*Environmental Engineering and Management Journal* July 2015, Vol.14, No. 7, 1721-1733
http://omicron.ch.tuiasi.ro/EEMJ/

*"Gheorghe Asachi" Technical University of Iasi, Romania*

# APPROPRIATE TECHNOLOGIES FOR DRINKING WATER TREATMENT IN MEDITERRANEAN COUNTRIES

**Sabrina Sorlini*, Luca Rondi, Andrea Pollmann Gomez, Carlo Collivignarelli**

*University of Brescia, Department of Civil Engineering, Architecture, Land, Environment and of Mathematics,CeTAmb LAB – Research laboratory on appropriate technologies for environmental management in resource-limited Countries, 43 Via Branze, 25123 Brescia, Italy*

**Abstract**

This paper aims at analyzing the drinking water issue in the Mediterranean region, highlighting the principal problems and the appropriate technologies applicable in the different countries. The countries of this area are characterized by a huge variety from social, cultural, economic and environmental point of view. In particular, water distribution is inhomogeneous between the North, East, and South; even the type of water sources and the related quantity and quality problems differ country by country.
Potable water comes from brackish and seawater, surface water, groundwater and water reservoirs with each source face different issues. The main problem of brackish and seawater for example is the high salinity and the contamination by disinfection byproducts, in addition to the microbiological and chemical contamination due to human activities that characterize also other surface water sources. Groundwater is also affected by human activity and it is not exempted from salinity because of the water intrusion. Moreover, water reservoirs are often contaminated by seasonal algal blooms.
Technologies applied for drinking water treatment vary country by country. The paper presents the main treatment processes associated with the main water pollutants, according to the Mediterranean region. Case studies of drinking water treatment plants are also analyzed, presenting alternative technologies appropriate for specific contexts, among others. The characteristics of each specific context should be carefully analyzed in order to develop the most appropriate technologies; high-end technologies for drinking water treatment may not be applied equally to all countries or communities of the Mediterranean region.

*Key words:* drinking water quality, Mediterranean region, water treatment technologies

*Received: December, 2014; Revised final: June, 2015; Accepted: June, 2015*

## 1. Introduction

The countries of the Mediterranean region are characterized by a great variety from social, cultural, economic and environmental point of view. Even the water resource has different characteristics in terms of quantity and quality in the various countries due to significant differences in climate, natural resources, development and, therefore, contamination.

The Mediterranean region has a supply of renewable water resources of about 1,500 km$^3$, which is distributed unevenly between the North (74%), the East (21%), and the South (5%) (Le Nouail, 2013). Precipitation tends to be scarce and concentrated in certain periods of the year and high rates of evapotranspiration cannot assure a sufficient and stable supply of water over time (Le Nouail, 2013). About 5% of the world population lives in the area, but it is among the zones characterized by lower concentration of fresh water in the world, having only 0.9% of global water resources. In the last decades, the situation has been getting worse, as it is possible to note that the number of countries defined in water scarcity were only 3 in 1955, 11 in 1990 and 18 are expected in 2025 (Blinda et al., 2007). Indeed, the change of hydro-climatic and socioeconomic conditions increased regional and global water scarcity problems in the past, as well as the current

* Author to whom all correspondence should be addressed: email sabrina.sorlini@unibs.it; Phone +39 030 371 1299; Fax: +39 030 371 1312

climate change, population growth, and the continuing increase in water demand, are expected to aggravate these water scarcity conditions in the future (Aktaş, 2014; Kiguchi et al., 2015; Navarro-Ortega et al., 2015; Shen et al., 2014; Stefanova et al., 2015; Veldkamp et al., 2015).

In the Southern and Eastern Mediterranean countries, the water issue is quantitative as well as qualitative. There is, in fact, a constant increase in water demand resulting from demographic pressure and from the development of water intensive activities such as in the tourism and manufacturing sectors (Galli et al., 2015; Lelieveld et al., 2012; Milano, 2010). The imbalance between supply and demand can be realized by the reduced availability of water resources on a per capita basis.

A severe water divide in the Mediterranean emerges from the data: the drinking water per capita demand varies from approximately 65 $m^3$/capita/year (175 liters/day) in the South and East to almost 120 $m^3$/capita/year (330 liters/day) in the North. In terms of access to improved water sources, the Northern Mediterranean countries and Israel have achieved a 100% rate of access to drinking water, while the remaining areas still stand at 90% with a strong internal imbalance between urban and rural areas (Ferragina, 2010).

The growing water demand creates a strong human pressure over water resources (Barbagallo, 2012; Bixio, 2006; Burnham et al., 2015), as measured by the Water Stress Indicator (WSI), among others.

This indicator represents the total water abstraction per year calculated as a percentage of renewable freshwater resources, thus indicating which countries have a high water demand compared to their available resources. Fig. 1 shows the worldwide WSI: lower values are represented by lighter green colors, whereas the highest values of WSI are characterized by dark green (gray represents countries for which data are missing or unavailable).

The pressure on water is due also to the technological progress and the improvement of pumping techniques that have led to intensive exploitation of aquifers causing their depletion and pollution.

Overuse of non-renewable water resources is one of the challenges in the Mediterranean but, presently, some of the most important water projects in the South and East area of the Mediterranean region are focused on fossil water creating a kind of "pumping race" between the countries that share common aquifers which fuels an unsustainable exploitation of non-renewable water sources. This is why, today, increasing water exploitation is strictly linked to and influenced by political, financial, social (e.g.: social impact of dams) and environmental (e.g.: reduction of new exploitable sources) aspects. However, new prospects are offered by non-conventional water supplies. Currently, desalination of seawater or brackish water in Mediterranean countries has a total installed capacity of over 1,800 $Mm^3$ per year and the reuse of treated seawater is about 30 $Mm^3$ per year (Ferragina, 2010).

In the Mediterranean region, the agriculture sector consumes the highest amount of water (64%), followed by the industry sector (22%), and then the domestic sector (14%) (Le Nouail, 2013). In the entire Mediterranean region, the efficiency in water distribution is very low due to poor network maintenance and operation as well as inadequate irrigation techniques: losses, leakages and wastage account for almost 40% of the total water demand (Ferragina, 2010). Because of water scarcity and the high use in the agricultural and industrial sectors, new technologies are being developed for grey and black water re-use (Garrido et al., 2007; Lazarova et al., 2001).

The aim of this work is to analyze the drinking water issue in the Mediterranean region, highlighting the main pollutants affecting water sources and the related technologies appropriate for their removal. Three main contaminants are analyzed: salinity, cyanobacteria and microorganisms. Related characteristics of the treatment technologies, advantages and disadvantages, management procedures and effectiveness are also described. The description of full-scale drinking water treatment plants (located in a country of the Mediterranean region) is also provided for each contaminant taken into consideration.

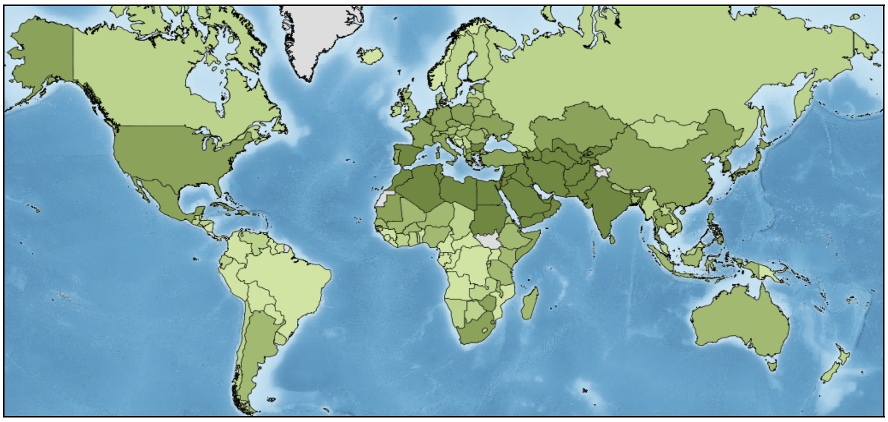

**Fig. 1.** Water Stress Indicator (FAO, 2015)

## 2. A focus on appropriate technology

Currently, the dictionary defines an Appropriate Technology (AT) as *a science or technology considered reasonable and suitable for a particular purpose, that conforms to existing cultural, economic, environmental, and social conditions*.

