Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.25519

Efficient use of water for food production through sustainable crop management: Kingdom of Bahrain

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ABSTRACT

Food production under unfavorable climatic conditions and limited water resources cannot be sustainably practiced unless crop water management techniques are designed to meet the present growing demands of water for increased food production. Bahrain, severely constrained by limited agricultural resources such as limited water resources, poor and declining quality of the soil, and unfavorable climate therefore water scarcity will reduce agricultural production and threaten country's food security. The aim of this paper is to analyze the efficient use of water for food production through better crop management. It focuses on the water use efficiency and water productivity of agricultural sector in Bahrain. The study provided a comprehensive analysis of the vegetable production activities in Bahrain and assessed their efficiency in terms of financial and economic profitability, especially their utilization of the scarce natural resources, water. The analysis conducted for three methods of certain vegetable production in different farms of vegetable production (traditional, green house and hydroponic methods). The irrigation method adopted under open agriculture is traditional, drip, sprinkler and bubbler irrigation while the protected house adopted drip irrigation. Policy analysis matrix (PAM) has been used in the study to analyze the comparative advantage of 12 crops production systems under traditional farming and protected and hydroponic farming systems in Bahrain using the 2016/2017 production data.

Keywords: Bahrain food production system; Water use efficiency; Sustainable crop management

1. Introduction

Due to arid climatic conditions natural sources of food production are limited in Bahrain. High temperatures limit yields for many stable food crops; soils are fragile and groundwater which can be renewed inherently scarce and are among the lowest in the world. Thus, due to shortage of fresh water, poor soil resources, low rainfall and high evapotranspiration in GCC countries constrain local agriculture production in meeting the food demand of the current and growing population (Salma Bani 2015). Also, climate change is likely to tighten these constraints.

Food production under unfavorable climatic conditions and limited water resources cannot be sustainably practiced unless crop water management techniques are designed to meet the present growing demands of water for increased food production. The deficit between available water and water demand is growing and expected to increase in the near future. Water scarcity will reduce agricultural production and threaten country's food security; therefore, the best

Presented at the 13th Gulf Water Conference – Water in the GCC: Challenges and Innovative Solutions. 12–14 March 2019, Kuwait

use of water must be made for efficient crop production and higher yields. The aim of this paper is to analyze the efficient use of water for food production through better crop management. It focuses on the water use efficiency and water productivity of agricultural sector in Bahrain. The present status of agricultural water use will be outlined to point out the main factors of inefficiency in the use of irrigation water such as losses in the conveyance of irrigation water; low efficient on-farm irrigation methods, inefficiency related to the irrigation systems setup and losses due to inadequate irrigation practices.

Policy analysis matrix (PAM) has been used in the study to analyze the comparative advantage of 12 crops production systems under traditional farming and protected and hydroponic farming systems in Bahrain using the 2016/2017 production data. The actual measurement of competitiveness in this study focuses mainly on private resource cost which indicates competitiveness under real market conditions and domestic resource cost (DRC) which gives an assessment on the social or economic efficiency of an activity, that is, whether domestic resources are really used efficiently in current production.

Water productivity will be analyzed from an economic point of view through a study on economic considerations. Two scenarios will be elaborated by means of crop water requirements, costs and income of agricultural production. Finally, the paper will recommend the cultivation of crops which have low crop water requirements but have a high economic return together with an extensive use of treated sewage water for agriculture.

2. Food production system in Bahrain

Bahrain was one of the richest countries in the Arabian Gulf even prior to the discovery of oil resources in 1932. Its' pearl was the famous and best in the region, an important agriculture and trading center. However due to urbanization and expansion of new towns and communities as well as industrial sector land consumption which all resulted in pressure on agriculture in Bahrain. The biggest challenges Bahrain agriculture facing are limited agricultural lands and shortage of water resources. The total arable land in Bahrain is estimated to be 64,000 donum (Agricultural Statistics Year book 2017), in other words it is about 10% of the total area which amounts to 622 km^2. Two thirds of this arable land is cultivated.

