Austin Journal of Hydrology

Open Access

Austin Publishing Group

Case Report

Management Options of a Brackish Water Spring. Case Study: Almyros Spring (Heraklion, Greece)

Alexakis D*

Laboratory of Reclamation Works and Water Resources Management, National and Technical University of Athens, Greece

***Corresponding author:** Alexakis D, Laboratory of Reclamation Works and Water Resources Management, School of Rural and Surveying Engineering, National and Technical University of Athens, 9 Heroon Polytechniou, 15780 Zografou, Athens, Greece

Received: October 05, 2015; **Accepted:** January 19, 2016; **Published:** January 22, 2016

Abstract

Management options of brackish water springs seemed to attract many researchers the last decades. The unsuitable quality of the brackish water resources is generally considered as a great barrier to their application for irrigation or human consumption. The main goal of the development of brackish spring water is to obtain a good quality status for water body. This goal can be achieved by taking measures against seawater intrusion (controlled withdrawals, increase fresh water head by dam construction) or by applying desalination methods (e.g. reverse osmosis, ε lectrodialysis). A simplified flowchart has been presented to develop the brackish spring water in coastal aquifers. The example of the Almyros Heraklion spring water (Crete, Greece) is discussed.

Keywords: Brackish water; Water quality; Karstic spring; Almyros spring; Crete

Introduction

Among the possible solutions to combat water scarcity problems in Mediterranean Region, the first priority is usually given to the sustainable use of existing water resources. According to many scientists [1-4], among the main pillars of water management strategies are: (a) to apply measures for efficient use of fresh water, and (b) to develop management of non-conventional water resources (e.g. rainwater harvesting, recycled water and brackish water). Brackish water use can be a possible solution to the water scarcity problems [4-6].

The karstic aquifers in many Mediterranean coasts are the main source of freshwater while they exhibit a very fragile behavior because these systems are prone to seawater intrusion and consequently to the deterioration of freshwater quality. Moreover, issues dealing with karstic springs seem to attract many scientists worldwide [6-8]. It is noteworthy to mention that a water mixture composed of only 5% seawater and 95% freshwater exceeds the parametric values and criteria for drinking and irrigation uses [4,6,9]. Needless to say that management problem of a brackish spring is not an exclusive matter of quantity but also of water quality.

Brackish water management options

The goals of the European Water Framework Directive [10] include, among others, the attainment of good chemical and ecological status for surface water bodies and of good quantitative and chemical status for groundwater bodies. The computation of water balances, the definition of the status of water body, the designing of monitoring networks as well as the management of exploitation plans are quite difficult tasks to be carried out in karstic coastal aquifers due to possibility of seawater intrusion.

Hydrogeological science has advanced the state of the art on seawater intrusion, but has not found a solution yet. The main goal of the management of brackish spring water is to obtain a good quality status for water body.

The main factors controlling the selection of a particular development method are: (a) geological conditions, (b) economic factors, and (c) water needs of the area. The main actions comprising a management plan of brackish water may be summarized as follows (Figure 1 & Table 1): (a) to prevent the water contamination by taking measures against seawater intrusion (upraise the fresh water hydraulic head by a dam construction at the spring mouth, to block entirely or at least partly the seawater intrusion by a special marine dam), (b) to treat the brackish water by selecting the most suitable desalination method (e.g. distillation, reverse osmosis, electrodialysis), and (c) to estimate the useful water potential of sources with varying water

