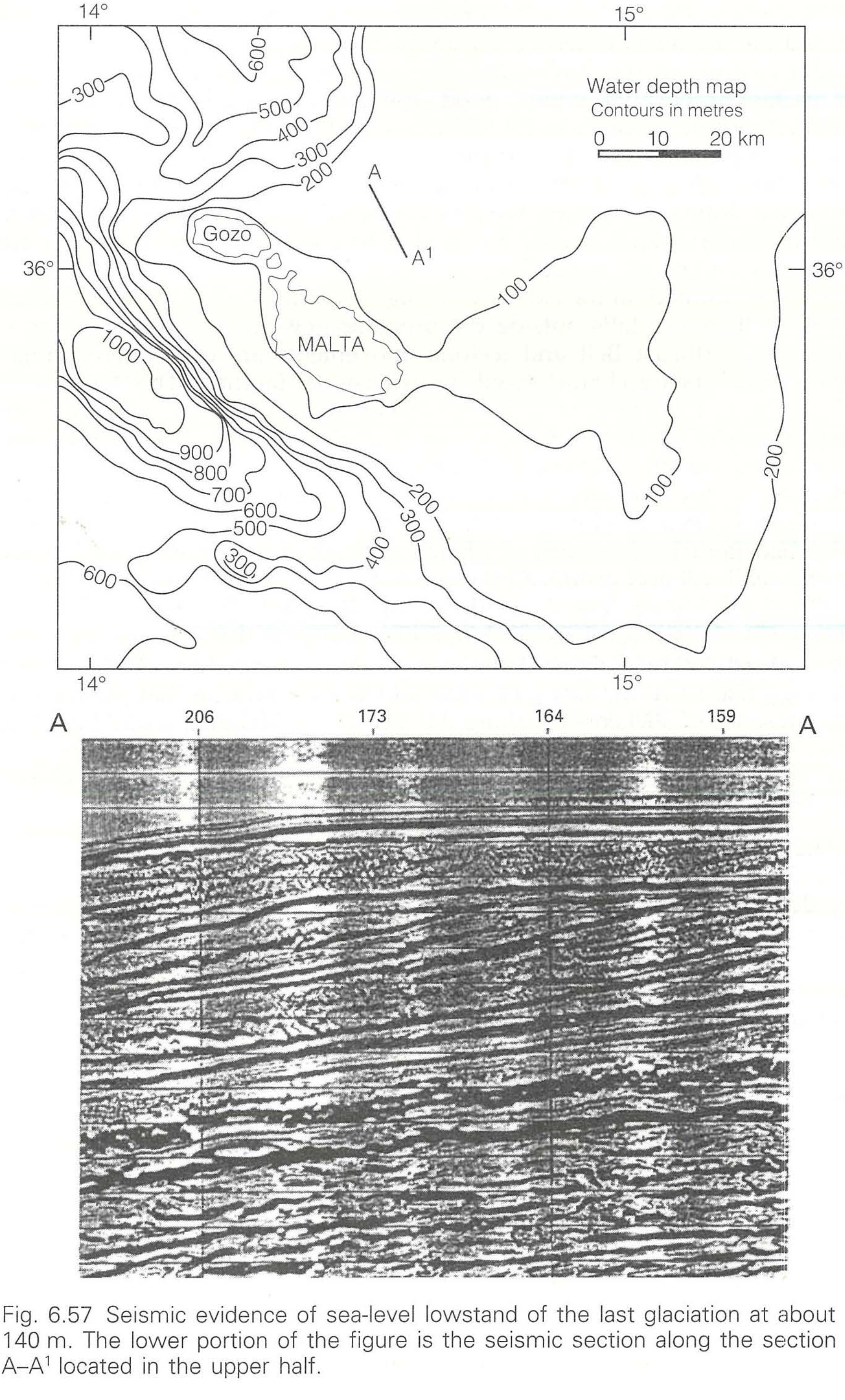

Fig. 6.57 Seismic evidence of sea-level lowstand of the last glaciation at about 140 m. The lower portion of the figure is the seismic section along the section A–A^1 located in the upper half.

