THE LIBYAN JOURNAL OF AGRICULTURE
Volume (25): No. (1-2), 2020: 1-12

Original Article

Irrigated Agriculture under Limited Water Supplies: Is It Sustainable? Northwestern Libya as a Case Study

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ABSTRACT

An intensive investigation has been undertaken to assess the negative impacts of irrigated agriculture in the Northwestern region of Libya. A total irrigated area of 90 thousand hectares has been cultivated with more than 15 major crops with a total irrigation water demand of no less than 730 million cubic meters per year (m^3/y). The analysis of water sample hydrological data collected from more than 90 wells representing the whole region shows clearly those groundwater resources are depleting at an alarming and increasing rate. The negative economic and environmental impacts of this excessive groundwater depletion have been reflected in severe water level and piezometric head declines, intensive and extensive irreversible seawater intrusions, deteriorating water quality, soil salinization, and exposure to nitrate pollution and reduced crop productivity. To prevent any further deterioration, the gap between the renewable water supplies of 200 million m^3/y and the agricultural water demand of 730 million m^3/y must be closed through the diversion of no less than 500 million m^3/y from phase two of the Man-made River Project (MRP) at the cost of 0.34-0.83 US$/$m^3$. This water supply will have to be subsidized, however, since irrigated agriculture is unable to pay back even 10% of this cost. The other alternative is to limit the irrigation water demand to the renewable water supplies through the importation of virtual water, reducing the irrigated area and the cultivation of crops that have the highest economic crop water productivity values.

Key Words: Crop water productivity, Man-made River Project, Northwestern Libya, Water use efficiency.

Introduction

The Southern Mediterranean region of North Africa is considered a transitional zone between the eremitic Sahara region and the sub-humid Southern European regions. Its population density and socioeconomic activities have always been in a delicate balance facing limited natural resource availability to provide basic human needs. In the second half of the last century, however, modern ways of intensively utilizing natural resources were introduced into the region. The balance has shifted towards resource exploitation at levels far exceeding their rates of renewal (Alghariani,

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Received: 19/10/2019 **Accepted: 12 / 3/ 2020**

1997). The situation has been exacerbated by population growth demanding food associated with a better standard of living. The scarcity of natural resources to support agriculture has dramatically increased. Traditional rain-fed practices have been replaced by irrigation based on intensively exploited groundwater resources. The available renewable water resources are insufficient to meet the present rate of expansion sustainably. The region's limited groundwater resources cannot support the very high evapotranspiration demands of extensively expanding irrigated areas. The deficit between renewal and utilization has been satisfied by overdraft and mining of the local groundwater aquifers. There has been an increased dependence on poor quality water supplies. The negative consequences of this practice have been reflected in seawater intrusions, soil salinization, increasing salt accumulation and pollution of the aquifers.

Urban water demands to meet the domestic and industrial uses compete with irrigated agriculture. The present situation is unsustainable and calls for serious consideration of new approaches to development and the water use. There is an urgent need for the establishment of socioeconomic growth models based on a better understanding of water resources endowments. The limited water must be managed in ways that are conducive to sustainable development. This paper aims to scrutinize the water use in North-west Libya that quantified the negative impacts of irrigated agriculture in this region and assesses its sustainability. Similar impacts are evident throughout North Africa, the Middle East and elsewhere in the rest of the world (Allan, 2011).

Materials and method

The study area

The study area is located in the northwest of Libya and represented by the Jefara plain. Jefara plain is a triangular area in shape with about 20 000 Km^2 (1% of Libya's total land surface). It is bounded on the north by the Mediterranean Sea, on the south and east by Jabal Nafusah escarpment, and on the west by the Tunisian border (figure.1). The Jafara plain is described as flat in general, but it is characterized by undulation especially in the southern part of it where the hills and sand dunes are scattered. The western part of the plain is the least complex part of the surface manifestations, while the northern part of it is not much higher than sea level The region is home to 49% of the population, produces 80% of industrial products, and contributes about 48% of total agricultural production in Libya and irrigated land accounts for more than 42% of the country's irrigated land. This region is counted on to contribute to the solution of problems resulting from overpopulation or food shortages (Ekhmaj and Almuntaser, 2015). Regardless of the region's contribution to Libya's food supply, the question is whether water used for agricultural purposes yields economic returns. Unfortunately, the data available to help answer this question is still scarce.

