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Water Accounting Plus (WA+) for Yarmouk Tributary Basin

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WAJ	Water Authority of Jordan
JVA	Jordan Valley Authority
MOAAR	Ministry of Agriculture and Agrarian Reform
OSoI	Occupying State of Israel
FAO	Food and Agriculture Organization of the United Nations
IWMI	International Water Management Institute
WA	Water Accounting
MWU	Managed Water Use
MLU	Modified Land Use
PLU	Protected Land Use
ULU	Utilized Land Use
WA+	Water Accounting Plus
ET	Evapotranspiration
ETc	Crop Evapotranspiration
ETinc	Incremental Evapotranspiration
ET0	Reference Evapotranspiration
T	Transpiration
E	Evaporation
I	Interception
P	Precipitation
MCM	Million cubic meter
CHIRPS	Climate Hazard Group Infra-red precipitation with Station
TRMM	Tropical Rainfall Measuring Mission
GPM	Global Precipitation Measurement
USGS	United States Geological Survey

EROS	Earth Resources Observation and Science Center
MODIS	Moderate Resolution Imaging Spectro-radiometer
WAPOR	Water Productivity Open-access portal
NTSG	Numerical Terra-dynamic Simulation Group
NASA	National Aeronautics and Space Administration
NDVI	Normalized difference vegetation index

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Abstract

This report provides the water accounting plus study for the Yarmouk Tributary Basin during 2009. Yarmouk is considered as an important basin that is shared between three countries: Jordan, Syria and OSOL. The study focuses on water resources within the basin, classification of land use categories, the processes by which water is depleted over all land use classes, as well as, beneficial and non-beneficial usage of water. The Yarmouk's water resources are facing many challenges. The over development of infrastructure, the ambiguous treaties done by the shared countries, and the over abstraction of surface and ground water from legal and illegal wells led to declining in river flow, lowering the water table, and water scarcity and pollution all over the basin. Moreover, data for stations within the basin are not available by which neither Syria nor Jordan provide complete and reliable gauge data. Among these difficulties and problems, Water Accounting Plus framework using remote sensing products derived from different satellites has been applied to scan Yarmouk Basin that leads to more understanding of the situation, provides a hydrological and political baseline that focus on water depletion over land use classes. It has been shown that more than the half of the water depleted in a non-beneficial way during 2009. Though the irrigated area only formed 8% of the total area, the water requirements for irrigation exceeded withdrawals from river flow, dams and legal wells, which reflects the presence of a huge number of illegal wells distributed in both Syria and Jordan. Moreover, a big part of water has not consumed within the basin and depleted outside the basin borders or wasted over bare lands. That will contribute to an equitable and sustainable water arrangement between the 3 countries and allow communities to make plans and monitor their targets with more data available.

1. Introduction

Yarmouk tributary basin is a common basin between 3 countries Syria (80%), Jordan (19.7%) and Palestine (0.3%). Each of these countries shows interest in the water sources of the Yarmouk basin, where the flows of the Jordan River are the main source of water for the residents of dozens of villages like Dera'a and Irbid. Moreover, many cultivated areas in Deraa, OSol Triangle, Quneitra, and Golan Heights are irrigated from surface water and groundwater abstracted by legal and illegal wells mainly located in the Syrian part of the basin. In addition, the livelihoods of over one million people across the Hauran Plain and beyond are supported by the flows of the tributaries (UEA, 2018).

Many efforts done by the three trans-boundary countries in order to manage and benefit from Yarmouk's water resources in different sectors: Agricultural, Domestic, and Industrial. Negotiations lasts for decades resulted in treaties in 1987 (Jordan-Syria) and 1994 (Jordan-OSol) that aims to a coordinated, sustainable use, and an equitable sharing of water resources in the basin. But more than a quarter of a century on, the treaties are proving to be part of the problem (Avisse et al., 2020). Both treaties are being inflexible in a constantly changing context, disregarding environmental and water quality concerns. They are considered unsustainable because they don't account for the impact on downstream users, and fail to reflect the actual use of water specifically groundwater and its availability (UEA, 2018). Within both treaties the allocation of water use between the three countries is being inequitable through a very ambiguous allocation mechanism. However, the two treaties structure carried on diplomacies that ignore the politics and hydrology of the area, this results in a skewed and ambiguous treaties that perpetuate the mistakes of the past into the future and lead to uncoordinated and inefficient infrastructure.

After the irrigation and urban development, the countries started building numerous dams and canals on the Yarmouk tributaries in the upper part of the YRB to increase water availability(Avisse et al., 2020), for drinking and irrigation purposes. The many infrastructure within the basin are contributing to political tensions and pushing beyond the sustainable limits of the resources, as an example of the Adassiyeh Diversion Weir completed in 1999, and the Wehdeh Dam completed in 2006 that affects the river flow.

Yarmouk's water resources are being used unsustainably (Zeitoun et al., 2012). The over-development where the land in the basin has gone through dramatic changes, and an inequitable sharing of the flows across the entire basin is straining the resources and remains a source of tension between Syria, Jordan, and OSol, and communities therein (UEA, 2018). This disuse led to many catastrophic impacts on the water resources. Over more than half a century the river flow has been declining steadily due to the upstream abstractions through more than 40 dams on yarmouk wadis, where Syria occupied about 32 of these dams. Nicolas Avisse (2020) states that it seems clear that the disuse of many reservoirs in 2013, after the Syrian civil war started, led to less water stored in the YRB and to larger runoff discharges during the following years. In addition, the drought period like the devastating one in 2008-2011 and the precipitation decrease since the first half of the 20th century have partly led to the river flow decline. According to WAJ/JVA data, the base flow and runoff show a sharp decrease, also the return of the runoff from 2013, when many Syrian refugees fled the civil war (Müller et al. 2016). The use of flood water locked solely for OSol by the mean of Jordan-OSol treaty. This decline in river flow mainly affects Jordan due to its downstream position as most springs and wadis feeding the Yarmouk are located in Syria and Golan Heights, moreover, it has to send $25hm^3$/year to Israel no matter the flow reaching Wahda Dam as listed in the OSol-Jordan treaty. In addition to surface water decline, groundwater levels found in different aquifers are being declined due to the over-abstraction beyond their sustainable limits via many wells due to irrigation purpose in Syria which lead to decrease in Yarmouk flows.

Irrigated crops area developed and kept expanding in Syria with the Government's objective to increase food security and ensure self-sufficiency (Salman and Mualla 2008), until irrigation accounted for more than 80% of water use in the Syrian part of the YRB (World Bank 2001). As a result, well licenses were more easily delivered and fuel was strongly subsidized to get farmers interest but some of these incentives also fostered the growth of illegal groundwater pumping: 50% of wells were unlicensed at the end of the century (World Bank 2001; Salman and Mualla 2008). Water withdrawals increased for irrigation purpose and an uncontrolled and inefficient irrigated agriculture in Syria, at the expense of inflows into the Wehdeh Dam.

Jordan blames Syria for the decrease in Yarmouk flows, because of excessive water abstractions and uncoordinated construction of dams in the Syrian part of the YRB (FAO 2009; Yorke 2016), it considers that Syria violated their 1987 bilateral agreement by building more dams than what was agreed on, while upstream Syria blames climate change and particularly precipitation decrease (Hussein 2017).