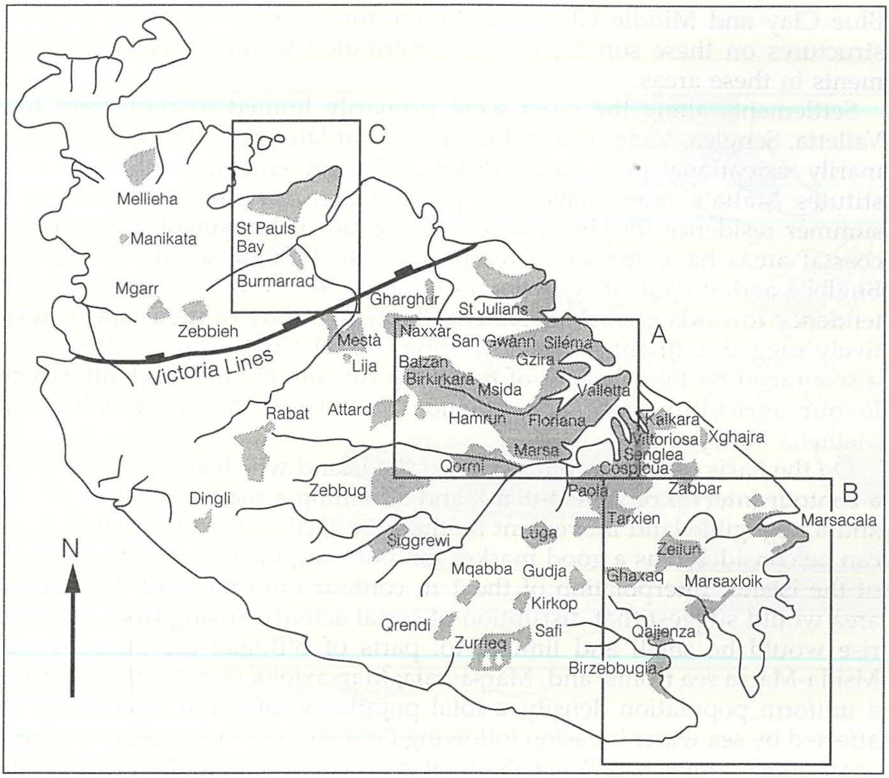

Fig. 6.58 Distribution of settlements and drainage systems.

strong, it is unlikely that any socio-economic change arising from climatic changes 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 acute as the population grows, it will not be affected in any practical terms by the loss of 1% of the total land area.

The age distribution of the population has changed between the two censuses as shown in Table 6.17. 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. These parameters are unlikely to be directly affected by climatic changes over the next century.

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

The land-use and demographic pattern in Malta shows that geology was a key factor in determining the spatial distribution of urban and rural settlements (Fig. 6.58). Most villages are congregated around outcrops of available building stone, the Lower Globigerina Limestone, whereas arable land is concentrated on rock formations that 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 in these areas.

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 have 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, where 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 builtup area would suggest that disruption of social activity arising from sea level rise would be small and limited to: parts of B'Bugia; the Strand-Pieta-Msida-Marsa sea fronts; and, Marsascala; Marsaxlokk (Fig. 6.59). 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, a proportion that is unlikely to increase due to the present high densities. Of the three remedial actions that may be employed to combat sea water inundation, elevating the coastal risk areas by means of backfilling would represent the easiest and most cost effective protective measure.

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 (Fig. 6.59c) where flooding, which is already a problem, will get worse as drainage gradients are reduced with a rise in sea level.

South of the Victoria Fault, the eastern half of the area 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. 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

