Water Resour Manage (2017) 31:655–669
DOI 10.1007/s11269-015-1057-0

Risk-Based Assessment of Drought Mitigation Options: the Case of Syros Island, Greece

A. S. Giannikopoulou[1] **· F. K. Gad**[1] **· E. Kampragou**[1] **·**
D. Assimacopoulos[1]

Received: 16 July 2014 / Accepted: 2 July 2015 /
Published online: 9 July 2015

Abstract Drought-related risk estimation is widely acknowledged as a tool towards enhancing drought preparedness and minimizing impacts on people, the economy and the environment. In this paper a method is proposed for the risk-based assessment and prioritisation of long-term drought mitigation options in order to support decision making for drought planning. The assessment combines water balance modelling, hazard analysis, and risk and cost effectiveness analysis. The proposed approach allows an improved understanding of drought-related risks by following a probabilistic analysis of drought impacts under different mitigation options. The method is applied in a drought-prone area with water scarcity problems, the Greek island of Syros. The assessment focuses on agriculture and domestic water use, the two main water using sectors in the island. Six mitigation options are cross-compared in terms of contribution to future drought risk reduction using three criteria: risk, vulnerability and benefit-cost ratio. The results validate the use of risk-based assessment of mitigation options as a valuable tool for improved drought management.

Keywords Drought risk · Vulnerability · Impact mitigation · Syros Island

1 Introduction

Drought management entails a series of actions and measures taken to assess drought hazard and mitigate its impacts on economic activities, the society and the environment. It includes four main components (UN/ISDR 2009): (i) policy development and governance, (ii) enhancement of drought awareness and knowledge, (iii) risk analysis, assessment and early warning, and (iv) selection of mitigation and preparedness measures. The overall procedure aims at introducing drought risk-related issues to stakeholders and

✉ E. Kampragou
ekamp@chemeng.ntua.gr

[1] School of Chemical Engineering, National Technical University of Athens, Zografou Campus, 9 Heroon Polytechniou str., Athens GR-15780, Greece

decision makers and at selecting suitable options for minimizing drought impacts (Hayes et al. 2004; Rossi et al. 2008).

The shift from the traditional reactive management approach to the proactive, risk-based development of drought management plans has been fostered (Fontaine and Steinemann 2009; Rossi et al. 2007, 2008; Wilhite et al. 2000) as a means to support decision making for investing in drought mitigation (Wilhite et al. 2007). Risk, typically expressed as a function of hazard and vulnerability (UNDP 2011), serves as a measure of anticipated consequences and can indicate an improvement (or not) after the implementation of a mitigation option. In addition, traditional cost-benefit analysis could be used to support the selection of the appropriate measures (Dziegielewski 2003; Rossi et al. 2005).

Specifically in water supply systems, risk assessment includes an analysis of water demands that cannot be fully met due to drought and the estimation of associated impacts (Cubillo and Garrote 2008; Rossi and Cancelliere 2013). Risk management, referring to the processes and measures for dealing with drought and minimizing risk to an acceptable level, can be supported by simulation to assess the contribution of measures to impact mitigation (Karavitis 1999; Querner and van Lanen 2001). Simulations are performed for a long-term horizon, setting the current state as the initial conditions for the system (Cancelliere et al. 2009).

This paper presents an approach for the assessment of long-term mitigation options in water supply systems, using drought risk and vulnerability, in addition to cost-benefit analysis, as the evaluation criteria. The approach combines hazard analysis, water balance modelling and risk analysis to assess options for future drought risk reduction and enables the probabilistic estimation of losses. The method is illustrated through its application in Syros Island, Greece.

2 Risk-Based Assessment of Drought Mitigation Options

A process for the risk-based assessment of drought mitigation options is proposed, which involves three steps (Fig. 1), starting from future hazard analysis and concluding with a comparative analysis of potential mitigation options:

1. First step: Risk identification. Drought conditions are analysed in terms of magnitude (severity), duration and frequency (probability of occurrence and return period), on the basis of climate projections;
2. Second step: Risk assessment regarding anticipated impacts. Impacts are quantified in monetary terms, for the different drought severity levels, and then aggregated to estimate the total risk of economic losses;
3. Third step: Risk management, through measures for dealing with drought and minimizing risk to an acceptable level. Water balance modelling is used to assess the effect of measures on drought mitigation, whereas measures are compared and ranked on the basis of three criteria: risk, vulnerability and cost-benefit ratio.

2.1 Step 1: Drought Risk Identification

The Standardized Precipitation Index (SPI), introduced by McKee et al. (1993), is used for analysing future meteorological droughts. SPI is a generally accepted indicator (Stagge et al. 2015), commonly used for monitoring drought conditions (e.g. European Drought

