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IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON THE ISLAND OF MALTA

THE IMPACT OF CLIMATE CHANGE ON THE HYDROLOGY OF THE MALTESE ISLANDS

by

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1. BACKGROUND:

Many climatologists today support the idea that the increase of carbon dioxide concentration in the atmosphere due to the burning of fossil fuels will cause an increase in the mean surface air temperature of the earth in the coming decades. Concentration of COz in the atmosphere in fact rose by about 25% since 1850. Three other man-made gases whose concentration is also on the increase also contribute, though to a less extent, to this global warming; ozone in the lower atmosphere, nitrous oxide and methane. Prospects of holding back the increase in concentrations of these gases are unfortunately very dim.

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

The IPCC's Workgroup I described various general circulation models to reflect different scenarios of greenhouse effect. These models agree quite well in forecasting a modest increase in global temperature. Less consistent however are the expected geographical distribution of change in air temperature and especially the redistribution of precipitation patterns across the continents. These are very complicated processes and only general conclusions can be drawn from existing climate models.

The objective of this paper is twofold. (i) to introduce the hydrological cycle of the Maltese Islands and (ii) to assess the impact of a global climate change on this cycle.

2. HYDROLOGICAL CYCLE

The availability of natural water in a locality depends on the local hydrological cycle which determines the nature of the various processes by which the inflow and outflow of water in the locality occurs. This cycle is largely influenced by climate and the catchment characteristics of the locality.

Despite the arid superficial appearance of the Maltese Islands, the local catchment characteristics are very favourable for the storage of rainwater and the hydrological cycle provides a generous supply of freshwater which undoubtedly contributed to the early settlement of inhabitants. Presently, this cycle accounts for the availability of about 37% (45,500 cu.m./day) of all potable water in the public supply, the rest being derived from expensive desalination plants. It also accounts for about 84% (17,300 cu.m./day) of all irrigation water. The economic benefit of this cycle is therefore substantial and the identification of ways in which it could be more effectively managed and used to achieve improvements in the social welfare of the Island have always been a major undertaking of every governing body as early as the first settling of the Knights of St. John. Whenever possible, the catchment characteristics have been modified by the construction of hydraulic structures (dams) and water development managed so as to maximize the economic benefit.

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

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

(ii) A small percentage of this water (6%) is lost directly to the sea as surface run-off. Geology, topography, urbanization and hydraulic structures determine the extent of this run-off which contrary to public opinion is only of minor significance.

(iii) The rest of the rainfall infiltrates through the ground where it is partly retained by the soil. This 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 70% of the total precipitation, is largely determined by the nature of this soil, vegetation and climatic factors such as humidity, wind, temperature and radiation.

(iv) The water that manages to pass the root-zone (24%) percolates through the fissures and fractures in the rock formations until it reaches the aquifers as recharge water. The characteristics of these natural underground storages of water are largely controlled by the local geology.

(v) This recharge water is eventually extracted from the aquifers by the local water development practice and what is left is ultimately returned to the sea by natural subsurface discharge along the coast.

2.1 Rainfall

Climate determines the abundance and distribution of rainfall which is the primary source of natural water in the cycle. This factor is especially important in the Hydrological cycle of small Islands such as Malta where the possibility of deriving water from far away by means of rivers does not exist. Other minor sources of water are dew, leakages in the public supply and back-irrigation.

Malta enjoys a Mediterranean type of climate with a well defined seasonal rhythm made up of a mild, wet winter that is invariable followed by a long dry summer. The rain season proper starts in October when rainfall is prone to be 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 recent, the importance of this rainfall pattern is very significant and daily rainfall records have been kept systematically for nearly 150 years. Official rainfall records started in 1840 with one station at Valletta. Presently, there are 128 stations scattered across Malta and 7 stations in Gozo. The distribution of precipitation for the period 1950-1970 is shown in Fig.1. An average annual precipitation of 550 mm is recorded over this period.

2.2 Surface Run-Off

Surface run-off losses to the sea is comparatively small due to favourable topography, good water storage capacity of the soil and infiltration into the rocks, and run-off interception by numerous dams and cisterns.

Structurally, Malta tilts gently to the east giving rise to a topography that is high along the western shores and gently reaches down to sea-level along the eastern shores. This implies that the surface drainage lines cross the entire width of the Island from their source close to the western shore before entering the sea on the east. This gives the surface water maximum time to seep into the ground and thus minimizes run-off losses to the sea. In fact, only about 6% of the total precipitation, measures over many years by run-off recorder located at the exit points of major drainage area such as Burmarrad, Msida and Marsa, finds its way into the sea.

Most run-off occurs after heavy downpours when the only surface water in Malta flows along the beds of the 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.2). Open reservoirs have also been constructed along recently made road to minimize run-off.

A large number of private cisterns, used during the dry season for irrigation, also have a certain influence on the surface run-off. Furthermore, every house in Malta has, by law, its water cistern to collect water falling on the roof.

