

An Application of Drought Indices in Malta, Case Study

D.S. Borg

Malta Resources Authority (MRA), Water Directorate
Millennia, Aldo Moro Road, Marsa
MRS 9065, Malta

Abstract: This paper focuses on the implementation of two drought indices, namely SPI (Standardised Precipitation Index) and RDI (Reconnaissance Drought Index) for Malta. Several problems regarding missing data were to be overcome and whenever multiple methodologies were available, these were implemented and compared so as to further validate the observations made. Eventually the indices were computed and analysed so as to draw as much information from the available data with respect to the occurrence and frequency of drought in the Maltese Islands in the light of current and future water demand.

Keywords: Drought, SPI, RDI, water availability, Maltese Islands.

1. INTRODUCTION

In this paper an analysis of hydrological data was carried out with the purpose of the identification and classification of the occurrence of drought episode in the Maltese Islands. As known there are several definitions of drought, among which is that given by the AMS glossary: “A period of abnormally dry weather sufficiently long enough to cause a serious hydrological imbalance”. This statement shows that drought is predominantly characterised by a long term deficiency in water availability. To identify a period as having abnormally dry weather, one first needs to define a period as being “normal”. Hence due to this apparent relativity in measuring and defining drought, analysis of drought must be carried out at a local or regional level. Consequently, so as to categorize the severity of drought in Malta, the SPI and RDI indices were chosen to be applied over the hydrological years commencing in September.

2. PRELIMINARY ANALYSIS

So as to be able to employ the SPI and RDI indices one must first understand how these work or at least identify the data requirements.

The SPI, Standardised Precipitation Index, requires monthly precipitation data and has been calculated for the four reference periods; September to November, September to February, September to May and also September to August, using the equations:

$$SPI_{i,k} = \frac{w_{i,k} - \bar{w}_k}{S_{w_k}} \quad \begin{array}{l} i = 1, 2, \dots \text{ (Hydrological Year)} \\ \text{and } k = 1, 2, 3, 4 \text{ (Reference Period)} \end{array} \quad (1)$$

where:

$$w_{i,k} = \ln(R_{i,k}) \quad i = 1, 2, \dots \text{ and } k = 1, 2, 3, 4$$

\bar{w}_k is the average of the $w_{i,k}$'s

3. COLLECTION OF DATA

For the best results in this analysis, it is desirable to have a long overlapping dataset for the two variables mentioned above. In the case of *monthly rainfall* data (in mm), this data is available as from around 1840 till the present day and has been recorded at Luqa Airport (NSO, 2002, 2004, 2005, 2006). There are some data points missing occurring prior to January 1865, after which the dataset is complete for 142 years (up to 2006). The data is summarized in the graph below.

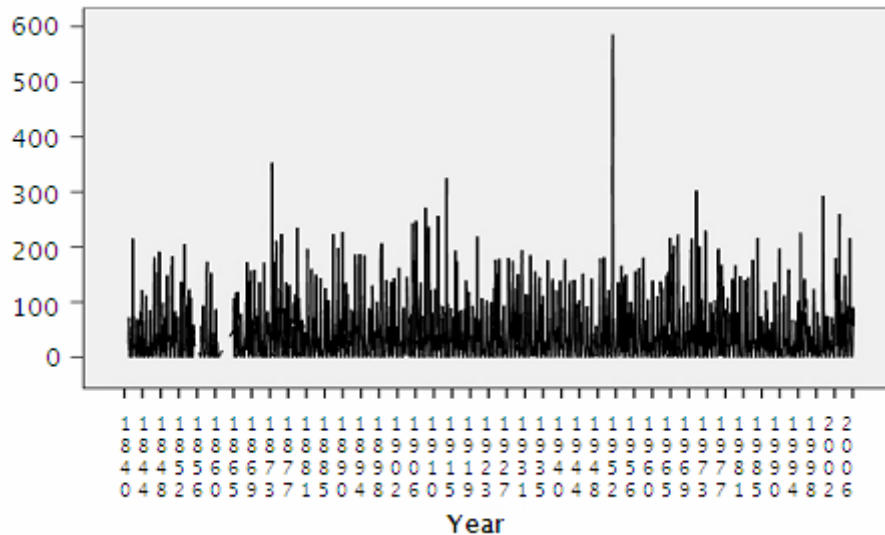


Figure 1: Rainfall data in mm from January 1840 to December 2006

On the other hand, the *potential evapotranspiration* data is not recorded by the National Statistics Office (NSO) and the only historical record available was the data recorded by BRGM – Bureau de Recherches Géologiques et Minières (1990, 1991), using the Penman equation as from January 1947 till December 1989.

This data set amounts to 43 complete consecutive years. As mentioned previously, it is desirable to have the longest datasets possible, hence, so as to maximise the potential of this dataset, time series analysis was employed to extrapolate the missing data from a model fitted to the 43 years available.