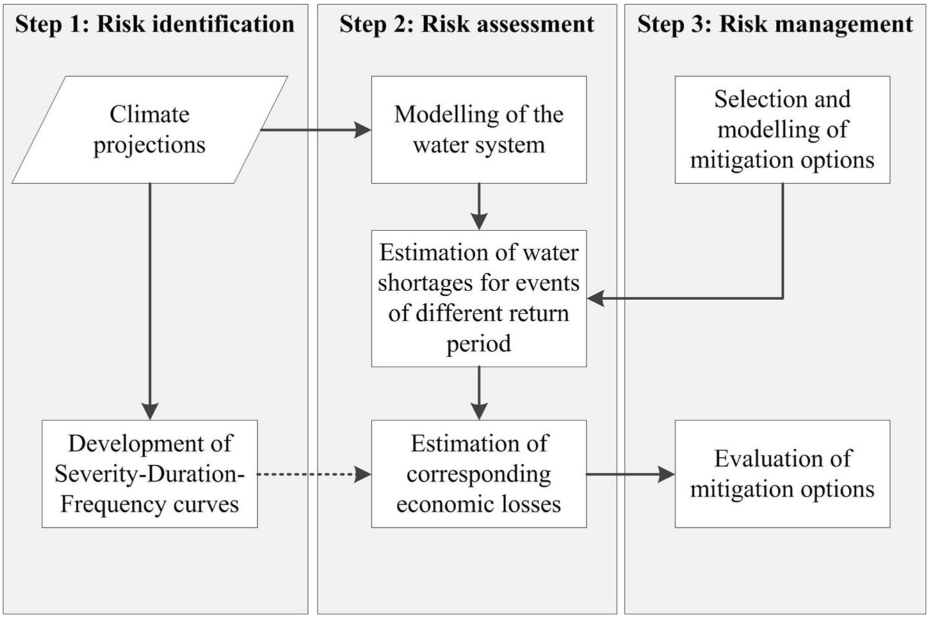


Fig. 1 The process for the risk-based assessment of drought mitigation options

Observatory, USA Drought monitor). Its wide applicability is attributed to (i) the limited data requirements (only precipitation data are required), (ii) the simplicity in its calculation (Hayes et al. 1999), and (iii) the ability to describe drought at different time scales (Tsakiris and Vangelis 2004; Mishra and Desai 2006; Cacciamani et al. 2007; Belayneh et al. 2014). A time series of future monthly SPI values is derived using precipitation data from climate projections, to assess future droughts and their properties using Severity-Duration-Frequency (SDF) curves. Negative SPI values describe drought conditions and the accumulative sum of these values defines severity. A statistical test is performed to find the probability density function that best represents the drought severity variable. Statistical information used in the subsequent steps is: (i) the return period of events of different duration, and (ii) the corresponding probability of occurrence.

2.2 Step 2: Risk Assessment

The analysis of the relationship between impacts and drought characteristics follows. The impact variable is selected according to the sector examined (Todisco et al. 2012), whereas its quantification is supported by water balance modelling to estimate water availability for each sector/activity. In this context the drought impacts can be expressed by the following generic formula:

$$\textit{Drought Economic Impact}_{\mathrm{s}} = \mathrm{DEI}\left(\mathrm{DI}_{T,D}, Q_s, I_s\right) \tag{1}$$

Where: *DI* refers to the drought intensity of events of different return period T (yrs) and duration D (months); Q_s (m^3) corresponds to water availability (or deficit) estimated for the specific sector (s) from the water balance model; and I_s to any other parameters that specify the economic impacts of drought for the specific sector.

Several approaches have been developed for risk assessment (Pliefke et al. 2007); in this work, risk (R) is defined as the probability of occurrence of economic loss (Iglesias et al. 2009) and is expressed as a function of the probability (p) of occurrence of a drought event with a given return period and the economic losses associated with this event (Eq. 2):

$$R_D = \sum_T p_{D,T} \bullet DEI_{D,T} \tag{2}$$

Where: $p_{D,T}$ is the probability of occurrence of a drought event of a given return period and duration and $DEI_{D,T}$ (€) is the associated economic impact.

Impact studies are mainly focused on the agricultural sector (e.g. Li et al. 2009; Wu et al. 2004) and domestic water supply (e.g. Jinno 1995; Merabtene et al. 2002; Shahid and Behrawan 2008), which are mainly affected by droughts. The main direct drought impacts are crop yield reduction and water deficit respectively. An equation similar to Eq. 1 can be derived by analysing impacts without the application of any new mitigation options.

2.2.1 Economic Losses in Agriculture

Drought impacts in agriculture refer to the reduction of farm income due to crop yield reduction. The estimation of the yield of irrigated crops and effective rainfall is based on Smith and Steduto (2012) and the Hellenic Ministry of Development (2008) respectively:

$$\frac{y}{y_o} = 1 - k_y \bullet \left(1 - \frac{R' + U}{ET_m}\right) \tag{3}$$

$$R' = \max \left\{ \begin{array}{l} 0, \text{ if } R - \left(a + \frac{R}{8}\right) < 0 \\ R - \left(a + \frac{R}{8}\right) \end{array} \right\} \tag{4}$$

Where, y_o is the maximum crop yield for the area (t/ha), y the actual crop yield (t/ha), ET_m the actual evapontraspiration (mm) calculated as a function of potential evapotranspiration using the Blaney-Criddle method (Blaney and Criddle 1950, 1962; Papazafeiriou 1999), k_y the crop response factor, R' and R is the effective and actual rainfall (mm), respectively, U the water delivered for irrigation (output of water balance modelling, m^3) and a coefficient with values ranging from 10 (for lowland areas, close to the sea) to 20.

The economic losses in agriculture ($DEI_{a,DI}$) are defined as the difference between the net economic benefit for crop (c) yield averages and the actual yields under drought conditions, as in Eq. 5:

$$DEI_{a,DI} = \sum_c \Delta y_c \bullet AC_c \bullet PP_c \tag{5}$$

Where, Δy_c is the crop yield reduction due to drought compared to the long-term average of crop yield (t/ha), AC_c the crop area (ha; no change in cultivated area assumed) and PP_c the product price (€/t, no change in market prices assumed).

Total economic losses for the affected system can be estimated for different crops that are characterized by different crop response factors, k_y.

2.2.2 Economic Losses in Domestic Use

The domestic water deficit is estimated by the water balance model on the basis of background information for water consumption per capita, population in the region and water availability. The economic impacts of drought on the domestic sector ($DEI_{u,DI}$) are estimated on the basis of the cost of using an alternative water resource to cover the water deficit, as in Eq. 6:

$$DEI_{u,DI} = Q_u \bullet PW \tag{6}$$

Where, Q_u is the water deficit (m^3) and PW the price of alternative water resource of adequate quality (€/m^3, no change in prices assumed).