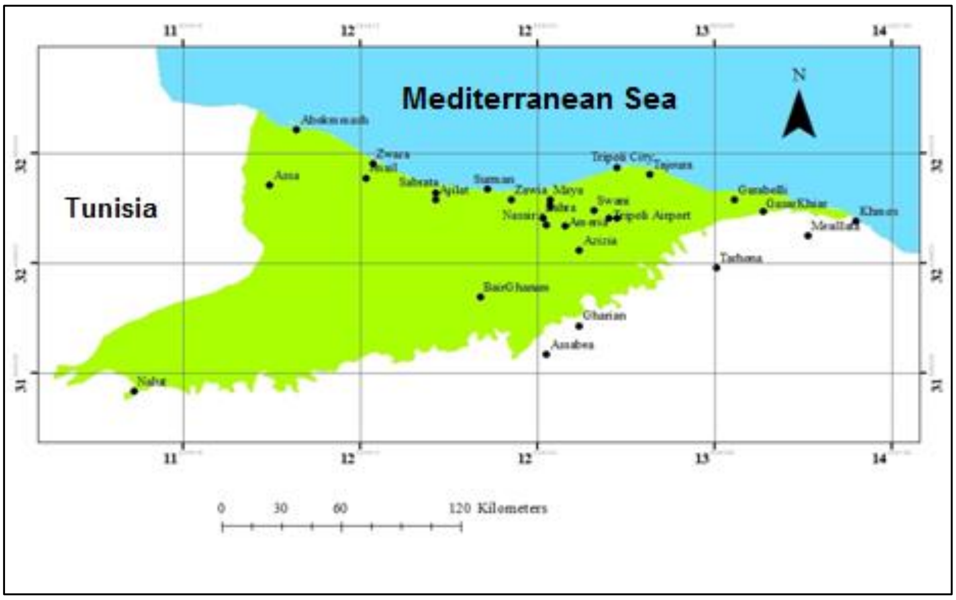

Figure 1. Jerfara Plain location.

Dataset Acquisition

This study relied on the published and unpublished secondary data issued by local official bodies and organizations, as well as on reliable scientific references which were more related to the study problem. These data were mentioned and indicated throughout the present paper. Such data were manipulated in order to describe and quantify the past, present and future situation of the irrigated area in Jefara Plain. Some of the estimated data of water and salt balance, water inflows, water outflows and changes in storage in 2010 were determined based on fitting the original data by using the best curve technique.

The annual change in water storage (ΔW) in (Mm^3/year) within the study area was calculated based on the continuity equation as follows: -

$$\Delta W = I - O \qquad (1)$$

Where:

I= the annual total of hydrologic inputs of water (Mm^3/year). Such inputs which are flows into the Jefara basin include the effective precipitation, surface and subsurface runoff due to irrigation and precipitation, non-conventional water like desalination water and transferred water which flows toward the basin from the other areas.

O= the annual total of hydrologic outputs of water (Mm^3/year). In addition to accounting for deep percolation and run off caused by surface and subsurface flows outside the basin, the annual total of hydrologic outputs of water also includes the losses due to seepage, evapotranspiration and wastewater which contains high levels of dissolved solids and toxic materials which in turn, limit its reuse in beneficial agricultural and nonagricultural purposes.

Remote Sensing and Landsat imagery

The primary data used in this study was Landsat data with 30m spatial resolution taken on 2006. The satellite image was obtained from the Libyan Remote Sensing Centre. In supporting the study, secondary data were obtained from the Libyan Survey and Mapping Centre which includes contour map. Landsat data, image processing, contour map, supervised and unsupervised classification, ground verification, accuracy assessment, and output derivation are the main components involved in this study. The Garmin GPS used to navigate the location of selected samples during ground verification. Digital camera utilized to photograph ground truthing sites. The digital image processing was carried out using a personal computer equipped with ERDAS IMAGINE software for classification and analysis of the different combination bands which were taken into consideration to produce different composite effects on land cover/ land use. A false colour composite of Red-Green-Blue band was applied for additional analysis. The algorithm applied in supervised classification is the Maximum Likelihood Classification.

Results and discussion

THE PRESENT SITUATION

The total irrigated area in the region has been estimated by satellite imagery (Figure, 2) as 90 thousand hectares with estimated annual gross irrigation water demand of no less than 723 million m^3 per year (Ministry of Agriculture, 2006). But as indicated in Table (1), the total renewable groundwater resources in the region are limited to 200 million m^3 per year (GWA, 2006). The deficit of more than 500 million m^3 per year has been compensated by groundwater. Severe water level declines have occurred and seawater intrusion has increased as indicated in Table (2) and Figures (3) and (4).