Work to clarify the causes of the flow decrease, to understand and manage Yarmouk's water resources has been difficult. Many obstacles and limitations face this study, where data about or from Syria is incomplete. Syria never published water resources data or shared it with neighboring basin states(Avisse et al., 2020) and there are difficulties in securing interviews with water users and key decision-makers, this means a scarce in the information concerning water resources of the Syrian part. Also MWI/JVA only published the in situ measurements of the Yarmouk River flow at the Wahda dam, or Maqarin station before the dam's construction. Another limitation derives from the mismatching format of the several forms of hydrological and rainfall data. The data available are aggregated country- or basin-wide estimates from international donor organizations like the FAO or World Bank. Many limitations to gather information about Yarmouk Basin while its study needs a comprehensive use of all available sources of information, including pumping and availability data provided by the Jordanian Ministry of Water and Irrigation, the Jordan Valley Authority, or available through the Jordan Valley Water Authority (in Israel), and the Hydrological Service of Israel.

For these reasons, the Yarmouk tributary basin is to be managed sustainably and required a coordinated action between the three main state actors for renewed efforts to improve the water-sharing arrangements and revisit the treaties that incorporate all sources of water available particularly groundwater for human use to make them more effective. The Syrian crisis brings into focus the links between agricultural water use and river flow, and the importance of effective trans-boundary water resources management. Allocative mechanisms should be flexible rather than rigid, based on water use rather than availability where it reflects needs, for example, water used for domestic purposes is often prioritized over water used for economic gain. Social and political tensions for the roughly 1.6 million people living in Jordan and Syria expected to greatly reduce by more efficient infrastructure, and an equitable and sustainable arrangement on the Yarmouk tributary. Effective trans-boundary water resource management, demand-management shifts in agricultural policy and consideration of food, technological innovation and refreshed diplomacy as well as main streaming in proactive policies oriented to water accounting are required for sustainable, efficient and more equitable use of Yarmouk tributary.

Accordingly, the objective of this project is to develop an operational water accounting system for Yarmouk basin. This should contribute to equitable and sustainable water arrangement between the 3 countries, effect support trans-boundary water resources management, provide a hydrological and political baseline and focus on water supply between domestic, agriculture and industrial sectors. It will allow communities to make plans and monitor their targets with more data available. Water accounting plus is a new reporting system for water resources that scans ungauged trans-boundary river basin or conflict-torn areas with earth observation satellites where data on both hydrological fluxes and on the management of reservoirs are either absent or incomplete. This implies that the majority of the geographically distributed data is available for water accounting at all times, because the data is owned by space agencies that allow the general public to use the data without charges. It is all open-access data bases (FAO, 2015). The framework uses both land measurements and remote sensing products in real time and use them as input to give a clear understanding and develop a common and more complete knowledge base of the study case. The Yarmouk tributary's is explored through extensive analysis of satellite images. The method proves very useful to track land use in the account year, to identify irrigation requirements, dams and patterns of agricultural water use, and to account for surface and groundwater withdrawals. The study evaluates the current distribution of control and use of Yarmouk flows over the account year. The methodology has the potential to provide decision-support information and to target an effective cooperation between parties.

2. Literature Review

2.1 History and development of the Yarmouk Tributary Basin

Over decades, Yarmouk tributary basin has been a point of interest for many cultures and countries due to its strategic location, richness in water resources and agricultural characteristics. It is characterized by many tributaries that extends from Jabal El Druze to the high lands of Golan. Yarmouk River comprised the basic principles of the policy between countries due to its importance, it is known in the past by "Hieromaxor" that reflects the Roman Empire and Hebraic settlement along its banks. Also Jordanians, Palestinians and Syrians referred to Yarmouk as Sharia't el Menadireh. Because of its position between different countries, it was the center of the political strategies of consecutive empires especially of the Levant.

Empires considered Yarmouk as a bridge to connect different regions, as the Hejaz Railway that built from Dera'a to Haifa by the Ottoman Empire to connect Medina to the Mediterranean in 1908. The area was then part of the Ottoman sanjaks Liwahand Hauruân (Schumacher 1889). After that, part of the Yarmouk and Jordan was given to Greek citizen Euripides Mavrommatis for hydro-electrical purposes (Zeitoun et al., 2019). However, Ottoman interest in Yarmouk area extended till the mid-19th century which reflected by taking Irbid as the center of its works.

Other interests have been shown to Yarmouk as that of French, British and Zionists ones, especially that corresponds to Jabal El Druze to maintain Druze unity. The British concerns was reflected in 1926 by their plan to operate a power planet within the area using both Yarmouk and Jordan flows with the aid of Russian and Zionists (Zeitoun et al., 2019). However, Zionist's plans go further that aims to expand British leverage towards Litani River in Lebanon as well as Yarmouk (Zeitoun et al., 2012).

As a result Yarmouk then shared between three strong powers at that time which are French ones in Syria, British in Jordan and Palestine both. However, after the Nakba (creation of Israel) in 1948 and the dependence of both Syria and Jordan, Yarmouk then has been formed between the boarders of Syria, Jordan and Israel.

2.2 Treaties and agreements within the Yarmouk tributary basin

Many negotiations and treaties have been performed between the countries that shared Yarmouk for many years in order to guarantee an equitable and far sharing of the water resources within the basin. Starting from the Franco-British water agreement in 1921 that done between the French in the Syrian part and the British in the Jordanian side. This agreement argues Yarmouk flows and tends to secure water rights for Palestine. The negotiations led to attribute

50% of Yarmouk flow to Palestine for irrigation purposes. Another agreement has done between Syria and Jordan in 1987 that aims to construct Maqarin dam for producing electricity and regulating the flow (Zeitoun & Elaydi, 2019). This dam is known nowadays by the Wehdeh or Unity dam that has been completed in 2006. This water agreement done after the intensive groundwater abstraction from the Syrian part for irrigation purposes in the Huaran Plan and the minor wastewater reuse in both Jordan and Syria (Feitelson and Rosenthal, 2012; Aviram et al., 2014). The two countries have agreed that Jordan shall design and build the Wehdeh dam for producing electricity but Syria will take 75% of this electricity. Also the agreement gave Syria the right to use the water of all springs except that below 250 m. However, Jordan has the right to store the water flowing into the Yarmouk river after the filling of the reservoirs of the Syrian dams (Zeitoun & Elaydi, 2019). As it is clear that this agreement does not take into consideration the impact on downstream users or the quality of water even the groundwater abstraction. On the other side, Jordan has made a peace treaty with Israel in 1994 in order to secure the use of water resources shared between the two countries. In contrary with the previous agreement, it includes a term to secure water quality against pollution. The most important agreement terms include the Adassiyeh Weir construction in order to improve diversion efficiency. Jordan was obliged to send 25 MCM/yr for Israel to receive 20 MCM/yr after desalination, however, the both sides can use the excess of flood water (Zeitoun & Elaydi, 2019). Also this agreement did not take in to account the downstream Palectinian water use, ignores the impact of groundwater on surface water, and did not deal with changed circumstances (Zeitoun et al., 2019).

2.3 Challenges of trans-boundary basins

Many trans-boundary basins all over the world face challenges and obstacles to secure, share and manage the water resources between the occupied countries. A common problem faces most of the trans-boundary basins is the underdeveloped water infrastructure that based on political decisions which result in exhaustion of the water resources, suffering of the downstream users, flood risks and water pollution (Co-promoters et al., 2016). However, during negotiations between the shared countries, not all the decision makers have a scientific or engineering background or knowledge of the complexities of river basins and their impact on social, environmental and economic spheres, which results in bad management of water resources (Co-promoters et al., 2016). Moreover, data availability forms an obstacle in water management due to its spatial and temporal variability between the shared countries, and not all the countries within the basin share their data and studies, even if the data shared it would be old or do not cover the whole basin, which lead to miss understanding of the hydrological processes and a high level of uncertainty (Karimi and Bastiaanssen 2014). As well as, water supply and demand may change due climate change then a new trans-boundary challenges and opportunities will emerge too (Co-promoters et al., 2016).