2.3 Step 3: Risk Management

The final step involves the assessment of drought mitigation options in terms of risk, vulnerability, and benefit to cost ratio. Risk is estimated for drought events of different return period, both for the baseline conditions (without mitigation) and the alternative states (with mitigation options).

Vulnerability is recognized as a complex concept with more than twenty-five definitions that explore methods for its systematic assessment (Birkmann 2006). In this work, vulnerability is expressed through the magnitude of losses and takes a value between zero (0) and one (1) indicating minimum to high vulnerability to drought, respectively (Tsakiris 2009). The following equation expresses the vulnerability of the system (V), after applying each mitigation option (the vulnerability of a system prior to the implementation of an option is assumed to be equal to 1):

$$V_{D,T,o} = \frac{DEI_{D,T,o}}{DEI_{D,T,b}} \tag{7}$$

Where, (o) refers to drought mitigation options and (b) refers to baseline conditions.

Benefit to cost (B/C) is defined as the ratio of risk reduction, due to the implementation of an option, and the associated cost of implementation, respectively to the lifetime of it, as given in Eq. 8:

$$B/C = \frac{\sum_D R_{T,b} - \sum_D R_{T,o}}{C_o} \tag{8}$$

3 The Case of Syros Island, Greece

3.1 Background Information

Syros Island is located in the Greek Cyclades complex (Fig. 2). It has a typical Mediterranean climate, with relatively low annual precipitation values. Based on 40 years of observation (1970–2010, Hellenic National Meteorological Service), mean annual precipitation is 293 mm, with very little to no precipitation during summer (4 % of annual precipitation occurs during June and September, long-term average), and mean annual potential evapotranspiration is 1675 mm (calculated using the Blaney-Criddle method). Total run-off is estimated at 3.7 hm^3/yr, whereas infiltration corresponds to 2.56 hm^3/yr (Hellenic Ministry of Development 2008) the majority of which is lost to the sea. The main economic activities in the island include agriculture, tourism, commerce and shipping. Syros faces water scarcity problems that mainly affect agriculture, as domestic water demand is mostly covered by desalination plants. The current desalination capacity equals 8340 m^3/day (thirteen reverse osmosis units with individual capacity ranging from 250 m^3/day to 2000 m^3/day) and the units operate on a daily basis using electrical energy, which is produced in the autonomous grid operated in the island by the local Public Power Corporation plant. Groundwater is primarily used for irrigation, and for domestic use only in some agglomerations, resulting into conflicts over groundwater use during drought periods.

Droughts are rather frequent (mainly mild, meteorological, events) in the Cyclades, corresponding to 45 % of the time for the period 1955–2005 (Tigkas 2008). The sectors mostly affected by drought in the past were agriculture and the urban sector, with significant water deficits. A crisis management approach has been followed so far, involving either restrictions in water supply or emergency water hauling from other areas and especially the Greek mainland. Traditional practices to cope with drought include water storage in cisterns (at the household and farm level), cultivation of local crop varieties that do not require water (e.g. melon, tomato), and land terracing as a means to reduce runoff.

The proposed methodology was implemented in Syros Island, to examine the contribution of long-term mitigation options to drought risk reduction. The aim was to analyse drought risk due to climate (change) conditions and the implementation of alternative mitigation measures, given that there is no change in the socio-economic system (i.e. population size, water use per capita, total cultivated area, crop pattern). The emphasis is on the proposed step-wise framework for assessing drought mitigation measures and not on the analysis of climate change and its effects on sectoral aspects, such as for example crop growing season or productivity. In this regard, results are illustrative of the process followed and its outcomes and should be considered with caution regarding the uncertainty involved in climate projections and future socio-economic conditions.

3.2 Results

The analysis for Syros Island covers the 2011–2050 period, with 2011 representing the baseline state for Syros. A water balance model was set up for the island, using the Water Evaluation and Planning (WEAP) software tool developed by the Stockholm Environment Institute (SEI). The model was based on the work undertaken by the Ministry of Development (2008) for developing a water management study for the island. The model was updated after consultation with local stakeholders to better represent water demand and supply nodes, their links, and their current status. Climate projections (output of the HIRHAM5 model forced by the ECHAM5 GCM for the A1B IPCC scenario) from the EU FP7 WASSERMed project (Pizzigalli et al. 2011) were used to assess drought conditions, water demand and availability in the future. Data for setting the water balance model were provided by the Hellenic Statistical Authority (2007 agricultural census, population census for 2001 and 2011, tourism statistics for the period 2005–2010), the water management study of the Hellenic Ministry of Development (e.g. per capita consumption, irrigation efficiency), the Municipal Enterprise of Water Supply and Sewerage of Syros (e.g. network losses, desalination capacity), Local Farmer

Fig. 2 Location of Syros Island, Greece

Associations (e.g. water demand for irrigation, demand coverage from water stored in cisterns), and Mpezes (2001; capacity of groundwater bodies).

For each Step of the analysis, indicative results are presented.