The agriculture products produced locally covers only 12% of total consumption needs. The major crops grown are dates and fruit trees with a yield of 7.5 tons ha^{-1}, vegetables, mainly tomatoes, with a yield of 11.7 tons ha^{-1}, and fodder crops, mainly alfalfa, with a relatively high yield of 74.5 tons ha^{-1}. The alfalfa tolerates high salinity and is a cash crop grown all year round with high local demand. However, because of the very high irrigation water requirements of alfalfa, it is expected that this trend will have negative implications for the country's groundwater resources.

Tolner (2013) comprehensively described various aspects of Bahrain. According to him, the limited arable lands, sandy texture and associated high infiltration rate, low organic matter (0.05%–1.5%), low inherent soil fertility, low water and nutrient holding capacity, limited good quality water has resulted into focused low agricultural activities in Bahrain. Agriculture is mainly focused along the north-western coast of Bahrain Island. Irrigated agricultural farms present soil salinity within a range of 4–12 dS m^{-1}, while in the areas of recently abandoned agriculture (1,065 ha) it could reach 60 dS m^{-1}. Tolner (2013) also expressed declining of agricultural lands between 1956 and 1977 from about 6,460 ha (with 3,230 ha cultivated) to about 4,100 ha (with 1,750 ha cultivated). This decrease was attributed mainly to urban expansion, waterlogging and soil salinization due to deterioration of the quality of the groundwater used in irrigation. In an attempt to reverse the situation, the government initiated a major agricultural development program in the early 1980s represented by (1) the replacement of surface irrigation methods with micro-irrigation (more water efficient) by subsidizing more than 50% of the cost of their implementation, (2) the construction of major drainage systems to alleviate waterlogging and salt accumulation, (3) the provision of agricultural extension services in terms of educating and advising farmers on types of crops suitable for agriculture under prevailing conditions, (4) the introduction of TSE water in irrigation and, (5) the reclamation of new agricultural lands (Tolner 2013). This resulted in a gradual increase and restoration of agricultural lands to about 4,230 ha, with 3,165 ha irrigated at present, all power irrigated. These 4,230 ha can also be considered as the irrigation potential, should there be an increasing future use of nonconventional water sources, in addition to groundwater. The quantity of groundwater available in the future for agriculture is difficult to estimate since groundwater quality, and hence its availability for irrigation, changes with time. The small size of agricultural landholdings, ranging between 0.5 and 10 ha with an average of 2.5 ha and the fragmentation of the agricultural land.

2.1. Soil, water and land resources

2.1.1. Soil resource

The soils of Bahrain are mostly moderate to shallow in depth. The topsoil texture ranges from sand to loamy sand whereas it subsoils texture varies from loamy sand to sandy loam. The water holding capacity is very low and the available moisture is about 2%–6%. Infiltration rates are very high, above 120 mm/h. Most of the cultivated land became saline, mainly due to heavy applications of saline water during irrigation.

2.1.2. Water resource

The demand for water in Bahrain comes from domestic, agricultural and industrial sectors. The water demands in Bahrain are met through groundwater desalinated water and treated sewage effluent. About 70% of the total water demand is met by the island's groundwater resources. Bahrain being an arid to extremely arid climate, due to which recharge of aquifer is very slow or not at all. Groundwater has become less accessible and less acceptable environmentally; therefore, sufficient availability and adequate water quality are of crucial importance for sustainable development and protection of the environment. The question, however, is pertinent that can we increase water productivity and ensure enough water for sustaining the resource base for food production?

2.1.3. Agricultural land

Bahrain, severely constrained by limited agricultural resources such as limited water resources, poor and declining quality of the soil, and unfavorable climate. Also, due to urbanization and expansion of new towns and communities as well as industrial sector land consumption which all resulted in pressure on agriculture in Bahrain as result of which agriculture contributes only 0.4% to Bahrain's real GDP.

Agriculture development is concentrated on the north and northwest coast, as prescribed by soil, and water quality and availability. In the past, springs located at the contact of the limestone uplands (Dammam black slope) and the coastal fringe deposits were used for irrigation on the coastal lowland soils. These large continuous areas of flat, easily filled, permeable soils are served by groundwater of moderate quality, and this zone has been intensively cultivated.