The first idea about the AT is attributed to Mahatma Gandhi. He advocated for small, local and predominantly village-based technology to support India's villages become self-reliant. He differed with the idea of technology that benefited a minority of people at the expense of the majority or that put people out of work to increase profit (Akubue, 2000).

Despite this, the first definition of AT, in that time named "Intermediate technology", was proposed in the 1970s by the British economist Dr. Fritz Schumacher (Schumacher, 1973). According to him, AT is an approach to technology that builds a strong sense of community and encompasses benefits from a social, environmental, cultural, economic, and spiritual point of view. Other past definitions, still accepted and used, prescribe that AT should be small-scale, requires low capital investment per worker, be energy efficient, environmental friendly and controlled and maintained by the local community. However, Ranis in the 80s, argued that "the appropriate process for a poor labor surplus economy is not always labor intensive and an appropriate good is not always a basic good" (Ranis, 1980). Also UNESCO publications (Ntim, 1988) criticized the standard AT requirements such as "low investment cost per workplace, small scale operation, use of locally available resources, low cost of final product", because this is not always possible or easy to achieve and can be contradictory implying bad results.

Today, we can say that AT not only refers to the tools and techniques used to problem solving in a development setting, but it also includes the less tangible aspects such as knowledge transfer mechanisms and social, cultural, and gender issues. The most important aspect of an AT is its sustainability, which is the balance of technical, social, economic, environmental, cultural and spiritual values in the long-term. AT is not a prerogative of developing countries because it plays a critical role in building sustainable communities in both southern and northern countries.

Effectively an appropriate technology has to be affordable, minimize the environmental impact, involve local people meeting the basic and real needs, be simple in operation and maintenance and use local materials and resources to reduce costs and transport and improve local market. Moreover AT should respect the traditions and values and include gender considerations, develop skills of local people, and reduce economic, social and political dependence between individuals and regions. Above all in the field of water and sanitation, the appropriateness of a technology depends on several factors, mostly related to social and economic aspects. Indeed, a crucial role is played by the willingness to spend money on technologies, the empowerment and the ownership, the educational level and the cultural customs (e.g. the possibility to use bone char as filtration material to remove fluoride in drinking water), among others. Even environmental/natural factors are influencing the design of an appropriate technology, as the type of resource (sea, surface water, groundwater) and the type and concentration of contaminants, among others.

## 3. Water quality management in the Mediterranean region

### *3.1. Water quality issues*

The Mediterranean region has significant heterogeneity among its countries from a social, demographic, economic and environmental point of view. This impacts the quantity and quality of potable water, in particular the kind of water source where it can be provided. Different water sources present different quality problems according to their nature and sources of contamination to which they are subjected.

Potable water comes from brackish water and seawater, surface water, groundwater and water reservoirs and quality problems that are to be faced in order to have safe water are often very different. The scarcity of water that characterizes the region makes it necessary in many coastal areas to supply from brackish and marine sources whose main problem is certainly the high salinity that can vary between 500 and 30,000 ppm in brackish water and between 30,000 and 50,000 ppm in marine water (Absar and Belhaminiti, 2013; Allal, 2010; Cipollina et al., 2005; DHV Water BV, 2004; Drami et al., 2011; El-Azizi, 2003; El-Sadek, 2010; Lindemann, 2004). Another problem is the microbiological and chemical contamination due to industrial and domestic discharges (Clemente, 2012; Heller-Grossman et al., 2001). Human activities also provide contamination of water disinfection byproducts, such as trihalomethanes, as described in study cases in Egypt (Abdullah and Hussona, 2013; Basiouny et al., 2008).

These problems are also faced in countries that use other kind of surface water other than sea such as rivers or lakes. These sources suffer additional kind of contamination due to anthropogenic and industrial discharges as nitrogen, phosphorus, heavy metals and suspended solids (Masoud, 2014; Golfinopoulos et al., 2005). In addition, groundwater sources are often poorly protected by human activities and thus contaminated with nitrates, heavy metals, arsenic and manganese and the underground sources are not exempted from the above-mentioned problem of salinity as they suffer the salt-water intrusion. Moreover recent studies (El-Aassy et al., 2015) reveal the presence of radioactivity in this kind of water source as new problem.

Finally, water reservoirs are another important water source. In this kind of source, in addition to issues related to microbiological contamination, suspended solids and other contaminants due to anthropogenic discharges, a major problem is the presence of cyanobacteria related to algal bloom (Cook et al., 2004; Dor, 1998; Douma et al., 2010; Nasri et al., 2007; Paerl et al., 2014; Yilmaz and Koç, 2014).

It is very important to control and minimize the release of pollutants from the agricultural and industrial activities because of their impact on water sources. Consequently, research is developing technologies through which it is possible to re-use the gray and black water, at least for the agricultural and industrial activities, due to the water scarcity that characterizes many of the countries of the Mediterranean region.

*3.2. Drinking water treatment technologies*

*3.2.1. General overview of treatment technologies*

As already stated, drinking water quality in the Mediterranean region varies widely due to several factors, such as the heterogeneity of the countries characterizing this region, the different climate conditions, available natural, economic and water resources, among others.Strictly related to these factors, technologies applied for drinking water treatment vary country by country. A list of the main specific treatment processes associated with the main water pollutants is shown in Table 1.

Owing to the heterogeneity of the countries of the Mediterranean region, the application and the efficiency of all these processes vary widely. Even regarding the management procedures, specific measures have to be applied for guaranteeing the removal of the different contaminants, such as the continuous supply of electricity, the climate conditions (temperature, humidity, etc.), the availability of resources to apply the treatment, and so on.

The heterogeneity of the technologies applied includes several aspects, which are not deepened in this paper. Indeed, the aim of this work is to focus on three main pollutants characterizing the Mediterranean area, for which specific processes are analyzed.

The first contaminant is the salinity (due to the use of seawater as resource); clearly seawater is a common issue among all the Mediterranean countries, and is becoming increasingly widespread for drinking purposes owing to the increasing water scarcity that threats these countries. The most spread process to desalinate seawater is the membrane filtration, by means of reverse osmosis. The second contaminant analyzed is cyanobacteria (or other algal blooms) due to their presence in artificial reservoirs, which are more and more used for drinking purpose in the Mediterranean region.