Yarmouk basin is a shared basin between three countries, similar to the trans-boundary basins it suffers from various problems in sharing and managing the water resources. Water resources within the basin have been used in an inequitable manner, Syria intensively abstract water by the aid of many dams and wells for irrigation purposes, which lead to unfair share of water and influence water quality for the downstream users (Hussein, 2017). Moreover, the two agreements between the shared countries proved to be a problem (Avisse et al., 2020). They are both suffers from rigidity regarding any change in the climate or water resources, also, do not take into consideration water pollution and biodiversity. The two agreements failed to ensure equitable distribution for water, they are done only for constructing dams that are part of the problem (Zeitoun & Elaydi, 2019). In addition, all over the basin there are a huge number of dams and wells that drain surface and groundwater. However, no provisions on surface and groundwater have been seen and no control for Yarmouk flows from the institutions. Data accessibility is another obstacle, the three countries do not share their data and many local stations either became out of service or lacks for maintenance.

2.4 Water Scarcity

Water use has been growing globally with the population increase, this demographic growth and economic development are putting a big pressure on renewable, but finite water resources. A combination of population growth, urban growth, rising and changing food demands and the need to secure environmental flows in rivers is leading to higher demands for water (Haddeland et al., 2014). However, Llamas & Martinez Santos (2006) states that the intensive use of underground water for agriculture has provoked a drastic decrease in the volume of the aquifers. As the human population and the need for water-intensive activities goods and services continues to increase so will the demand for water. Many areas in the world are already experiencing the effects of the depletion of water resources something that is directly affecting food security and the agricultural sector. Therefore, supplies of predictable clean water are less common and less affordable due to pollution, changing in climate and land use, and depletion of major aquifers because of agricultural intensification. Water as a resource is scarce, it is fundamentally dynamic, varies with increasing demand by users and with the decreasing quantity and quality of the resource. We are suffering from scarcity in availability of fresh water; scarcity in access to water services and equitable distribution because of institution's failure in place to ensure reliable supply of water to users and bad diplomacies; and scarcity due to the lack of adequate infrastructure, irrespective of the level of water resources. However, many countries are unable to capture, manage and distribute these water resources.

That brings the need for effective and sustainable water resources utilization which is important for maintaining and protecting the available freshwater reserves. Protecting the water resources for the future begins with more effective water management, which is why the Global Environment Facility and Water Resources Management through a joint project, have been working to ensure the equitable and sustainable management of water. Water management can be defined as planned water resources development, distribution and utilization. Therefore, effective trans-boundary water resource management and refreshed diplomacy as well as mainstreaming in proactive policies oriented to water accounting are required. Water accounting provides a clear understanding for the current situation, shows the distribution of water resources on all sectors, and clarify how water is consumed by ecosystem services (FAO, 2015).

2.5 Previous Water Accounting Frameworks

Water management has been a topic of discussion and research for over 20 years where several international organizations such as FAO, IWMI, UN-Water, and the Australian governments have developed many water accounting frameworks. Water accounting is based on quantifying water resources where it consists of many approaches to study the current status and specify water supply, demand, distribution, accessibility and use in a case study (FAO, 2018a). Therefore, Water accounting is central to the integrated hydrology, water management, water allocations, landscape management, reporting and communication, quantifying the water use benefits, and policy decisions (Karimi, 2014). Different water accounting frameworks developed according to the definition of water resources and to the measurement of water consumptions.

The System of Environmental-Economic Accounting for Water (SEEAW), a recent framework that has been developed by United Nations Statistics Division. The SEEAW consists of an agreed international framework that links the water resource system with the economy in a coherent and consistent manner (*SEEA*, 2012). The methodology yields to the SEEA-W physical tables focusing on the quantitative assessment of the stocks and their changes in a river basin during the accounting period (Vicente et al., 2016). This framework takes into account water resources and return flow, where water resources defined as freshwater, brackish surface water, ground water, in addition to precipitation and soil water. However, it refers to evapotranspiration as one cause of decreasing water stock. SEEA-W was very useful and efficient where it separates consumptive use from non-consumptive use, moreover, flow accounting is represented in a well-documented way. On the other side, natural and agricultural landscapes are not regarded in this approach, and many of the required data are not available.

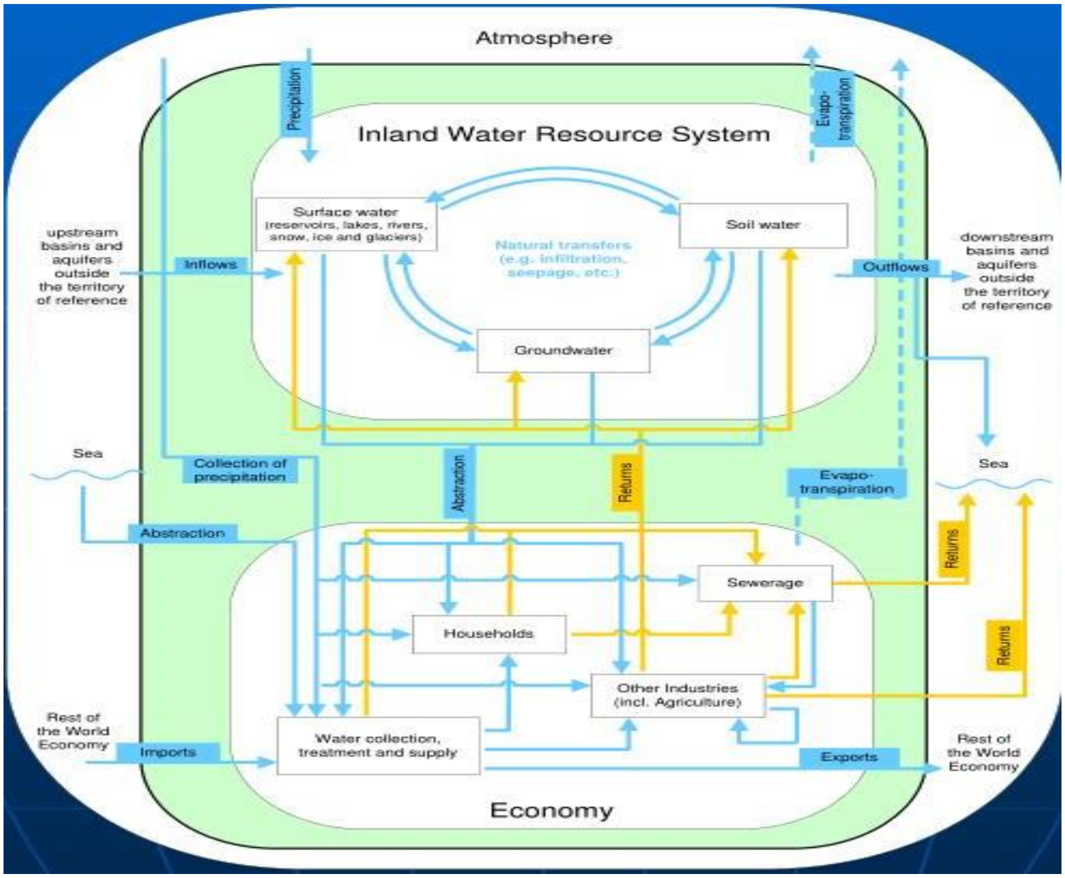


Figure 1: The System of Environmental-Economic Accounting for Water (SEEAW) framework

The ABS Water Accounts have built upon previous reports on Australian water resources and the System of Environment and Economic Accounting (United Nations, 2003). The framework does not account for the total water resources only for a small portion of the flow-rivers and for withdrawals only. ABS Water Account is followed by the Australian Water Accounting Standard (AWAS) that have been applied in South Africa, it discusses the total water resources and provides a more understandable flow accounting. However, both consider in accounting only runoff regarding rain and natural evapotranspiration.

