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The water crisis in Libya: causes, consequences and potential solutions

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ABSTRACT

Libya is located in a dry and semi-arid region of Africa with no perennial rivers or real freshwater lakes and an average yearly rainfall of less than 100 mm. The limited access to surface water resources has resulted in heavy dependence on groundwater. Extensively use of conventional water resources like groundwater, poor awareness of how to optimally use and save water and seawater intrusion into the coastal water aquifers, all contributed to a severe water crisis in Libya. Libya's water crisis issues are further compounded by the distribution of the population relative to the available water resources. 75% of Libya's population is concentrated in only 1.5% of the total land area in the western coastal centers of Jiffarah plain and Misurata, and the eastern coastal area of Al Jabal Al Akhdar. The objective of this paper is to highlight the conventional and non-conventional water resources in Libya. In this context, the paper aims to present an overview of seawater desalination technology in Libya and why desalination should be accommodated as a strategic and ultimate solution for the water shortage.

Keywords: Water resources; Water shortage; Man-made river; Seawater desalination

1. Introduction

The state of Libya has an area of about 1.7 million km^2 with a total population of about 6.5 million. 90% of the people live in less than 5% of the land, mostly along the coast. The population density in the central and southern parts of the country is below 1/km^2 [1].

North Africa is considered to be one of the driest regions in the world. Libya's annual rainfall ranges from 100 to 600 mm in the northern areas. The coastal regions receive the largest amounts of precipitation, while the southern areas receive as little as 10 mm. Only 5% of the entire area of Libya receives more than 100 mm of rain annually. Some parts of Libya get no rain at all [2,3].

The total amount of water available in 2012 was estimated at 3,890 Mm^3 (3,650 Mm^3 groundwater, 170 Mm^3 surface water and 70 Mm^3 desalinated water). The total water withdrawal in 2012 was estimated at 5,830 Mm^3. This included 4,850 Mm^3 for agriculture (83%), 700 Mm^3 for domestic use (12%) and 280 Mm^3 for the industrial sector (5%) [4,5]. The amount of water consumption in 2012 exceeded the amount of water available and the imbalance amounted to 1,940 Mm^3.

Water scarcity is currently one of the greatest challenges in Libya, and this will be the case in the future unless serious decisions are taken to solve this dilemma. According to some reports; Libya has been constantly ranked as one of the most water-insecure places in the world [6,7].

Due to the shortage of clean and fresh water, especially in the coastal regions, there is an urgent need to look for alternative water sources to meet people's needs and compensate for the reduction in groundwater. Desalination is one of such alternative water sources that can solve the water shortage problem in Libya and other countries where faced the same conditions. Desalination is the main technology that has been developed globally over the past three decades to meet the increasing demand for fresh and clean water.

Despite the fact that desalination is a proven alternative water supply technology that is growing in importance

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worldwide, the previous government regime in Libya did not seriously invest in the field of desalination, even though establishment of desalination plants started in the sixties. The main focus of the former government to provide drinkable water for the Libyan people living in the North was the man-made river project (MMRP). Although the MMRP is considered to be one of the biggest civil engineering projects in the world [8], it has not resolved the water crisis in Libya.

This paper attempts to reveal the reasons for and consequences of the water shortage in the country. The causes of the water problem in Libya are first highlighted, next the current status of water resources is reviewed, followed by a short discussion about the project of the man-made river which was adopted by the government as an important source for water for the last three decades. The Libyan experience with the desalination technology is briefly touched on and, finally desalination technology is considered as the first and ultimate alternative water resource to be adopted in Libya.

2. Water shortage problem in Libya

Several countries in the world such as the Arab countries, West Asia, and Australia face severe water shortage issues today. Libya is considered to be one of the top 36 countries in the world facing water stress with a baseline water stress score of 4.84 [6]. The following reasons are believed to be the main causes of water problems in Libya:

- Excessive groundwater exploitation
- Decreased annual average of rainfall
- Intensive agricultural activities in the coastal plains
- Seawater intrusion
- Low water tariffs
- Lack of institutional framework
- Lack of clear strategy related to the local water sector
- Lack of awareness in the public of the need for the rational use and management of water resources
- Poor management in the General Water Authority (GWA)

3. Water resources in Libya

There are two types of water resources in Libya; conventional water resources (natural) including surface and ground water that represent about (97.3%) of the nation's water resources, and non-conventional water resources including seawater desalination and treated wastewater accounting for (2.7%) [9].

