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Water Management Initiative (WMI)

Remote Sensing for Crop Mapping and Assessment for Groundwater Abstraction During 2018

Azraq Basin – Report



AUGUST 2020

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WATER MANAGEMENT INITIATIVE (WMI)

Remote Sensing for Crop Mapping and Assessment for Groundwater
Abstraction during 2018

Azraq Basin – Report

Intervention 4.1.3: Improve Groundwater Monitoring Standards,
Procedures, and Capacity

August 2020

DISCLAIMER

The author's views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

TABLE OF CONTENTS

LIST OF FIGURES	ii
LIST OF TABLES	ii
LIST OF ABBREVIATIONS	iii
EXECUTIVE SUMMARY	iv
SUMMARY IN ARABIC	vi
1.0 INTRODUCTION	1
2.0 OVERVIEW OF METHODOLOGY	2
3.0 RESULTS AND DISCUSSION	4
3.1 AREA OF IRRIGATED CROPS.....	4
3.2 COMPARISON BETWEEN IRRIGATION IN 2017 AND 2018.....	7
3.3 WATER CONSUMPTION AT HOTSPOTS.....	7
4.0 KEY RECOMMENDATIONS	9

LIST OF FIGURES

Figure 1: Examples of field observations in Azraq GWB during 2019.....	3
Figure 2: Map of irrigated crops in Azraq GWB during 2018.....	5
Figure 3: Map of ETa for irrigated crops in Azraq GW basin during 2018.....	6
Figure 4: Maps of irrigation and ETa for hotspots in Azraq GW basin during 2017 (Left) and 2018 (Right).....	11
Figure 5: ETa changes between 2018 and 2017 in the hotspots of Azraq.....	12

LIST OF TABLES

Table 1: Summary of dates of Landsat 8 images and ETr for Azraq basin during 2018.....	2
Table 2: Summary of irrigated crops and their water consumption in Azraq GWB.	4
Table 3: Summary of irrigated areas, water consumption (GIWR) and recorded abstraction in Azraq GWB.....	7
Table 4: Summary of locations and hotspots with high water consumption and possible water savings in Azraq GWB.....	10

LIST OF ABBREVIATIONS

du	dunum
ET _a	Actual Evapotranspiration
ET _r	Reference Evapotranspiration
GIWR	Gross Irrigation Water Requirements
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
K _c	Crop Coefficient
MCM	Million Cubic Meter
MWI	Ministry of Water and Irrigation
NDVI	Normalized Difference Vegetation Index
NIWR	Net Irrigation Water Requirements
RS	Remote Sensing
SEBAL	Surface Energy Balance Algorithm for Land
WAJ	Water Authority of Jordan
WMI	Water Management Initiative

EXECUTIVE SUMMARY

This report presents results for mapping the irrigated crops and their water consumption in Azraq groundwater basin in year 2018. In addition, it compares results year 2018 with that of 2017 at the basin level and at the hotspots identified from the work for 2017. The approach of mapping was based on the use remote sensing data, SEBAL model, climatic data and ground truthing. The work was carried out within the activities of the water management initiative (WMI) of USAID for developing and empowering the aspects of groundwater monitoring carried out by the Ministry of Water and Irrigation and Water Authority. The irrigated areas that were considered by WMI included the irrigated highlands in the basins of Azraq, Yarmouk, Amman-Zarqa, Dead Sea and Jafr.

Results showed that the total irrigated area in Azraq GW basin slightly increased from 73.3 thousand dunums in 2017 to 79.2 thousand dunums in 2018. The GIWR were 56 MCM in year 2018, compared to 60 MCM in year 2017. Changes in cropping pattern were mainly the decrease in the total area cultivated with fodder and the increase in the total area cultivated with vegetables. The main irrigated area (>60% of the total irrigated area in the basin) was the area to the east of Azraq depression, where dominant cropping patterns included olives, fruit trees and mixed patterns of forage and fruit trees. Groundwater abstraction recorded by WAJ was 40 MCM in year 2018 compared with 49 MCM in year 2017. These figures indicated that abstraction estimates by WAJ were lowered for farmers, although the total irrigated area slightly increased.

Changes inside the hotspots that were identified for the crop map of 2017 included the significant recession in irrigated area in Hazeem that decreased from 4,631 to 2,832 dunums following the actions of WAJ that included the shutdown of 20 illegal wells in this area and an estimated savings of 3 MCM. Results from this study confirmed the estimates of WAJ and a total savings of 4.7 MCM was achieved due to recession of irrigated area and change of cropping patterns that replaced alfalfa with barley, as observed during the 2019 field visit. Subsequently, the GIWR decreased from 6.5 MCM in 2017 to 1.8 MCM in year 2018, indicating the effectiveness of WAJ actions taken by the Basin Directorate of Azraq. The two hotspots in the east and southeast of Azraq depression did not show reductions in GIWR. However, the average water consumption in both areas decreased. Therefore, it is recommended to continue the work of water auditing by WAJ field crews, using remote sensing approach, to improve water consumption in this basin and to save more groundwater.