The water accounting and water auditing framework developed by FAO (2012, 2013, 2016), this approach connects water accounting to water auditing with specific aim of reforming water governance. The framework incorporates the quantitative rigor of water accounting with a wider social process and dialogue-driven analysis of water governance. It goes a step further than studying water demand, supply, accessibility and use in a specific domain to the broader context of governance, institutions, public and private expenditure, laws, and the wider political economy of water in specified domains. Awash Basin, Malta, Cyprus, Helmand basin, Okavango basin are examples of basins for which WA&A studies are ongoing or planned.

Another framework that developed by FAO is Aquastat. This framework includes two main sheets: Country Fact Sheet and Water Resources Sheet. The latest one gives information on surface water and ground water. While the Country Fact Sheet provides a general description about the case study including area, population, water resources, and withdrawals for each sector.

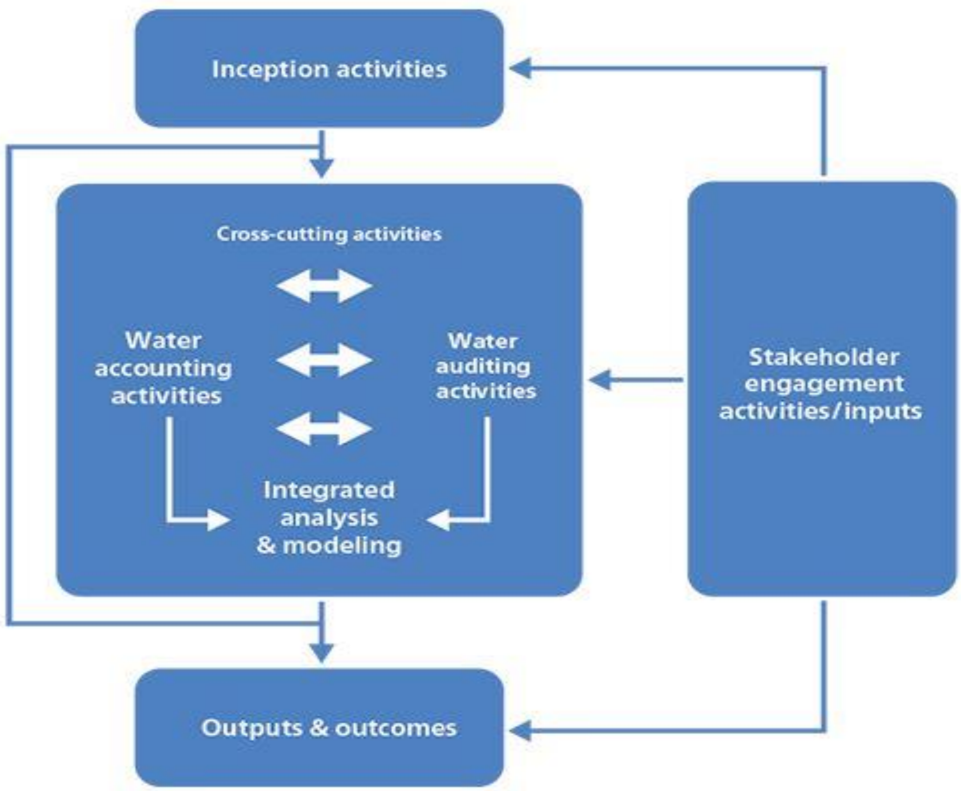


Figure 2: Aquastat framework

IWMI WA is a framework that developed by International Water Management Institute (1999) which is based on water balance approach that translates water balance into various water accounting categories, the net inflow, committed outflow, uncommitted outflow, process consumption, and un-process depletions (Karimi, 2014). It tracks for evapotranspiration and depletion rather than withdrawals. Moreover, it separates depletions into beneficial and non-beneficial. The analysis of this framework was applied for three main scales, the basin, service level, and field scale, however, its originally designed for irrigation schemes within a basin but later used for basin analysis, as a result part of the information are not covered in a basin context. East Rapti River in Nepal, Nile Delta, and Zhanghe Irrigation System in China are some examples of basins where WA has been applied.

A lot of water accounting frameworks have been published and used before: Water Footprint, Neutrality, and Efficiency, UNEP (2009), and Framework of the Challenge Program on Water and Food, CGIAR (2010) and many others. However, these previous frameworks listed above have been adopted by only some studies due to many reasons. Some of these frameworks are complex to be used, is heavily dependent on data and lacks for input requirements, it has been mostly limited to the well-gauged basins of Europe, Australia, the USA and Canada (Karimi 2014; Godfrey and Chalmers 2012). Others do not offer the possibility to produce time series for accounting, moreover, some of them do not offer link between land use and water flows. However, most frameworks exclude natural landscapes, ET and rain-fed agriculture, which are important variables in the most basins (Karimi 2014; Mainuddin, Eastham, and Kirby 2010)

Due to the many problems, water management for countries and basins where these frameworks applied was inaccurate and non-reliable because most of them lacks for standard data collection and doesn't cover the whole water resources in the case study which forms a problem (Karimi, 2014). Another obstacle faces these frameworks is the misconception and misinterpretation terms of water productivity, water depletion and water use between the professionals involved in water management. This leads to a difficulty in management, confusion and wrong decisions.

As a result of the many limitations and problems facing previous water accounting frameworks, governments and institutions were interested to develop a new water accounting framework that overcome all these problems and could facilitate the description of the current case study and the opportunities to exploit effective, efficient, productive, sustainable and equitable management of water flows. A new framework based on Remote Sensing is being developed by both UNESCO-IHE (Delft) and IWMI (Colombo) in partnership with FAO (Rome) that is a continuation of the Water Accounting framework introduced by (IWMI) during 1997. "Water Accounting +" makes use of global public domain datasets to estimate water balance components and report on the results through a set of standardized indicators sheets (FAO, 2015). This framework is very use full in complicated, shared and ungauged basins as the current case in Yarmouk basin where local data are not available. It is a very detailed framework that focuses on agriculture and irrigation system as it tracks for hydrological and water management processes and focus on land uses. Many applications of WA+ done by Bastiaanssen and Chandrapala (2003), Karimi et al. (2012), Simonset al. (2011), Shilpakar et al. (2012), Karimi et al. (2013b) and Dost et al. (2012) for ungauged river basins in Sri Lanka, Nile basin, Okavango basin, East Rapti basin, Indus basin, and Awash basin respectively.

2.6 Water Accounting Plus (WA+)

2.6.1 General Definition – Procedure

Because of the great water challenges that the world community is facing, Institutions are interested in changing land and water management practices, and developing joint versions and targets for sustainable water and environmental management. It has found that UNESCO-IHE, IWMI the International Water Management Institute and the United Nations Food and Agriculture Organization (FAO) worked together to develop a new water accounting system platform www.wateraccounting.org that provides information, literature, reports, sheets, work methodology and procedure for Water Accounting Plus (WA+). Water Accounting Plus (WA+) system have been suggested by Bastiaanssen (2009) and Karimi et al. (2013) as a new framework based on earth observations to measure all water flows and fluxes in a river basin with multiple water users (Bastiaanssen et al., 2015). Its framework has been applied to several large, complex and international river basin systems mainly in South Asia and Africa (i.e. Nile RB and its sub basins) which have previously been difficult to understand because of the limited availability of data. Similarly, this approach has been adopted for this academic work over one accounting year 2009: Yarmouk River Basin. The framework draw information from hydrological models and satellite information rather than relying on monitoring data, it is filled by satellite data which is based on early definitions introduced by International Water Management Institution (Karimi 2014) and freely available in Data Active Archives. The methodology covers many sectors and water practices such as irrigation management, surface and ground water management, infrastructure design and river basin management.