3.1 Time Series Analysis on Evapotranspiration

First and foremost it is appropriate to define the term evapotranspiration. This is a joint term which accounts for both evaporation and plant transpiration. Evaporation is the process by which water moves to the air from surfaces like soil and free water (lakes, rivers, oceans, and so on). On the other hand, transpiration is the movement of water within a plant and the eventual loss of water as vapour which is released through its leaves. There is no direct way of measuring evapotranspiration. The potential evapotranspiration (PET) is a figure resulting from the multiplication of a *surface coefficient* and the *reference evapotranspiration* (which is obtained through a standard exercise for the approximation of evapotranspiration). In the case where there is ample water, PET and evapotranspiration are said to be equal. However, evapotranspiration can never be greater than the value of PET, but can be lower if there is not enough water to be evaporated or if plants are not readily able to transpire. Thus the PET provides an upper bound for the value of evapotranspiration.

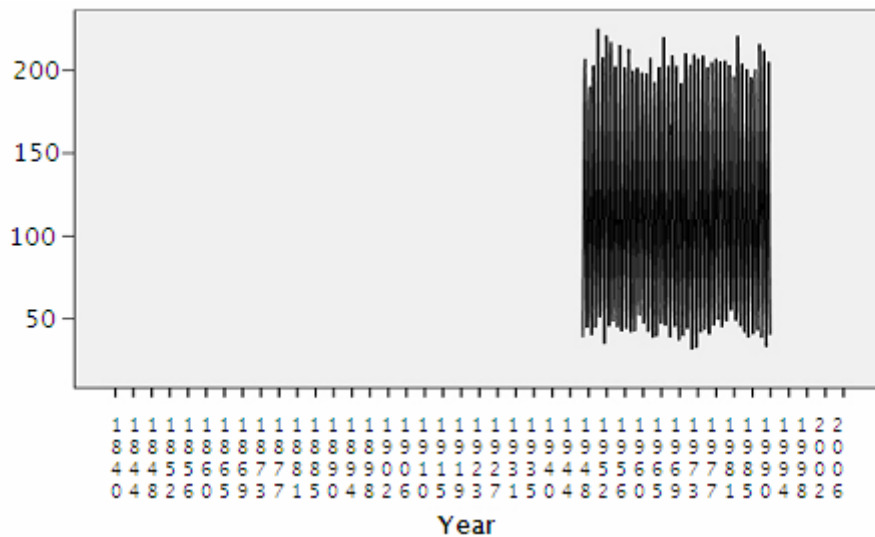


Figure 2: Monthly PET in mm as recorded by BRGM for January 1947 to December 1989

PET peaks in summer because of the higher temperatures. It is also significantly larger on less cloudy days, in locations closer to the equator and on rather windy days. Hence, due to Malta's geographic position and climate, the values for PET are on average particularly large, while actual evaporation may occur at lower rates because of scarcity of water. However, the RDI was especially designed to use the PET not actual evapotranspiration values.

Unlike the case for monthly rainfall, there has not been a continuous recording of PET throughout the years. The only data available at the time of this study consists of monthly PET in mm using the Penmen equation from January 1947 to December 1989 during a study conducted in Malta by BRGM (Bureau de Recherches Géologiques et Minières) and is shown in Figure 2.

These values which range from 31.8 mm to 225 mm were obtained by an adaptation of the Penman equation to the particular environmental conditions of Malta and several parameter values used (specific to Malta) are not specified hence it was not possible to calculate the missing values up to December 2006.

For this reason, alternative measures were considered to obtain this data. The first attempts consisted of fitting various statistical models to the BRGM dataset and from them extrapolate the required values. The best fitting model obtained is shown in Figure 3.

The model was created by splitting the recorded values into a seasonal, trend and error component and produced 720 consecutive readings in all which range between 44.3 mm and 211.7 mm with an average of 116.9 mm over 60 years. This is equivalent to an extension of 17 years to the BRGM dataset.

By means of this fitted model, the missing data from January 1990 till December 2006 could be extrapolated, hence all the required data for the indices was made available and these were calculated for the four reference periods described in the "Preliminary Analysis" section.

At a second stage, the DrinC software - Drought Indices Calculator (Tsakiris et al., 2007) was made available for use with this research and besides its purpose of calculating Indices, this software can also calculate the values of PET using the Thornthwaite equation which involves monthly temperature data. Temperature data was obtained from the National Statistics Office (NSO) dating from January 1970 up to December 2006 and is shown in Figure 4.

This dataset consists of 444 consecutive monthly values ranging between 10.1°C and 29.3°C having a mean of 18.95°C along these 37 years, which produced another dataset of monthly PET values for the same 37 years. These values which range between 14.2 mm and 202.4 mm with an average of just 80.4 mm are shown in the Figure 5.

Since this dataset was compiled after the SPI and RDI indices have been calculated using the fitted model data, it was then used to run a parallel comparison of the two methodologies and these were in turn combined in section 4.2.