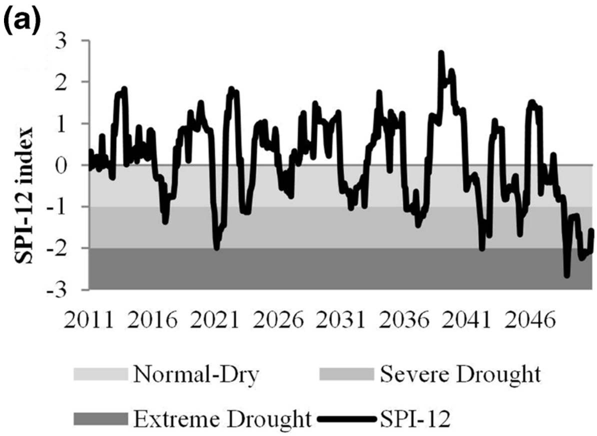
3.2.1 Drought Risk Identification

The SPI-12 index was calculated for the 2011–2050 period (Fig. 3a). Drought duration, in this work, is defined as the consecutive months with SPI-12 negative values, whereas the corresponding severity (magnitude) was the sum of the SPI-12 values for the whole drought duration. Events were classified according to their duration into five classes (1, 2, 11–13, 20–24, >25 months), to distinguish between short and prolonged events. Severity-duration-frequency (SDF) curves were developed to estimate the return period of drought events of different severity. A statistical test was performed to select the probability function that best fits the SPI data and the Gumbel Max distribution was found to be the best for the drought frequency analysis (Fig. 3b), in line with the results from similar analyses for Greece (Dalezios et al. 2000). The corresponding probability of occurrence was estimated at 28 %, 17 %, 22 %, 22 % and 11 % respectively for each one of the above duration classes. Dry spells of up to 2 months and events of 1 to 2 years duration show almost the same probability of occurrence.

3.2.2 Drought Risk Assessment

Impacts were estimated for the agricultural and domestic sectors using Eq. 3 to 6. The estimation of economic losses in agriculture was based on the existing crop pattern, classified into arable crops, vegetables, citrus, olives and grapes. The total cultivated area was assumed constant in the time period of analysis, as well as product prices, in order to examine only drought effects on water availability for irrigation and thus crop productivity. The values of crop-related parameters were obtained from the FAO Irrigation and Drainage Paper no. 66 (Smith and Steduto 2012). For the urban sector, desalination was considered to be the alternative water source for covering water deficit.

Economic losses in agriculture and the domestic sector were calculated for each drought event of given duration and return period. Figure 4 presents an example of total estimated monetary losses (sum for the two sectors) in Syros for the baseline case (no mitigation actions), due to future drought events of more than 1 year duration (accounting for almost 50 % of drought events). No economic losses were estimated for drought events of 1 month duration, whereas the losses for 2 months duration are relatively low compared to those estimated for prolonged drought events (<10 % of losses of events of the same return period and longer



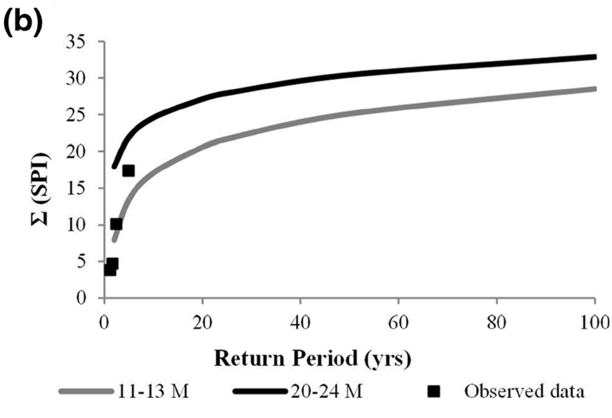


Fig. 3 **a** SPI-12 for the period 2011–2050, **b** SDF for events of one and 2 years duration

duration). Economic losses in the domestic sector account for 2 to 9 % of total losses, indicating that emphasis should be placed on mitigating impacts on the agricultural sector.

3.2.3 Drought Risk Management in Syros

Modelled drought mitigation options include: (i) Rainwater harvesting in cisterns for domestic use (up to 10 % coverage of demand), (ii) Rainwater harvesting in cisterns for irrigation (up to 25 % coverage of demand), (iii) Direct wastewater reuse for irrigation, (iv) Increase of desalination capacity to meet peak water demand, (v) Artificial aquifer recharge (wastewater reuse for groundwater recharge), and (vi) Crop substitution to more drought resilient ones (e.g. soya). For each option, the water delivered for irrigation and the deficit of the domestic use, as estimated by the water balance model, were used for calculating economic losses during drought (Fig. 5). All options contribute to the reduction of total economic losses as a result of increased water availability, with rainwater harvesting having the lowest contribution, and crop substitution the highest. Water storage in cisterns cannot support mitigation, particularly during prolonged events, as cisterns cannot be (re)filled. Even though the increase of desalination capacity increases water availability in the urban sector, significant water deficits are still estimated by the water balance model for agriculture (which is mainly supplied with groundwater) and consequently total economic losses remain high. Wastewater reuse also appears to be an effective option in mitigating drought impacts, particularly in the agricultural sector. Direct reuse has a higher effect on minimizing losses, as all the available reclaimed water is directly used for irrigation. On the contrary, in the case of aquifer recharge, a portion of the volume stored in groundwater reservoirs is also used by the domestic sector and its availability is restricted by the extraction rates of the existing drills.

On the basis of estimated economic losses for each mitigation option, total risk (Fig. 6) and vulnerability (Fig. 7) are significantly reduced for five out of six options. Given that risk