To remedy the present deteriorating situation, it was decided during the early 1990's to transfer 800 million m^3 of water from the southern desert aquifers to the northwestern region through phase two of the national network (Figure. 5) known as the Man-made River Project (MRP). However, the cost of development of this source of water supply has proved to be relatively high. The MRP is also non-renewable and hence, unsustainable.

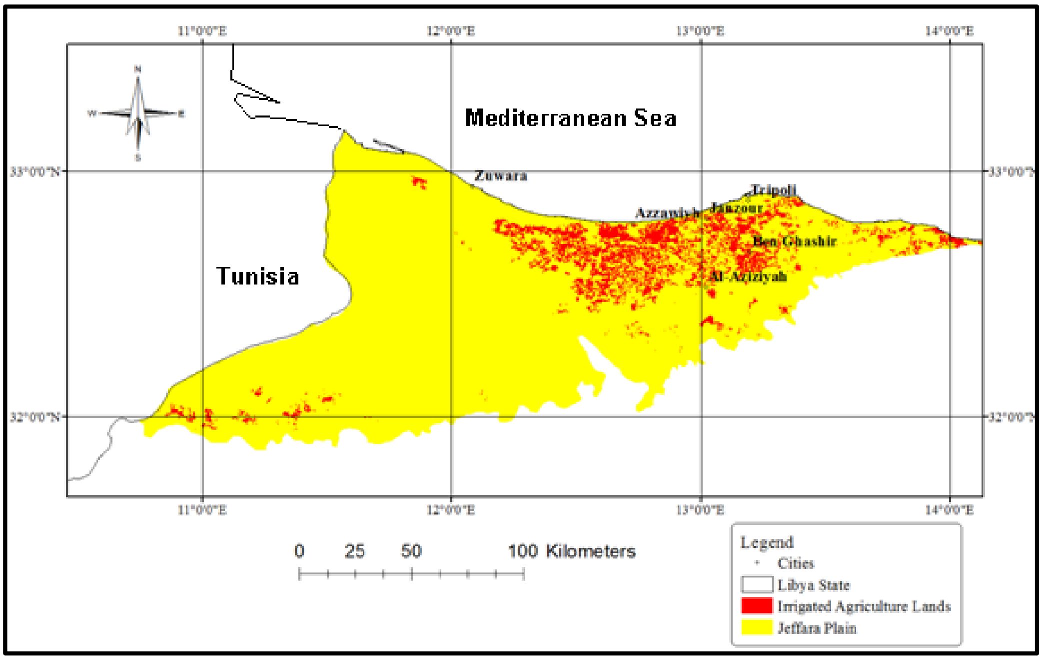

Figure 2. Irrigated areas in Jefara Plain (Ministry of Agriculture. 2006)

Table 1. Sustainable water supplies from all available sources in the major water basins of Libya in million cubic meters per year(Mm^3/y)*.

Water Basin	Groundwater	Surface Water	Unconventional Water	Total
Northwestern region	200	52	27.5	297.5
Jabal Alakhdar	200	92	45.5	337.5
Alhamada	230	48	50.5	238.5
Kufra and Srir	563	-	-	563
Murzuk	771	-	-	771
Total	1964	192	123.5	2279.

*General Water Authority (GWA, 2006).

Table 2. Water and salt balance (Mm^3/y)*

Year	Inflows (I)	Outflows (O)	Change in storage	Intruded seawater
1949	581.4	581.9	-0.5	0.0
1972	598.5	731.4	-132.9	2.6
1980	650.1	962.1	-312.0	31.9
1993	790.5	1374.7	-584.2	166.1
2010	980.0	1900.0	-920.0	340.0

*Calculated by the authors.