A summary for results obtained from the RS study for 2017 and 2018 are presented in the following Table.

Component	Year 2017	Year 2018
Abstraction recorded by MWI	49 MCM	40 MCM
Abstraction calculated from RS study	60 MCM	56 MCM
Possible water savings (MCM):	11-29	16-30
By water auditing and monitoring	11	16
By improving irrigation efficiency	6	6
By changing cropping patterns	12	8
Irrigated area mapped from RS	73,300 du	79,234 du
Cropping pattern in the basin:		
Olives	37%	35%

Component	Year 2017	Year 2018
Fruit Trees and mixed cropping	18%	21%
Vegetables	25%	29%
Fodder crops	20%	15%
Changes in GIWR (MCM) at hotspots:	16.7	13.7
East of Azraq Depression	7.2	8.7
Southeast of Azraq Depression	3.0	3.2
Hazeem	6.5	1.8
Irrigated area in 1987 mapped from RS	14, 000 du, GIWR = 12 MCM	
Irrigated area in 2002 mapped from RS	57,600 du, GIWR = 49 MCM	

SUMMARY IN ARABIC

يعرض هذا التقرير النتائج الخاصة باستنباط خرائط المحاصيل المروية والاستهلاك المائي في حوض الأزرق للعام 2018. كذلك Hotspots) يشمل التقرير مقارنة لنتائج العام 2018 مع العام 2017 على مستوى الحوض وعلى مستوى المناطق الساخنة (والمسوحات الأرضية لاستنباط خرائط SEBAL شملت منهجية العمل استخدام تقنيات الاستشعار عن بعد، البيانات المناخية، نموذج المحاصيل المروية واستهلاكها للمياه في المناطق الواقعة على هذا الحوض. شكل العمل جزءاً من أنشطة مبادرة إدارة المياه وسلطة المياه، حيث تركز (MWI) ، التي ركزت على تطوير جوانب مراقبة المياه الجوفية من قبل وزارة المياه والري (WMI) المبادرة من خلال هذا العمل على أحواض اليرموك ، عمان - الزرقاء ، الأزرق ، البحر الميت والجفر .

أظهرت النتائج زيادة طفيفة في المساحة المروية في مناطق حوض الأزرق حيث زادت المساحة المروية من 73 ألف دونم في حوالي 56 مليون متر مكعب (GIWR) العام 2017 إلى 79 ألف دونم في العام 2018. وقد بلغ إجمالي متطلبات مياه الري في العام 2017. شملت التغيرات في الأنماط الزراعية تراجعاً طفيفاً في (MCM) في العام 2018، مقارنة بـ 60 MCM) المساحات المزروعة بالأعلاف وزيادة المساحات المزروعة بالخضراوات، وقد شكلت المنطقة الشرقية من قاع الأزرق الجزء (أكثر من 60%) من المساحة المروية في الحوض، حيث كانت الأنماط السائدة تشمل المحاصيل الشجرية من زيتون الأكبر وفاكهة، الأنماط الخليطة من أشجار وأعلاف. أظهرت سجلات سلطة المياه أن كميات المياه المقدرة للمزارع المروية كانت 40 في العام 2017، على الرغم من الزيادة في المساحة المروية بين العامين MCM في العام 2018، مقارنة بـ 49 MCM

في الحوض التراجع في المساحة المروية في منطقة الهزيم من 4631 Hotspots شملت التغيرات في المناطق أو النقاط الساخنة دونم في العام 2017 إلى 2832 دونم في العام 2018، وذلك بعد سلسلة الإجراءات التي قامت بها كوادرات الأحواض المائية التابعة لسلطة المياه ، وخصوصاً ردم الآبار المخالفة وعددها الإجمالي 20 بئر في هذه المنطقة، حيث أشارت تقديرات السلطة إلى توفير من المياه MCM نتيجة هذا الإجراء. وقد أكدت دراسة الاستشعار عن بعد هذه التقديرات حيث تم توفير ما مقداره 4.7 MCM 3 للعامين 2017 و2018 على التوالي) نتيجة ردم الآبار المخالفة MCM من 6.5 إلى 1.8 GIWR في منطقة الهزيم (انخفاض وتغيير الأنماط الزراعية المستهلكة للمياه، حيث تم زراعة محصول الشعير بديلاً للبرسيم، كما تبين خلال الزيارات الميدانية ومن خلال دراسة الاستشعار عن بعد. أما الموقعين الآخرين في منطقة قاع الأزرق فقد شهدوا انخفاض المعدل العام للاستهلاك المائي نتيجة تغير النمط الزراعي، مع بقاء الاستهلاك الكلي مرتفعاً في المنطقتين. لذلك توصي الدراسة بالاستمرار بتطبيق نهج التدقيق المائي المعتمد على تكنولوجيا الاستشعار عن بعد لضبط الاستنزاف المائي والتحول لأنماط زراعية أقل استهلاكاً للمياه الجوفية.