2.3 Evapotranspiration

Superficially, most of Malta is covered by a thin layer soil which has a relatively high water storage capacity. This soil is responsible for the major loss of water in the hydrological cycle since all the water that is retained in it is lost to the atmosphere by evapotranspiration. In fact, infiltration of rainwater into the rocks underneath takes place only when the entire storage capacity of the soil is saturated. This evapotranspiration loss is not constant across the Islands but varies with topography, soil characteristics, exposure and land use.

Shallow water-table zones, such as the ones at Marsa and Burmarrad, where the aquifer is located just below the root-zone, have high evapotranspiration. Luckily, despite the small size of the Islands the topography is relatively high and such low lying catchment areas are few. There are also large tracts of land with barren rock outcrops or a thin gravel cover with sparse vegetation. Here rainwater enters the ground directly, with little retention, and evapotranspiration is very low.

Vegetation accelerates the process of evapotranspiration and the intensive use of land for agriculture in certain parts of the Island contribute to a high water loss.

Climatic factors such as temperature, humidity, hours of sunshine and wind intensity have a decisive influence on these evapotranspiration losses. Temperature variations range from 6 degrees C in winter to 32 degrees C in summer, whereas the daily sunshine hours range from 5.1 hours in December/January to 12.6 hours in July. This and other meteorological data for the Maltese Islands is shown in Fig. 3 on a monthly basis.

2.4 Aquifer Recharge

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 unit 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.

(a) The Perched Aquifer -

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

(b) The Mean Sea Level Aquifer -

This is by far the most important aquifer and accounts for 98% of all potable groundwater on the Islands. It lies in the pores and fissures of the Lower Coralline Limestone and Globigerina Limestone located at sea level. This body of fresh water is in the form of a "lens" with the thicker part situated in the central parts of the Island where presently it reached a height of 4m. above mean sea level. This height reduces gradually towards the coast where it finally levels off to zero. The aquifer "floats" on saline waters by virtue of its lighter density and owes its existence to the fact that every winter the rainwater that percolates through the ground beyond the root zone adds more freshwater to this underground storage than can be dissipated by direct discharge to the sea at the coast. It is defined best by the Gheyben-Herzberg model with the base of the "lens" located at a depth below sea level 36 times its height above sea level (Fig. 4).

(c) Other Aquifers -

A number of smaller aquifers of secondary importance are also 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 (examples Marfa Ridge, Mizieb Valley, Mellieha Bay and Pwales Valley). A perched aquifer also exist at Mellieha Ridge and Mgarr-Wardija Ridge. These small broken up aquifers do not allow for economical large scale exploration and are exclusively used by the local farmers for irrigation.

2.5 Water Development

Extraction of potable groundwater from the aquifers accounts for about 37% of all potable water on the Islands, the rest being derived from desalination plants. 98% of this water is derived 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/day (45,500 cu.m./d). Extraction is achieved by means of a system of 36 kilometers of underground galleries located at about sea level and a complex network of about 100 boreholes spread across the Island. The galleries re excavated within the aquifer from where water seeps out and is channelled to central sumps under the flow of gravity. The water is chlorinated in the sumps before it is pumped to surface reservoirs for distribution. In the case of boreholes, these have the bottom parts drilled within the aquifer where water collects, is chlorinated and pumped to reservoirs.

Private extraction by farmers almost exploits the Perched Aquifer to the full, leaving only about 250,000 gallons daily (1,100 cu.m./d) for potable use. This is extracted from 4.2 kilometers of galleries excavated at the base of the aquifer.

2.6 Subsurface Discharge

The recharge water that reaches the aquifer flows away more or less horizontally. Part of this lateral flow is recovered by public and private extraction by means of galleries and boreholes while the remaining part continues its outward journey to the coast where it is finally discharged into the sea. In fact, this outflow of freshwater into the sea takes place all around the coast of the Islands. In Malta, the major ones are at Burmarrad, Marsa, Msida, Marsaxlokk Bay, Blue Grotto, Fomm ir-Rih, St. Paul's Bay, Mistra and Mellieha Bay (Fig.6).

Besides this lateral flow of freshwater, there is also an upward flow of freshwater at the fresh-saltwater interface which also discharges along the coast where it gives rise to submarine springs.

3. IMPACT OF A CLIMATE CHANGE

Global warming has two effects on the hydrological cycle, one is eustatic and the other purely climatic. Whereas the assessment of the former impact is rather straightforward, the climatic one is more complicated due to the difficulty of assessing the complex variations in the atmospheric conditions as the global climate changes and hence the uncertainties of making prediction on localized climates especially on precipitation.

Considering these uncertainties in predicting future precipitation changes around Malta, two extreme regional forecasts have been chosen to assess the direct climatic impact. One forecast predicts little, if any, change in precipitation by the year 2050. The other extreme forecasts an increase by as much as 40%.

One of the IPCC's Business-as-Usual Scenario-A combined with the University of East Anglia sub-grid scale study of climatic change for the Central Mediterranean. This combination predict a rise in sea level by 66 cm best estimate by the year 2050 and only a slight, if any, increase in precipitation.