2.2. Farming systems for efficient use of natural resources

Bahrain's agricultural policy reflects overall economic policy, which emphasizes diversification of the production base. Bahrain implemented a 2004–2015 plan for sustainable agricultural development to improve production and raise productivity. Development efforts in agriculture have included the promotion of intensified farming, Government assists agricultural producers mainly by offering subsidies for a number of inputs, such as 84% of the cost of machinery services; 40% of the price of modern irrigation equipments; and 50% of the price of pesticides; 40 percent of the price of plastic sheet; 50% of the price of veterinary drugs and animal vaccines; and 5% of the price of local poultry meat. Loans are also provided to farmers intending to launch programmes to protect date palms, and other farming activities.

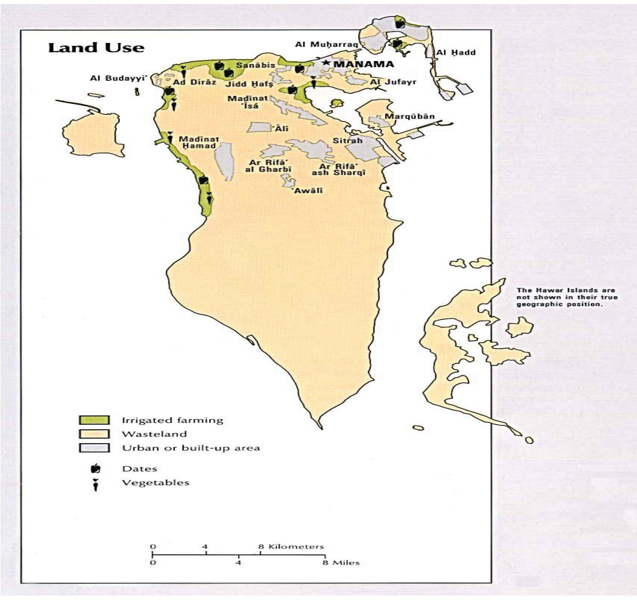


Diagram 2:1 Bahrain Agricultural Land Use
Source: Agricultural Engineering & Water Resources Directorate. Ministry of Municipal Affairs & Urban Planning Agriculture Affairs, Kingdom of Bahrain.

Water is given high priority among other national priority issues in Bahrain due to the limited freshwater resources and escalating water demand. The highest consumption of abstract ground water is by agriculture sector at estimated rate of 66% as a whole. Committee for the protection of freshwater resources was formed with four main tasks: defining and evaluating freshwater resources; protecting freshwater quality, ecosystems and preventing groundwater pollution; integrating development and management of water resources; and, studying climate change effects on water resources. Bahrain has ratified the Convention on Wetlands of International Importance as Waterfowl Habitats (Ramsar Convention). To sustain water, two guiding principles have been followed to manage water more effectively in agriculture. The first approach dealt with the issue of reducing groundwater abstraction, while the second concentrated on finding alternative irrigation water for agriculture and ever-growing landscape projects. A number of actions have been worked on to reach these two objectives, including: enacting and strictly enforcing laws to reduce groundwater abstraction; increasing water use efficiency in agriculture; improving irrigation methods (modern irrigation techniques 75% of agricultural area is under flood irrigation); replacing high-irrigation requirement crops with others of less water demand; introducing tariffs for using groundwater; and using treated sewage effluent. Management of water used, agriculture under greenhouse was introduced in 1976 with the aim of increasing production and achieving a higher level of self-sufficiency in various agricultural products, particularly high-quality fresh vegetables crops. The main greenhouse crops produced are tomato, cucumber, pepper, squash, eggplant, lettuce, strawberry, bean and cauliflowers. However, new policies and institutions are needed for implementing a sound water use development program under these conditions.

Field crop production in Bahrain is diverse. There are three systems of producing a wide variety of fresh vegetables. The three systems of vegetable production are traditional agriculture, protected agriculture, and hydroponic system. Protected agriculture was introduced in Bahrain in 1976, and significant changes in the total area of greenhouse vegetable production have occurred. The total area under cultivation was 59.46 ha in 1996. An increasing number of farmers are now attracted to this new system of intensified cropping. Other investors with capital and land are also becoming interested.