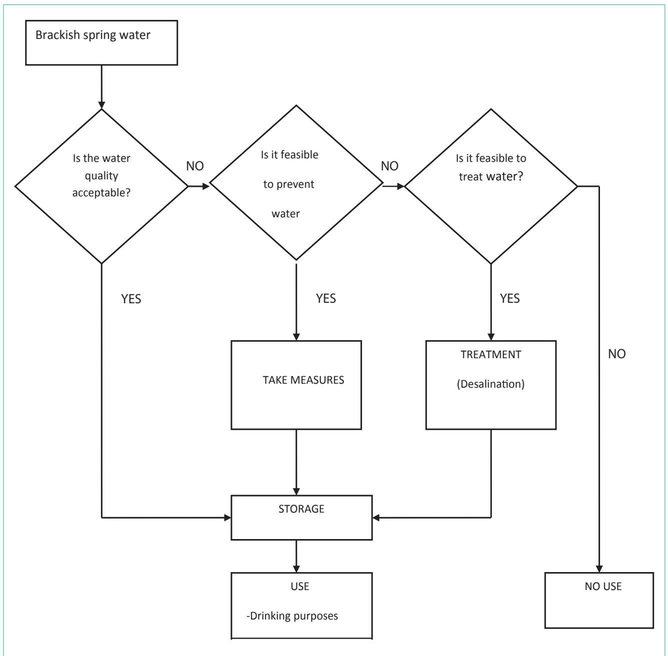

Figure 1: Proposed simplified flowchart for the development of a brackish water spring.

Citation: Alexakis D. Management Options of a Brackish Water Spring. Case Study: Almyros Spring (Heraklion, Greece). Austin J Hydrol. 2016; 3(1): 1017.

Table 1: Development technologies matrix for a brackish water spring.

Main goal	Method of development	Technology	Advantages	Disadvantages
Preventing water contamination	Interception of fresh water inland of the seawater influence	Construction of boreholes or tunnels	No further water treatment is required	• Difficulties to locate the fresh water • Difficulties in the determination of the amount of fresh water that could be taken from the aquifer without sea water intrusion going further inland
	Upraise the fresh water hydraulic head and block the seawater intrusion	Construction of a dam in front of the karstic spring	Many possibilities to block seawater intrusion	• Difficulties in the determination of the sufficient upraising • Difficulties in the estimation of the freshwater loss to the sea
	Block at least partly the lower conduit	Construction of a special marine dam	Many possibilities to block seawater intrusion	• Difficulties in locating the saturated karstic conduit
Treating water	Desalination	Reverse osmosis, vapour compression, distillation	The last years desalination methods have been technically improved	• High economic cost of basic overhead • High requirements of energy amounts which is costly both in environmental pollution and in money terms • Concentrate disposal ($NaSO_4$, NaCl, etc)
Estimation of useful water potential	Assessing the water potential	Apply fuzzy sets	No further water treatment is required Low economic cost	• Strong quality seasonality • The estimated suitable water quantities are a small proportion of the annual water volumes discharged

Table 2: Cost of water produced (per m^3) and thermal methods.

Desalination Technology	Short Description	Size of unit (m^3/day)	Cost (Euro per m^3)	Source of Information
Reverse osmosis (RO)	Membrane method	< 20 20-1200 40000-46000	4.50 – 10.32 0.62 – 1.06 0.21 – 0.43	[12, 34]
vapour compression (VC)	Thermal method	1000-1200	1.61 - 2.13	[12,35]

quality which is based on the identification of the period at which all quality parameters are within the acceptable limits which are dictated by the quality requirements of the use.

A variety of technologies for treating brackish water has been developed over the years, including primarily reverse osmosis, vapor compression and distillation. Desalination systems can be categorized in the following types: (a) those powered by renewable energy sources (solar, wind, etc), and (b) those powered by conventional energy sources (gas, oil, electricity). Spain has the largest in Europe and the world's fifth largest desalination capacity at 800 km^3 per day from facilities at Almeria (5), Alicante (7), Barcelona (1), Murcia (5), Malaga (2) and Girona (1) which allow the Spanish regions to maintain their hydro-independence [11]. The price of desalinated water has been expensive in comparison with conventional water supplies. Since desalination plants consume vast quantities of power, water prices and drinking water availability are influenced from fossil fuel prices. Karagiannis and Soldatos [12] reported that desalination is still not a desirable option due to the large amounts of the required energy (Table 2). The desalination facility in Lastovo (Croatia) produces high costly water (\$2.05 per m^3) as a result of a high investment costs, especially civil works [13].

Many researchers have performed cost analysis of desalinated water [12,14,15]. According to these studies, the price of desalinated water in 2010 varied between \$0.2-1.2/m^3 for brackish water and \$ 0.3-3.2/m^3 for seawater. Other researchers [16,17] reported that the prices for water abstracted from wells, lakes or rivers are at least two or three times lower than prices for desalinated water.