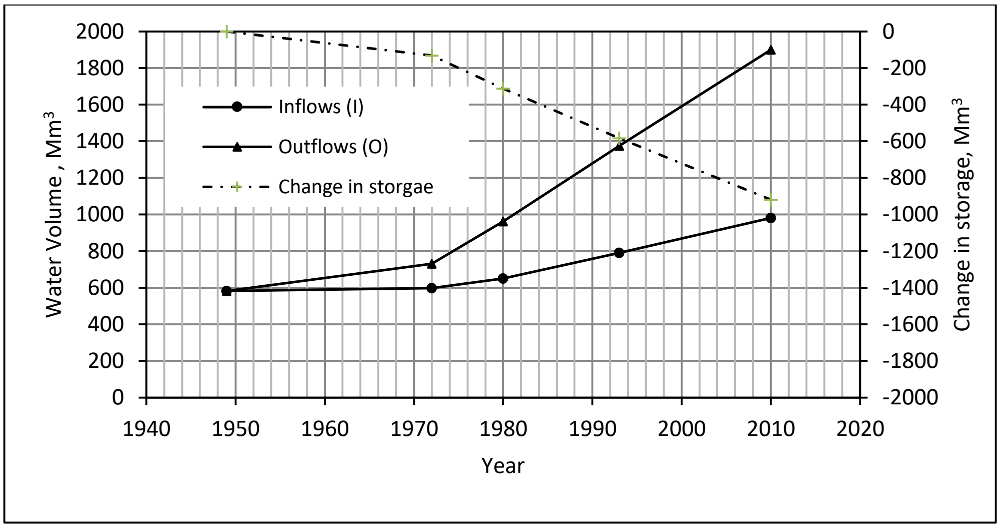

Figure 3. Water inflows, Water outflows and changes in storage from 1949 to 2010 as estimated by the authors.

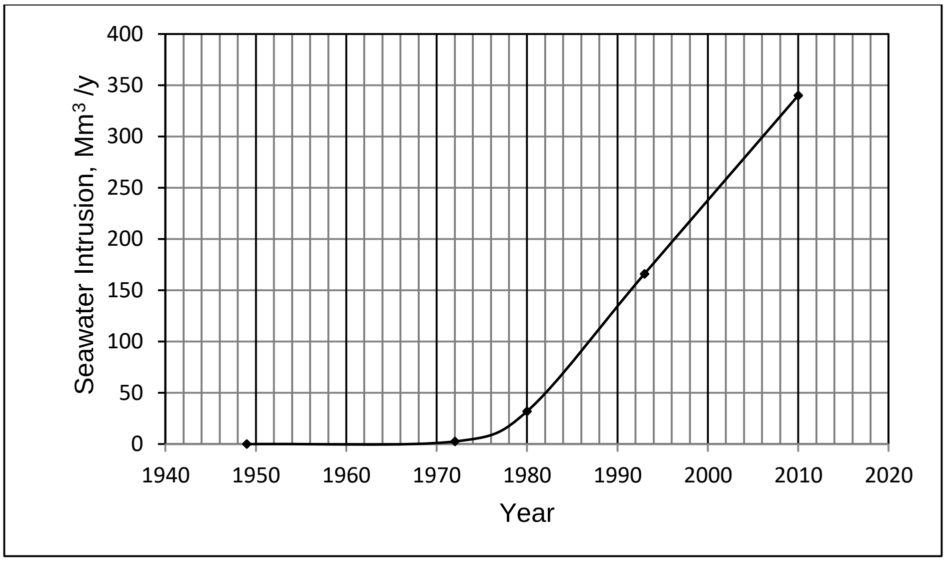

Figure 4. Rate of Seawater intrusion.