للعامين 2017 و2018 يشمل الجدول التالي ملخصاً لنتائج دراسة حوض الأزرق

عام 2018	عام 2017	المكون
40 MCM	49MCM	1- استخراج المياه المسجل على مستوى الحوض
56 MCM	60MCM	2- استخراج المياه المقدر بواسطة الاستشعار عن بعد
30-16	11- 29	(الممكن توفيرها على مستوى الحوض، 3MCM- كميات المياه الكلية) وتفصيلاتها على النحو التالي:
16	11	بتفعيل التدقيق والمراقبة المائية
6	6	برفع كفاءة الري بمقدار 10%
8	12	بتغيير النمط الزراعي
79.2	73.3	4- المساحة المروية (ألف دونم)
		5- النمط الزراعي للمساحة المروية
35%	37%	أشجار زيتون
21%	18%	أشجار فاكهة وأنماط خليطة
29%	25%	خضراوات
15%	20%	أعلاف

عام 2018	عام 2017	المكون
13.7	16.7	التغيرات في إجمالي متطلبات مياه الري في المناطق الساخنة:
8.7	7.2	منطقة شرق قاع الأزرق
3.2	3.0	منطقة جنوب شرق قاع الأزرق
1.8	6.5	الهزيم
14 ألف دونم، 12 MCM		6- المساحة المروية في عام 1987، واستهلاكها التقديري
58 ألف دونم 49MCM		7- المساحة المروية في عام 2002، واستهلاكها التقديري للمياه

1.0 INTRODUCTION

As part of its support to MWI efforts, the USAID water management initiative (WMI) is working with Ministry of Water and Irrigation (MWI) and Water Authority of Jordan (WAJ) to develop the current groundwater monitoring aspects using Remote Sensing (RS) Techniques. This work is part of the Intervention No. 4.1.3 of WMI “Improve Groundwater Monitoring Standards, Procedures, and Capacity”. The work is listed under the Protection of Water Supply component and aims to improve the sustainability of Jordan’s water supply systems, improve water conservation, water governance systems, and protect water resources.

This report provides results for mapping irrigated areas and their water consumption for Azraq groundwater basin in 2018. The work was carried out by the WMI experts to compare groundwater abstraction records, received from WAJ, with actual water consumption estimated from RS. The general objective of RS work is to prepare maps for irrigated crops and their water consumption in five groundwater basins in Jordan and transfer knowledge in RS applied during the assignment to the MWI and WAJ. Specific objectives of the work are:

1. To produce maps for the different irrigated crops using medium and/or high-resolution RS data, for the main irrigated basins.
2. To prepare maps of ETa for the irrigated areas in the groundwater basins included in the work of RS, using SEBAL model.
3. To assess the records of groundwater abstraction at MWI in terms of groundwater over-pumping and irrigation efficiency in the selected basins.
4. Prepare change detection maps for high water consumed crops in addition to area and crop pattern identification.
5. Build capacity and transfer knowledge to the MWI and WAJ in the applied RS through on-job training for the staff involved in data collection and analysis.

The approach followed by the RS component of WMI was based on the use of Landsat 8 data to derive maps for the extent of irrigated crops and their water consumption in the main irrigated basins in highlands. The work of RS covered five basins; namely Yarmouk, Azraq, Jafr, Amman-Zarqa and Dead Sea.

2.0 OVERVIEW OF METHODOLOGY

The remote sensing methodology for mapping crops and their water consumption was based on the use of remote sensing data of Landsat 8 to derive crop map and the use of multi-temporal NDVI images to derive crop coefficient and to calculate ET_a (NIWR) which was transferred to GIWR using irrigation efficiency. Results were then verified with observations collected during the field visit to the basin. The work of ET_a and crop mapping was carried out for year 2018. Remote sensing data of Landsat 8 that were downloaded and processed to derive NDVI and KC layers is shown in Table 1.

Table 1: Summary of dates of Landsat 8 images and ET_r for Azraq basin during 2018.

No.	Date (DD/MM/YYYY)	DOY*	ET _r (mm)	No.	Date (DD/MM/YYYY)	DOY*	ET _r (mm)
1.	01/02/2018	32	90.4	10.	27/07/2018	208	224.2
2.	05/03/2018	64	143.5	11.	12/08/2018	224	242.2
3.	21/03/2018	80	138.3	12.	28/08/2018	240	197.6
4.	06/04/2018	96	136.4	13.	13/09/2018	256	192.2
5.	22/04/2018	112	141.8	14.	29/09/2018	272	150.1
6.	24/05/2018	144	328.5	15.	15/10/2018	288	138.8
7.	09/06/2018	160	200.5	16.	31/10/2018	304	129.8
8.	25/06/2018	176	232.1	17.	02/12/2018	336	125.4
9.	11/07/2018	192	242.1	18.	18/12/2018	352	73.8

Total ET_r = 3,129

* DOY = day of the year or Julian day.