**Table 1.** Main water pollutants versus main treatment technologies

| *Water pollutant* | *Treatment technology* |
|---|---|
| Salinity | Membrane filtration (nanofiltration, reverse osmosis, electrodialysis) |
| | Ion exchange |
| | Thermal processes (e.g. solar still) |
| | Dilution with rainwater |
| Settleable solids | Screen filter |
| | Sedimentation |
| | Sand filtration |
| Colloids | Coagulation and flocculation |
| Fecal bacteria | Disinfection |
| Iron and manganese | Chemical oxidation (air/oxygen, chlorine etc.) |
| | Biological filters |
| Organic compounds | Chemical oxidation (air/oxygen, chlorine, ozone etc.) |
| | Activated carbon adsorption |
| Nitrogen compounds (ammonia, nitrates, nitrites) | Stripping (suitable only for ammonia) |
| | Biological filters |
| | Membrane filtration (nanofiltration, reverse osmosis, electrodialysis) |
| | Ion exchange |
| Arsenic | Chemical precipitation |
| | Activated carbon adsorption (iron oxide carbon) |
| | Membrane filtration (nanofiltration, reverse osmosis, electrodialysis) |
| | Ion exchange |
| Cyanobacteria (or other algal blooms) | Micro-screen filter |
| | Chemical oxidation |
| | Coagulation and flocculation |
| | Sand filtration |
| Cyanotoxins | Activated carbon adsorption |
| Heavy metals | Chemical precipitation |

*Coagulation and flocculation* are considered in the following, since they represent efficient technologies for reducing cyanobacteria (or other algal blooms) and they can be applied by means of alternative and appropriate solutions, such as the use of natural resources instead of chemical reagents.

Moreover, microorganisms are considered since they are typical contaminants characterizing surface water. The traditional process applied for their removal is *disinfection*, which is one of the most important drinking water treatment but poses some constraints for the possible production of Disinfection By Products (DBPs). Even in this case, alternative and appropriate solutions such as the use of sunlight or boiling water can be applied depending on the specific context in which the process is developed.

*3.2.2. Reverse Osmosis*

Seawater is widely used as drinking water source along the coasts of the Mediterranean countries. The most applied technology for its treatment is represented by reverse osmosis (RO). This is a process in which salts (and in general all the dissolved inorganic solids) are removed by pushing water under pressure (higher than $30*10^5$ Pa) through a semi-permeable membrane. The membrane allows only water to pass through, and not salts or other impurities (with size larger than 0.001 μm).

The main advantages of this technology are the effective salt removal (95-99%), the jointly disinfection action (RO is able to remove almost all the viruses, bacteria and protozoa) and the jointly removal of several ions and metals. Regarding the disadvantages, it has to be underlined that RO requires pre- and post-treatments in order to protect the membrane from obstruction of the pores and to be re-hardened and re-mineralized (for adjusting values of alkalinity and salt content), respectively. Even membrane fouling is a process to take into account as a disadvantage. This phenomenon happens since particles can deposit onto the membrane surface or pores and decrease its performances. For this reason, backwashes or washing by means of chemical reagents need to be applied in order to avoid the pores' occlusion.

Another notable constraint of this technology is represented by the high energy consumption, due to the high pressure that the process needs for guaranteeing the desalination. However, Lindemann (2004) demonstrated by a multicriteria analysis, that RO requires less energy power compared to other desalination technologies like multi-effect desalination and vapor compression.

As already stated and reported in the scientific literature (Fritzmann et al., 2007), and despite these disadvantages, RO is widely spread in the Mediterranean countries, such as Italy (Cipollina et al., 2005), Greece (Manolakos et al., 2008), Israel (Drami et al., 2011), Egypt (El-Sadek, 2010), Libya (El-Azizi, 2003), Algeria (Absar and Belhamiti, 2013), Morocco (El Azhar et al., 2012), Spain (Molina and Casañas, 2010), and so on.

An interesting seawater treatment plant, adopting the reverse osmosis, is located in Larnaca, Cyprus (Fig. 2) (Water Technology, 2014).

The plant is the largest desalination facility in Cyprus, and it is served by a long seawater intake that catches water depth in the sea in order to ensure a clean seawater feed (avoiding algae that are highly present along the coast). The plant treats about 64,000 m³ of seawater on a daily base. As shown in Fig. 2, the plant is composed by the following treatments: rotary screen, coagulation and flocculation, dual-media gravity filtration, microfiltration and finally reverse osmosis. The desalinated water is further treated for re-mineralization and pH adjustment; afterwards, the chlorination treatment completes the process before the supply into the distribution system.

The Larnaca plant has been designed to ensure that power consumption could be reduced. Indeed, frequency converters enable the adjustment of the suction pressure and Pelton turbines are used to recover the energy from the brine stream (Water Technology, 2014).

The heterogeneity of the countries characterizing the Mediterranean region does not permit the application of this treatment technology at all levels. This is mainly due to the high investment and operation costs, as well as for the management practices.

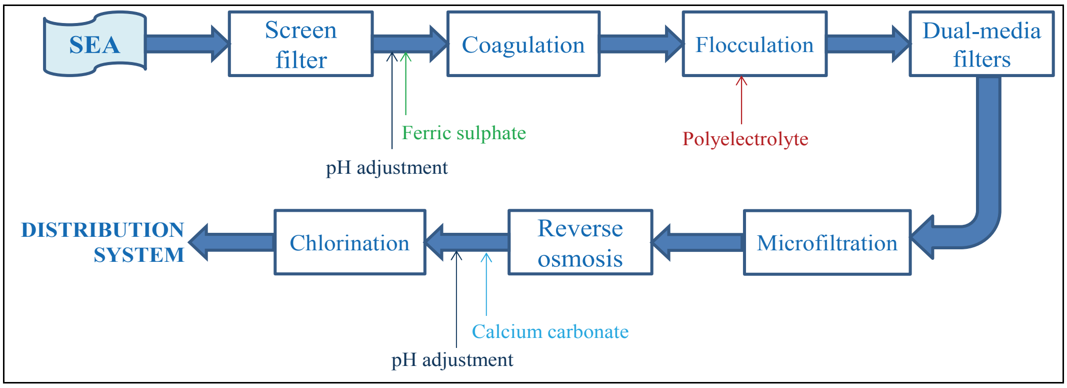


**Fig. 2.** Scheme of Larnaca seawater treatment plant (Cyprus)

Indeed, in order to control high pressure operations, avoid membrane fouling, apply proper pre- and post-treatments (which require chemical reagents dosage), good technical and management skills would be needed. A technology, for being considered appropriate, should be not only environmental friendly or economic sustainable, but should even guarantee a technical effectiveness (easy to be managed).

Due to the economic and technical conditions that characterize Cyprus (availability of continuous electricity and economic resources), the RO process can be considered appropriate for the specific context. The same technology applied in another country of the Mediterranean region could be inappropriate and unsustainable, depending on the local conditions.

*3.2.3. Solar-powered reverse osmosis*

An interesting and more sustainable approach, at least from the environmental point of view, for the implementation of the reverse osmosis process, is the RO water desalination using solar technology. The implementation of large-scale concentrating solar-powered desalination systems has been identified as promising solution. Indeed, the high solar energy available above all in the south Mediterranean areas can easily produce the energy required by RO processes to treat water. It has been estimated that, within two decades, solar thermal power plants will become the less expensive technology for electricity and desalted water. Moreover, combining the efficient use of water with large-scale solar desalination systems, overexploitation of groundwater in the Mediterranean region should be ended by 2030 (Allal, 2010).

The city of Guadix (Granada Province, Spain) is provided by a RO drinking water treatment plant, powered by electricity from a Concentrating Solar-Powered (CSP) system. The energy plant produces the maximum electricity during the day for RO operation, in a way that allows the RO system to operate even during night-time. Fig. 3 shows the configuration of the entire Guadix plant, which combines CSP with RO.