Water scarcity in the region has been an issue for a long time, given the current trends of unsustainable water withdrawals, population increase and degradation of land resources. Bahrain being an arid to extremely arid climate as a result of which natural sources of water in Bahrain is limited to groundwater which can be renewed either very slowly or not at all. Groundwater has become less accessible and less acceptable environmentally; therefore, sufficient availability and adequate water quality are of crucial importance for sustainable development and protection of the environment. The question, however, is can we increase

Traditional agriculture

Protected agriculture

Hydroponics system

Traditional irrigation systems

Drip irrigation systems

Modern irrigation hydroponic

water productivity and ensure enough water for sustaining the resource base for food production?

Unfortunately, due to lack of rain, agriculture is irrigated and mainly depends on ground water, therefore, the agriculture sector is the main groundwater consumer and consumes about 80% of the groundwater abstracted. The irrigation method adopted under open agriculture is traditional, drip, sprinkler and bubbler irrigation while the protected house adopted drip irrigation. Water scarcity will reduce agricultural production and threaten country's food security. Therefore, strategies to optimize water use in agriculture under conditions of scarcity need be developed to maximize return per unit of water instead of per unit of land and to improve local livelihoods.

The need to reduce groundwater abstractions has prompted the Government to consider the use of treated sewage effluent as an additional source of water for agricultural purposes. However, it is not utilized to its full capacity, and only 20% of the treated effluent is used, mainly on experimental farms, landscaping and certain industrial uses. Bahrain being an arid to extremely arid climate, due to which recharge of aquifer is very slow or not at all. Groundwater has become less accessible and less acceptable environmentally; therefore, sufficient availability and adequate water quality are of crucial importance for sustainable development and protection of the environment. The question, however, is pertinent that can we increase water productivity and ensure enough water for sustaining the resource base for food production?

The water withdrawal and use and their percentages for the year 2017 (the latest figures) are as follows:

Items	Quantity (Mm^3)	Percentage (%)
Gross total water withdrawal/ production and use	437.1	
Minus losses during transport	5.1	
Net total water withdrawal/ production and use	432.0	100
Of which from:		
• Renewable groundwater	103.8	24
• Non-renewable groundwater	54.6	12.6
• Desalinated water	234.1	54.2
• Treated wastewater	39.5	9.2
Of which used by:		
• Agriculture	143.0	33.1
• Municipal	258.4	59.8
• Industrial	30.6	7.1

Note: Wastewater from urban wastewater is excluded.
Source: Agricultural Engineering & Water Resources Directorate. Ministry of Municipal Affairs & Urban Planning Agriculture Affairs, Kingdom of Bahrain.

I asked a question in my previous email but you did not answer it. We were using the term exploitable before for certain reasons. The best is to use water withdrawal/ production and use format to make things comparable with our database and international requirements. The water withdrawal and use and their percentages for the year 2017 (the latest figures) are as follows:

3. Problem identification

Due to arid climatic conditions natural sources of water in Bahrain are limited to groundwater. Water scarcity will reduce agricultural production and threaten country's food security. Agriculture in the Kingdom of Bahrain witnessed in recent years many obstacles that affected its role in the development process and achieving food security in the country. Agricultural products produced locally cover only 12% of total consumption needs. The value of agricultural output is 16.2 million dinars at a contribution rate of 23% of the GDP, and the value of food imports amounted to more than 202 million Bahraini dinars, and the deficit of the balance of commodity trade in the Kingdom of Bahrain up to the borders of almost 173 million dinars. Therefore, with the world facing perfect storm of food scarcity, Bahrain needs to focus on lowering its food imports and increasing agricultural production to boost the contribution of agricultural sector to its gross domestic product. However, food production under unfavorable climatic conditions and limited water resources cannot be sustainably practiced unless crop water management techniques are designed to meet the present growing demands of water for increased food production. The deficit between available water and water demand is growing and expected to increase in the near future. The best use of water must be made for efficient crop production and higher yields.

4. Methodology

The aim of this paper is to analyze the efficient use of water for food production through better crop management. It focuses on the water use efficiency and water productivity of agricultural sector in Bahrain. The study provided a comprehensive analysis of the vegetable production activities in Bahrain and assessed their efficiency in terms of financial and economic profitability. Especially their utilization of the scarce natural resources, which is water in particular. The analysis conducted for three methods of certain vegetable production in different farms of vegetable production (traditional, green house and hydroponic methods). The irrigation method adopted under open agriculture is traditional, drip, sprinkler and bubbler irrigation while the protected house adopted drip irrigation. This paper employs the concept of comparative advantage of international trade theory to analyse the competitiveness of Bahrain vegetable production. In order to do this analyses, we will construct a modified PAM for the selected vegetable major competitive crops (cucumber, tomato, lettuce) in three production systems. The PAM framework and its modifications are discussed and applied in Monke and Pearson (1989), Monke et al., Yao and Tinprapha, and Yao. The framework will be adapted to the specific conditions of Bahrain and changed to incorporate aspects that are different from PAM approach.