The other extreme is based on IPCC's Business-as Usual scenario coupled with the results of IHP's regional models run for the Northern Hemisphere grid and published in 1989. These again predict:

(i) Rise in Sea Level:

Most climate models predict a rise of 3-5 degrees C in the mean surface air temperature by the next century. The poles will however warm considerably more and a large quantity of permanent ice that forms part of the ice-caps will melt. This extra water together with the thermal expansion of the oceans will cause a rise in the sea-level which according to IPCC's Scenario-A will be between 0.3 and 1.1 metres by the year 2100 with a best estimate of 66 cm. This means that all aquifers located at sea level will be affected.

Since the main aquifer in Malta is located at such a level this effect is of primary concern and has great implications on the development of water resources in the Island. The most striking effect is that a rise in sea level will put the majority of the 40 km. of galleries in Malta at a level that is no longer optimal for the safe extraction of groundwater. As a result the extraction of groundwater from these galleries will become more

prone by seawater intrusion depending on the extent of the rise in sea level. A mere rise of 1m. will force production to be reduced by as much as 40% in order to maintain a safe extraction rate.

The major economic benefit of extracting groundwater from galleries over other types of extraction practice would therefore be seriously impaired. Recalling that 50% of all groundwater is derived from such galleries, the magnitude of this problem is not small. To compensate for this loss three solutions can be applied:

(i) drill more boreholes at an estimated capital cost of about 6 million Malta Lira in today's money.

(ii) undertake structural alterations to the galleries; the price of this is prohibitive for a large rise in sea level.

(iii) substitute the lost production by mans of desalinated water at an estimated cost of 3 to 5 million Malta Lira per year.

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

Because of favourable topography, the impact of a 1 meter rise in sea level on the catchment area is negligible and will not effect the volume of precipitation that is available in the cycle.

(ii) Change in local Climate:

Climatic factors influencing the hydrological cycle are precipitation, radiation, temperature, humidity and wind. By and large the most significant factor is that of precipitation and its impact on the hydrological cycle is the most significant.

Although there is no state-of-the-art climate model that can accurately predict the redistribution of precipitation of a locality, tentative and approximate forecasts of variations in the annual precipitation of the Northern Hemisphere have been published for various stages of global warming. As far as the Central Mediterranean is concerned, the following two extreme predictions for the area around Malta have been made by the Climatic Research Unit of the University of East Anglia (1991) and by Refsgaard, Alley, Vergllinsky - IHP (1989):

IHP (1989):

Global Warming	Change in the Norm of Precipitation	Year
1.0 C	0 cm.	2000
1.5 C	+ 20 cm.	2025
3-4 C	+ 18 cm.	2050
-	-	2100

University of East Anglia:

Global Warming	Change in the Norm of Precipitation	Year
1.0 C	0 cm.	2000
1.5 C	0 cm.	2025
3.0 C	little change	2050
4.3 C	little change	2100

According to these forecasts, no appreciable change in precipitation is expected before 2025. After that, an increase in precipitation from little to as much as 20 cm. (40% of annual) is expected by the year 2050. This latter increase will favourably effect the hydrological cycle as more water becomes available.

The relations of run-off, evapotranspiration and recharge to precipitation are not constant but change with the annual precipitation. Thus, although the absolute value of evapotranspiration increases with annual precipitation, its value as percentage of the annual precipitation decreases. On the other hand, run-off tends to increase both in absolute value and as a percentage of the annual precipitation. As a result, recharge to the aquifers increases both in absolute terms and as a percentage of precipitation.

A tentative water balance for Malta is shown below for these extreme forecasts of zero to an optimistic 40% increase in precipitation by the year 2050.

In absolute terms this mans that between zero and 27,500 cu.m. of water per day could become available for further development. This potential maximum increase represents a notable 60% of the current groundwater production.

The problem of assessing possible changes in the hydrological cycle attributed to changes in the remaining climatologic factors (radiation, temperature, humidity and wind) is even more difficult and the results less reliable. However, their impact is much less pronounced than that of precipitation and considering the low confidence in precipitation forecasts, no accuracy is lost by neglecting them in the assessment.

4. CONCLUSIONS AND RECOMMENDATIONS

A global warming will effect the hydrological cycle of Malta in two ways. One effect will be attributed to the expected rise in sea level and the other to the changes in the local climatic conditions.

A rise in the mean sea level by 1 meter by the year 2050 will adversely effect the existing system of water extraction from the principal aquifer. Costly measures will have to be implemented to rectify the base of the galleries to a new optimal level.

Because of favourable topography, this rise in sea level will however have a negligible effect on the catchment area.

Of the various climatic conditions that influence the hydrological cycle, that of precipitation has the major impact. Forecast on the changes in precipitation for Malta are however very nebulous and range from zero change to an increase of about 40% in the yearly norm by the year 2050. The latter extreme is equivalent to a further potential extraction of about 27,500 cu.m. of potable groundwater per day.

More reliable estimates of future changes in the precipitation around Malta should be attempted as more accurate global and regional climate models become available. Links with international organizations and networks should be maintained for continued scientific and technical assistance.

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