*3.2.4. Water treatment by coagulation -flocculation*

Coagulation and flocculation processes promote the aggregation of small and dispersed particles into larger-size clusters, and they deal with dispersed particles such as mineral turbidity (clay, silt), larger molecular weight natural organic matter, and microorganisms (including cyanobacteria, among others). Chemicals employed for drinking water coagulation include various aluminum and ferric iron salts, while flocculation is usually characterized by the use of polyelectrolytes. For instance, the removal rate of algae by the coagulation-flocculation process is strictly dependent on the optimization of chemical doses and pH (WHO, 1999).

Focusing on the management procedures, which, as previously stated, are one of the factors determining the appropriateness of a technology, it has to be underlined that the main difficulties of these treatment processes arise from the correct dosage of the chemical reagents and the proper mixing speed. These aspects should be carefully controlled in order to guarantee the effectiveness of both coagulation and flocculation. This is the reason why the occurrence of cyanobacteria and their toxins in water bodies used for the production of drinking water poses a technical challenge for water utility managers.

An interesting alternative to the use of chemical reagents is represented by *Moringa oleifera*. *Moringa oleifera* is the best natural coagulant discovered so far that can replace aluminum sulfate (alum), which is used widely for water treatment around the world. *Moringa oleifera* seeds are non-toxic, and their use as coagulant is recommended in water treatment in developing countries (Ali et al., 2010).

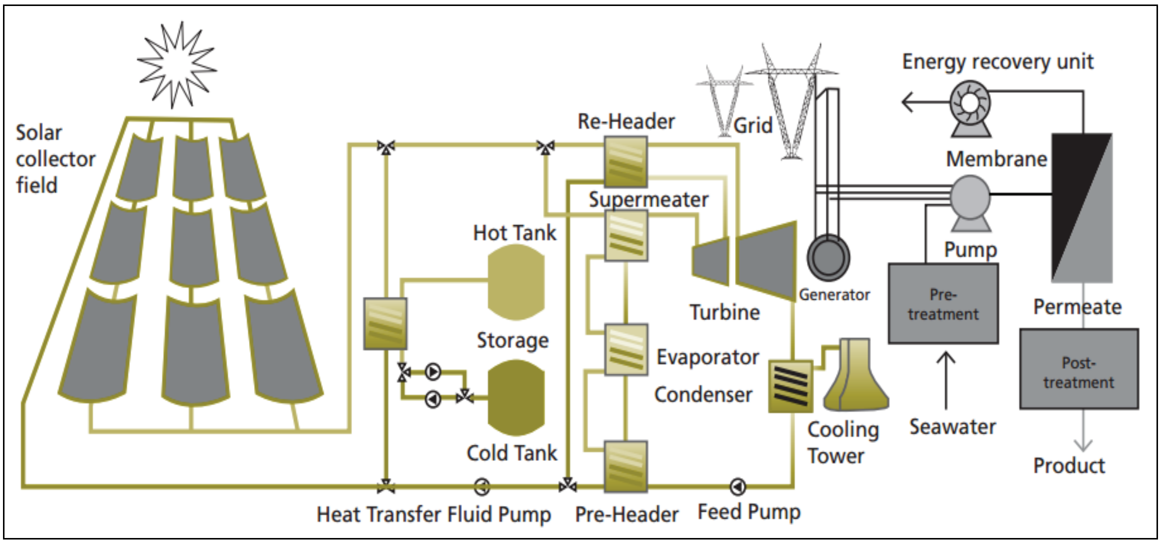


**Fig. 3.** Scheme of Guadix CSP/RO treatment plant (Allal, 2010)

The seed kernels contain significant quantities of a series of low molecular-weight, water-soluble proteins which, in solution, carry an overall positive charge. When added to raw water these proteins bind to the predominantly negatively charged particles (silt, clay, bacteria, algae, etc.). Under proper mixing, these particles grow in size to form flocs, which are then removed by filtration (Folkard et al., 1994). However, at the moment, *Moringa oleifera* use as natural coagulant is not widely spread in the Mediterranean region owing to the need for warm climates (such as the tropical or sub-tropical) for the plants to grow.

The coagulation-flocculation process is one of the main technologies used for the removal of cyanobacteria; in the international literature, several studies (Bernhardt and Clasen, 1991; Ewerts et al., 2013; Gonzalez-Torres et al., 2014; Lambert et al., 1996; Mouchet and Bonnélye, 1998; Velzeboer et al., 1995) have already investigated roles and removal rates of coagulation and flocculation concerning this contaminant.

Cyanobacteria algal blooms represent one of the most waterborne microbial hazards to human and agricultural water supplies, fisheries production, and freshwater and marine ecosystems (Codd et al., 2005; Paerl et al., 2011). This hazard is mostly due to the production of secondary metabolites, called cyanotoxins, which are a various group of natural toxins, both from chemical and toxicological points of view. Cyanobacteria, and thus cyanotoxins, are contaminants of concern in the Mediterranean countries. In the international literature, several case studies are reported, related to France (Réveillon et al., 2014), Italy (Naselli-Flores et al., 2007), Greece (Cook et al., 2004), Lebanon (Fadel et al., 2014), Israel (Dor, 1998), Egypt (Mohamed et al., 2015), Algeria (Amrani et al., 2014), Morocco (Douma et al., 2010), and so on.

Conventional water treatments involve the combination of coagulation-flocculation with rapid sand filtration, in order to maximize the removal of cyanobacteria. On the contrary, cyanotoxins are usually removed by activated carbon processes, since they arise in dissolved form.

One of the main advantages of coagulation-flocculation processes is the high removal rate of cyanobacteria that guarantees the complete elimination of this algal formation after a sand filtration system. Moreover, this kind of process allows a decrease in the formation of potential precursors of DBPs (Disinfection By Products). On the contrary, the main disadvantages are represented by the need for chemical reagents (as ferric or aluminum salts), which increase the operational costs of the technology.

An interesting drinking water treatment plant, adopting the coagulation-flocculation process (followed by a sand filtration and an activated carbon treatment), is located in Chaiba, Algeria (Fig. 4) (Nasri et al., 2007).

The treatment plant takes its water from the Cheffia dam. The complete treatment chain is composed by pre-chlorination, coagulation and flocculation, slow sand filtration, activated carbon adsorption and chlorination before storage and distribution.

The Cheffia dam contains an unusual morphospecies of *Microcystis* that is the dominant autumn phytoplankton in this reservoir. The cyanobacteria community is also characterized by the presence of a toxin-producing morphospecies of *Microcystis sp*. Cyanobacteria concentration reaches picks up to about 450 µg/L, while cyanotoxins up to about 30 µg/L. Due to the seasonality of these contaminants, removal rates widely vary during the year. Available monitoring data referred to 2004 have underlined values between 20 and 100% of microcystins removal.

Conventional water treatment techniques such as coagulation and flocculation, followed by slow sand filtration and powdered activated carbon at 15 mg/L, are effective and efficient in removing high density cyanobacteria cells and their toxic microcystins from raw water (Nasri et al., 2007).

### *3.2.5. Water treatment by disinfection*

The last pollutant and related technology considered in this work is represented by microorganisms and disinfection. Disinfection is an important step in ensuring that water is safe to be consumed, and its main objective is to control disease-causing microorganisms by killing or inactivating them.