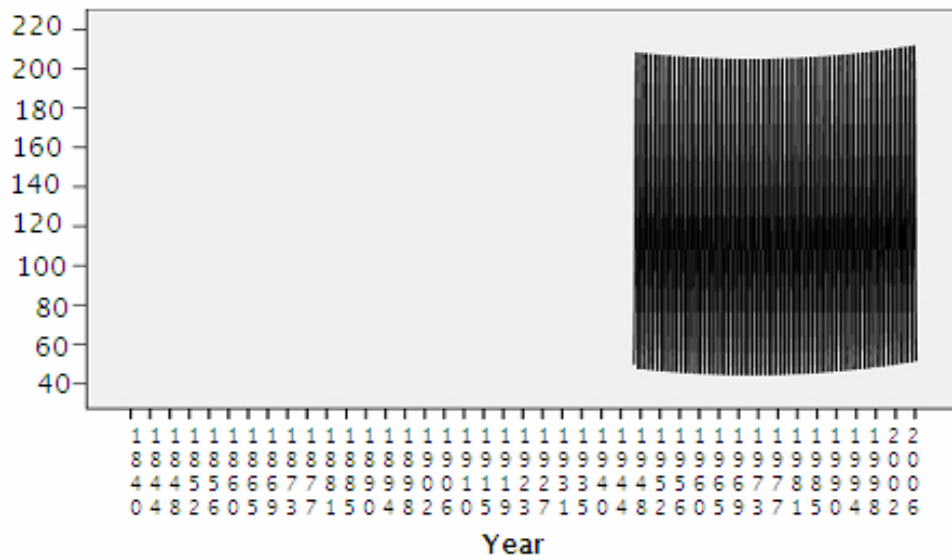


Figure 3: Monthly PET in mm as calculated by Time Series Extrapolation for January 1947 to December 2006