4.1. Policy analysis matrix structure

The policy analysis matrix is a product of two accounting identities, one; defining profitability as the difference between revenues and costs and the other measuring the effects of divergences (distorting policies and market failures) as the difference between observed parameters and parameters that would exist if the divergences were removed. By filling in the elements of the PAM for an agricultural system, an analyst could measure both the extent of transfers occasioned by the set of policies acting on the system and the inherent economic efficiency of the system. Profits are defined as the difference between total (or per unit) sales revenues and costs of production. This definition generates the first identity of the accounting matrix. In the PAM, profitability is measured horizontally, across the columns of the matrix, as demonstrated in Table (4.1), Profits, shown in the right hand column, are found by the subtraction of costs, given in the two middle columns, from revenues, indicated in the left-hand column. Each of the column entries is thus a component of the profits identity-revenues less costs equals' profits. Each PAM contains two cost columns, one for tradable inputs and the other for domestic factors. Intermediate inputs-including fertilizer, pesticides, purchased seeds, compound feeds, transportation and fuel are divided into their tradable-input and domestic factor components. This process of disaggregation of intermediate goods or services separates intermediate costs into four categories – tradable inputs, domestic factors, transfers (taxes or subsidies that are set aside in social evaluations) and non-tradable inputs (which themselves have to be further disaggregated so that ultimately all component costs are classified as tradable inputs, domestic factors or transfers).

As shown in the Table (4.1), Monke and Pearson arranged the data in three rows; the first row for the private prices, the second row for social prices and the third row for the transfers, which are the difference between profits measured at private prices and those measured at social prices. This difference is also referred to as the effects of government intervention or divergences.

whereas: -

A = total revenue in private price (market prevailing price)
B = cost of tradable inputs in private price
C = cost of domestic factors in private price
D = private profit
E = total revenues in social price (price which are adjusted for government intervention)
F = cost of tradable inputs in social prices
G = cost of domestic factors in social prices
H = social profits

Table (4.1): the policy analysis matrix

	Revenues	Costs		Profit
		Tradable inputs	Domestic factors	
Private prices	A	B	C	D
Social prices	E	F	G	H
Divergences	I	J	K	L

Source: Erik and Pearson (1989).

The matrix is thus made up by the following identities: -

Private or financial profit	(D)	D = A-B-C
Social profit	(H)	H = E-F-G
International value added	(IVA)	E-F = H + G
Output transfers	(I),	I = A-E
Input transfers	(J),	J = B-F
Factors transfers	(K),	K = C-G
Net transfers	(L),	L = D-H = I-J-K

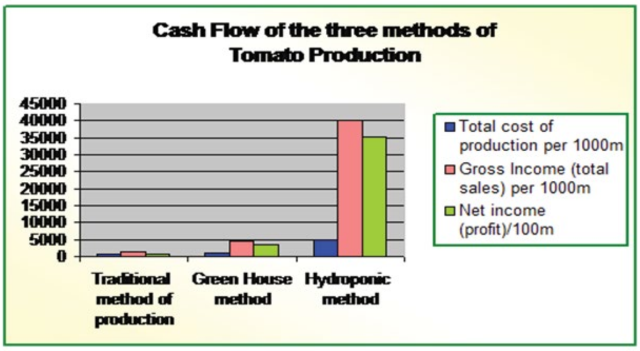
5. Findings/results

The study provided a comprehensive analysis of the vegetable production activities in Bahrain and assessed their efficiency in terms of financial and economic profitability. Especially their utilization of the scarce natural resources, which is water. The analysis conducted for three methods of certain vegetable production in different farms of vegetable production (traditional, green house and hydroponic methods). The irrigation method adopted under open agriculture is traditional, drip, sprinkler and bubbler irrigation while the protected house adopted drip irrigation. The activities that appear to have the best comparative advantage (i.e., lowest DRC values) are the greenhouse production of cucumbers and tomatoes (0.45 and 0.48, respectively). However, the production of vegetables under traditional irrigation systems did not show a very clear comparative advantage, with possible exception of green onions (DRC = 0.53). Therefore, result of the study shows that the green house and hydroponic methods outperformed the traditional method.