3.1. Conventional water resources

3.1.1. Surface water

Libya has very limited surface water resources. Its contribution to the water resources in use is less than 3%. The country has no perennial river and very few of natural lakes, but there are a number of natural springs, many of which have good quality water. Some springs have a high discharge rate, for example Ayn Zayana (flow 5,580 L/s), Ayn Kaam (flow 350 L/s), Ayn Dabbousia (flow 170–230 L/s) and Ayn Tawargha (flow 2,000 L/s). There are about 185 springs of discharge rate less than 5 L/s such as Ayn Brada (flow 3.0 L/s), Ayn Al shershaar (flow 1.0 L/s), Ayn Shisa (flow 0.8 L/s), Ayn Tibah (flow 0.5 L/s) and Ayn Tanget (flow 0.1 L/s) [1,4,5].

It has to be mentioned that the available data concerning the natural springs is quite old and needs to be updated. The data was collected during the seventies and eighties and may no longer represent the conditions of these springs. Consequently, the actual current conditions of such natural springs cannot be stated here.

Around 16 major dams with a total capacity of 385 Mm^3 and an average annual storage capacity of 61 Mm^3 have been constructed in Libya in order to harvest rainwater (Table 1). Water collected in these major dams is used for agricultural water supply, industrial projects, and, in some cases, for domestic use. The biggest three dams are: Wadi Quattara, Wadi Kaam, and Wadi El-Magineen, with design capacities of 135 Mm^3, 111 Mm^3, and 58 Mm^3 respectively. Furthermore, a considerable number of new dams have been approved for construction. It is believed that the total amount of water that will be captured annually by these new dams will reach 120 Mm^3 [4].

3.1.2. Groundwater

Groundwater is the main water source in Libya, supplying more than 98% of the water consumed [10]. The total volume of groundwater in Libya is estimated to be 99,500 km^3 with a range in uncertainty of between 64,600 km^3 and 234,000 km^3 [11].

There are two types of groundwater resources in Libya; shallow aquifers that obtain water from rainfall and surface runoff and are renewable, and what is often called deep aquifers, which are not renewable. Shallow aquifers are mainly found in the northern underground basins such as the Jiffarah Plain system, Al Jabal Al Akhdar system, and Al Hamada basin, while the deep aquifers (fossil water) are found in most of the southern half of Libya such as the

Table 1
Constructed dams in Libya

No.	Water basin	Number of dams	Total capacity (Mm^3)	Average annual storage (Mm^3)
1	Al Jabal Al Akhdar	5	160.6	15.95
2	Kufra and Sarir	4	8.14	1.8
3	Jiffarah plain	3	96.6	25.5
4	Al Hamada	4	119.4	17.4
	Total		384.74	60.65

Murzuq basin, Kufra basin, and Sarir basin (Table 2). It has to be mentioned that the second type (fossil water) was accidently discovered in the mid 20th century when oil exploration in the Libyan southern desert was started. As a result of this discovery, five main underground basins were identified [1]. Fig. 1 shows the main groundwater basins.

3.1.3. Water supply-demand balance

According to the General Water Authority, there are 6,822 × 10^6 m^3 of water available in major basins. The water supply and demand situation for these basins in 2010 is summarized in Table 3 and Fig. 2.

Table 2
Main underground basins and their characteristics in Libya

Basin name	Area (km^2)	Basin type	Estimated groundwater capacity (km^3)
Jiffarah plain	18,000	Renewable[a]	–
Al Hamada	215,000	Renewable	4,000
Al Jabal Al Akhdar	145,000	Renewable	–
Murzuq	350,000	Non-renewable[b]	4,800
Kufra and Sarir	700,000	Non-renewable	–

[a]Renewable groundwater is water that can be replenished annually through rain.
[b]Non-renewable groundwater basins are groundwater bodies (deep aquifers) that have a negligible rate of recharge on the human time-scale and thus can be considered non-renewable.