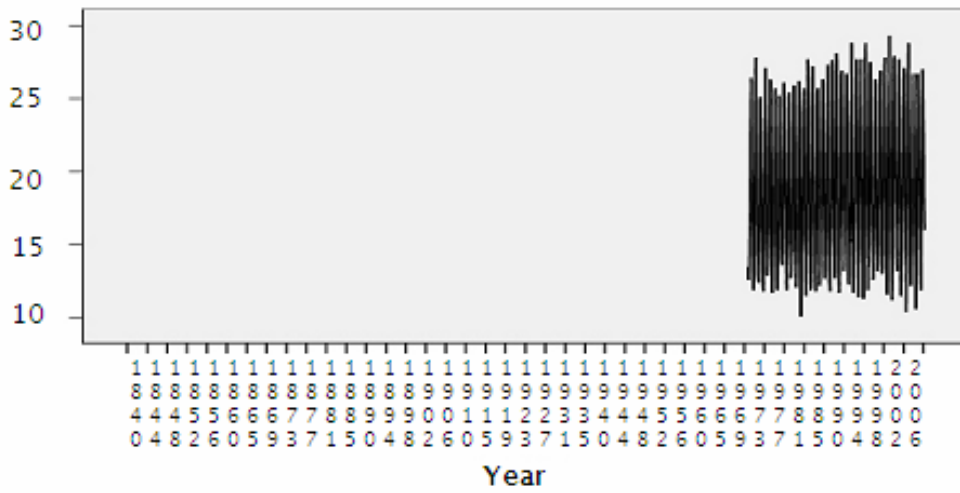


Figure 4: Monthly Temperature data in °C from January 1970 to December 2006

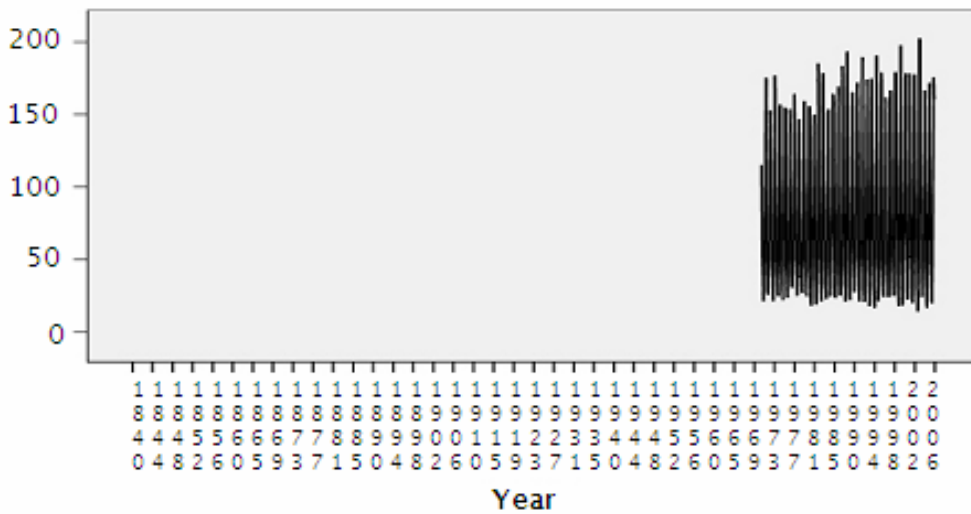


Figure 5: Monthly PET in mm using DrinC for January 1970 to December 2006

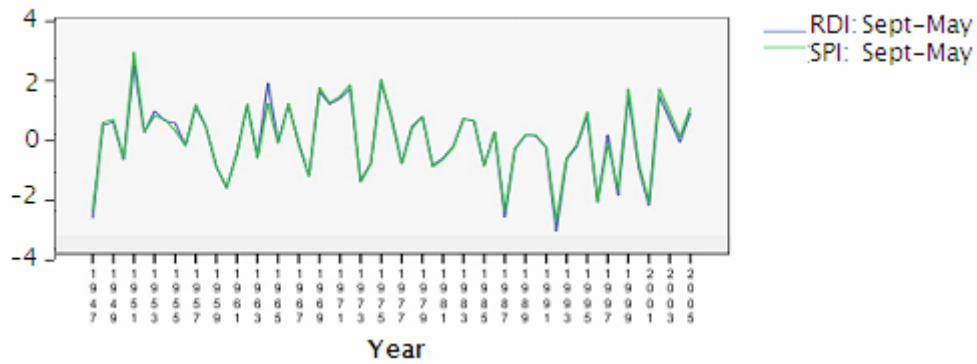


Figure 8: Comparison of SPI and RDI for Reference Period 3

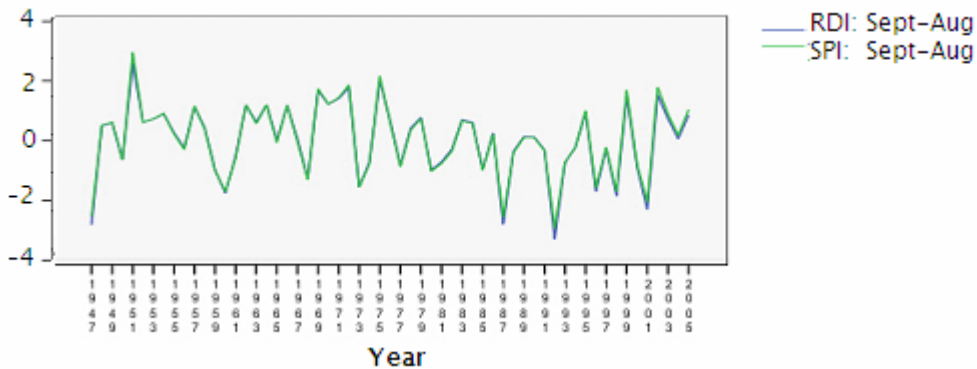


Figure 9: Comparison of SPI and RDI for Reference Period 4

Even in this particular reference frame, the two indices overlap each other almost perfectly and the hydrological year 1992-1993 is the driest with an SPI value of -2.646 and an RDI value of -2.650. It is yet again followed by 1987-1988 with an SPI value of -2.277 and an RDI value of -2.256 and also by 1947-1948 with an SPI value of -2.249 and an RDI value of -2.269.

From this comparison the following conclusions were drawn.

- All four reference periods confirm that 1992-1993, 1987-1988 and 1947-1948 are the driest hydrological years (in decreasing order) of all the years under analysis ranging from September 1947 to August 2006
- Since the indices are close in value even though SPI is independent of PET, the fitted *additive model* is assumed to be a very good approximation for PET.
- Whenever discrepancies occurred, the value of RDI was preferred since it encompasses more parameters than the SPI.

The availability of DrinC software provided a new methodology in calculating PET with the Thornthwaite Equation using monthly Temperature data in °C and Latitude. So as to verify further the validity of the extrapolated data, a comparison between the values of the indices presented above and those calculated by DrinC was performed.

4.1 Comparison of RDI values using PET values obtained from Time Series Model and DrinC

The temperature data, which is available by NSO for Luqa Airport on a monthly basis as from January 1970, has been loaded in DrinC to obtain values for PET over the same period. Once the PET data being calculated with the Thornthwaite Equation was available, it was combined with monthly Rainfall data for the same period to obtain the values of RDI for the four reference periods as used in the previous section. Figure 10 shows a simultaneous plot of the yearly figures of RDI as obtained by the two methodologies, and one can immediately notice the identical distribution of

hydrological years into the various categories except at one point, namely 1970-1971 (This is the first year in which DrinC data is available). For this particular hydrological year the *Time Series model* gives an RDI value of 0.979 while the *DrinC model* gives a value of 1.04, which when rounded up to the first decimal place gives a value of 1.0 in both cases so the difference is negligible.

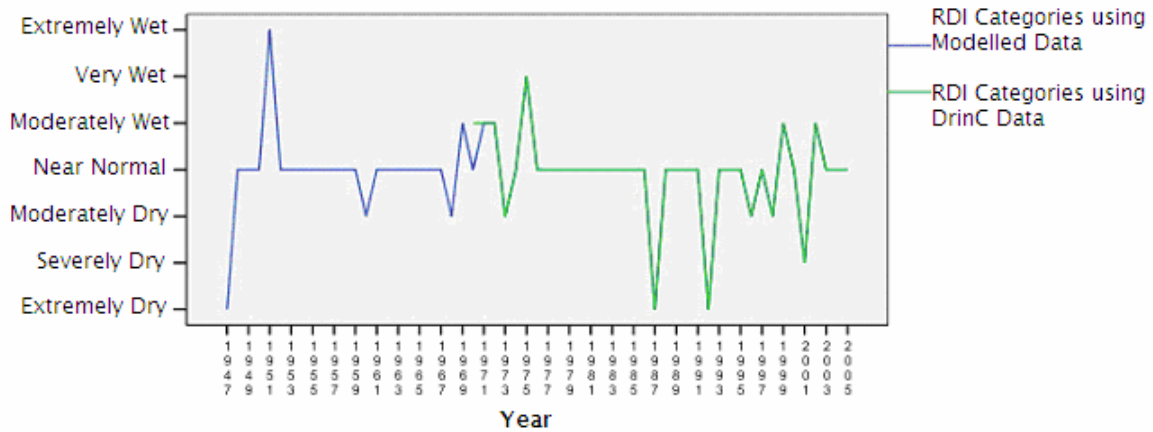


Figure 10: Comparison of RDI obtained using Modelled Data and DrinC Data

4.2 Further Results

Since the two methodologies for the calculation of PET have been applied in this analysis complement each other they can be united to give one reliable value of PET since it is a main contributor in the analysis of Drought. It has been concluded that the data calculated using the Penman equation is more realistic to the Maltese scenario. Thus by using Linear Regression over the period in which the original BRGM data and PET data calculated using DrinC overlap, was performed. The data satisfied the basic assumptions in Linear Regression and this analysis provided the following equation:

$$PET_{Penman} = 1.052 * PET_{Thorntwaite} + 33.036$$

This model caters for 83% of the variation of the response variable (Penman PET). Figure 11 shows the original BRGM data points compared to the expected values obtained by the Regression model.

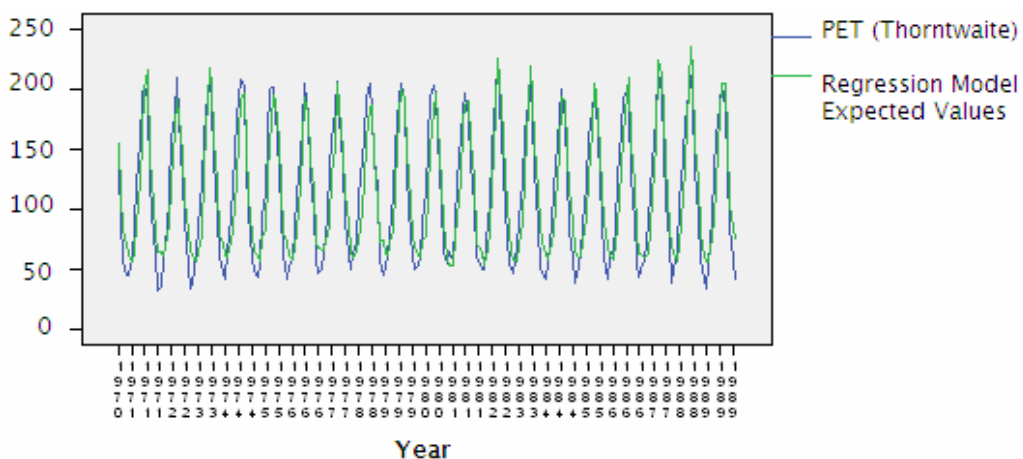


Figure 11: Simultaneous plot for BRGM PET data and Regression Model's Expected Values

In this way a more reliable value for PET can be quoted when analysis is made on PET in particular, since as shown in the previous comparisons, the different values of PET from various methodologies provide negligible changes in the computation of the values of RDI.

Due to the fact that the indices for the hydrological years 1992-1993, 1987-1988 and 1947-1948 have shown them to be the driest for each of the four reference periods, the graph below places these years in context with the previous and subsequent years (where available).

The points above are grouped between bars separating each hydrological year and represent the category given by the indices for each of the four reference periods, September to November, September to February, September to May and also September to August respectively.

One may notice that each overall “Extremely Dry” year lies among overall “Near normal” years, rendering the occurrence of these events almost unpredictable from year to year. The signs of the possibility of drought are visible within a hydrological year itself and this occurrence is independent of previous years.

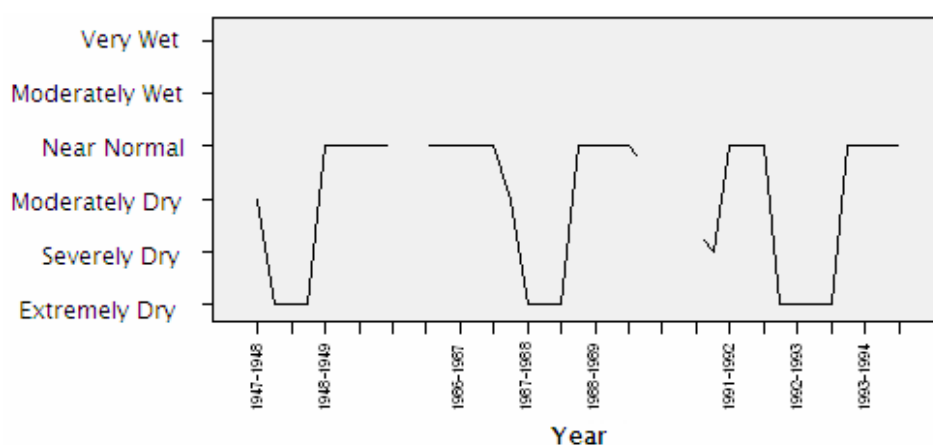


Figure 12: Extract from RDI Sequence Plot with all 4 Reference Periods

5. ESTIMATION OF CURRENT AND FUTURE WATER AVAILABILITY AND DEMAND

Parts of this section are adapted from Malta Water Resources Review (FAO, 2006).

5.1 Water Demand by the Domestic Sector

The consumption by the domestic sector is at an increase because of higher living standards and the demand for a superior quality in drinking water. This has created the market for other sources of water supply like bottled water, whose consumption ranges around 50 to 60 million litres, while leisure activities, like swimming pools are being supplied, from privately owned bowzers whose main source is groundwater.