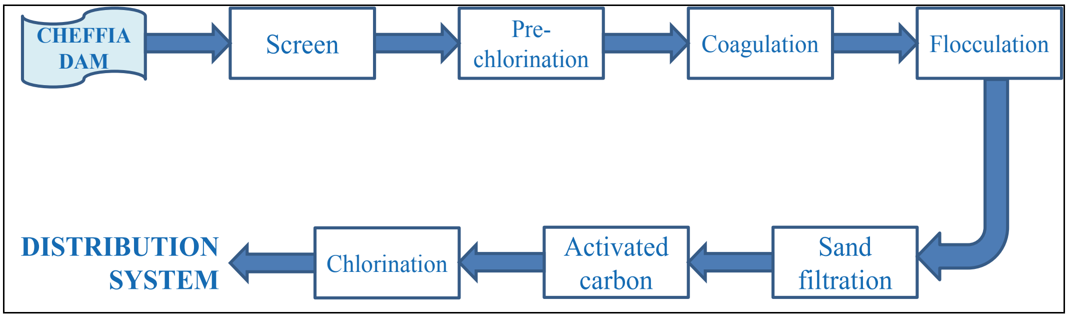


**Fig. 4.** Scheme of Chaiba treatment plant (Algeria)

However, in the last decades, the strategy is to apply a multi-barrier approach, which consists in minimizing the concentration of fecal bacteria through the action of the different treatments characterizing the drinking water treatment plant. In such a way, final disinfection should, theoretically, only protect the quality of water along the distribution system. Indeed, the most significant and important results are obtained when disinfection is combined with conventional treatments, such as coagulation, flocculation, sedimentation and filtration.

Conventional disinfection treatment methods include chlorination, chlorine dioxide, chloramines, ozone, and ultraviolet light. Table 2 shows the main characteristics, advantages and disadvantages of these methods.

The disinfection methods aforementioned refer above all to chemical disinfection. Due to the heterogeneity of the countries characterizing the Mediterranean region, which includes poor rural parts of the northern Africa states, these methodologies are not always suitable to be carried out.

An interesting alternative for these areas is represented by SODIS (Solar Water Disinfection), developed by EAWAG (Swiss Federal Institute for Aquatic science and Research)/SANDEC (Dept. of Water and Sanitation) and shown in Fig. 5. Solar Water Disinfection (SODIS) is a simple, environmentally sustainable, low-cost solution for drinking water treatment on a household or community level for people consuming biologically contaminated wild water. Raw water is filled in a transparent plastic (PET) or glass bottle and exposed to the sun for 6 hours. During this time, the UV-radiation destroys pathogenic microorganisms, causing water-borne diseases, improving the quality of drinking water. Pathogenic microorganisms are vulnerable to two effects of the sunlight: radiation in the spectrum of UV-A light (wavelength 320-400 nm) and heat (+50 °C).

**Table 2.** Main characteristics, advantages and disadvantages of disinfection methods (NESC, 1996)

| ***Disinfectant*** | ***Characteristics*** | ***Advantages*** | ***Disadvantages*** | ***Used form*** |
|---|---|---|---|---|
| Chlorine gas | At normal pressure it is a toxic, yellow-green gas, and is liquid at high pressures | It is very effective for removing almost all microbial pathogens and is appropriate as both pre-oxidant and disinfectant | It is a dangerous gas that is lethal at concentrations as low as 0.1 percent air by volume | Chlorine gas is employed as liquid solution |
| Sodium hypochlorite | It is commercially available as a solution in concentrations of about 5-15 % of active chlorine | It is easier to handle than gaseous chlorine or calcium hypochlorite | It is highly corrosive and its solutions rapidly decompose. It must be stored in a cool, dark, dry area | Sodium hypochlorite solution is readily available |
| Calcium hypochlorite | It is a white solid that contains some of 60-70 % of active chlorine | It is very stable, allowing a year's supply to be bought at one time. | It is a corrosive material with a strong odor. Reactions between it and organic material can generate enough heat to cause a fire or explosion | Calcium hypochlorite can be purchased in granular, powdered, or tablet form |
| Chlorine dioxide | It is a yellowish-green gas with a strong odor | It is effective at low concentrations-dosages and is appropriate as both pre-oxidant and disinfectant | It is highly instable, thus, it requires to be produced *in situ*. It is characterized by a low redox potential | Chlorine dioxide is employed as liquid solution |
| Chloramines | They are formed when water containing ammonia is chlorinated or when ammonia is added to water containing chlorine | They are effective bactericides. Usually, chloramine-forming reactions are 99 % complete within few minutes | They are much less effective against viruses or protozoa than free chlorine. They might be harmful to humans and release a disagreeable taste and odor to water | Chemicals used to generate chloramine from ammonia and chlorine gas depend on the ammonia-based chemical used |
| Ozone | It is formed by passing dry air through a system of high voltage electrodes | It requires shorter contact time and dosage than chlorine. It has the highest redox potential among all the disinfectants | Ozone gas is highly unstable and must be generated onsite. It does not guarantee adequate residual protection to water along the distribution system | Ozone is employed as gas |
| UV light | UV radiation penetrates the cell wall of an organism, the cell's genetic material is disrupted and the cell is unable to reproduce | It effectively destroys bacteria and viruses, and requires short contact times | It may not inactivate *Giardia lamblia* or *Cryptosporidium* cysts. It does not guarantee adequate residual protection to water along the distribution system | Radiation |

As stated, the heterogeneity of the countries characterizing the Mediterranean region does not permit the application of chemical disinfection at all levels. This is mainly due to the availability of chemical reagents or energy (in the case of ozone or UV radiation), as well as management practices. Indeed, in order to control the proper dosage of disinfectants, good technical and management skills are needed. These are crucial points for considering the appropriateness of a technology. Moreover, while protection against microbial contamination is the top priority, water treatment systems must also control disinfection by-products (DBPs), chemical compounds formed unintentionally when chlorine and other disinfectants are added. A number of factors can affect the formation of DBPs. These include concentrations of organic materials when chlorine is added, dosage of chlorine, concentrations of bromide ion when ozone is added, dosage of ozone, temperature and pH of water, reaction time, among others. The main DBPs that can affect drinking water quality out of a treatment plant (thus post-disinfection process) include trihalomethanes (THMs), chlorite and chlorate (even bromate should be considered if seawater is used as drinking water source and ozone is employed as oxidant/disinfectant). In almost all the countries characterizing the Mediterranean region, the study of DBPs formation (and thus their minimization) has been carried out. Research data have been provided by Greece (Golfinopoulos and Nikolaou, 2005), Cyprus (Pieri et al., 2014), Israel (Heller-Grossman et al., 2001), Egypt (Smith and Kamal, 2009), Algeria (Achour et al., 2014), Morocco (Zidane et al., 2014), and many other states. An interesting drinking water treatment plant, adopting the final disinfection with chlorine and presenting formation of THMs, is located in Casablanca, Morocco (Fig. 6) (Zidane et al., 2014).

Raw water coming from the Bou Regreg dam is treated in a drinking water treatment plant and serves the cities of Casablanca and Mohammedia. Since the distribution system is extremely long (more than 30 km), 36 storage tanks are located along the supply network, in order to provide a security reserve of 24 hours. The drinking water treatment chain is conventional, comprising a physical-chemical treatment of coagulation, flocculation and settling, followed by sand filtration and chlorine disinfection before storage and distribution of water. Pre-oxidation by chlorine (before coagulation and flocculation steps) is even required, owing to the raw water characteristics. Chlorination, in addition to pre-oxidation and disinfection, is also carried out at the inlet and outlet of each storage tank and during the distribution of water at different points of the supply network.

In a research experience, Zidane et al. (2014) have analyzed the presence of the four main THMs (chloroform ($CHCl_3$), bromoform ($CHBr_3$), bromodichloromethane ($CHBrCl_2$) and dibromochloromethane ($CHBr_2Cl$)) along the distribution system. Table 3 shows the results of the investigation, indicating the trend of THMs in the water network.