Classification of multi-temporal layers of Landsat 8 was based on density slicing of maximum NDVI to derive the map of irrigated crops. Mapping of crop water consumption was based on the concept of ET_a derived from ET_r summed for the periods shown in Table 1 and multiplied by the crop coefficient. The NIWR or ET_a was then transferred to GIWR by using an irrigation efficiency of 60% (Application = 70%, Conveyance = 85%), as evaporation losses from reservoirs were already detected by ET_a maps. Assessment of groundwater records was carried out by comparing GIWR with recorded abstraction, which was 40 MCM for year 2018. The maps of crop type and spots with high ET_a were verified with field visits (Figure 1) during to Al-Hazeem hotspot (in February 2019) with WAJ staff and to the southwest of the basin (in May 2019).

	
<p>Fields of irrigated barley in Hazeem hotspot and the team of WAJ during the field visits of Feb. 2019.</p>	<p>Grazing of irrigated fodder crops in Hazeem hotspot</p>
	
<p>An overview of abandoned fields in Hazeem area, following shutdown of illegal wells by WAJ.</p>	<p>An overview of abandoned fields in Hazeem area, following shutdown of illegal wells by WAJ.</p>
	
<p>Fields of zucchini in Zamil in the southwest of Azraq basin</p>	<p>Fields of garlic in Zamil in the southwest of Azraq basin</p>

Figure 1: Examples of field observations in Azraq GWB during 2019.

3.0 RESULTS AND DISCUSSION

3.1 AREA OF IRRIGATED CROPS

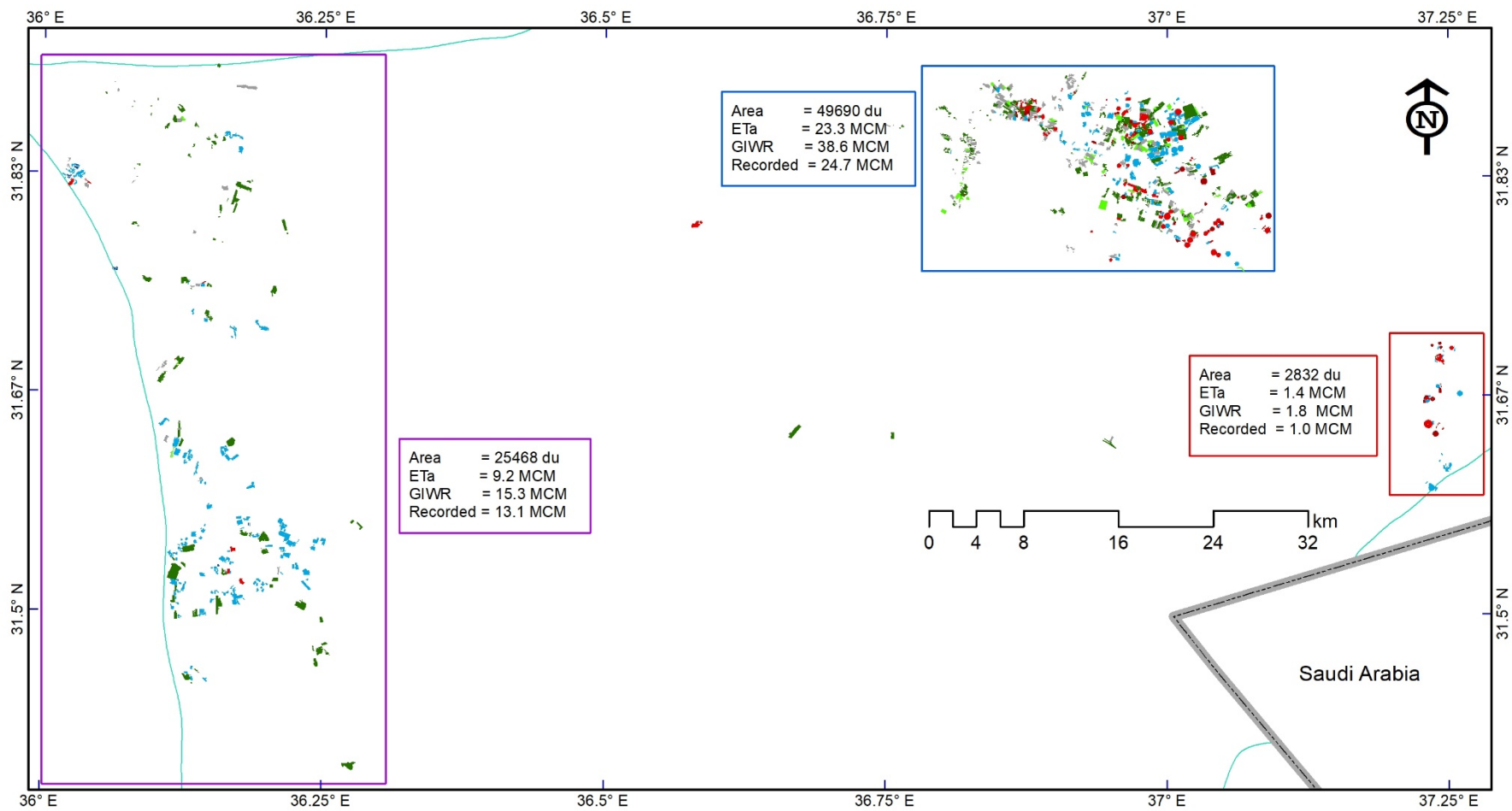
The total irrigated area using all water resources was 79.2 thousand dunums (du) during 2018. The figure includes about 343 dunums of plastic houses. The main zone of irrigation in this basin is the area of Azraq where 50.7 thousand dunums were irrigated, while the second important zone is in the southeast of Amman where about 25.5 thousand dunums were irrigated during 2018. Analysis of irrigated cropping pattern in this basin is shown in Table 2. Generally, year 2018 cropping pattern was like that in year 2017 with an increase in vegetable areas and reduction in fodder crop area from 20% in year 2017 to 15% in year 2018. Differences in areas of olives and fruit trees were very small and could be attributed to accuracy of the digital classification method that was used to derive the map. The total GIWR in 2018 reached 56 MCM, while recorded abstraction 39.6 MCM.