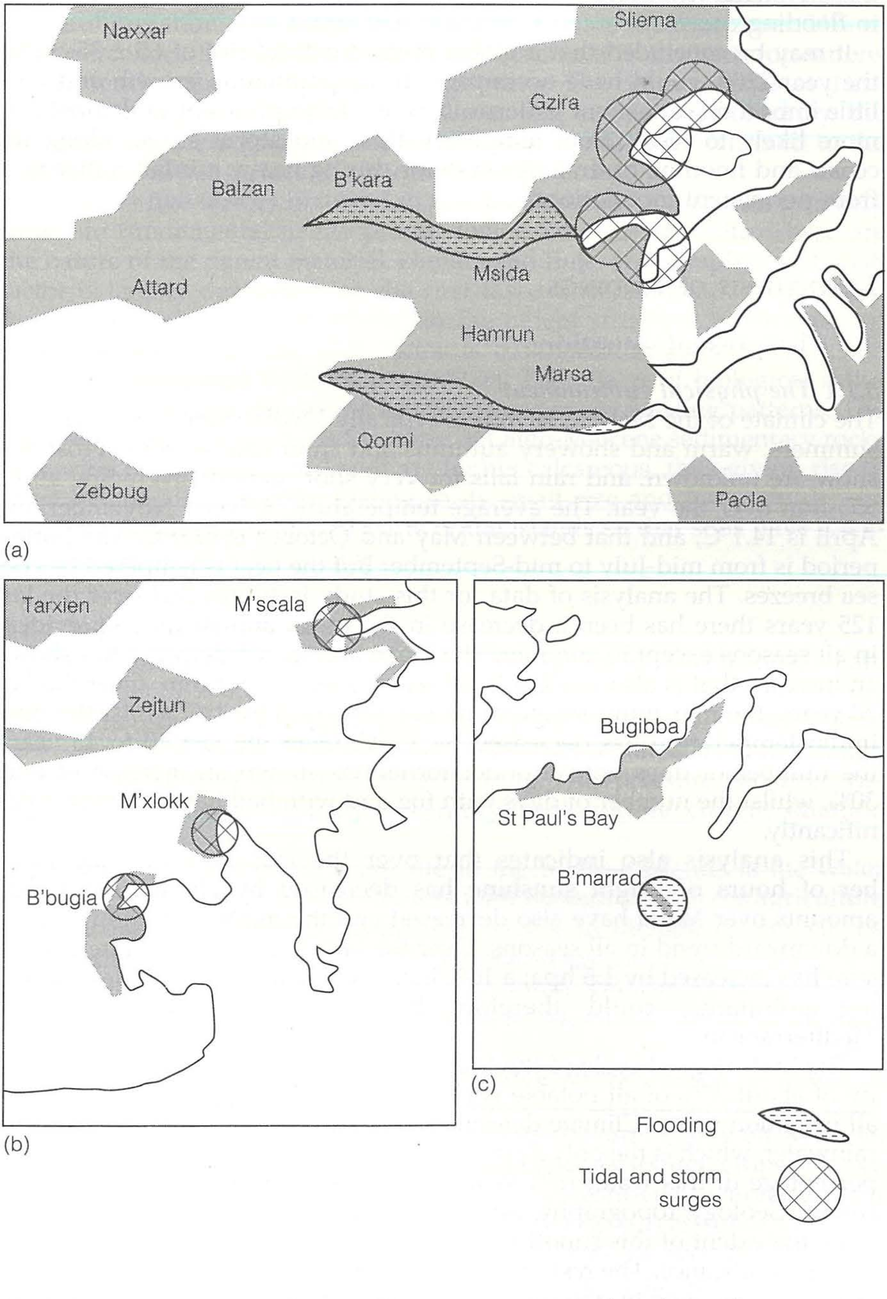

Fig. 6.59 Low lying coastal areas. The areas correspond to the outlined areas in Fig. 6.58.

B'Kara, Msida, Qormi and Marsa (Fig. 6.59a) 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.

It may be concluded that a global mean sea level 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 The 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, and 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 that is also evident in all seasons except autumn. Over the last 70 years, the maximum temperature has increased by 1°C whilst the minimum temperature has decreased by 1.5°C. Over the last 40 to 45 years, the number of days with thunderstorms has shown an increase of over 30%, whilst the number of days with fog and with hail have decreased significantly.

This analysis also indicates that over the last 44 years, the number of hours of bright sunshine has decreased by about 11%. Cloud amounts over Malta have 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. A small percentage of this water (6% to 10%) is lost directly to the sea as surface runoff. Geology, topography, urbanization and hydraulic structures determine the extent of this runoff which, contrary to public opinion, is only of minor significance. 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 about 60–70% 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% to 30%) 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.

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 is biological influences, which are presently dominated by human activities. The effects of biological influences are secondary, producing modifications to the existing patterns. 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. Owing to its small size and low altitude, sea spray can reach practically all parts of the islands so that soils have a tendency to be more or less saline.

3.1.2 The biological environment

Malta's vascular flora consists of some 1000 species, of which some 20 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 semiarid category.

Maltese agriculture is geared to cope with a 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 were 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 woodland is confined to the areas of Buskett, Mizieb and Marfa Ridge.

Although 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 nearshore 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. Nevertheless, such habitats support a significant number of rare, endemic and endangered animal and plant species. Freshwater communities are being degraded at a rapid rate, possibly due to reduced water replenishment of the aquifers resulting from rapid urbanization.

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 a 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 communities.

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: of sea bass, sea bream and tilapia.

3.1.3 The human environment

Population growth in Malta is heavily dependent on prevailing socioeconomic 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 landuse and the 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 that 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 lowlying 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, who visit the island all year round, and 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 Liras 175.3 million or about US$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, September, with nearly half 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, oils and gas. Nearly two thirds of all imported fuel 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 twofold reduction in carbon dioxide emissions due to energy conversion inefficiencies. Industry is predominantly of a light nature characterized by the manufacture of textiles and electronic components although there is a foundry and a ship repair yard.

Transport in the Maltese Islands depends on road communications although a ferry service connects the three islands of Malta, Gozo and Comino. Sea and air links 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 that 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, transshipment 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 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 with 45% from the commercial and industrial sectors. With a view to reducing the levels of potential greenhouse gases, new owners of motor vehicles are being encouraged to make sure that their cars are equipped with threeway catalytic converters.