Results indicate that the supplied water contains significant levels of THMs, proving that chlorination has a significant effect. Although water extracted from the Bou Regreg dam is slightly contaminated by organic matter (TOC), it contains important concentrations of benzene and toluene, which are other precursors of THMs formation. Total THMs concentration was high in all the water samples analyzed, with the higher contents corresponding to the water in the outlet tank (89 μg/L) and in the tap water (85 μg/L). Despite this, concentrations remain slightly below the Moroccan limit (100 μg/L).

### *3.3. Further considerations*

Nowadays, advanced drinking water treatments are applied widely and worldwide in order to control the concentration of new specific pollutants. The trend to continuously push for more sophisticated water treatment processes, and thus more expensive and complicated to manage, should be considered together with existing severe economic crisis and the feasibility of implementation of these technologies.

Considering the heterogeneity of countries worldwide (and in this specific context, of the Mediterranean countries), appropriate technologies should be developed, in order to guarantee technology sustainability, and even the protection of the environment.

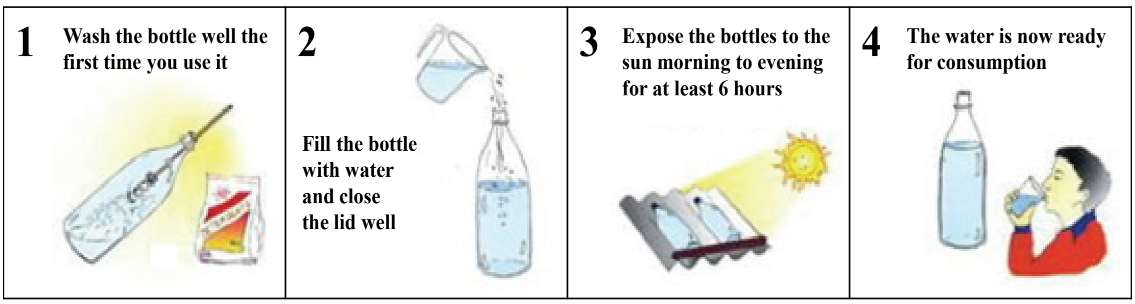


**Fig. 5.** SODIS methods for disinfecting drinking water

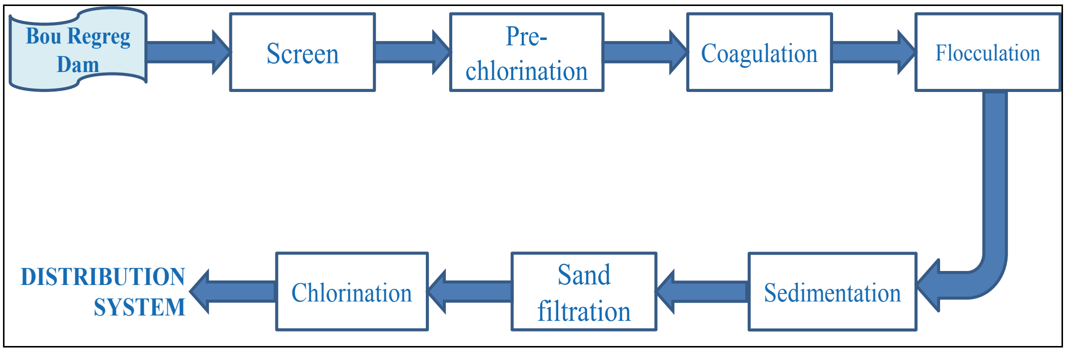


**Fig. 6.** Scheme of Casablanca treatment plant (Morocco)

**Table 3.** Trend of THMs concentration along the drinking water supply chain

| *Parameter* | *Raw water* | *Outlet plant* | *Inlet tank* | *Outlet tank* | *Tap water* |
|---|---|---|---|---|---|
| $CHCl_3$ | 0.19 | 20 | 27 | 29 | 33 |
| $CHBr_3$ | < 0.10 | 2.5 | 2.6 | 4.1 | 2.6 |
| $CHBrCl_2$ | 0.10 | 20 | 24 | 31 | 29 |
| $CHBr_2Cl$ | < 0.10 | 16 | 18 | 25 | 21 |
| Total THMs | 0.29 | 59 | 71 | 89 | 85 |

Consequently, some basic criteria that emphasize the concept of appropriate technology can be summarized as:

– allowing for greater consideration of local needs;

– full respect of the traditions and social values;

– developing technologies that enhance the work and skills of humans rather than mechanical ones;

– developing technologies that can be understood and controlled through easy management procedures;

– enhancing the use of local resources, materials and energy, reducing costs and implementation/process management;

– developing a wealth of experience and expertise within the community from the expertise already available;

– contributing to a local economy that also acts against economic mutations/crises in international markets;

– reducing the dependence on economic, social and political aspects between individuals, regions and nations.

## 4. Conclusions

The present work aimed at analyzing the drinking water quality issue in the Mediterranean region, highlighting the possible appropriate technologies applicable in the different countries. Case studies of full-scale drinking water treatment plants were proposed in order to report how drinking water quality contaminants are faced in the region, presenting technologies appropriate for specific contaminants and contexts (e.g., solar disinfection by means of SODIS methodology, use of *Moringa oleifera* as natural coagulant, etc.).

High-end technologies for drinking water treatment may not be applied equally to all countries or communities of the Mediterranean region, due to the different characteristics of each specific context. A technology can be appropriate for a context only if can guarantee its efficacy along the time, hence be sustainable.

For these reasons, it is not possible to define *a priori* which technology is more appropriate. Local needs, cultures, traditions, economic conditions, natural resources, technical skills to manage the technology, among others, are aspects that should be carefully considered in order to develop and implement an appropriate technology.

Models of appropriate technologies (e.g., the solar-powered reverse osmosis treatment plant) are already in place in the Mediterranean region, but further efforts should be put in this direction in order to enhance the management of water resources for drinking use.

**Acknowledgments**
Authors wish to thank the Organizing Committee of the 18th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO 2014, for the opportunity given for carrying out this research activity. Sabrina Sorlini planned and supervised the research activity and the paper drafting; Luca Rondi and Andrea Pollmann Gomez did data collection and were responsible for the paper drafting, Carlo Collivignarelli was responsible for the activity as coordinator of CeTAmb LAB.

## References

Abdullah A.M., Hussona S.E., (2013), Predictive model for disinfection by-product in Alexandria drinking water, northern west of Egypt, *Environmental Science and Pollution Research*, **20**, 7152-7166.

Absar B., Belhamiti O., (2013), Modeling and computer simulation of a reverse osmosis desalination plant-case study of Bousfer plant-Algeria, *Desalination and Water Treatment*, **51**, 5942-5953.

Achour S., Chabbi F., Guergazi S., (2014), Drinking water chlorination and adverse public health outcomes in Algeria, *Advanced Materials Research*, **1030-1032**, 501-508.

Aktaş Ö., (2014), Impacts of climate change on water resources in Turkey, *Environmental Engineering and Management Journal*, **13**, 881-889.

Akubue A., (2000), Appropriate technology for socioeconomic development in third world countries, *The Journal of Technology Studies*, **26**, 33-43.

Ali E.N., Muyibi S.A., Salleh H.M., Alam M.Z., Salleh M.R.M., (2010), Production of natural coagulant from moringa oleifera seed for application in treatment of low turbidity water, *Journal of Water Resource and Protection*, **2**, 259-266.

Allal H.B.J., (2010), *Water Desalination and Solar in the Mediterranean Region*, In: *Building Trust Can Take the Form of Investment - Energy & Regional Integration in the Western Mediterranean. The Mediterranean in a Multipolar World up to 2030*, Dalmases F.B. (Ed.), CIDOB Foundation, Barcelona, Spain, 25-41.