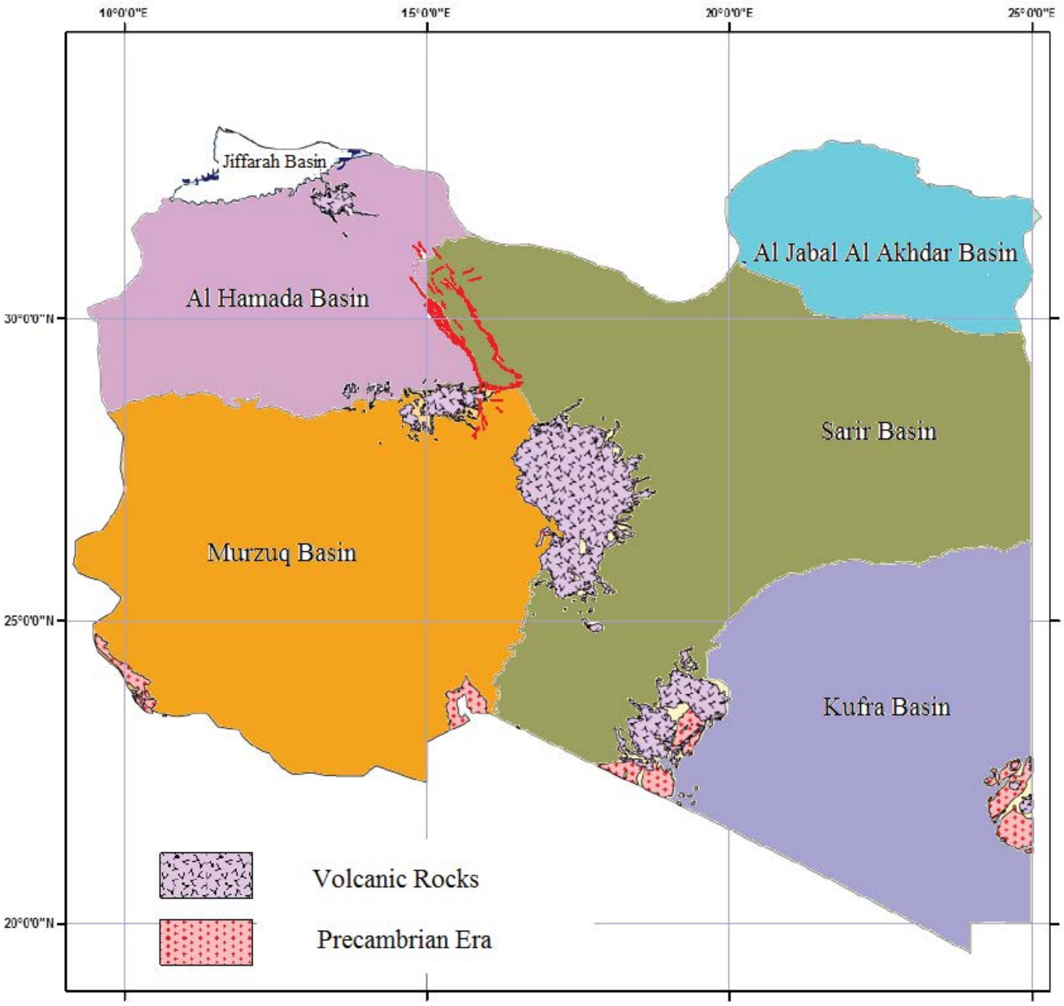

Fig. 1. Libya underground basins.

Table 3
Water balance in 2010

Basin name	Available water (×10⁶ m³/year)						Total (×10⁶ m³/year)	Water use (consumption (×10⁶ m³/year)			Total (×10⁶ m³/year)	Total balance
	Conventional water			Non conventional water								
	Renewable	Non renewable	Surface	Desalinated	Treated waste water	Transported		Irrigation	Domestic	Industrial		
Jiffarah plain	300	50	25.5	19.70	11.10	215.64	621.94	995.2	228.59	12.3	1,236.09	−614.15
Al Hamada	50	350	16.4	12.26	12.99	45.52	487.17	289	91.72	6.6	387.32	99.85
Al Jabal Al Akhdar	300	50	15.65	35.47	14.89	154.89	570.9	378	192.59	6.94	577.53	−6.63
Murzuq	–	2,500	–	–	5.48	−261.16	2,244.32	1,658	47.30	6.7	1,712	532.32
Kufra	–	1,650	–	–	–	−166.10	1,483.90	377	12.28	–	389.28	1,094.62
Sarir	–	1,570	3.84	–	–	−159.50	1,414.34	446.83	37.81	154.44	639.08	775.26
Total	650	6,170	61.39	67.43	44.46	–	6,822.57	4,144.03	610.29	186.98	4,941.30	1,881.27