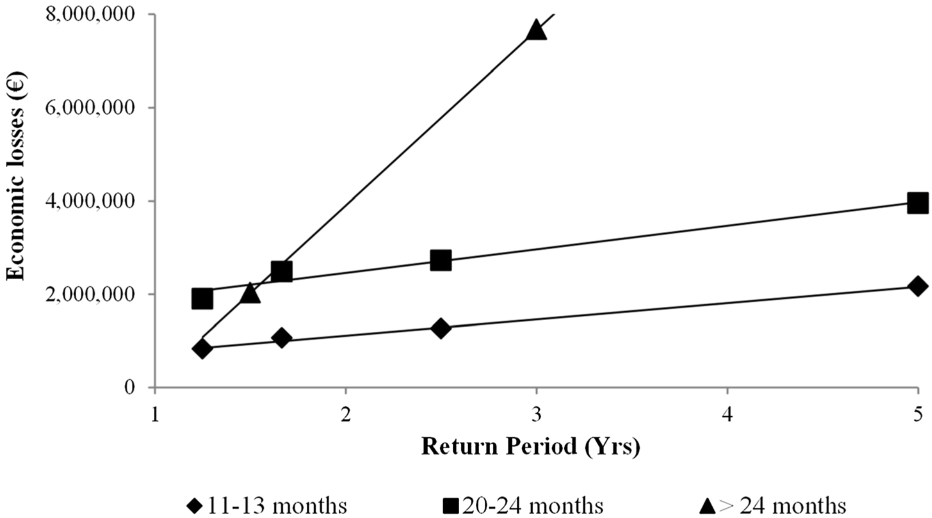


Fig. 4 Economic losses for a drought event of over 1 year duration as a function of return period (agriculture and domestic sectors)

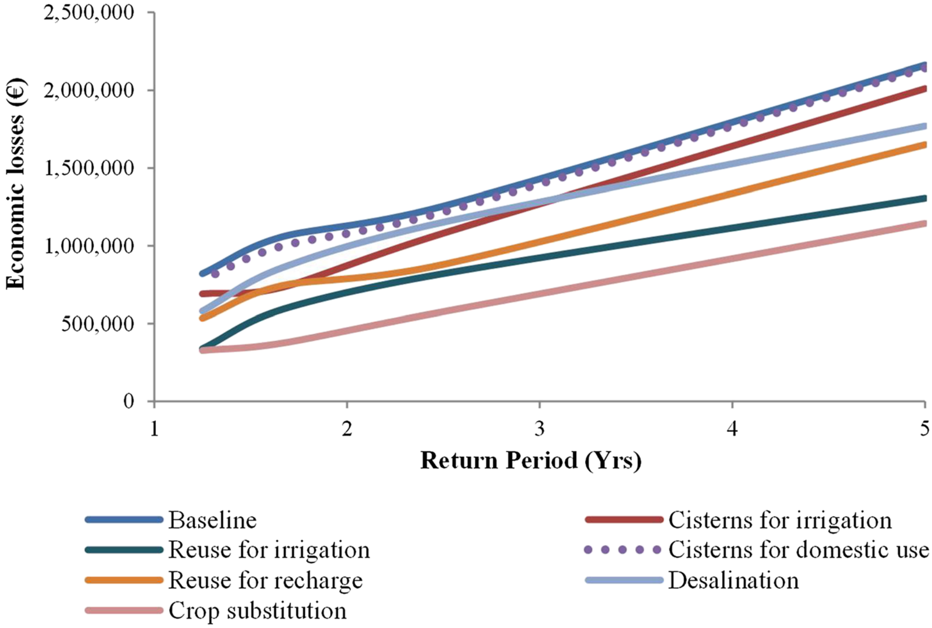


Fig. 5 Economic losses for a drought event of 1 year duration as a function of return period (agriculture and domestic sectors) with and without the implementation of mitigation options

expresses the probability of occurrence of economic losses, the contribution of each option to the reduction of risk in Fig. 6 follows the same pattern as in Fig. 5. Table 1 presents the contribution of options in risk and vulnerability reduction in the domestic and agricultural

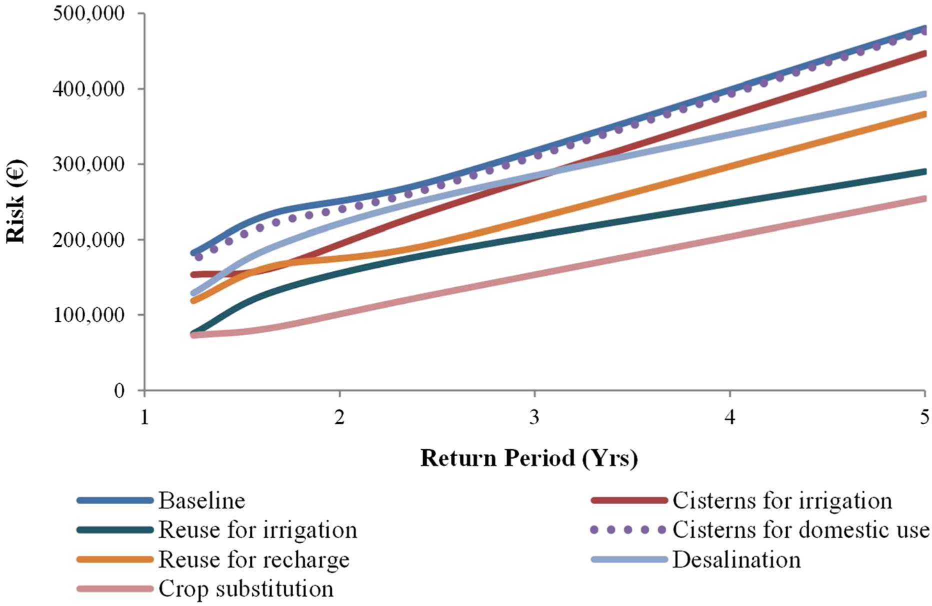


Fig. 6 Risk estimated for a drought event of 1 year duration as a function of return period