Water Accounting Plus (WA+) provides explicit special information that helps to understand the current state of the Yarmouk basin, issues and challenges, also to take decisions in the future management and improvement opportunities.

The methodology of this framework is based on water balance and tracks water depletion rather than withdrawals only (Co-promoters et al., 2016) and incorporates potential uses of rainfall other than runoff (Karimi 2014), where depletion includes ET and flow to sinks.. WA+ have been trialed in recent years to focus on the consumptive use of water including water consumption for natural processes (green water consumption) as well as human uses (blue water consumption) (Karimi 2014; Falken mark and Rock strom 2006).

Rainfall and Evapotranspiration are key hydrological processes in WA+. The approach assesses spatial and seasonal variations in precipitation and separates Evapotranspiration into rainfall ET (ETprec) and incremental ET (ETinc) to identify managed water flows. Incremental ET is referred to an extra amount of water that is available for consumptive use (Evapotranspiration) and cannot be explained by rainfall as a single source of water (ET>P) (Karimi and Bastiaanssen (2013a). Beneficial and non-beneficial depletion processes are clarified by separating the total evapotranspiration into evaporation, transpiration and interception processes, where the definition of beneficial depends on the user. Thus WA+ provides the main source of water in streams and aquifers, as well as quantifying water consumption. WA+ gives detailed information on water supply, flows, fluxes, storage changes, processes of water depletion, beneficial and non-beneficial depletion, biomass production, water and land productivity, and withdrawals.

Water Accounting Plus links all water resources with land use classes, land use changes have an essential role in water accounting and determined by satellite data basis. Flows, fluxes, storage and ET are computed of the different land use classes in order to assign benefits from managed water use, to understand the impact of land use changes on water resources and to improve the link between land and water use, as well as, to focus on the water consumption of the different land use types, including irrigated and rain-fed agriculture, as well as protected areas. WA+ separate land use classes into four main categories: Managed Water Use (MWU), Modified Land Use (MLU), Protected Land Use (PLU), and Utilized Land Use (ULU).

The methodology of WA+ is based on Remote-sensing, special models, GIS and software tools in order to collect, analyze data and derive clear and organized results. The output of WA+ is a number of sheets, tables, graphs and supporting spatial maps. In this project Resource Base Sheet, Evapotranspiration Sheet, Agricultural Sheet and Utilized Sheet are discussed among the eight sheets that provided by WA+ framework (Karimi et al. (2013a)) that are discussed in this work. Through these sheets the reader will understand the state of the Yarmouk basin as well as its water resources and management perspectives. As a result, this framework provides a standardized way of collecting water resource data in Yarmouk basin and describes its management by a well-organized system.

2.6.2 Remote Sensing

Solving water problems require reliable, accessible and coherent data. A large obstacle for water accounting plus is collecting data in international basins from various sources and institutions. In-situ station data are available only at selected locations in the river basins and are not being free from errors, so, its maintenance is not straight forward (Karimi, 2014). Then, one of the solutions to acquire an overall data for hydrological and land processes is to rely on measurements by earth observation satellites (FAO, 2015). Therefore, there is no need for extensive field monitoring and manpower to collect and interpret the data because remote sensing data is applicable for water accounting. This implies that for all major river basins in the world that suffer from data scarce its water accounts can be computed easily. This is particularly important in regions affected by conflict or violence or where conditions do not permit sharing data or regular access to monitoring sites (Hrachowitz et al. 2013) also when the data quality from field observatories is of bad quality, including such as outliers and missing data. However, after obtaining the raw data from multiple satellite systems, the presenter need to organize it an understandable framework to all professionals. Remote Sensing products are open source data that can be downloaded freely and extremely good as input for water accounting framework to generate excellent outcomes for this matter.

WA+ is designed to assimilate satellite based measurements of land and water resources in a spatiotemporally distributed manner, it shows the water depletion processes for every land use category. Precipitation, Evapotranspiration, biomass production and land use are raw inputs for WA+ framework and estimated by satellite measure radiances. The only feasible approach to estimating ET with a reasonable degree of accuracy at the catchment scale is through the use of remote sensing techniques (Guerschman et al. 2009). WA+ sheets mostly depend on satellite measurements data as an input except for withdrawal sheet. This provides the study an advantage to be done in a short time without depending on field data that might or might not have been collected already (FAO, 2012a). As a result, water accounts are based on open-acess datasets without referring to a particular basin organization or Ministerial Department; and this work will be distributed to all stakeholders involved in the water scarce resources. The use of publicly available satellite imagery has enormous benefits for global understanding of resource consumption and management (Karimi and Bastiaanssen 2014).

3. Study area description

3.1 General description:

The Yarmouk tributary basin is the largest tributary of the Jordan River with a total catchment area 7,387 km2 which is shared by three countries Syria (80%), Jordan (19.7%) and OSol (0.3%). Yarmouk's river has a general East to West flow, along a length of 154Km. It originates from different sources in Syria and Jordan, however, the general E-W flow, surrounded by peaks of Jabal Ash Shaykh in the west and Jabal al Arab in the East, runs through the Hauran towards the "Jordan River Valley" and joins the Jordan River a few kilometers south of Lake Tiberias. Over decades many tributaries have been formed between southern Syria and northern Jordan due to water discharge and surface runoff. Raqqad, Allan, Hareer/Arram, Thahab, Zeidi, Shallala are the main tributaries constituting Yarmouk basin that meet just upstream of Maqarin apart of wadi Raqqad. The only shared wadi between Syria and Jordan is wadi Zeidi. The basin experience many rolling hills and a gentle slope that affects snowmelt and evaporation rates. Its mountainous areas characterized by steep slope in the northwest, southwest and south near Quneitra, Jabal Al Arab and Ajloun respectively. The area characterized by its different sectors: Diverse agricultural sectors, urban zones and industrial areas (UEA, 2018).