Adapted from [12]

It has to mentioned that population is not distributed evenly around the basins. The Libyan population is mostly concentrated in the coastal regions (Jiffarah plain and Al Jabal Al Akhdar). The uneven distribution of population and the intensive agricultural activities in the coastal regions make the gap between water supply and demand wider. Although the information illustrated in Table 3 is for 2010, experts expect the imbalance between supply and demand will grow wider in the future for the northern basins if serious steps are not taken urgently.

3.2. Non-conventional water resources

The non conventional water resources in Libya include mainly the man-made river, and water supplies through wastewater treatment and desalination technology. These resources are discussed in detail below.

3.2.1. Man-made river project

This project is considered to be the largest and most expensive groundwater pumping and conveyance project in the world. According to the United Nations Environmental Program (UNEP), the MMRP is among the "largest civil engineering projects in the world".

This project was undertaken to meet the Libyan population's water needs by drawing water from aquifers beneath the Sahara – mainly the Nubian Sandstone Aquifer System- and conveying it along a network of huge underground pipes to the Northern coastal cities where most of the Libyan population live and fresh water is considered scarce. According to the UN International Atomic Energy Agency (IAEA), the Nubian Sandstone Aquifer System is one of the largest and most important underground aquifers in the world. The two million square km water system holds twice the water of the Caspian Sea.

At the time of deciding about this project, it emerged that the MMRP would be five times more cost-effective than any alternative water supply option.

The project was designed in five stages and the optimum target of the project once its all five stages were completed was to convey a large amount of water (estimated to be 6 million m^3) on a daily basis from the sources in the South to the North, where there is an increasingly urgent need for clean and safe water. As this project was considered to be one of the largest water conveyance systems in the world it was classified as one of the non-conventional water resources, although the transported water is groundwater [4].

The first stage of construction work on this project began in the mid 1980s. The management and the implementation authorities of the MMRP were created to take responsibility of this big project. The construction of this project relied on funds from government collected taxes on gasoline, tobacco and travel, with no foreign or international support.

It was decided that the water brought from the MMRP would be used in the following activities: agricultural use (80%), domestic use (12%) and only 5% for industrial use. The water usage cost was estimated at 47 Derhams ($0.033) for one m^3 for agricultural use, 80 Derhams ($0.057) for one m^3 for domestic use, and 796 Derhams ($0.57) for one m^3 for industrial use.

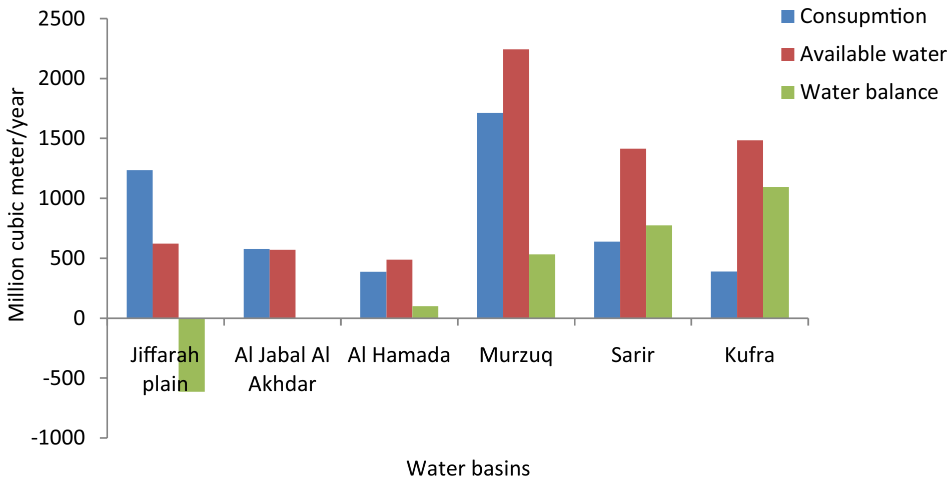

Fig. 2. Water supply-demand balance (2010).