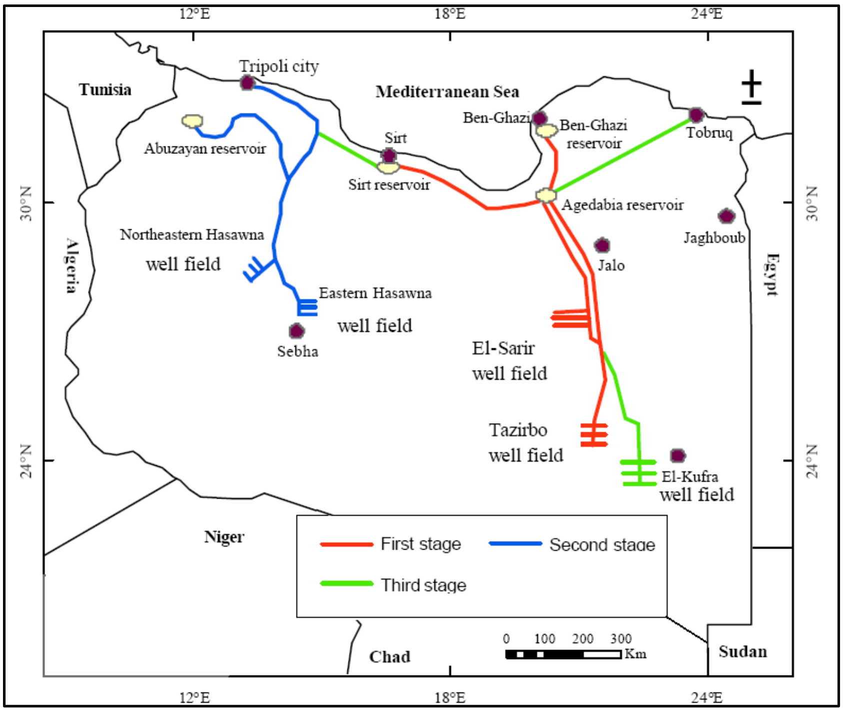

Figure 5. The national Man-made River Project network. Phase Two feeding the Northwestern region is indicated in blue color (MRP, 1992).

Table (3) indicates that the cost per cubic meter of water is around 0.34 US Dollars as calculated on the basis of free investment - no interest on the invested capital has been calculated. At 7% interest for capital investment, the cost of water to the user's gate would increase to 0.83 US Dollars per m^3 (Brown & Root, 1990). It was planned that 500 million m^3/y of MRP water would be diverted for irrigated agriculture in addition to 300 million m^3/y that will be allocated for domestic consumption. This strategy, if perfectly implemented, would limit groundwater abstraction for irrigation to 200 million m^3 per year. This approach would prevent further deterioration of groundwater in the region.

Table 3. Development cost of the Man-made River Project(MRP)*.

Phase and Stage**	**Cost of water USD/m³**	**Cost of water LD/m³**	**Water production m³/50 y**
Sarir- Sirte-Tazerbo- Benghazi	0.30	0.40	29,473,750,000
Hasawna -Jefara	0.34	0.45	36,842,187,500
Ghadamis-Zuara- Zawia	0.36	0.48	3,684,218,750
Jaghbub- Tubrok	0.33	0.45	2,018,951,875
Kufra- Tazerbo	0.21	0.28	24,757,950,000
All phases and stages	0.30	0.40	96,777,058,125

*Man-made River Project Authority, Benghazi, Libya.

**The total cost of all phases of the MRP project has been estimated at US$ 22.4 Billion.

The Economic Impacts:

The major negative economic impacts of irrigated agriculture in the region can be summarized as follows:

1. Increased cost of irrigation water and reduced availability from the major sources both groundwater and MRP.
2. Declining crop water productivity as a result of increasing soil salinity and deteriorating irrigation water quality.
3. Inefficient agricultural planning and escalating cost of publically subsidized irrigation water.

Table (4) presents the results of an investigation of water use efficiency (WUE) and crop water productivity (CWP) in irrigated agriculture in two different hydro-climatic regions of Libya. These concepts have been defined by Alghariani (2013). Table (5) presents estimates of the financial returns (US$/m^3) in the prevailing market prices of some major crops during the period of this investigation.

It is clear from these two tables (4) and (5) that:

1. Crop water productivity values are depressingly low, even though these values in the Northwestern region are almost double those in the southern desert region.
2. With the exception of few cash crops such as potatoes, onions and tomatoes, even when the other costs of production are ignored, the financial return per m^3 of irrigation water of most crops is relatively low in relation to the actual cost of the MRP water which is close to 0.83 US Dollars per m^3 (Brown & Root Limited, 1990).

3 - According to the results of previous detailed studies (MRP Water Utilization Authority, 1993) that are based on economic farm budgeting and the farmer's ability to pay for the MRP water, it was found that the maximum irrigation water charge that can be imposed should not exceed 0.04 US dollars per m3. This figure is less than 5% of the actual cost of the MRP water and does not even cover a significant portion of the operational and managerial costs of the project. Therefore, the delivery of MRP water will have to be continuously subsidized by public funding throughout its operational life if the irrigated areas that depend on its water supply are to be kept in place.

The Environmental Impacts:

The major negative environmental impacts of irrigated agriculture in the region can be summarized as follows:

1. Declining piezometric heads and groundwater levels by excessive pumping.
2. The deterioration of groundwater quality by seawater intrusion.
3. Increasing groundwater pollution by nitrates as a result of excessive application of nitrogen fertilizers.
4. Increasing soil salinity.