Table 2: Summary of irrigated crops and their water consumption in Azraq GWB.

Crop	Area (du) in 2017	% in 2017	GIWR (MCM) in 2017	Area (du) in 2018	% in 2018	GIWR (MCM) in 2018
Olives	26,925	36.7	12.7	28,012	35.4	14.6
Fruit trees	3,626	5.0	2.7	4,219	5.3	3.0
Mixed crops	9,655	13.2	11.5	12,307	15.5	13.1
Vegetables (Open fields)	17,642	24.1	8.7	22,633	28.6	11.2
Vegetables (Plastic houses)	420	0.6	0.7	343	0.4	0.6
Fodder crops	15,032	20.4	23.7	11,720	14.8	13.7
Total	73,300	100.0	60.0	79,234		56.2

* Figures from farmers for tomato and cucumber 800 m³ for one plastic house for two seasons of cultivation and an overall efficiency of 0.65.

Distribution of irrigated areas in Azraq basin is shown in Figure 2. The main changes to irrigated areas are mainly the recession in irrigated areas in Hazeem and increased irrigated area in South Amman and in Azraq depression. The map of ETa for the 2018 cropping pattern is shown in Figure 3. Areas with high water consumption were mainly concentrated in Azraq depression area and in few spots (centre pivots in Hazeem). an increase in ETa was observed in the southwest of the basin, mainly for olives and some farms of fodder.



Crop

- | | | | | | |
|---|--|---|---|---|--|
| ■ Vegetables-Open fields | ■ Olives | ■ Fodder-mixed | ■ Mixed crops | Hazeem irrigation zone | Azraq GW basin |
| ■ Vegetables-Plastic houses | ■ Fruit trees | ■ Fodder-Alfalfa | Azraq irrigation zone | Southeast Amman irrigation zone | |

Figure 2: Map of irrigated crops in Azraq GWB during 2018.