The first stage of the project was partially operated on 28 August 1993, while the second stage was partially operated on 28 August 1996. Around 400 million m^3 of water was transferred in the first stage and 230 million m^3 in the second stage, which continued till the end of 1998, mostly for domestic use. The third stage was an extension of the first stage and added 1.68 million m^3 of transferred water per day. The MMRP has not been completed, as the fourth and fifth stages still need to be accomplished.

Despite the fact that some coastal cities were supplied with water from the MMRP, people feel skeptical about the quality of the water; therefore a large percentage of the population in the big cities such as Tripoli, Benghazi and Misurata do use this water for washing, cleaning, industrial purposes and agriculture but never for drinking. The concern about the quality of the MMRP water not being good enough for drinking came up as people think that water which is collected in big reservoirs is not analyzed or treated regularly, which could prevent it from meeting the standards for drinking water [13].

Recently and due to violence and conflicts in some areas in the Southern part of Libya, citizens of Tripoli have experienced difficulties getting access to water from the MMRP. The water supply was deliberately cut off by some rebels and protesters. Rebels and protesters and their commanders shut down the man-made river water supply system as a mechanism to force the government to make decisions in their favour. The present government is struggling to take control of the entire land of Libya and if this scenario continues, people of the capital and other coastal cities supplied by this water source will continue to suffer.

Based on the above-mentioned information concerning the quality of water, and due to the current situation regarding the MMRP, water shortage is a continuing problem in most parts of Libya.

3.2.2. Wastewater treatment

As the population of Libya had grown in the last three decades, especially in Jifffarah plain and Al Jabal Al Akhdar region, it was necessary to establish a number of wastewater treatment plants in urban and rural areas to preserve public health. According to data obtained from the General Company for Water and Wastewater (GCWW), there are around 23 wastewater treatment plants distributed all over the country. Only 10 plants out of the total number are working and in operation, 8 plants are out of service and the company's management teams are doing maintenance on 5 plants.

Wastewater treatment plants were mostly designed for producing water suitable for agricultural use. The largest operating wastewater treatment plants are located in Tripoli, Misurata and Sirt, with design capacities of 110,000 m^3/d, 24,000 m^3/d and 21,000 m^3/d respectively. Most of the remaining wastewater facilities are medium and small sized plants (370–6,700 m^3/d).

The estimated amount of wastewater to be treated is 1,324,054 m^3/d, and the estimated amount of treated wastewater is about 145,800 m^3/d which accounts for only 11% and the remaining percentage of wastewater is being pumped into the sea, artificial lagoons and black wells without any treatment.

3.2.3. Desalination technology

Desalination is the process of removing dissolved salts from water, thus producing fresh water from seawater or brackish water. Desalting technologies can be used for many applications. The most prevalent use is to produce potable water from saline water for domestic or municipal purposes [14]. Based on the previous definition desalination of seawater is the technology used for alleviating the problem of water shortage in coastal regions. There are currently over 15,150 desalination plants in operation in more than 150 countries worldwide, with over half of them in the Middle East, and the number is continuously growing. The total capacity of these plants is estimated at about 95.59 million m^3 of fresh water per day. As the world's population grows, the demand for water intensifies; therefore, seawater desalination is becoming an attractive option as an alternative water supply to meet demand and solve the persistent water shortage problem in many countries around the world. Desalination technologies can be broadly classified as either membrane or thermal. Membrane desalination technologies account for 93% of the global market and thermal desalination technologies account for the remaining 7% [15].

Desalination of seawater offers a range of human health, socio-economic, and environmental benefits by providing an apparently unlimited, constant supply of high quality drinking water without damaging natural freshwater ecosystems [16].

As any other technology, desalination is likely to have significant effects on the environment. Fortunately, these effects can be optimally reduced by means of mitigation measures. The main local environmental impacts that arise from the desalination process are from brine concentrate and from discharges of chemicals in the desalination process [16,17]. Energy intensity and resulting emissions of greenhouse (thermal desalination techniques) are also considered [18,19].

To prevent or reduce the environmental impacts of desalination process mentioned above, there are some general mitigation measures that may be applied; Institutional development, which include proper enforcement of any existing environmental or water laws or regulation, effective water resources management planning with environmental aspects, and further awareness-raising for water conservation might be the main mitigation measures of local impacts of desalination plants.