As shown in Table 2, groundwater withdrawals during the period 1949-2010 have been estimated at 18 billion m^3. The consequence has been severe groundwater level decline that has resulted in the intrusion of no less than 6.2 billion m^3 of seawater. To assess the impact of groundwater level decline and seawater intrusion on irrigation water quality, the chemical analysis of water samples collected by the authors from 91 wells representing the whole region revealed a weighted average total dissolved salt concentration of no less than 1500 ppm (parts per million).

Table 4. Values of Water Use Efficiency (WUE) and Crop Water Productivity (CWP) for some major crops grown under different hydro-climatic regions of Libya*.

Major Crops	**The Northwestern region**		**The Southern desert region**	
	WP (Kg/ m^3)	WUE	WP (Kg/ m^3)	WUE
Wheat	0.66	0.72	0.29	0.66
Barely	0.96	0.74	0.42	0.67
Alfalfa	1.03	0.67	0.53	0.63
Oats	1.45	0.75	0.67	0.69
Sorghum	0.97	0.61	0.38	0.61
Citrus	1.56	0.64	0.74	0.61
Grapes (sprinkler)	1.73	0.63	0.72	0.61
Grapes (localized)	3.02	0.87	1.28	0.85
Potatoes	4.73	0.67	2.10	0.52
Onions (winter)	7.10	0.57	2.53	0.58
Onions (summer)	4.03	0.59	1.58	0.58
Tomatoes (spring)	3.54	0.65	2.16	0.63
Tomatoes (summer)	3.11	0.64	2.08	0.64
Water melons	2.87	0.64	1.28	0.63
Olives (sprinkler)	0.49	0.68	0.16	0.63
Olives (localized)	0.80	0.87	0.28	0.80

*Alghariani (2013).

Table 5. Crop Water Productivity and the economic return per m^3 of irrigation water used in different hydro-climatic regions of Libya*.

Crop	The Northwestern region		The Southern desert region	
	WP (kg/ m^3)	Financial return (USD/m^3)	WP (kg/ m^3)	Financial return (USD/m^3)
Wheat	0.66	0.11	0.29	0.06
Barely	0.96	0.03	0.48	0.04
Oats	1.45	0.15	0.67	0.09
Alfalfa	1.03	0.09	0.54	0.06
Citrus	1.56	0.64	0.70	0.30
Potatoes	4.73	1.04	2.10	0.46
Melons	2.87	0.98	1.28	0.74
Onions	7.10	1.38	2.53	0.65
Tomatoes	3.54	1.92	2.16	1.17
Peas	0.56	0.80	0.35	0.48

*Alghariani (2013).

With the estimated annual irrigation water consumption in this study of about 723 million m^3/year, this salt concentration, if maintained, can initiate a process that will accumulate 1,085 tons of salt per year resulting in increasing soil salinity, poor drainage, lower crop productivity and deteriorating environmental quality.

The analysis of the groundwater samples also indicated very high nitrate content in the relatively shallow wells of the upper quaternary groundwater aquifer system that supplies most of the agricultural and domestic water uses of the region. Taking into consideration the added water supply from the MRP, the final weighted average nitrate concentration of both sources will be about 70 ppm. It is almost certain that the major source of this high nitrate concentration in groundwater has been caused by the excessive application rates of Nitrogen fertilizers and other sources of wastewater contamination. Unless preventive and precautionary measures are undertaken, using this water sources for domestic purposes may lead to serious health problems. To minimize any further pollution of the upper quaternary groundwater aquifer by nitrate, the nitrate content of irrigation water must be taken into account when determining the rates and application regime of nitrogen fertilizers for the different crops grown in the region. Table 6 presents the estimated balance between the seasonal nitrogen demand of the major crops and the amount of nitrogen supplied by their seasonal irrigation water requirements.