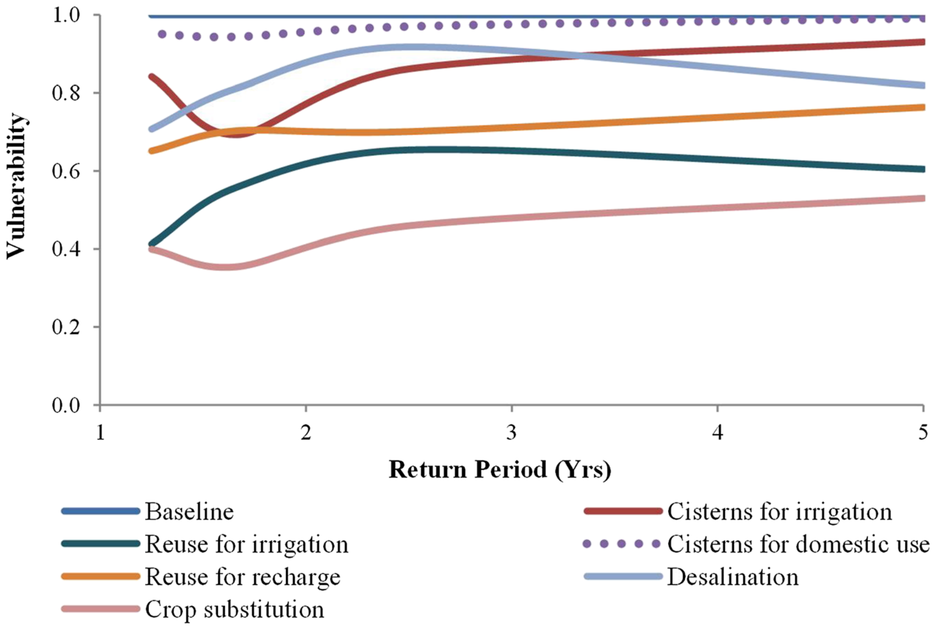


Fig. 7 Vulnerability estimated for a drought event of 1 year duration as a function of return period

sectors separately. Direct wastewater reuse for irrigation reduces risk and vulnerability both in agriculture and domestic sector (Table 1), as water irrigation needs are fully met, the demand for groundwater is reduced and there is more water available for domestic use (for those agglomerations in the island supplied with water from groundwater sources). Increase of desalination capacity to meet water demand also eliminates water deficit in the urban sector and thus significantly reduces vulnerability to drought. Crop substitution appears to be the best option for agriculture, as the cultivation of more drought resilient crop minimizes economic losses. Considering total risk and vulnerability, crop substitution and direct wastewater reuse are the two options that minimize impacts.

Table 1 Cross-comparison of options for a drought event of 5 years return period

Option	Risk of losses (M€)		Vulnerability		Capital cost	
	Agriculture	Domestic use	Agriculture	Domestic use	€/m^3	Annualised (€; 40 years depreciation period & 5 % rate)
Baseline (no options)	0.45	0.02	1.00	1.00	–	–
Cisterns for irrigation	0.42	0.02	0.93	1.00	100	323,444
Reuse for irrigation	0.29	0.00	0.63	0.00	935	61,432
Cisterns for domestic use	0.45	0.02	0.99	0.94	100	79,841
Reuse for groundwater recharge	0.35	0.02	0.76	0.81	1168	94,722
Desalination	0.39	0.00	0.86	0.00	1100	32,956
Crop substitution	0.24	0.01	0.52	0.64	–	2,158,281

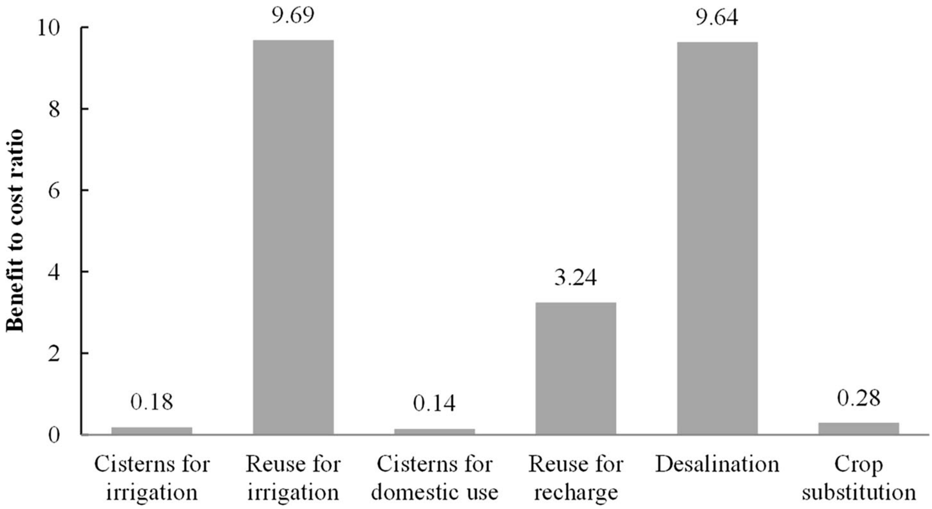


Fig. 8 Benefit to cost ratio for each drought mitigation option

The B/C ratio (Fig. 8), for the options examined, was estimated considering the total risk of all possible drought events with a 5-year return period, not just the events with 11–13 months duration. Cost (Table 1) involves the implementation costs of each option (capital and O&M costs), with the exception of the crop substitution option, in which case cost corresponds to the net economic output foregone by the farmers (permanent crop substitution assumed). The unit cost for investment, operation and maintenance of wastewater reuse facilities was obtained from the study of Gonzalez-Serrano et al. (2005). The options with higher benefit to cost ratio are wastewater reuse for irrigation and increase of desalination plant capacity. Even though crop substitution is estimated to be the best option in minimizing losses in case of drought, the annual cost for farmers as a result of the permanent change in crops (from current crop pattern to more drought resilient crops) is extremely high and thus this option has a very low B/C ratio. Reuse for recharge is estimated also to have a low B/C ratio, as the implementation cost and the drought-related economic losses are higher than those of direct reuse. Low-cost options, such as rainwater harvesting, do not significantly minimize total risk and vulnerability and thus can only be used as supplementary to other drought mitigation options, supporting mitigation in drought events of low duration (<2 months).