3.2.3.1. Desalination plants in Libya

Desalination is considered to be the second most important non-conventional water resource adopted in Libya. Desalination technology has been used in Libya since the early 1960s, although few desalination plants have been established since then. There are currently about 21 operating desalination plants, with a total capacity of 525.680 m^3/d. Thermal processes represent about 95% of the operable desalination plants, while reverse osmosis (RO) membrane technology represent about 5%. The contribution of desalination in the overall local water supply represent was 1.4% in the year 2002 [20].

In the early seventies a number of desalination plants with limited capacities were installed, for example Tubrok, Darna, Sussa, Benghazi, Zwiteena, Ben Jawad, Sirt, Zliten, Tripoli West, and Zwara. The total designed capacity reached 136,900 m^3/d. These plants are currently out of service due to their age as well as their design capacity limitations, which made their maintenance uneconomical. Due to the increased demand for clean water in the early eighties a number of new plants of medium capacity were established, for example Bomba and Khoms, and some of the old plants, such as Zwiteena, Sirt, Zliten and Zwara were extended. The total production capacity of these plants reached 123,500 m^3/d. In the early nineties, and with the availability of expertise in the field of desalination and increased demand for potable water for urban use, a number of plants with a total capacity of 40,000 m^3/d were implemented (West of Tripoli ext, Zliten ext). At the beginning of 2000, plants with a total capacity of 130,000 m^3/d were implemented to meet the needs of the coastal areas (Tubrok ext, Sussa ext, Zwara, and Abou Traba).

Documents obtained from the national co-operations and authorities indicate that there is some uncertainty regarding the real number of desalination plants currently operating in Libya. Careful comparison between all the obtained documents was done by the author in order to gain a clear idea regarding the actual operating desalination plants. Table 4 presents the desalination plants on the Libyan coastline as well as their production capacities.

It should be mentioned that the data included in Table 4 was the most updated data obtained from the formal authorities; however the out-of-service desalination plants are excluded.

The desalination plants presented in Table 4 belong to different authorities, although all of them are owned by the government. The General Electricity Company of Libya (GECOL), General Desalination Company (GDC) and GCWW are the responsible authorities for the desalination plants. According to the data obtained from the GDC, the total amount of desalinated water produced in 2010 from desalination plants belonging to the company was 71 Mm^3. GDC stated that about 15 new desalination projects are being approved for constructing. Table 5 gives a list of the newly approved projects.

As can be noticed in Table 5, most of the newly approved desalination projects are using membrane technology (RO). RO is a liquid/liquid separation process that uses a dense semi-permeable membrane, highly permeable to water and highly impermeable to microorganisms, colloids, dissolved salts and organics [21]. Due to the new developments, RO desalination was proved to have lower investment cost and higher energy efficiency [22,23].

3.2.3.2. Desalination is the solution for the water scarcity problem

Desalination is becoming a solution for water scarcity in most arid countries, and yet is not a strategic option adopted by the Libyan government [24]. Based on the detailed review presented in the previous sections and including the current conditions of the MMRP there is an urgent need to invest in the field of desalination. Desalination is the first and best solution for water crisis in Libya for the following reasons:

- Over-exploitation of groundwater;
- The increasing demand of water;
- The current unstable conditions of the MMRP, which make it unreliable future water source. Besides, the maintenance work involved in continuing to extract groundwater from the Saharan aquifer and transport it by conduits to the northern coastal cities makes it unfeasible;
- The availability of seawater in high quantities and relatively free of industrial pollutants;
- Libya has the longest Mediterranean coastline among African nations (around 1770 km);
- The biggest and the most populated Libyan cities are located along the coast;
- Opportunities are created for spatial development;
- The availability of natural gas may contribute to lowering the cost of water production, especially when taking into consideration the possibility of building joint power and desalination plants; and