Case Study

Description of the almyros spring

The spring of Almyros is located about 8 km from Heraklion city (Crete Island, Greece). The average annual volume of water discharged at the spring is about 240 million m^3 [18]. It is a periodically brackish spring, its discharge range from 4 $m^3 s^{-1}$ in dry period to 70-80 $m^3 s^{-1}$ in the wet period [19]; while the electric conductivity value of Almyros spring water ranges from 331 to 18430 $\mu S\ cm^{-1}$ [20]. Regarding the mechanism of seawater intrusion of the Almyros karstic system, most geologists, following Breznik [21], assumes that fresh water is becoming brackish at a mixing reservoir.

Development of the almyros spring

The development of the spring is of prominent socio-economical importance for both the irrigation and drinking demands of Heraklion-Crete. Obtaining water of suitable quality from Almyros brackish spring is a challenging issue that requires interdisciplinary scientific cooperation. Development of this spring seemed to attract many researchers [3,4,6,21-31] in order to better understand the function mechanism of the Almyros karstic system, but still, successfully realized solutions of coastal karstic springs protection from sea water intrusion were not achieved. The scope of the Almyros experiment conducted in 1987 [32] was to artificially raise the fresh water level in the Almyros spring reservoir up to 10 m a.s.l. and finally to increase the hydraulic head in the karstic conduit aiming to block, at least partly, the intrusion of seawater. The experiment results were not negative, since it is outlined that a dam with a height of 6 m can improve the water quality of the spring only by a magnitude of about 500 mg L^{-1}. Maramathas et al. [19] applied a model for the simulation of the periodically brackish spring of Almyros and concluded that an upraising of the outlet point of Almyros spring up to the elevation of 26 m will block totally the seawater intrusion. Panagopoulos and Lambrakis [8] presented that the Almyros karstic system presents a bimodal character: (a) the first component presents a decorrelation time of the first 6 days which is attributed to the quick drainage of the aquifer by the karstic conduits, and (b) the second component shows a decorrelation time of 55 days, which is explained by the presence of a dominant base flow. Arfib et al. [20] concluded that the distance between the Almyros spring and the zone where the seawater intrudes into the conduit can be calculated by using the salinity variations as a tracer and that the volume of the karstic conduit between the spring and the mixing zone was calculated to be constant. Tsakiris et al. [31] have applied two fuzzy methodologies in order to assess the water quantity of the spring which is suitable for various uses. The min intersection rule is more appropriate for the appraisal of the water potential for drinking purpose; while the multicriteria filtering method is a flexible method for classifying annual water quantities into quality categories in respect to European Union directives and irrigation guidelines. Alexakis and Tsakiris [4] reported that the statistical analysis test identified significant trends for the determined quantity parameters (annual discharge) and the determined quality parameter (chloride concentration). Moreover, they concluded that climate change is most likely to provoke the seawater intrusion in Almyros karstic system which will be caused by the reduction of freshwater hydraulic head. Concerning desalination option, Karagiannis and Soldatos [12] reported that the cost of a desalination system with capacity of 60000 m^3 per day, which is comparable with the water demands of the city of Heraklion, is in the range of 0.26-0.54 \$. According to Mohsen [33], the cost of a major desalination plant with a capacity of 250 million m^3 per year, is about \$ 1 billion (about \$250 million for required operating expenses for fifteen years and \$ 600-700 million for basic overhead). For a major desalination unit with capacity of 250 million m^3, which is comparable to the average annual volume of Almyros spring water, the cost of brackish water desalination is about 4\$/m^3. Consequently, desalination of Almyros spring water is still an expensive solution to obtain acceptable water quality (Table 2).

A study conducted by Tsakiris and Alexakis [6] indicated that a significant impact on the water quality and quantity of the Almyros spring can be attributed even to the abstraction of a relatively small quantity of groundwater, in other words, Almyros karstic system exhibits a very fragile behavior. According to Tsakiris and Alexakis [6], the detected changes in the water quality of the Almyros spring during the dry period could be attributed to the withdrawal of groundwater from the recharge area.