Figs. 1–3 show that the green house and hydroponic methods outperformed the traditional method. There is huge potential for increase in vegetable production by using non-traditional method of production. The expansion of vegetable production by non-traditional methods of production may lead to reduction of the import of fresh vegetables to zero. Accordingly, yes, for increasing the vegetable production by non-traditional method.

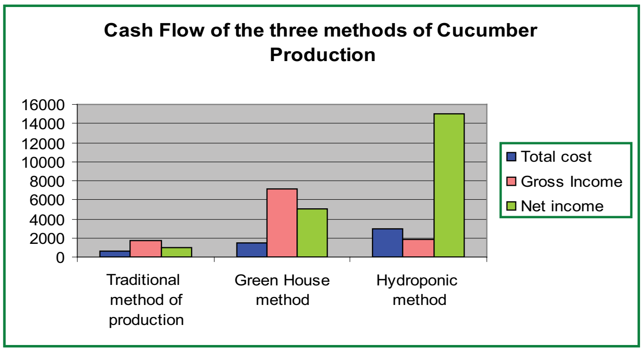
The best use of water must be made for efficient crop production and higher yields. Bahrain's local vegetable production can be increased by promoting vertical intensifying faming. Accordingly, in order to reduce ground water over pumping, total agricultural water use should be reduced by 50% and applying water tariff of 15fils/CM. The application of water tariff has very slight effect on the net profit and it increases significantly the returns to water which gives a good signal of financial and economic viability of such policy option.

Table 5.1
Cash flow statement (costs and revenue) of the three methods of tomato production.



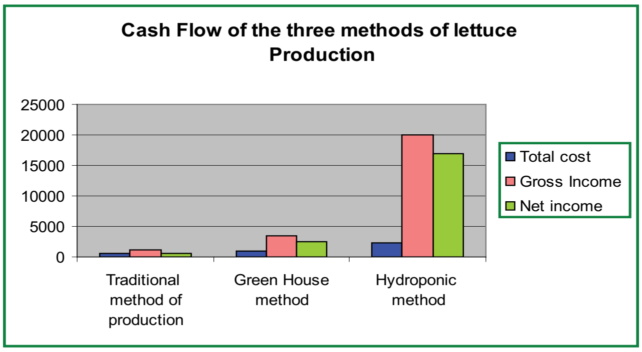
Source: different farms detailed cash flow statement (costs and revenue) of the three methods of lettuces production.

Table 5.2
Cash flow statement (costs and revenue) of the three methods of cucumber production.



Source: different farms detailed cash flow statement (costs and revenue) of the three methods of cucumber production.

Table 5.3
Cash flow statement (costs and revenue) of the three methods of lettuce production:



Source: different farms detailed cash flow statement (costs and revenue) of the three methods of lettuces production.

6. Conclusions and recommendations

The agricultural sector of Bahrain is facing many challenges including the inadequacy of water resources necessary for production process and the dependability of the cultivated space. Also, the effect of climate change worsens the challenges of dry areas which are characterized by acute water scarcity and land degradation. Since, climatic challenges impose constraints on sustainable agricultural development, greater emphasis is needed to safeguard natural resources and agro-ecological practices. Also, for food security purpose, there is an urgent need for adapting sustainable and economically viable crop production system to enhance production efficiency, productivity and quality.

In spite of these challenges, advances in science and technology, and closer cooperation and partnerships with between various organizations provide numerous opportunities. Increased agricultural production through vertical expansion by supporting infrastructure needed for developing and facilitating utilization of modern techniques that will contribute to raising productivity and increased self-reliance in some food commodities.

References

Abbasi B, Al Baz I (2008) Integrated wastewater management: A Review. In: Efficient management of wastewater. Its treatments and Reuse in Water Scarce Countries (Al Baz I, Otterpohl R, Wendland C (eds.)), Springer-Verlag Berlin Heidelberg, pp. 29–40.