Table 4
Existing operating desalination plants in Libya

Location	Desalination type	Design capacity m³/d	Number of units	Operation year
Tubrok	MED-TVC	40,000	–	1977–2002
Bomba	MSF	30,000	3	1988
Darna	MED-TVC	40,000	–	–
Sussa	MED-TVC	10,000	2	2000
Sussa ext.	MED-TVC	40,000	–	–
Abou Traba	MED-TVC	40,000	–	2006
Zliten	MSF	30,000	3	1992
Azawia	MED-TVC	80,000	–	–
Zwara	MED	40,000	–	2006
Zwara ext.	MED-TVC	40,000	–	–
Tubrok	MSF	24,000	4	1977
Tajoura	RO	10,000	2	1984
Misurata	MSF	30,000	3	1987
Sirt	MSF	10,000	1	1986
Azawia double	MED	2,500 × 2	2	2006
Tripoli west	MED-TVC	5,000 × 2	2	1999
Homes	MSF	10,560 × 3	4	1985
Benghazi North	MED-TVC	4,800 × 1	1	2005
Benghazi North double	MED-TVC	2,500 × 2	2	2007
Darna	MED-TVC	4,700 × 1	1	1998
Hrawa	MSF	500 × 1	1	1989
Total design capacity		525,680		

MED - Multi-effect distillation, TVC - Thermal vapour compression, MSF - Multi-stage flash, RO - Reverse osmosis.

Table 5
List of new, approved desalination projects along the Libyan coast

Plant	Capacity m³/d	Desalination technology type
Tubrok	40,000	SWRO
Bomba	30,000	MED-TVC
Zliten	20,000	SWRO
Tripoli East	500,000	SWRO
Tripoli West	200,000	SWRO
Benghazi	400,000	SWRO
Darna	50,000	SWRO
Sussa	50,000	SWRO
Bou Traba	50,000	SWRO
Zwiteena	60,000	SWRO
Sirt	50,000	SWRO
Misurata	85,000	SWRO
Zliten	50,000	SWRO
Khoms	150,000	SWRO
Sabrata	50,000	SWRO
Total capacity	1,695,000	

SWRO - Seawater reverse osmosis

- Reduction worldwide in total cost of water produced by desalination

In addition to the above-mentioned reasons, countries can learn from experience of the Arabian Gulf States in the field of desalination technology. Saudi Arabia is one of the Gulf countries, located in a dry region and is considered among the poorest countries in the world in terms of natural renewable water resources. However, Saudi Arabia has invested heavily in water desalination facilities and has become the world's largest producer of desalinated water with 28 operational plants providing 1.3 billion m³/year of drinking water and 37.03 million MWH/year of electricity to major urban and industrial centers through a network of water pipes more than 7,000 km long [25]. The Saudi's remarkable experience with desalination can be an additional reason to make desalination technology an important source for providing water in the present and future for the Libyan people especially, those who are living along the coastline.

4. Conclusions

Based on the detailed review of conventional and unconventional water resources in Libya presented in this paper, Libya is heading toward a severe shortage of fresh water if its government does not take action regarding this severe problem. The following conclusions and recommendations are put forward:

- The agricultural sector is the biggest consumer of water (80%) and contributes little to the country's economy; therefore, proper irrigation technologies should be implemented.
- The absence of good management in all water authorities caused many problems regarding documentation; therefore, there must be cooperation between the national authorities to solve the water shortage problem.
- Despite the fact that the manmade river has partly solved the water crisis in the northern parts of the country, it cannot be reliable for all situations. What happened in the past five years has approved this point: The people of Tripoli suffered many times due to the manmade river's network being deliberately cut off by some rebels. Hence, the manmade river implementation company in cooperation with the government should deal with such rebels in a serious manner; otherwise Libya's national water crisis will continues to escalate.
- Desalination of seawater or brackish water has been proved to be a cost effective technology. There are great expectations for capital cost reduction of desalination due to technological advances in membrane manufacture. Accordingly, desalination of seawater should be adopted in all coastal Libyan cities, while desalination plants for brackish water should be installed throughout the country.
- The responsible water authorities should urgently create professional inspection teams to investigate the out-of-service desalination plants and write reports describing the technical status of these plants, including the maintenance cost when it is required. Based on these reports, governments and private sector would be able to make the right decisions with regard to these plants. If these out-of-service plants stay as they are, many technical, social and environmental problems will appear sooner or later.
- It is recommended that the manmade river project continue as a second water supply source for the northern coastal cities and other parts of the country to compensate for the loss of water when it is needed.
- The government should take initiative regarding water reuse and recycling by encouraging research in this field. This can be conducted by research centers and universities.

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