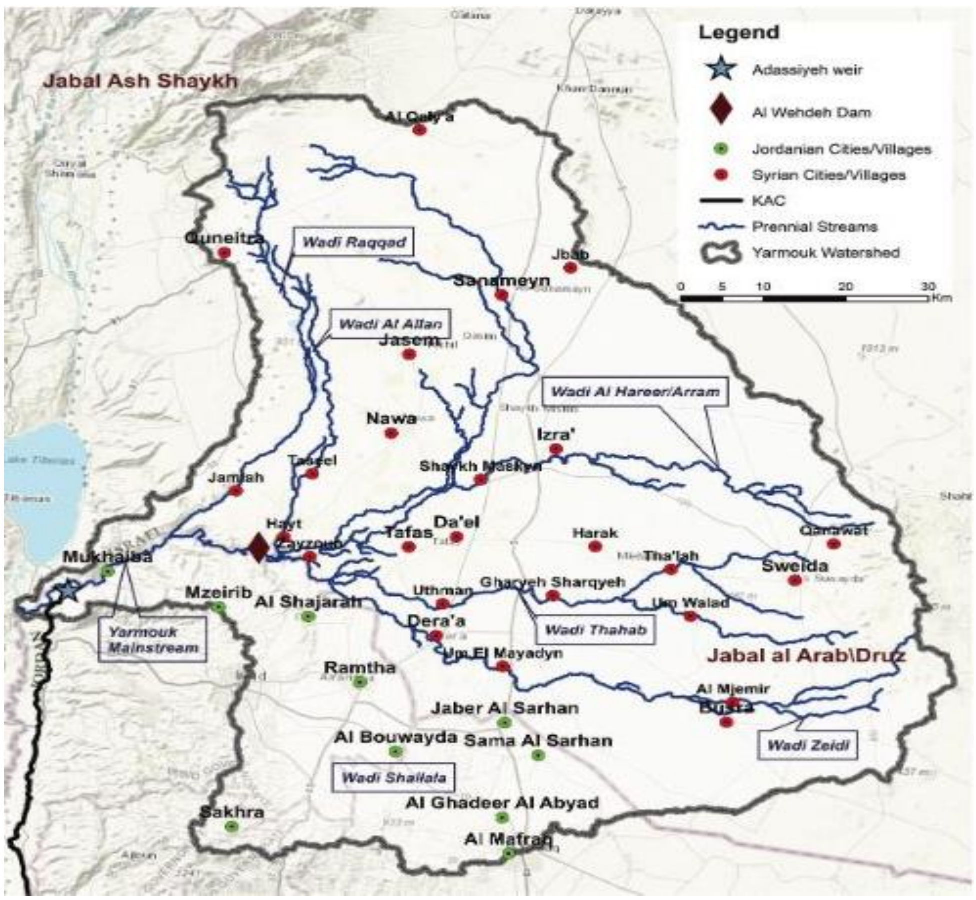


Figure 3: The Yarmouk tributary basin and its main tributaries, shown in relation to the main cities and villages. Source: UEA (2018)

3.2 Climatic Characteristics

Yarmouk basin has a Mediterranean climate, it is characterized by cold and wet winter and a dry summer. During winter season that lasts for about 8 months from October till April, precipitation occurs over the villages with different rates along the season, however, in the summer period there is no rain recorded but it is characterized by high rates of evapotranspiration. The precipitation accumulates in the hilly part of Yarmouk (Nasser, 1999).

The annual precipitation in year 2009 is estimated to be 365 mm/yr of which 60% are lost by evapotranspiration and the others drained either by infiltration to ground or gone by runoff. However, studying the trend of precipitation over a period of 38 years, it have showed that the average annual precipitation is increasing from 296 mm/yr in 1981 to 365 mm/yr in 2009 reaching 402 mm/yr in 2019 the end of the study. Evapotranspiration values estimated by this project shows high rates in summer which induces a negative water balance in this season.

According to the Standardized Precipitation Index (SPI), Yarmouk basin suffers from many drought periods as that in 2004 and 2010, as listed by (Nasser, 1999) that for each nine years there were 5 dry periods and they are larger than that of wet ones. The accounting year 2009 for this project seems to be a normal year.

In general Yarmouk basin is experiencing a variation in the precipitation rates and surface temperatures which reflects a climate change. Over a time series the maximum and minimum temperatures recorded an increase about 1℃ and 1.6℃ respectively (Nasser, 1999).

3.3 Population and socio-economic characteristics

Figure 4 shows the distribution of population over all Yarmouk basin in 2004, which is estimated to be about 1.6 million people distributed in the cities and villages of the two countries, where Syria occupies 1.4 million alone in 2009 before crisis. Most of the people in Syria lives in villages which reflects their work in the agricultural sector and efforts to develop it specially in the Hauran plain, about 1.1 million people estimated to live in the village in comparison to only 0.4 found in cities.

However, this distribution changed after Syrian crisis and many people displaced from their initial locations either toward the Jordanian part or toward other villages within the Yarmouk basin. This is the case in Dera'a for example, many people leave this city to live in other villages more secure. This influx contributes many impacts on both sides, the agricultural sector in the Syrian part affected negatively where many farmers leave their work for years. On the other hand, Jordan suffers from refugees that come from Syria to many countries such as Mafraq and Irbid.

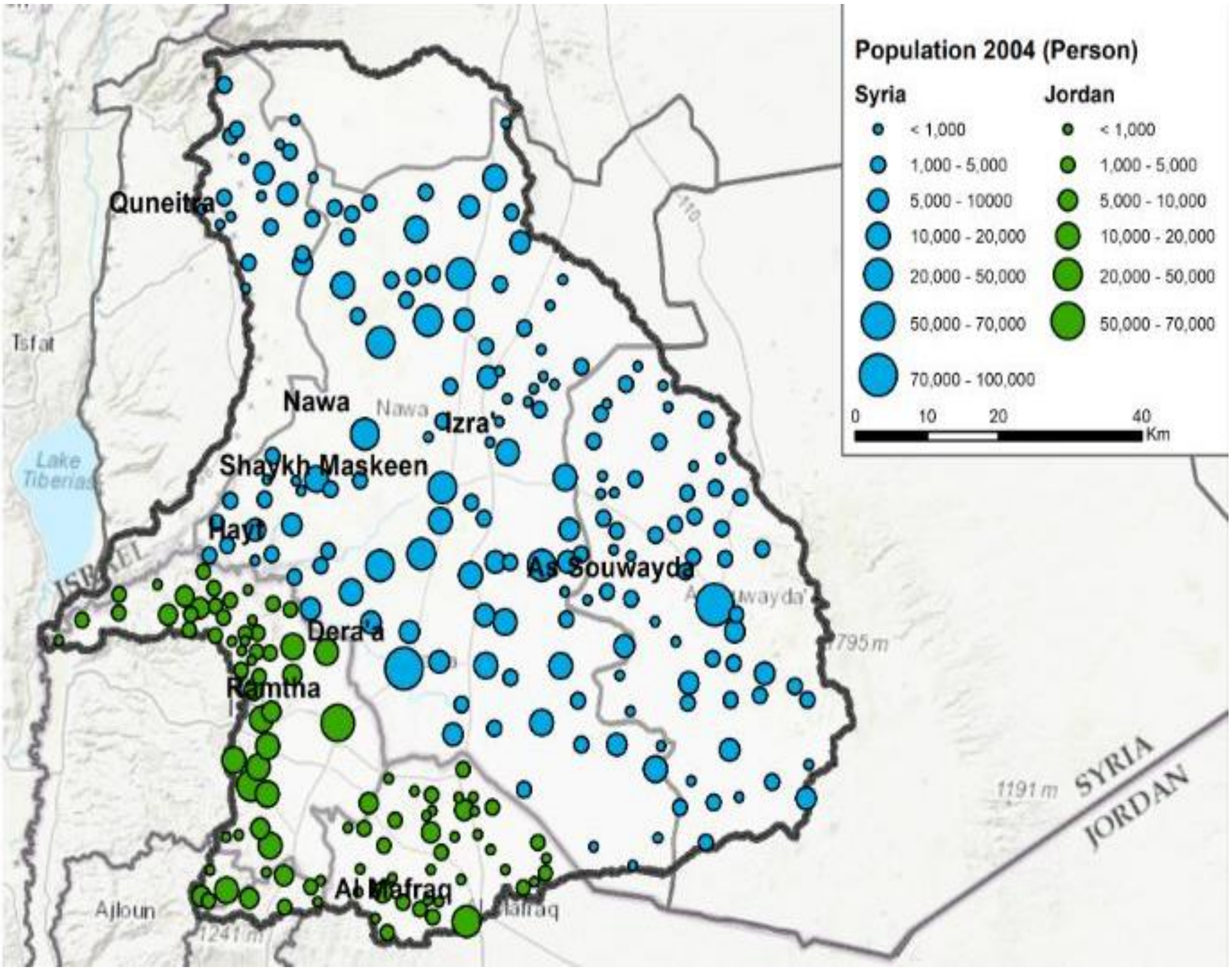


Figure 4: Population distribution in Yarmouk basin in year 2004. Source: UEA (2018)

3.4 Agricultural characteristics

The agricultural sector covers more than 49% from the total area of Yarmouk tributary basin. The three countries that shared Yarmouk basin show a great interest in cultivation, different irrigated/rain-fed crops are planted in many villages such as Dera'a, Quneitra, Irbid, Mafraq and the Yarmouk triangle. After 1994, Syria stopped importing wheat and depends on self-wheat planting, which lead to reclaim many bare lands and convert it to cultivated ones. However, the three countries depend on agriculture to improve their economy.