The Maltese air carrier, Air Malta, is an important communication link with major capitals of Europe, with scheduled services to 22 major airports and regular charter flights. Air Malta's aircraft have one of the highest utilization rates in Europe. A helicopter airlink 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 assess quantitatively the potential impacts of such change. Nevertheless, it was possible to identify and estimate the nature of the impacts that predicted climatic changes are likely to have on the Maltese Islands.

3.2 Major expected changes and their impacts

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:

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 with present values;
- the mean spring (March, April, May) rainfall should decrease by 27 to 21.6% compared with present day values; and
- the mean autumn (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 with present day values;
- the mean spring rainfall should decrease by between 33.8 and 27% compared with present day values;
- the mean summer rainfall should remain unchanged; and
- the mean autumn rainfall should increase by 31% compared with 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 with present values;
- the mean winter rainfall should decrease by 31.5% compared with present day values;
- the mean spring rainfall should decrease by between 52.5 and 42% compared with present day values;
- the mean summer rainfall should remain unchanged; and
- the mean autumn rainfall should increase by 49% compared with present day values.

No major impacts due to climatic changes 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 inadequate coastal zone management.

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 naturalization 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 they may diversify catches. Immigrant seaweeds may actively compete with the valuable *Posidonia oceanica* meadows on which most of Malta's 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 in turn 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. It is difficult to quantify the likely changes in volumes of flow, transport and environmental fate of land-based pollutants in the near-shore marine environment.
- Increased sediment inputs during heavy rain storms may lead to changes in offshore bottom profiles and to altered substrate types and therefore to changes in the benthic communities, and may also increase the resultant disturbances and habitat alterations in valley-bottom communities.
- 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 climate conditions would also have a detrimental effect on beaches and tourist infrastructure.
- 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. The predicted changes in precipitation would worsen the problem of freshwater 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 of 65 ± 35 cm will take place by the year 2100 under a 'Business as usual' scenario of fossil fuel consumption. In addition to this rise in mean global sea level, local land subsidence can contribute to a further relative rise. This will not be significant in the case of 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. The main aquifer in Malta is so located and the majority of the 40 km of galleries in this aquifer will become situated at a level that is no longer operational for the safe extraction of groundwater. A rise of 1 m will reduce production by 40% in order to maintain a safe extraction ratio. At present 50% of all ground water is derived from such galleries. This would increase pressure on water resources and on the 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;
- 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 lowlying 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 that 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 UV 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 nonmelanotic skin cancer and cataracts.
(5) Formulate an Energy Plan that would:
    (a) ensure rational energy use and determine strategies for reducing harmful gas emissions;
    (b) analyse the sectoral demand and consumption trends with the aim of reducing present and future energy supplies by determining the right fuel mix;
    (c) introduce building energy regulations, whereby the building sector would eliminate energy waste and make new buildings more energy efficient. This would not only reduce greenhouse gas emissions but also favourably affect the country's economic affairs;
    (d) introduce incentives, through taxes and levies in relation to energy consumption in industry. A feasibility study should be undertaken to consider the subsidization offered by the electricity utility in favour of energy efficient light bulbs, which at present have a low market penetration because of their relative expense. Introduce energy labelling of household appliances to enable purchasers to base their choice on running cost as well as the capital outlay. The individual would benefit from lower electricity bills and, at the same time, emissions at the generating end are reduced;
    (e) carbon dioxide emissions can also be reduced by resorting to renew-

able energy appliances. The production of hot water by solar energy has been tried and tested in other countries with a similar climate to that of the Maltese Islands. The widespread use of domestic solar water heaters in Malta would reduce the country's energy bill by not less than 3%. Such systems make economic sense since their life expectancy is in the region of 20 years and the amortization period is normally less than three years;

(f) electricity generation accounts for almost two-thirds of Malta's energy bill. The existing tariff structure is not related to the time of use — consequently electricity demands peak during the day and drop during the night. Encouraging the use of electricity during low demand night periods leads to a more efficient use of the generating plant and hence savings of energy; and

(g) control emissions from motor vehicles. Encourage the consumption of lead-free petrol and the installation of three-way catalytic converters 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 (GEF) 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 comprehensive risk assessment at the local and regional levels. This will enable a periodic reassessment, e.g. every one or two years, 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 that 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 an 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. Improve the existing water catchment areas and reservoirs and the provision for new ones to meet with the expected increase in rainfall intensity.
(3) Increase the use of sea water in industrial and domestic systems wherever freshwater is not essential. Maintain 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 that a predicted rise in sea level of 65 ± 35 cm would have on settlements along the coast and principal drainage lines, to cope with any disruption that 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 a 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 habitable, 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 would 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 that 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 cope adequately 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 nonclimatic effects on local ecosystems.

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