Amrani A., Nasri H., Azzouz A., Kadi Y., Bouaïcha N., (2014), Variation in cyanobacterial hepatotoxin (microcystin) content of water samples and two species of fishes collected from a shallow lake in Algeria, *Archives of Environmental Contamination and Toxicology*, **66**, 379-389.

Barbagallo S., Cirelli G., Consoli S., Licciardello F., Marzo A., Toscano A., (2012), Analysis of treated wastewater reuse potential for irrigation in Sicily, *Water Science & Technology*, **65**, 2024-2033.

Basiouny M., Elmitwalli T., Rabee M., (2008), *Formulation and modeling of trihalomethane in new Benha water treatment plant*, *Egypt*, 12$^{th}$ International Water Technology Conference, IWTC12 2008, Alexandria, Egypt.

Bernhardt H., Clasen J., (1991), Flocculation of micro-organisms, *Journal of Water Supply: Research and Technology - Aqua*, **40**, 76-87.

Bixio D., Thoeye C., De Koning J., Joksimovic D., Savic D., Wintgens T., Melin T., (2006), Wastewater reuse in Europe, *Desalination*, **187**, 89-101.

Blinda M., Boufaroua M., Carmi N., Davy N., Detoc S., Froebrich J., Gabina D., Iglesias A., Khalid A.-L., Khalifa E., Margat J., Moneo M., Tagar Z., (2007), *Mediterranean Water Scarcity and Drought Report. Technical report on water scarcity and drought management in the Mediterranean and the Water Framework Directive*, Mediterranean Water Scarcity & Drought Working Group (MED WS&D WG) within Joint Mediterranean Euwi/Wfd Process. On line at: http://www.emwis.net/topics/WaterScarcity/PDF/MedWSD_FINAL_Edition.

Burnham M., Ma Z., Zhu D., (2015), The human dimensions of water saving irrigation: lessons learned from Chinese smallholder farmers, *Agriculture and Human Values*, **32**, 347-360.

Cipollina A., Micale G., Rizzuti L., (2005), A critical assessment of desalination operations in Sicily, *Desalination*, **182**, 1-12.

Clemente R.R., (2012), *Report on the Mediterranean sea pollution situation addressed by the Horizon 2020 program of the ENPI, and challenges in the research domain*, FP7 INCO.Net MIRA PROJECT WP 7, IDAEA-CSIC, Barcelona, Spain, On line at: http://www.miraproject.eu/workgroups-area/workgroup.wp6/workgroup-documents-library/task-7-preparation-of-technical-reports/MEDITERRANEAN%20SEA%20POLLUTION%20CHALLENGES%20IN%20THE%20RESEARCH%20DOMAIN%20FINAL%205.5.12.pdf/view.

Codd G.A., Lindsay J., Young F.M., Morrison L.F., Metcalf J.S., (2005), *Harmful Cyanobacteria: from Mass Mortalities to Management Measures*, In: *Harmful Cyanobacteria*, Huisman J., Matthijs H.C.P., Visser P.M. (Eds.), Springer, Dordrecht, The Netherlands, 1-23.

Cook C.M., Vardaka E., Lanaras T., (2004), Toxic cyanobacteria in greek freshwaters, 1987-2000: occurrence, toxicity, and impacts in the Mediterranean region, *Acta Hydrochimica et Hydrobiologica*, **32**, 107-124.

DHV Water BV, (2004), *Seawater and brackish water desalination in the Middle East, North Africa and Central Asia – A review of key issues and experience in six countries*, Final Report, Amersfoort, The Netherlands, BRL Ingénierie, Nimes, France, On line at: http://siteresources.worldbank.org/INTWSS/Resources/Desal_mainreport-Final2.pdf.

Dor I., (1998), A checklist of cyanophyta (cyanobacteria) of Israel and adjacent regions, *Israel Journal of Plant Sciences*, **46**, 239-254.

Douma M., Ouahid Y., del Campo F.F., Loudiki M., Mouhri Kh., Oudra B., (2010), Identification and quantification of cyanobacterial toxins (microcystins) in two Moroccan drinking-water reservoirs (Mansour Eddahbi, Almassira), *Environmental Monitoring and Assessment*, **160**, 439-450.

Drami D., Yacobi Y.Z., Stambler N., Kress N., (2011), Seawater quality and microbial communities at a desalination plant marine outfall. A field study at the Israeli Mediterranean coast, *Water Research*, **45**, 5449-5462.

El-Aassy I.E., El-Feky M.G., Issa F.A., Ibrahim N.M., Desouky O.A., Khattab M.R., (2015), Uranium and $^{234}U/^{238}U$ isotopic ratios in some groundwater, wells at Southwestern Sinai, Egypt, *Journal of Radioanalytical and Nuclear Chemistry*, **303**, 357-362.

El Azhar F., Tahaikt M., Zouhri N., Zdeg A., Hafsi M., Tahri K., Bari H., Taky M., Elamrani M., Elmidaoui A., (2012), Remineralization of Reverse Osmosis (RO)-desalted water for a Moroccan desalination plant: optimization and cost evaluation of the lime saturator post, *Desalination*, **300**, 46-50.

El-Azizi I.M., (2003), Seawater desalination plants influents and effluents analysis in Libya, *Desalination*, **156**, 87.

El-Sadek A., (2010), Water desalination: An imperative measure for water security in Egypt, *Desalination*, **250**, 876-884.

Ewerts H.E., Swanepoel A., du Preez H.H., (2013), Efficacy of conventional drinking water treatment processes in removing problem-causing phytoplankton and associated organic compounds, *Water SA*, **39**, 739-750.

Fadel A., Lemaire B.J., Atoui A., Vinçon-Leite B., Amacha N., Slim K., Tassin B., (2014), First assessment of the ecological status of Karaoun reservoir, Lebanon, Lakes and Reservoir, *Research and Management*, **19**, 142-157.

FAO, (2015), AQUASTAT website, Food and Agriculture Organization of the United Nations (FAO), On line at:

http://www.fao.org/nr/water/aquastat/maps/World-Map.MDG_eng.htm.

Ferragina E., (2010), *Environmental and Sustainable Development in the Mediterranean*. In: *10 Papers for Barcelona 2010*, Scoullos M., Ferragina E., Published by the European Institute of the Mediterranean and the EU Institute for Security Studies, 53-78.

Folkard G., Sutherland J., Shaw R., (1994), *Water clarification using Moringa oleifera seed coagulant, Environment and Development*, Proceedings of the 19th WEDC Conference, WEDC, Loughborough, 109-112.

Fritzmann C., Löwenberg J., Wintgens T., Melin T., (2007), State-of-the-art of reverse osmosis desalination, *Desalination*, **216**, 1-76.

Galli A., Halle M., Grunewald N., (2015), Physical limits to resource access and utilisation and their economic implications in Mediterranean economies, *Environmental Science & Policy*, **51**, 125-136.

Garrido A., Iglesias A., (2007), *Groundwater's role in Managing Water Scarcity in the Mediterranean Region,* In: *The Global importance of groundwater in the 21st Century: Proceeding of the International Symposium on Groundwater Sustainability*, Ragone S., Hernandez-Mora N., de la Hera A., Bergkamp G., McKay J. (Eds.), National Groundwater Association Press, OHIO, EEUU, 189-203.

Golfinopoulos S.K., Nikolaou A.D., (2005), Survey of disinfection by-products in drinking water in Athens, Greece, *Desalination*, **176**, 13-24.