Yarmouk tributary basin characterizes by its diversity in plantation, where each governorate plant a different crop type. After a research on the crop types combined with remote sensing analysis, it has been specified for each governorate the most popular crop cultivated, plantation and harvest dates, and withier it is irrigated or rain-fed as shown in Table 1. The most popular winter crop was found wheat, which is planted mainly in the Syrian part (FAO & Ministry of Agriculture and Agrarian Reform, 2006), it is planted in November to be harvested in the beginning of May.

Rain-fed wheat is found in Al Suweida governorate, however, in the western parts of Dera,a it is found to be irrigated. However, vegetables are mostly found in the other governorates such as Quneitra, Rifdimashq, Golan and Irbid. They are planted in February to be harvested in July, most of the vegetables have been irrigated during 3 summer months that lasts from April to June. It is specified for Quneitra the most popular type of vegetable to be protected tomato that planted in August and harvested in November, this type needs irrigation between September and October.

In addition to crops, trees plantation is distributed widely in Yarmouk basin where olives, vines and fruit trees are mostly found. Part of these trees depend on irrigation in specific months while others are rain-fed. It is found that vines and olives are irrigated in May in most of the governorates, whereas, fruit trees depends on irrigated water in different months based on fruit types. It is found to be irrigated during July month in Irbid while in Golan it is irrigated during August.

As it is shown in Figure 5 the irrigated area is found to be in the western and northwestern parts of the Yarmouk basin, mainly located in Dera'a, Quneitra, Rifdimashq and Golan where we have plantation of irrigated wheat, protected tomato and potato. After specifying crop type and its characteristics for each governorate that combined with remote sensing analysis based on NDVI and Transpiration, an irrigation map for Yarmouk basin (2009) has been derived with total irrigated area of 38114 Ha for crops, 3427.7 Ha for Olives, 1279.8 Ha for fruit trees and 964.7 Ha for vines.

Table 1: Crop types and their characteristics in Yarmouk tributary basin

Governorate	Type of crop	Plantation date	Irrigation date	Harvest date
Dar'a	Wheat	November	January-March-April	May
	Vegetables	February	April-May-June	July
Quneitra	Protected Tomato	August	Sep-Oct	November
Suweida	Rain-fed Wheat and barley	November	_	May
Rif dimashq	Potato	February	April-May-June	July
Golan	Vegetables	February	April-May-June	July
Irbid	Vegetables	February	April-May-June	July

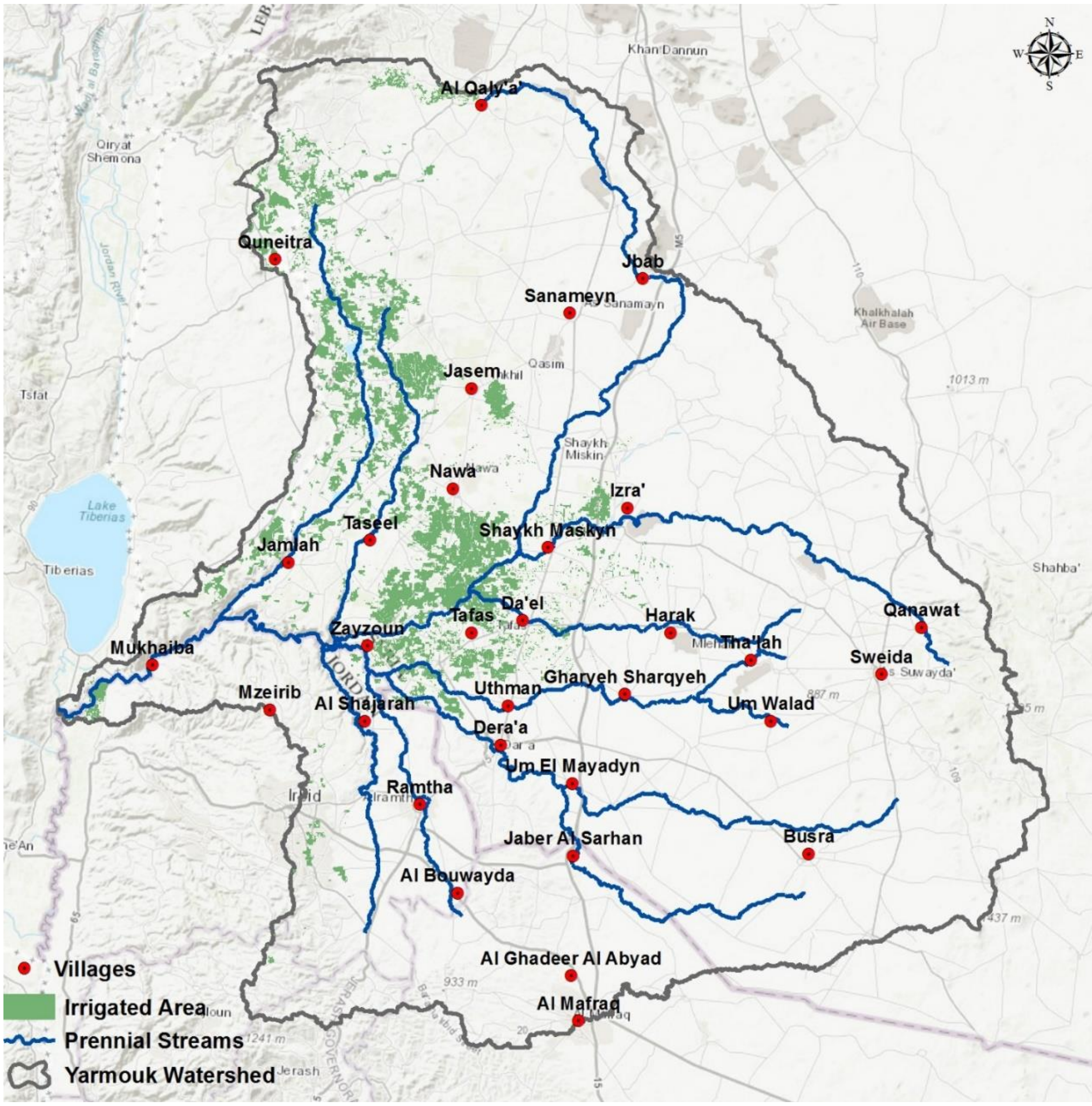


Figure 5: Distribution of irrigated area over the Yarmouk tributary basin in 2009 based on remote sensing analysis

3.5 Geology

Yarmouk tributary basin occupies two countries Syria and Jordan which have different geological characteristics. Three major and linked aquifer systems form the geology of Yarmouk basin which are: Upper aquifer system, Middle aquifer system and the Deep aquifer system. Yarmouk basin characterizes with high precipitation rates which form a major source of groundwater recharge in aquifers. Another source for groudwater recharge is the flow in wadis, on the other hand, groundwater is being intensively abstracted by wells in both countries for agricultural usage mainly (ETANA, 2015) in many regions such as Dera'a, Irbid, Quneitra and Golan. This usage lead to water table decline which force to deep the wells more inorder to acess water.