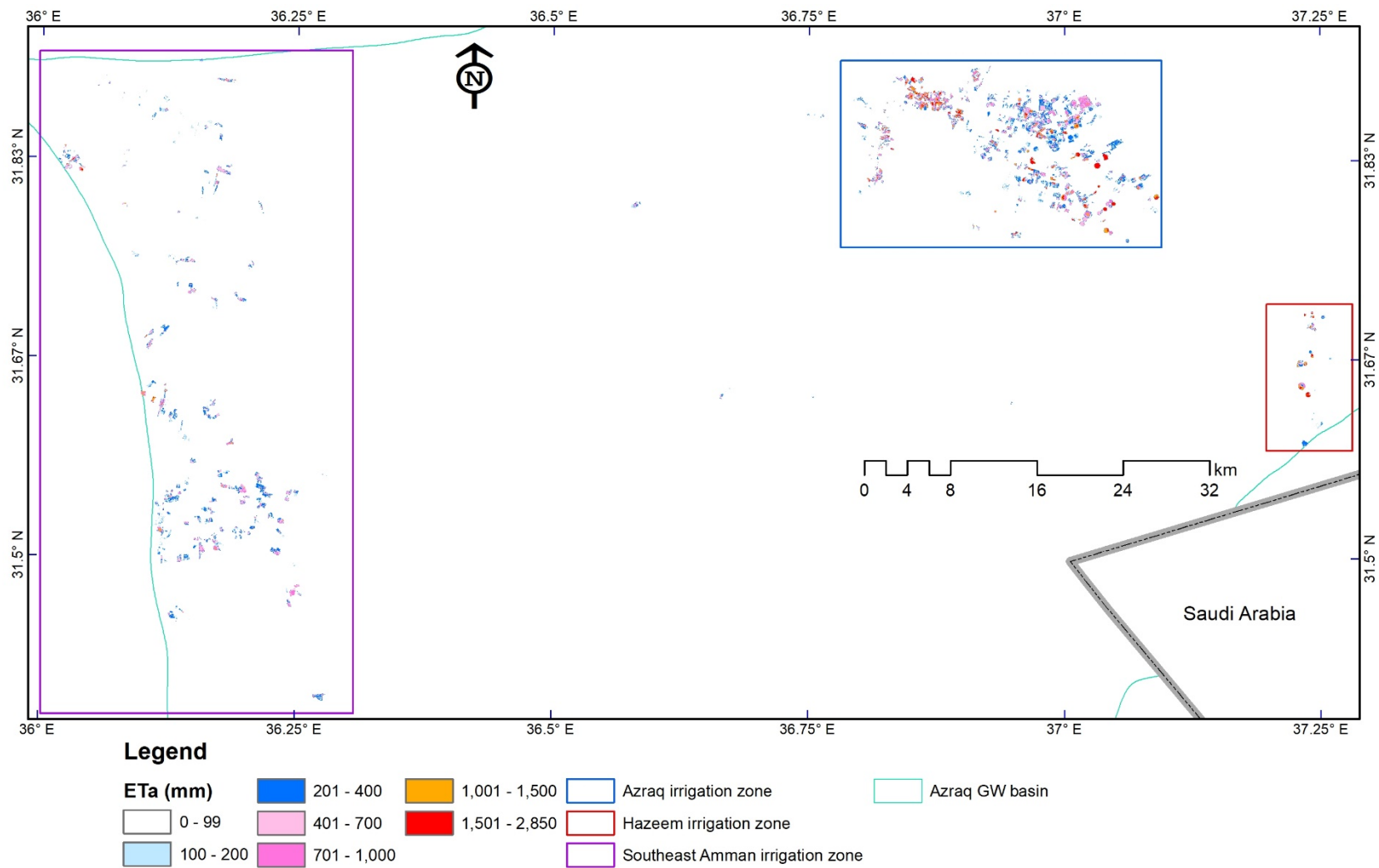


Figure 3: Map of ETa for irrigated crops in Azraq GW basin during 2018.

3.2 COMPARISON BETWEEN IRRIGATION IN 2017 AND 2018

Results for irrigated crops and irrigated showed slight variations in the total irrigated area and distribution of crops in Azraq GW basin. The total irrigated area increased from 73.3 thousand dunums to 79.2 thousand dunums in year 2018. The GIWR on the other hand slightly decreased from 60 MCM in 2017 to 56 MCM in 2018 (Table 3). This reduction was mainly to recession in the area cultivated with fodder, especially in Hazeem (Figure 4). The recorded abstraction for 2018 was 39.6 MCM, compared to 49 MCM in year 2017. Therefore, it could be concluded that WAJ and MWI underestimated the abstraction in both years, particularly 2018.

The total operational wells that were recorded by WAJ were 544 and 553 in years 2017 and 2018, respectively. The data of 2018 and the maps derived from 2018 showed no new hotspots in 2018 compared to 2017. The area in the southwest of the basin (southeast of Amman) is showing an expansion in irrigation with an average GIWR of 600 m³/du. This figure is still reasonable and attributed to the cropping pattern which is dominated by vegetables. The field visit in May 2019 showed that the main irrigated crops in this area are zucchini, garlic and tomatoes. No fodder crops or fruit trees farms are cultivated in this area, which resulted in a relatively low GIWR when compared with the area to the east of Azraq depression where the average GIWR in 2018 was about 900 m³/du.

Table 3: Summary of irrigated areas, water consumption (GIWR) and recorded abstraction in Azraq GWB.

Zone	2017			2018		
	Irrigated area (du)	GIWR (MCM)	Abstraction (MCM)	Irrigated area (du)	GIWR (MCM)	Abstraction (MCM)
Azraq	44,561	40.0	33.3	49,690	38.6	24.7
Hazeem	4,631	6.5	1.7	2,832	1.8	1.0
Southwest of the basin (Southeast of Amman)	23,040	13.1	12.9	25,468	15.3	13.1
Other areas	1,068	0.4*	1.1	1,244	0.5	0.8
Total	73,300	60.0	49.0	79,234	56.2	39.6

*The difference between recorded abstraction and GIWR could be attributed to water selling for livestock herders.

3.3 WATER CONSUMPTION AT HOTSPOTS

Results showed an improvement in water auditing carried out by WAJ in the hotspots identified for the water year of 2017. The actions taken by WAJ were obvious in Hazeem and a water saving of 4.0 MCM was achieved in this area of the basin (Table 4) due to shutdown of illegal wells and changing the cropping pattern. Ground observations during February 2019 showed that many fields of alfalfa were replaced with barley which had shorter season and lower water consumption when compared with alfalfa. The actions taken by WAJ during 2018 and early 2019 were the shutdown of 20 unlicensed wells in Hazeem area. According to WAJ estimates, this action resulted in a total water saving of 3 MCM. Results from this study agreed with this figure and the reduction in GIWR at Hazeem was obvious in 2018 when compared to 2017.