Investigation of innovative methods for the mapping of almyros karstic system

The karstic conduits and large voids that present in karstic aquifers are difficult, even impossible to be localized from the surface by any method, geophysical as well as geological investigation. Sinkholes and paleo-karstic conduits in karstic environments can be a nightmare or a dream [36]. Geophysics can help to investigate a karstic aquifer but the geophysical method and parameters that may be best suited for the problem at hand are a less certain choice. A karst mapping by using the new geophysical methods could investigate the karstic conduits that hydraulically connect the sea with the brackish springs.

The method of MRS (Magnetic Resonance Sounding) has been applied to Hortus karst area (Lamalou spring, France). According to Vouillamoz et al. [37] the MRS proved a useful tool for karst mapping because it can identify the spatial variations of transmissivity and permeability that delineate karstic structures bearing water (as caves and conduits). Consequently, the objective of the Almyros karst mapping using the new method of MRS is to localize the saturated karstic aquifer and delineate the spring function mechanism. The localization of the karstic conduit is a very important parameter in order to better develop and manage the brackish springs and combat the water scarcity problems.

Conclusion

The spring function mechanism of coastal karstic springs has not been yet fully understood. The localization of the saturated karstic aquifer, the knowledge of the geometry and position of the main karstic conduit should be used successfully for the implementation of the necessary measures for the management of the spring water. The detailed exploration of the Almyros karstic conduit is necessary in order to delineate the hydraulic connection between the sea and the spring. The proposed management and development scenario of Almyros karstic spring has the following steps: (a) to prevent water contamination by taking measures (e.g. raising up artificially the fresh hydraulic head, constructing a dam, controlled withdrawals), and (b) to apply fuzzy methodologies for evaluating the water potential with varying water quality and store suitable water. The high economic cost of basic overhead as well as the high operating expenses of a desalination plant should be considered. The desalination is already an important water management option in energy-rich and water scarce regions of the world.

References

1. Saadi A, Quazzani N. Perspectives of desalination of brackish water for valorisation in arid regions of Morocco. Desalination. 2004; 165: 81.
2. Agoramoorthy G. Rainwater Harvesting Essential for Dryland Sustainability. Austin J Hydrol. 2014; 1.
3. Alexakis D. Brackish water use. Case Study: Crete Almyros spring water. Proceedings of International Symposium on Water Shortage Management. Athens, Greece: EWRA Publications. 2008.
4. Alexakis D, Tsakiris G. Drought impacts on karstic spring annual water potential. Application on Almyros (Heraklion Crete) brackish spring. Desal Water Treatment. 2010; 16: 229-237.
5. Helfer F, Sahin O, Stewart RA. Bridging the water supply–demand gap in Australia: coupling water demand efficiency with rain-independent desalination supply. Water Resour Manage. 2015; 29: 253-272.
6. Tsakiris G, Alexakis D. Karstic spring water quality: the effect of groundwater abstraction from the recharge area. Desalination and Water Treatment. 2014; 52: 2494-2501.
7. Fiorillo F. Some Considerations on Hydrograph Recession of Karst Springs. Austin J Hydrol. 2014; 1.
8. Panagopoulos G, Lambrakis N. The contribution of time series analysis to the study of the hydrodynamic characteristics of the karst systems: Application on two typical karst aquifers of Greece (Trifilia,Almyros Crete). J Hydrol, 2006; 329: 368-376.
9. European Community. Council Directive 2000/60/EC. Directive of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy. The European parliament and the Council of the European Union. Official Journal L 327, 22/12/2000. 2000.
10. European Community. Council Directive (98/83/EC) of 3 November 1998 on the quality of water intended for human consumption. Offic J Eur Commun, L 330. 1998.
11. Downward SR, Taylor R. An assessment of Spain's Programa AGUA and its implications for sustainable water management in the province of Almeria, southeast Spain. J of Environ Manage. 2007; 82: 277-289.

12. Karagiannis IC, Soldatos PG. Water desalination cost literature: review and assessment. Desalination. 2008; 223: 448-456.

13. Sambrailo D, Ivic J, Krstulovic A. Economic evaluation of the first desalination plant in Croatia. Desalination. 2005; 170: 339-344.

14. Gude VG, Nirmalakhandan N, Deng S. Renewable and sustainable approaches for desalination. Renew Sust Energ Rev. 2010; 14: 2641-2654.

15. Ziolkowska JR. Is desalination affordable?-Regional cost and price analysis. Water Resour Manage. 2015; 29: 1385-1397.