Al Baz I, Otterpohl R, Wendland C (eds.) (2008) Efficient management of wastewater. Its treatments and Reuse in Water Scarce Countries. Springer, p. 303.

Al-Ghazawi Z, Amayreh J, Rousan L, Hijazi A (2008) Wastewater reuse for agriculture pilot project at the Jordan University of Science and Technology. In: Efficient management of wastewater. Its treatments and Reuse in Water Scarce Countries (Al Baz I, Otterpohl R, Wendland C (eds.)), Springer-Verlag Berlin Heidelberg, pp. 283–297.

Ansari M, Al-Naomi M (2000) Forecasting water requirement beyond Millennium, Conference to Combat Desertification, King Saud University, Riyadh, February, 2000.

Al-Zubari WK (2001) Political water alternatives in GCC Countries, 5th Gulf Water Conference, Doha, Qatar, 24th-28th March 2001.

Al-Zubari W, Al-Ansari M (2009) Water deficit in Bahrain in the shadow of extension project–Internal report, 1999 Bahrain National Assessment Report on Implementation of the Mauritius Strategy (MSI) of the Barbados Programme of Action (BPOA) 2009.

AQUASTAT, FAO (2005) Water availability information by country.

Bani S (2011) Assessing the competitiveness and sustainability of Bahrain food production system. Unpublished PhD thesis.

Basheer et al. (2000) Development of water resources in Bahrain.

Bohle et al. (1994) Climate change and social vulnerability: toward a sociology and geography of food insecurity. Global Environmental Change 4(1):37–48.

CIA World Fact book - September 2017.

FAO (2003) Multidisciplinary programming mission for sustainable agricultural development. Terminal statement. Project UTF/BAH/002/BAH.

Halalsheh M, Ghunmi LA, Al-Alami N, Fayyad M (2008) Fate of pathogens in tomato plants and soil irrigated with secondary treated wastewater. In: Efficient management of wastewater. Its treatments and Reuse in Water Scarce Countries (Al Baz I, Otterpohl R, Wendland C (eds.)), Springer-Verlag Berlin Heidelberg, pp. 81–89.

IAASTD (2008) Global Report. International assessment of agricultural knowledge, Science and Technology for Development, Johannesburg. Available at: www.agassessment.org.

Maxwell S (2001) the evolution of thinking about food security. In: Devereux S,

Maxwell S (eds) (2001) Food security in sub-Saharan Africa. ITDG Publishing London.

Maxwell (1995) Measuring food insecurity: The frequency and severity of coping strategies, FCND Discussion Paper No 8, Washington, DC: International Food Policy Research Institute.

Ministry of Municipalities, Affairs and Agriculture (2017) Annual Agricultural Statistical Report.

Ministry of Municipalities, Affairs and Agriculture (2017) National strategy for sustainable agricultural development, Ministry of Municipalities, Affairs and Agriculture.

Monke EA, Pearson SR (1989). \1 \2. Cornell University Press, Ithaca and London.

Sheikh B (2008) Socioeconomic aspects of wastewater treatment and water reuse. In: Efficient management of wastewater. Its treatments and Reuse in Water Scarce Countries (Al Baz I, Otterpohl R, Wendland C (eds.), Springer-Verlag Berlin Heidelberg, pp. 249–257.

Shuval HI, Yekutiel P, Fattal B (1985) Epidemiological evidence for helminth and cholera transmission by vegetables irrigated with wastewater. Jerusalem case study. Water Science and Technology 17(4/5):433–442

Shuval HI, Adin A, Fattal B, Rawitz E, Yekutiel P (1986) Wastewater irrigation in developing countries: health effects and technical solutions. Technical Paper No 51. World Bank, Washington DC.

The GCC in 2020: Resources for the future. The Economist intelligence unit limited.

Trade Policy Review (2009) Bahrain Economic Environment.

Tollner E (2007) Water profile of Bahrain. In: Encyclopedia of Earth. Cutler J. Cleveland (eds.) (Washington DC). Environmental Information Coalition, National Council for Science and the Environment). FAO (Content Source). First published in the Encyclopedia of Earth December 4, 2007; Last revised Date December 4, 2007; Retrieved January 26, 2013 <http://www.eoearth.org/article/Water_profile_of_Bahrain.