The two other hotspots witnessed slight expansion in irrigated areas in year 2018 compared to 2017 (Table 4 and Figure 3), resulting in higher GIWR and a relatively high average GIWR that was about 1200 m³/du. Considering the figures of GIWR presented in Table 4, the total water savings in the three hotspots reached 3 MCM. However, the recorded abstraction for the basin and for the three hotspots is still below the GIWR. Maps of ETa difference between 2018 and 2017 are shown in Figure 5, which summarizes the changes in level of water consumption and extent of irrigation. The changes in Hazeem hotspot were the reduction of water consumption and the recession in irrigated areas. For the two other hotspots in the east of Azraq depression, irrigated areas increased in 2018 when compared with 2017. The ETa, and subsequently GIWR, had increased in the hotspot to the north of Azraq, while most of the area in the southeast of the depression had lower ETa values in 2017, indicating obvious changes in cropping patterns from alfalfa to barley and vegetables.

4.0 KEY RECOMMENDATIONS

The specific recommendations for the area to the east of Azraq are:

1. Changing the patterns of mixed cropping and fodder to vegetables or seasonal fodder crops (barley and/or sorghum).
2. Improving irrigation efficiency by 10-15%, which will save about 8 MCM in this area of the basin.
3. Empowering WAJ field crews to continue the work of water auditing which will eventually lead to more water savings in the future.

Table 4: Summary of locations and hotspots with high water consumption and possible water savings in Azraq GWB.

	East of the depression, south of Ain Al-Baidah		SE of irrigated area in Azraq depression		Hazeem	
	2017	2018	2017	2018	2017	2018
Cropping pattern (%) *	M&T (66), F (27), V (7)	M&T (74), F (19), V (7)	M&T (23), F (65), V (12)	M&T (27), F (63), V (10)	M&T (1) F (61) V (38)	M&T (1) F (58) V (41)
Area (du)	6,563	6,898	2,407	2,638	4,631	2,832
GIWR (MCM)	7.2	8.7	3.0	3.2	6.5	1.8
Recorded abstraction (MCM)	3.3	2.9	1.0	1.2	1.7	1.0
Non-recorded abstraction (MCM)	3.9	5.8	2.0	2.0	4.8	0.8
Remarks	Total GIWR increased by 1.5 MCM		GIWR increased by 0.2 MCM		GIWR decreased by 4.7 MCM	

* M&T= mixed patterns and tree crops that include fruits and olives, F =Fodder, V =vegetables.