16. Afgan NH, Darwish M, Carvalho MG. Sustainability assessment of desalination plants for water production. Desalination. 1999; 124: 19-31.

17. Daniels T, Daniels K. The environmental planning handbook for sustainable communities and regions. Chicago: APA/Planners Press. 2003.

18. Paritsis S. Preliminary report on the potable water potential of the karstic saline Almyros spring, Heraklio, Crete, Greece. O.AN.A.K. 2007.

19. Maramathas A, Maroulis Z, Marinos-Kouris D. Blocking Sea Intrusion in Brackish Karstic Springs. The case of Almiros Spring at Heraklio Crete, Greece. Europ Wat. 2003; 1/2: 17-23.

20. Afrib B, Marsily G, Ganoulis J. Locating the zone of saline intrusion in a coastal karst aquifer using spring flow data. Ground Water. 2007; 45: 28-35.

21. Breznik M. Mechanism and development of the brackish karstic spring Almyros Herakliou. Annal Geolog des Pays Helleniques. 1978; 29:29-46.

22. Breznik M. Development of Brackish karstic spring Almyros in Greece. Geologija. 1988; 31-32: 555-576.

23. Burdon DJ, Papakis NJ. Preliminary note on the hydrogeology of Almyros spring Heraklio Crete. In: Geological and Geophysical Studies, Rep. 1964; IX: 121-144.

24. FAO – Breznik M, Re R. Les problemes des sources d'Almyros-Heraklio. Note technique no2 FAO, document provisoire. 1968.

25. FAO – Dietrich G, Re R. Study of the Almyros spring of Heraklion, Technical report no3, UNDP-FAO-GRE/31. 1972.

26. FAO – Thomas R. Captage des eaux douces de la source Almyros d'Heraklio Greece, Conclusions et recommendations du project, UNDP-FAO-GRE/72002. 1977.

27. Monopolis D, Mastoris K. Hydrogeological investigations of Almyros spring. Inst. Geol. and Subsurface Research Athens. 1969; 1: 210.

28. Gersar/Scp-Barbier JL. L'Armyros d'Heraklion. Rapport general de synthese. 1992; 65.

29. Lambrakis N, Andreou AS, Polydoropoulos P, Georgopoulos E, Bountis T. Non-linear analysis and forecasting of a brackish karstic spring. Water Resour Res. 2000; 36: 875-884.

30. Platakis EK. Cave and Others Karstic Form of Crete (in Greek). Heraklion, Greece: Tome A. 1973.

31. Tsakiris G, Spiliotis M, Paritsis S, Alexakis D. Assessing the water potential of karstic saline springs by applying a fuzzy approach: The case of Almyros (Heraklion, Crete). Desalination. 2009; 237: 54-64.

32. Breznik M. Storage Reservoir and Deep Wells in Karst Regions.Rotterdam, the Netherlands: A.A.Balkema. 1998.

33. Mohsen MS. Water strategies and potential of desalination in Jordan. Desalination. 2007; 203: 27-46.

34. Tian J, Shi G, Zhao Z, Cao D. Economic analyses of nuclear desalination system using deep pool reactors. Desalination. 1999; 123: 25-31.

35. Voivontas D, Misirlis K, Manoli E, Arampatzis G, Assimacopoulos D, Zervos A. A tool for the design of desalination plants powered by renewable energies, Desalination. 2001; 133: 175-198.

36. Hoover R. Geophysical choices for karst investigations. Prepared for 9th Multidisciplinary Conference on Sinkholes & the Engineering and Environmental Impacts of Karst. Huntsville Alabama, USA, 2003.

37. Vouillamoz J, Legchenko A, Albouy Y, Bakalowicz M, Baltassat J, Al-Fares W. Localization of Saturated Karst Aquifer with Magnetic Resonance Sounding and Resistivity Imagery. Groundwater. 2003; 41: 578-586.

Austin J Hydrol - Volume 3 Issue 1 - 2016
ISSN : 2380-0763 | www.austinpublishinggroup.com

Citation: Alexakis D. Management Options of a Brackish Water Spring. Case Study: Almyros Spring (Heraklion, Greece). Austin J Hydrol. 2016; 3(1): 1017.