4 Summary and Conclusions

The proposed framework addresses the evaluation and selection of long-term drought mitigation options using a risk-based approach. As socio-economic damages from drought cannot be accurately forecasted, the estimation of risk can support decision making for long-term preparedness, particularly under the framework of uncertainty related to climate projections. The process encompasses drought hazard analysis, drought impact assessment and risk management, and provides an objective tool for the comparison and evaluation of options, facilitating drought management efforts.

SPI has been selected due to its usefulness for planning and decision-making and limited data requirements. However, the approach is straightforward and other drought (single or composite) indices can be used instead to better represent either drought intensity in a region or drought impacts on a specific sector (e.g. agriculture). The same also applies for the estimation of other parameters. Depending primarily on data availability, more sophisticated (or data intensive) methods can be applied for estimating for example irrigation-related parameters (e.g. evapotranspiration, effective rainfall). In this work, it was selected to illustrate the methodology using easily applicable calculation methods, in order to stress that risk-based assessments can still be performed in cases with limited data availability.

Results have been illustrated for the case of events of a 5-year return period. Similar analysis for events of different return periods provides the range of future drought-related risks. The contribution of each option to the mitigation of impacts and risk reduction could thus be assessed for alternative "drought conditions", and drought planning could be oriented towards minimizing total risk or risk associated to drought events of specific characteristics. In addition, the assessment of total and sectoral risks could guide individual mitigation efforts along with the overall drought planning.

Risk and vulnerability are by definition interrelated concepts and therefore provide the same results in terms of option ranking. The use of an additional economic criterion in the analysis (benefit to cost ratio) enhances the selection process. However, further criteria should be used to account for the social-related component of drought management, as the social acceptability of an option could affect its adoption or rejection. In addition, the acceptable level of drought risk is a social and political decision that reflects region-specific priorities and values.

For the case of Syros Island, results from hazard analysis show that drought episodes with duration longer than 1 year account for almost 50 % of events. Emphasis should thus be placed on managing prolonged events through the appropriate mix of short-term and long-term measures. However, a similar analysis is recommended (i) using climate projections from other models and IPCC scenarios, to deal with uncertainty in climate projections and have a more complete view of the anticipated future drought conditions, and (ii) incorporating scenario analysis to account for social characteristics (e.g. population growth) and sectoral development policies. Furthermore, the analysis indicated that a long-term strategy for drought-risk reduction should consider wastewater reuse. The Joint Ministerial Decree 145116/11 (GG B' 354/2011) sets the standards, measures and processes for wastewater reuse and could guide a more detailed analysis of the reuse potential in Syros.

Acknowledgments Climate projections used in this paper are a result of the EU-funded FP7 project WASSERMed 'Water Availability and Security in Southern EuRope and the Mediterranean' (Grant agreement no.: 244255), WP2 'Regional Climate and Water Scenarios'. This study has been partially financed by the EU-funded FP7 project DROUGHT-R&SPI 'Fostering European Drought Research and Science-Policy Interfacing' (Grant agreement no: 282769).

References

Belayneh A, Adamowski J, Khalil B, Ozga-Zielinski B (2014) Long-term SPI drought forecasting in the Awash River Basin in Ethiopia using wavelet neural network and wavelet support vector regression models. J Hydrol 508:418–429

Birkmann J (ed) (2006) Measuring vulnerability to natural hazards – towards disaster resilient societies. United Nation University Press, Tokyo

Blaney HF, Criddle WD (1950) Determining water requirements in irrigated area from climatological irrigation data. US Department of Agriculture, Soil Conservation Service, Tech. Pap. No. 96, 44 p

Blaney HF, Criddle WD (1962) Determining consumptive use and water requirements. USDA, Technical Bull. No. 1275, 59 p

Cacciamani C, Morgillo A, Marchesi S, Pavan V (2007) Monitoring and forecasting drought on a regional scale: Emilia-Romagna region. Water Sci Technol Libr 62(1):29–48

Cancelliere A, Nicolosi V, Rossi G (2009) Assessment of drought risk in water supply systems, In: A. Iglesias et al. (eds) Coping with Drought Risk in Agriculture and Water Supply Systems, Advances in Natural and Technological Hazards Research 26, Springer, pp 93–109. doi: 10.1007/978-1-4020-9045-5_8

Cubillo F, Garrote L (2008) Drought risk and vulnerability in water supply systems. In: López-Francos A. (ed) Drought management: scientific and technological innovations, Options Méditerranéennes: Série A. Séminaires Méditerranéens, n80, Zaragoza: CIHEAM, pp 21 - 27

Dalezios NR, Loukas A, Vasiliades L, Liakopoulos E (2000) Severity-duration-frequency analysis of droughts and wets periods in Greece. Hydrol Sci J 45(5):751–770. doi:10.1080/02626660009492375

Dziegielewski B (2003) Long-term and short-term measures for coping with drought. In: G. Rossi et al. (eds) Tools for drought mitigation in mediterranean regions, Kluwer, Dordrecht, The Netherlands, pp 319–339

Fontaine M, Steinemann A (2009) Assessing vulnerability to natural hazards: impact-based method and application to drought in Washington State. Natural Hazards Review 10(1):11–18. doi: 10.1061/(ASCE)1527-6988(2009)10:1(11)

Gonzalez-Serrano E, Rodriguez-Mirasol J, Codero T, Koussis A, Rodriguez J (2005) Cost of reclaimed municipal wastewater for applications in seasonally stressed semi-arid regions. J Water Supply Res Technol AQUA 54(6):355–369

Hayes M, Svodoba M, Wilhite D, Vanyarkho O (1999) Monitoring the 1996 drought using the Standardized Precipitation Index. Bull Am Meteorol Soc 80(3):429–438