Gonzalez-Torres A., Putnam J., Jefferson B., Stuetz R.M., Henderson R.K., (2014), Examination of the physical properties of Microcystis aeruginosa flocs produced on coagulation with metal salts, *Water Research*, **60**, 197-209.

Heller-Grossman L., Manka J., Limoni-Relis B., Rebhun M., (2001), THM, haloacetic acids and other organic DBPs formation in disinfection of bromide rich Sea of Galilee (Lake Kinneret) water, *Water Science and Technology: Water Supply*, **1**, 259-266.

Kiguchi M., Shen Y., Kanae S., Oki T., (2015), Re-evaluation of future water stress due to socio-economic and climate factors under a warming climate, *Hydrological Sciences Journal*, **60**, 14-29.

Lambert T.W., Holmes C.F., Hrudey S.E., (1996), Adsorption of microcystin-LR by activated carbon in full scale water treatment, *Water Research*, **30**, 1411-1422.

Lazarova V., Levine B., Sack J., Jeffrey P., Muntau H., Salgot M., Brissaud F., (2001), Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries, *Water Science and Technology*, **43**, 25-33.

Le Nouail M., (2013), *Information Report. Managing water-related challenges in the Euro-Mediterranean region*¸ Working group: European Economic and Social Committee - Economic and Social Council of Israel - Economic and Social Council of Morocco - Tunisian civil society representative, REX/379, 1-10, Bruxelles, 11 September 2013.

Lelieveld J., Hadjinicolaou P., Kostopoulou E., Chenoweth J., El Maayar M., Giannakopoulos C., Hannides C., Lange M.A., Tanarhte M., Tyrlis E., Xoplaki E., (2012), Climate change and impacts in the Eastern Mediterranean and the Middle East, *Climatic Change*, **114**, 667-687.

Lindemann J.H., (2004), Wind and solar powered seawater desalination. Applied solutions for the Mediterranean, the Middle East and the Gulf Countries, *Desalination*, **168**, 73-80.

Manolakos D., Mohamed E.Sh., Karagiannis I., Papadakis G., (2008), Technical and economic comparison between PV-RO system and RO-Solar Rankine system. Case study: Thirasia island, *Desalination*, **221**, 37-46.

Masoud A.A., (2014), Groundwater quality assessment of the shallow aquifers west of the Nile Delta (Egypt) using multivariate statistical and geostatistical techniques, *Journal of African Earth Sciences*, **95**, 123-137.

Milano M., (2010), *The foreseeable impacts of climate change on the water resources of four major Mediterranean catchment basins*, Plan Bleu, Sofia-Antipolis.

Mohamed Z.A., Deyab M.A., Abou-Dobara M.I., El-Sayed A.K., El-Raghi W.M., (2015), Occurrence of cyanobacteria and microcystin toxins in raw and treated waters of the Nile River, Egypt: implication for water treatment and human health, *Environmental Science and Pollution Research*, in press.

Molina V.G., Casañas A., (2010), Reverse osmosis, a key technology in combating water scarcity in Spain, *Desalination*, **250**, 950-955.

Mouchet P., Bonnélye V., (1998), Solving algae problems: French expertise and worldwide applications, *Journal of Water Supply: Research and Technology - Aqua*, **47**, 125-141.

Naselli-Flores L., Barone R., Chorus I., Kurmayer R., (2007), Toxic cyanobacterial blooms in reservoirs under a semiarid mediterranean climate: the magnification of a problem, *Environmental Toxicology*, **22**, 399-404.

Nasri H., Bouaïcha N., Harche M.K., (2007), A new morphospecies of microcystis sp. forming bloom in the Cheffia Dam (Algeria): seasonal variation of microcystin concentrations in raw water and their removal in a full-scale treatment plant, *Environmental Toxicology*, **22**, 347-356.

Navarro-Ortega A., Acuña V., Bellin A., Burek P., Cassiani G., Choukr-Allah R., Dolédec S. et al., (2015), Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project, *Science of the Total Environment*, **503-504**, 3-9.

Ntim B., (1988), *Technology Transfer – Nine Case Studies,* Buatsi S. (Ed.), IT Publications London, UK, 7.

NESC, (1996), *Disinfection*, A National Drinking Water Clearinghouse Fact Sheet, West Virginia University, National Environmental Services Center, 1-4, On line at: http://www.nesc.wvu.edu/pdf/dw/publications/ontap/2009_tb/disinfection_dwfsom50.pdf.

Paerl H.W., Hall N.S., Calandrino E.S., (2011), Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change, *Science of the Total Environment*, **409**, 1739-1745.

Pieri P., Andra S.S., Charisiadis P., Demetriou G., Zambakides N., Makris K.C., (2014), Variability of tap water residual chlorine and microbial counts at spatially resolved points of use, *Environmental Engineering Science*, **31**, 193-201.

Ranis G., (1980), *Appropriate Technology and the Development Process*, In: *Appropriate technology and social values – a critical appraisal*, Long F.A., Oleson A. (Eds.), Ballinger Publishing Company, Cambridge, USA, 99-120.

Réveillon D., Abadie E., Séchet V., Brient L., Savar V., Bardouil M., Hess P., Amzil Z., (2014), Beta-N-Methylamino-L-Alanine: LC-MS/MS Optimization, Screening of Cyanobacterial Strains and Occurrence in Shellfish from Thau, a French Mediterranean Lagoon, *Marine Drugs*, **12**, 5441-5467.

Schumacher E.F., (1973), *Small is beautiful: economics as if people mattered*, Ed. Blond and Briggs, London.

Shen Y., Oki T., Kanae S., Hanasaki N., Utsumi N., Kiguchi M., (2014), Projection of future world water resources under SRES scenarios: an integrated assessment, *Hydrological Sciences Journal*, **59**, 1775-1793.

Smith E., Kamal Y., (2009), Optimizing treatment for reduction of disinfection by-product (DBP) formation, *Water Science and Technology: Water Supply*, **9**, 191-198.

Stefanova A., Hesse C., Krysanova V., (2015), Combined Impacts of Medium Term Socio-Economic Changes and Climate Change on Water Resources in a Managed Mediterranean Catchment, *Water*, **7**, 1538-1567.

Veldkamp T.I.E., Wada Y., de Moel H., Kummu M., Eisner S., Aerts J.C.J.H., Ward P.J., (2015), Changing mechanism of global water scarcity events: Impacts of socioeconomic changes and inter-annual hydro-climatic variability, *Global Environmental Change*, **32**, 18-29.

Velzeboer R., Drikas M., Donati C., Burch M., Steffensen D., (1995), *The Removal of Cyanobacterial cells by Alum Flocculation*, Proceedings of the Australian Water and Wastewater Association 16$^{th}$ Federal Convention, Sydney.

Water Technology, (2014), *Larnaca SWRO, Cyprus*, Kable Intelligence Limited, London (UK). On line at: http://www.water-technology.net/projects/larnaca-swro-desalination/.

WHO, (1999), *Toxic Cyanobacteria in Water: A Guide to their Public Health Consequences, Monitoring and Management*, Chorus I. and Bartram J. (Eds.), World Health Organization, E & FN Spon, London and New York.

Yilmaz E., Koç C., (2014), Research on water quality of lake Bafa in Turkey, *Environmental Engineering and Management Journal*, **13**, 153-162.

Zidane F., Cheggari K., Blais J.F., Khlil N., Ahmed S.I., Bensaid J., Drogui P., (2014), Effect of organic pollution on trihalomethanes formation and halogenated organic compounds in feed water of Casablanca in Morocco, *Journal of Materials and Environmental Science*, **5**, 338-349.