Table. 6. Nitrogen balance of the irrigated crops *

Crop	Nitrogen requirements kg/ha	Water requirements m^3/ha	Added Nitrogen in irrigation water kg/ha	Nitrogen balance kg/ha
Citrus	65	12098	170	+105
Olives	100	5000	70	-30
Figs	150	8453	118	+32
Almonds	100	8453	118	+18
Date palm	100	11930	167	+67
Grapes	160	3750	52	-107
Onions	120	3575	50	-70
Legumes	0	4422	62	+62
Potatoes	280	4643	65	-215
Watermelons	230	9211	130	-100
Grain crops	250	4277	60	-190
Oats	190	4651	65	-125
Alfalfa	40	29785	417	+377

*Calculated by the authors

Conclusions

The information and analysis presented in this study clearly indicates that irrigated agriculture in Northwestern Libya is facing serious threats to its sustainability. To minimize the associated negative economic and environmental impacts, attention should be directed to implementing the following interventions:

1. Regulation of the cultivation of low value cereal and forage crops such as barley, oats and alfalfa.

2. Improvement of the Crop Water Productivity of the more valued crops, such as tomatoes, potatoes and onions, through targeting their potential yields and the most water efficient growth seasons.

3. Improvement of Water Use Efficiency of row crops, such as citrus, olives and vegetables through replacing sprinkler irrigation systems by the more water efficient localized irrigation methods.

4. Increased dependence on virtual water in the form of imported cereal, forage and other water inefficient crops instead of growing them locally in the region (Allan, 2011).

5. Raising the water users' awareness of the potential health problems associated with the excessive usage of the transferred water for human consumption.

6. Since the nitrate concentration varies among the different wells in the region and ranges from less than 40 ppm up to more than 75 ppm, it is recommended that water abstraction must cease from the wells with high nitrate concentrations.

7. The formulation of a sound nitrogen fertilization program based on a reasonable balance between the amounts of nitrogen added to the agricultural crops in irrigation water and

their seasonal nitrogen requirements in order to minimize the exposure of the local groundwater aquifers to pollution by excess nitrates that may seep down with drainage water.

Acknowledgement

The authors thank with high regards and appreciation the Libyan Authority for Research, Science, and Technology (LARST) for supporting the research project from which the presented information in this paper is derived.

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المجلة الليبية للعلوم الزراعية
المجلد (25): العدد (1-2): 2020: 1 - 12

الزراعة المروية تحت محدودية الإمدادات المائية هل هي مستديمة؟ شمال غرب ليبيا كحالة دراسية

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المستخلص

تم إجراء دراسة مكثفة لتقييم الآثار السلبية للزراعة المروية في شمال غرب ليبيا. حيث تصل المساحة الكلية المروية فيها إلى ما يقارب 90 ألف هكتار وبتركيبة محصولية تجاوز 15 محصولاً رئيسياً وبمتطلبات ري كلية لا تقل عن 730 مليون متر مكعب سنوياً. كما أظهرت نتائج تحليل عينات المياه المجمعة من 90 بئراً والتي تمثل آبار منطقة الدراسة، أن المياه الجوفية تعرضت إلى استنزاف متزايد وحاد.وقد تجلت مظاهر الآثار السلبية الاقتصادية والبيئية الناجمة عن الاستنزاف المتزايد للمياه الجوفية في انخفاض مستواها البيزومتري (piezo metric) وتعرضها إلى تداخل مياه البحر وتدهور نوعية المياه الجوفية وارتفاع ملوحة التربة، بالإضافة إلى تعرضها إلى التلوث بالنترات وانخفاض إنتاجية الأراضي المروية. وللحد من أي تدهور لاحق، يجب تخفيض الفجوة المائية بين إمدادات المياه القابلة للتجدد بحجم يصل إلى 200 مليون متر مكعب سنوياً والإمدادات المائية المحولة للزراعة والتي يصل حجمها إلى 730 مليون متر مكعب سنويا عبر تحويل ما لا يقل عن 500 مليون متر مكعب سنويا عبر منظومة النهر الصناعي المرحلة الثانية، وبتكلفة تتراوح بين 0.34 و 0.83 دولارا أمريكيا للمتر المكعب. كما يجب أن يتم دعم هذه الإمدادات من المياه المحولة، حيث أن الزراعات المروية غير قادرة على إعادة 10% من تكلفة تلك الإمدادات. ويكمن البديل الآخر للحد من الطلب على مياه الري في التوجه نحو المياه المحملة مع السلع، وكذلك في التقليل من المساحات المروية وزراعة المحاصيل ذات المردود الاقتصادي المرتفع.

الكلمات الدالة: الإنتاجية المائية للمحاصيل، مشروع النهر الصناعي، شمال غرب ليبيا، كفاءة استخدام الماء.

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استلمت بتاريخ: 2019/10/19 **أجيزت بتاريخ: 2020/3/12**