Despite the fact that tariff increases may initially dampen domestic demand, overall demand is expected to increase steadily in the next ten years. Given the deterioration in groundwater quality, it seems likely that an increasing proportion of domestic water demand will be met from reverse osmosis plants or further treatment (desalination) of abstracted groundwater. With an increased use of cisterns, demand for WSC water can be expected to increase substantially in periods of low rainfall when the potential for rainwater harvesting is minimal.

5.2 Water Demand by the Agricultural Sector

Possible changes in the agriculture sector can be projected from the developments of the negotiations preceding Malta's accession to the EU. Assuming that the utilized agricultural land area remains constant, attaining these new thresholds will result in net irrigated land increasing to about 2,250ha.

The proposed expansion in agricultural demand will not be satisfied without further deterioration of water quality in the sea-level aquifers and demand is highest during the summer months. As *Treated Sewage Effluent* (TSE) production is continuous throughout the year, it may be necessary to create surface storage for TSE or use TSE as a source of water for artificial recharge when irrigation water requirements are low.

The demand of the sector cannot be met by groundwater alone so other sources must be adopted, in particular treated effluent and rainwater harvesting. Annual TSE production is estimated to reach about 14Mm³ by 2008. Agricultural areas in the region of the Malta South plant have a current water demand of 2.7Mm³, projected to increase to about 3.3Mm³ by 2010. In fact, TSE production in the Malta South plant is expected to exceed the irrigation demand throughout the whole year.

5.3 Industrial Water Demand

Water efficiency and water recycling are being introduced slowly, particularly in the major industrial concerns as it is recognized that these measures reduce costs in the long term. The construction industry and the food and beverage industry are the most dependent on groundwater in this sector. However, no appreciable expansion is envisaged, thus, the demand for groundwater by this sector will most probably remain stable. Currently, industry in the Bulebel region meets part of its water needs from the TSE produced at the Sant' Antnin sewage treatment plant.

5.4 Tourism Water Demand

NSO publications show that the total annual guest nights in year 1998 up to year 2000 varied between 10 and 11 million nights; which is equivalent to an average daily tourist load of 32,000 tourists which peak in the summer months, particularly in July and August. Simultaneously hotel accommodation increased to 40,688 beds along with another 7,500 beds in holiday apartments. The WSC estimates that tourism activity accounts for 10% of water consumed amounting to 1,740,000m³ over 2000 and 2002. This would mean that each tourist used about 149 L of water per day. These official figures for consumption of water by the tourist industry are low when compared with the situation in other Mediterranean countries.

It is customary for hotels with a bed capacity of 350 to 400 to install a 125m³/day RO unit. Assuming this RO unit to be the sole water supply for such a hotel would yield a water production figure of 312 L/bed/day. These facts indicate that the tourist industry in Malta could be acquiring up to half of its water from sources outside the potable water distribution network. Moreover, the RO unit is a more reliable form of supply of better-quality water. Therefore, any increases in tourism demand are expected to be met by private RO production, hence, the dependence of the sector on private groundwater sources gradually decreasing.

5.5 Environmental Water Demand

Groundwater is also an essential element in sustaining terrestrial surface-water ecosystems. These fragile habitats depend on a year-round supply of freshwater. Thus, they are particularly rare and limited in distribution and in the same time they support distinctive types of flora and fauna, some of which are endemic to the Maltese Islands.

5.6 Identification of areas under high water shortage risk

There are no particular areas over others having an increased water shortage risk because the water distribution system is centralised and available in all parts of the Maltese Archipelago.

5.7 Quantification and estimation of water shortage risk.

Table 2 shows the monthly figures in cubic metres of Water by Source of Production for 2005 as published by NSO (2006).

Table 2: Monthly Water Production by Source in m³ for 2005

Month	RO plants	Pumping Stations	Boreholes	Spring	Total
January	1,171,339	647,014	557,536	0	2,375,889
February	1,114,627	620,620	485,314	0	2,220,561
March	1,250,081	740,864	550,748	0	2,541,692
April	1,240,340	720,739	511,918	0	2,472,997
May	1,445,322	728,857	529,034	0	2,703,214
June	1,585,137	607,598	512,073	0	2,704,808
July	1,767,185	672,971	523,094	0	2,963,250
August	1,823,191	609,783	521,763	0	2,954,737
September	1,593,108	623,369	509,693	0	2,726,170
October	1,490,287	555,030	549,828	0	2,595,145
November	1,352,694	558,545	531,867	0	2,443,106
December	1,215,731	584,806	541,497	0	2,342,034
Total 2005	17,049,042	7,670,196	6,324,364	0	31,043,602
(%) of production	54.92	24.71	20.37	0	100

This shows that water is mainly obtained by pumping from the groundwater bodies since the availability of surface water is negligible. Hence, so as to estimate the current conditions of groundwater, a groundwater recharge exercise was performed using the values of RDI for complete hydrological years (the fourth reference period).

6. THE USE OF RDI IN GROUNDWATER BALANCE ESTIMATION

Based on the Categories of RDI as shown in Figure 13, Table 3 shows the probability of occurrence and the average annual rainfall as recorded during the observed 59 hydrological years (1947-2006). The three categories “Extremely Wet”, “Very Wet” and “Severely Dry” all have a probability of 0.017 which is equivalent to 1 on 59; hence the average annual rainfall in these categories is equal to the single recorded annual values.