Hayes M, Wilhelmi O, Knutson C (2004) Reducing drought risk: bridging theory and practice. Nat Hazards Rev 5(2):106–113. doi:10.1061/(ASCE)1527-6988(2004)5:2(106))

Hellenic Ministry of Development (2008) Development of Systems and Tools for Water Resources Management in the Hydrological Department of the Aegean Islands. 2001-2008, Athens

Iglesias A, Garrote L, Martin-Carrasco F (2009) Drought risk management in Mediterranean River Basins. Integr Environ Assess Manag 5(1):11–16. doi:10.1897/IEAM_2008-044.1

Jinno K (1995) Risk assessment of a water supply system during drought. Int J Water Resour Dev 11(2):185–204. doi:10.1080/07900629550042399

Karavitis CA (1999) Decision support systems for drought management strategies in Metropolitan Athens. Water Int 24(1):10–21. doi:10.1080/02508069908692129

Li Y, Ye W, Wang M, Yan X (2009) Climate change and drought: a risk assessment of crop-yield impacts. Clim Res 39:31–46. doi:10.3354/cr00797

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. Eighth Conference on Applied Climatology, American Meteorological Society, Jan17-22, 1993, Anaheim CA, pp. 179–184

Merabtene T, Kawamura A, Jinno K, Olsson J (2002) Risk assessment for optimal drought management of an integrated water resources system using a genetic algorithm. Hydrol Process 16:2189–2208. doi:10.1002/hyp.1150

Mishra AK, Desai VR (2006) Drought forecasting using feed-forward recursive neural network. Ecol Model 198(1–2):127–138

Mpezes K (2001) Water Management Study for the Cyclades Complex, Directorate of Technical Services, Prefecture of Cyclades, Syros Island

Papazafeiriou GZ (1999) Crop water requirements. ZITI Publications, Thessaloniki

Pizzigalli C, Congedi L, Lionello P, Fahmi AH, Shatanawi M, Chabaane ZL (2011) Climate data analysis in the WASSERMed project. Geophysical Research Abstracts, Vol. 13, EGU2011-8920-1

Pliefke T, Sperbeck ST, Urban M, Peil U, Budelmann H (2007) A Standardized Methodology for Managing Disaster Risk – An Attempt to Remove Ambiguity. The 5th International Probabilistic Workshop, Ghent: ACCO, pp. 283–294

Querner R, van Lanen HAJ (2001) Impact assessment of drought mitigation measures in two adjacent Dutch basins using simulation modelling. J Hydrol 252:51–64. doi:10.1016/S0022-1694(01)00452-8

Rossi G, Cancelliere A (2013) Managing drought risk in water supply systems in Europe: a review. Int J Water Resour Dev 29(2):272–289. doi:10.1080/07900627.2012.713848

Rossi G, Cancelliere A, Giuliano G (2005) Case Study: Multicriteria Assessment of Drought Mitigation Measures. Journal of Water Resources Planning and Management, November/ December, 131(6):449–457. doi: 10.1061/(ASCE)0733-9496(2005)131:6(449)

Rossi G, Castiglione L, Bonaccorso B (2007) Guidelines for planning and implementing drought mitigation measures. SPRINGER VERLAG GMBH, Netherlands

Rossi G, Nicolosi V, Cancelliere A (2008) Strategic water shortage preparedness plan for complex water supply. Eur Water 23(24):13–28

Shahid S, Behrawan H (2008) Drought risk assessment in the western part of Bangladesh. Nat Hazards 46:391–413. doi:10.1007/s11069-007-9191-5

Smith M, Steduto P (2012) Yield response to water: the original FAO water production function. In: Steduto P, Hsiao TC, Fereres E, Raes D (eds) Crop yield response to water, FAO Irrigation and Drainage Paper No66. Food and Agriculture Organisation of the United Nations, Rome, pp 6–13

Stagge JH, Tallaksen LM, Gudmundsson L, Van Loon AF, Stahl K (2015) Candidate distributions for climatological drought indices (SPI and SPEI). Int J Climatol. doi:10.1002/joc.4267

Tigkas D (2008) Drought characterization and monitoring in regions of Greece. Eur Water 23(24):29–39

Todisco F, Mannocchi F, Vergni L (2012) Severity–duration–frequency curves in the mitigation of drought impact: an agricultural case study. Nat Hazards. doi:10.1007/s11069-012-0446-4

Tsakiris G (2009) A paradigm for applying risk and hazard concepts in proactive planning. In: Iglesias et al. (eds) Coping with drought risk in agriculture and water supply systems, advances in natural and technological hazards research 26, Springer, pp 81–89. doi: 10.1007/978-1-4020-9045-5_7

Tsakiris G, Vangelis H (2004) Towards a drought watch system based on spatial SPI. Water Resour Manag 18(1): 1–12

UN/ISDR (2009) Drought risk reduction framework and practices: contributing to the implementation of the Hyogo Framework for Action. UNISDR, Geneva, Switzerland & NDMC, Lincoln, Nebraska, U.S.A

UNDP (2011) Mainstreaming Drought Risk Management: A primer. UNON Printshop, Nairobi

Wilhite DA, Hayes MJ, Knutson C, Helm Smith K (2000) Planning for drought: moving from crisis to risk management. J Am Water Resour Assoc 36(4):697–710. doi:10.1111/j.1752-1688.2000.tb04299.x

Wilhite DA, Svoboda M, Hayes M (2007) Understanding the complex impacts of drought: a key to enhancing drought mitigation and preparedness. Water Resources Management 21:763–774. doi:10.1007/s11269-006-9076-5

Wu H, Hubbard KG, Wilhite DA (2004) An agricultural drought risk-assessment model for corn and soybeans. Int J Climatol 24:723–741. doi:10.1002/joc.1028