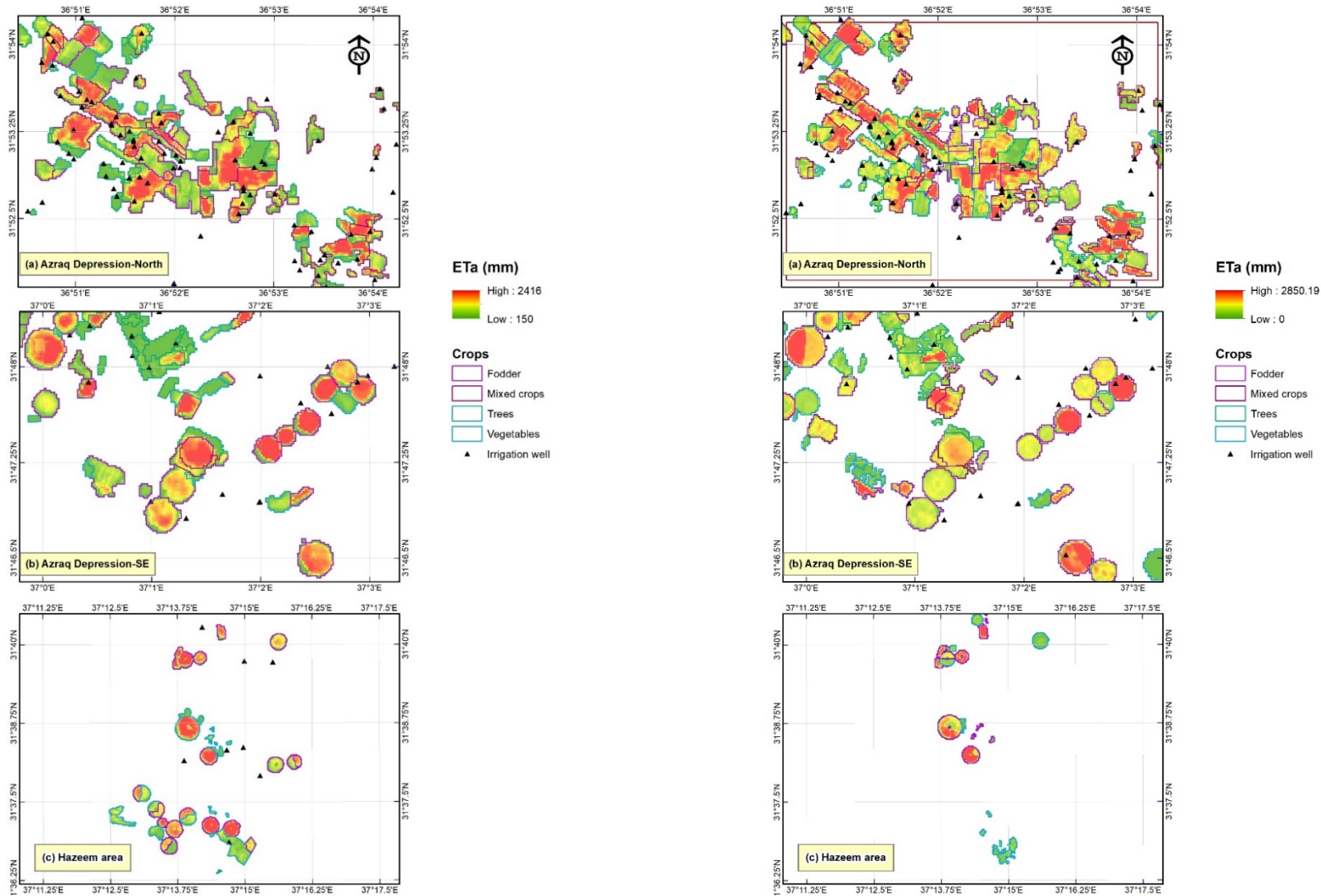


Figure 4: Maps of irrigation and ETa for hotspots in Azraq GW basin during 2017 (Left) and 2018 (Right).

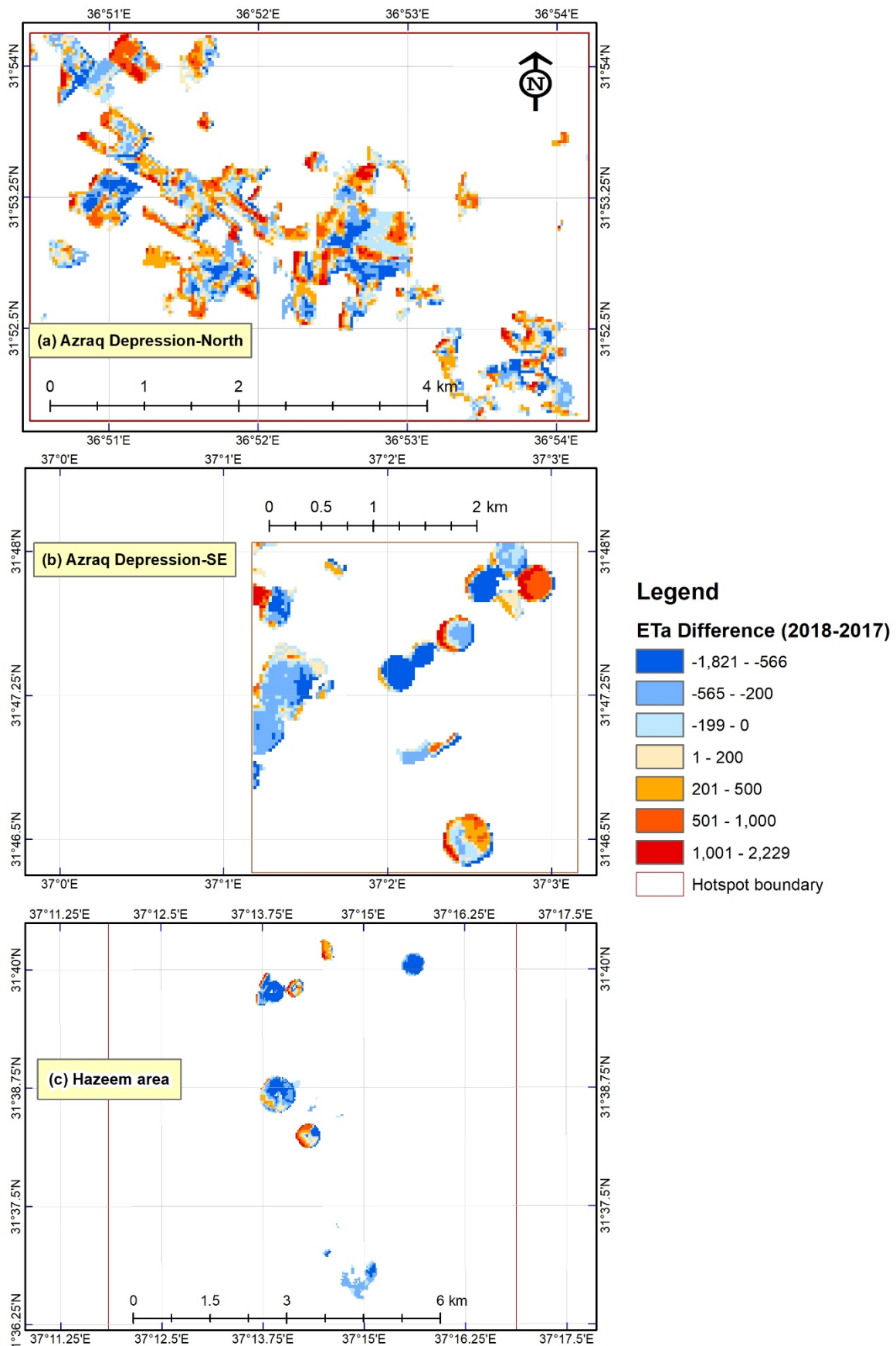


Figure 5: ETa changes between 2018 and 2017 in the hotspots of Azraq.



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