From these approximations to total precipitation per category, one may estimate the Groundwater Balance at the end of a hydrological year. This is equal to the difference between Groundwater Recharge and Groundwater Abstraction and this is positive when recharge is greater than abstraction. Table 4 summarizes this estimation.

Even in near normal years, the Groundwater Balance has a negative value equal to -2.949 Mm³. Table 5 divides the data show in Figure 10 into 6 ten year period (except for 1947-1956 which is made up of only 9 years) while Figure 14 below illustrates the accumulated annual groundwater balances for the same ten year periods.

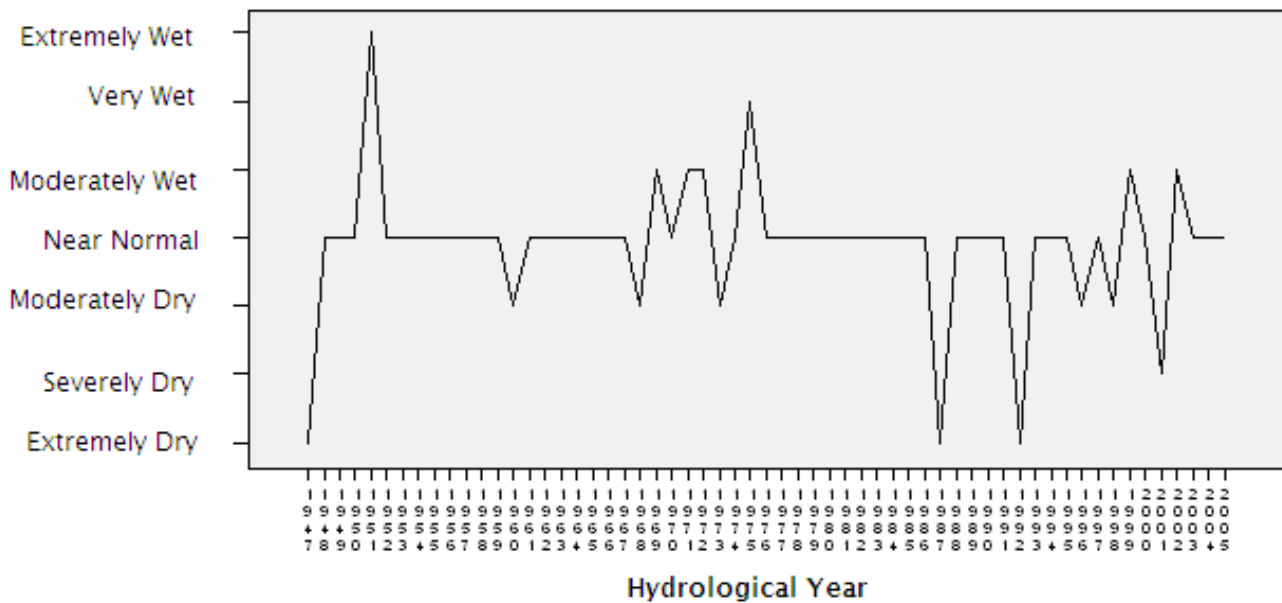


Figure 13: Classification of Hydrological Years as per RDI Categories

Table 3: Probability of Occurrence and Average Rainfall per RDI category

Category	Occurrence in 1957-2006	Average Rainfall (mm)	Precipitation (Mm ³ /year)
Extremely Wet	1	976.88*	308.6941
Very Wet	1	819.80*	259.0568
Moderately Wet	5	738.45	233.3502
Near Normal	43	507.95	160.5122
Moderately Dry	5	304.43	96.19988
Severely Dry	1	259.64*	82.04624
Extremely Dry	3	211.39	66.79924

* Only one year fitted in this category.

Table 4: Estimation of Groundwater Balance per RDI Category

Category	Recharge of Groundwater* (Mm ³ /year)	Artificial Recharge from Leaks** (Mm ³ /year)	Total Inflow (Mm ³ /year)	Abstraction ⁵ (Mm ³ /year)	Overflow to the Sea*** (Mm ³ /year)	Total Outflow (Mm ³ /year)	Groundwater Balance (Mm ³ /year)
Extremely Wet	61.74	12	73.74	31	30.87	61.87	11.87
Very Wet	51.81	12	63.81	31	25.91	56.91	6.91
Moderately Wet	46.67	12	58.67	31	23.34	54.34	4.34
Near Normal	32.10	12	44.10	31	16.05	47.05	-2.95
Moderately Dry	19.24	12	31.24	31	9.62	40.62	-9.38
Severely Dry	16.41	12	28.41	31	8.20	39.20	-10.80
Extremely Dry	13.36	12	25.36	31	6.68	37.68	-12.32

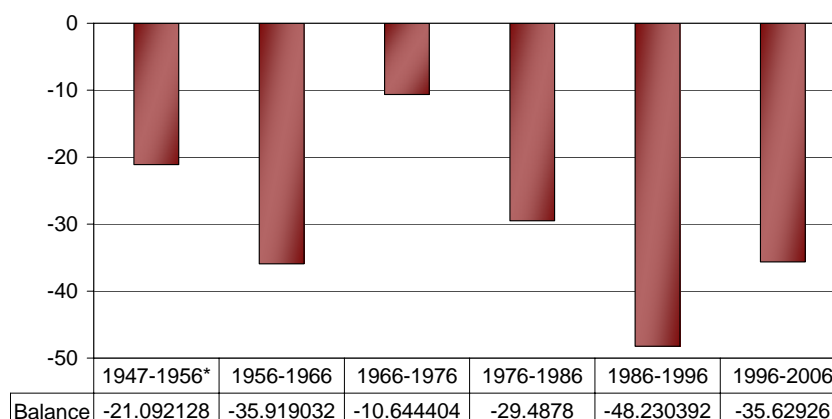
* Estimated at 20% of Annual Precipitation

** Source: MRA 2003

*** Estimated at 50% of Recharge (based on ATIGA 1972)

Table 5: Occurrence of each Drought Category in ten-year periods

Category	1947-1956*	1956-1966	1966-1976	1976-1986	1986-1996	1996-2006
Extremely Wet	1	0	0	0	0	0
Very Wet	0	0	1	0	0	0
Moderately Wet	0	0	3	0	0	2
Near Normal	7	9	4	10	8	5
Moderately Dry	0	1	2	0	0	2
Severely Dry	0	0	0	0	0	1
Extremely Dry	1	0	0	0	2	0
Total	9	10	10	10	10	10

Figure 14: Estimated Groundwater Balance (Mm^3)

The balance is always at a deficit; with the most pronounced estimated value being equal to $-48.23 Mm^3$ occurred during 1986-1996 which is a period of eight “Near Normal” years and two “Extremely Dry” years (refer to Table 5). It is also important to mention that the groundwater has a residence period of forty years. This means that water being recharged today will be abstracted in forty years time hence by means of this subdivision of the data obtained from these estimates one can better describe the situation of ground water availability as being faced currently in the light of what has happened in the previous decades as a result of the occurrence of drought.

7. CONCLUSIONS

Based on the results obtained from this analysis, the Maltese meteorological data used has shown that the SPI and RDI values are very close to each other. This comparison was facilitated by the fact that both indices can take the same range of values and are then subdivided into the same categories as shown in the Table in section 2. Furthermore, the categorization of years in each reference period is independent of the different datasets for PET used. This is due to the fact that the index when applied to the modelled data and the DrinC data for PET gave the same categories as shown in Figure 10. However, even though the categories are similar, the index values are different. The length of the time series of monthly data used has an influence on the values obtained and for this reason the process of maximising the length of PET data available was fundamental to the results obtained by this study. Despite this, statistical analysis on the index values obtained has shown that these values follow random patterns and for this reason extrapolation is not possible.

In practice this means the Indices considered in this study are not a tool powerful enough to be used in identifying the possibility of occurrence of drought in advance. For this reason, the indices may be calculated on a more frequent monthly scale to be able to determine inter-annual occurrence

of drought since as seen in the comparison of the reference periods, the extreme events always occur before and after near-normal years. Once the indices start to indicate that some month is particularly dry, drought mitigation measures or practices for prevention of water wastage may be reinforced.

ACKNOWLEDGEMENT

The work presented in this paper was conducted in the framework of the project PRODIM - Proactive Management of Water Systems to Face Drought and Water Scarcity in Islands and Coastal Areas of the Mediterranean (INTERREG IIIB / ARCHIMED).

REFERENCES

- BRGM, Service Sol et Sous-Sol, Département Eau, 1990. Study of the fresh water resources of Malta, Hydroclimatological study, Calculation of effective rainfall at Luqa Airport Meteorological Station (1947-1989). 15-21
- BRGM, Service Sol et Sous-Sol, Département Eau, 1991. Study of the fresh water resources of Malta, Hydroclimatological study, Study of the fresh water resources of the Upper Coralline Limestone perched aquifer, Lumped hydrological model simulation of the Wignacourt springs discharge. 45
- Nalbantis, I., Tsakiris, G., 2008. Assessment of hydrological drought revisited. *Water Resour Manage* DOI 10.1007/s11269-008-9305-1
- National Statistics Office (NSO), 2002. Environment Statistics. 17-20, 30-36, Valletta
- National Statistics Office (NSO), 2004. News Release: World Meteorological Day, Valletta
- National Statistics Office (NSO), 2005. News Release: World Meteorological Day, Valletta
- National Statistics Office (NSO), 2006. Environment Statistics. 5-11, 25-29, Valletta
- National Statistics Office (NSO), 2006. News Release: World Meteorological Day, Valletta
- National Statistics Office (NSO), 2007. News Release: World Meteorological Day 2007, Valletta
- Food and Agriculture Organisation of the United Nations (FAO), 2006. Malta, Water Resources Review. Rome
- Tsakiris, G., Pangalou, D., Vangelis, H. 2006. Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI). *Water Resour Manage* 21:821-833
- Tsakiris G., Tigkas D., Vangelis H., Pangalou D., 2007. Regional Drought Identification and Assessment – Case Study in Crete. In ‘Methods and Tools for Drought Analysis and Management’, Rossi et al. (eds.). Springer, The Netherlands