As shown in Figure 6, the Upper aquifer known as B4/B5 -Pg22/Pg23 which corresponds to Quaternary Basalts is found in the Syrian part and Golan height mainly. The majority of Yarmouk basin covered by this type of aquifer which consists of limestone, chalk, basalts and marls (Nasser, 1999). The recharge rate of the basalt aquifer in Syria estimated at 10% by Burdon (1954), and 12% for the basalts in Golan by Dafny et al (2003). However, the recharge comes from Jabal Al Arab in the northeast and the western part of the Hauran Plain to discharge in Mzeireb and Lake of Teberias (UEA, 2018).

The Middle aquifer system lies near north Jordan, it is known as A7/B2 –Cr2cn cp / Cr2m-d aquifer and formed of massive lime stones, marls and chalks, as well as, its thickness varies between 300 m and 500 m. As it is clear that this aquifer is being exploited in Jordan by agricultural wells due to its location near Irbid that characterizes by agricultural practices, as well as , the groundwater is being discharged by many springs where the average discharge is estimated to be 17 MCM/yr between 1983/84 and 1992/93(Hobler, et al.2001).

The Deep aquifer is located in Jordan and known as K -Cr1-Cr2t, it is mainly formed of limestone and characterizes by a thickness from 120 m to 350 m (UEA, 2018). It is not considered as an important aquifer due to the difficulty to access it except for some farmers in the Jordanian part who deepen their wells to exploit water for irrigation purposes.

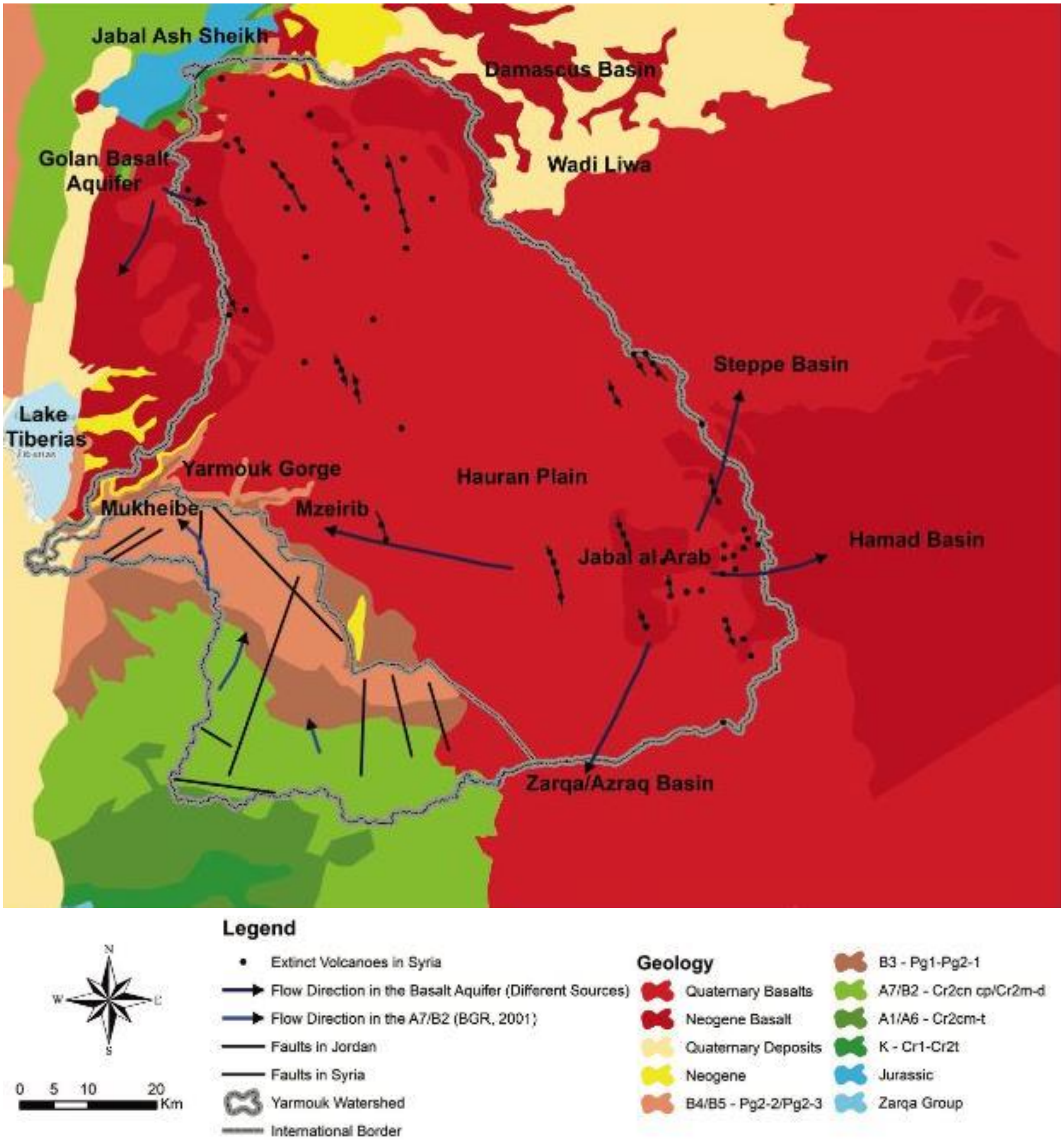


Figure 6: Geology of the Yarmouk tributary basin and ground water flow direction. Source: UEA (2018)

3.6 Hydrology

3.6.1 Surface water and dams

Yarmouk tributary basin is rich in water resources that are divided into surface water flows in rivers and tributaries, and groundwater that accessed by wells and natural springs. There was a difficulty to compute these resources within the basin and to release an exact estimation about inflow, outflow and withdrawals. The only obtained data from gauged stations are from the Jordan Valley Authority (JVA) and the Hydrological Service of Israel (HSI), whereas, the data from the Syrian side were not available. Due to the deficiency in local data, lack of communication and unclear method used to measure or estimate the flow there was a discrepancy in the flow data. Moreover, another obstacle faces this project is the difficulty to separate flood and base flow.

In general the inflow water from outside the basin to Syria is estimated to be about 11821 (MCM) coming from Lebanon and Turkey as surface and groundwater. While, the outflow from the basin is estimated based on Addasiyeh gauge data that is considered as the last station located on the Yarmouk tributary, for the period between 1999 and 2018 it gives information on flows that bypass the weir and overspill it to be 69 MCM/year, and the flows that diverted to KAC to be 72 MCM/year (Zeitoun et al., 2019).

The citizens in Yarmouk basin depend on surface water resources to cover their irrigation, domestic and industrial needs in many cities such as Dera'a, Irbid, Golan and Yarmouk triangle. So, for increasing the cultivated area and cover other needs such as generating electricity, many dams were built on the tributaries of the Yarmouk River between 1970 and 2006 (ETANA, 2015). The two treaties in 1987 (Jordan-Syria) and 1994 (Jordan-OSol) listed in their terms building many infrastructure projects to manage surface water within the basin and re-allocate water resources in between the three shared countries. Then, between 1970 and 2008 many dams and other infrastructure projects have been constructed to access water resources for development aims in the agricultural sector and other sectors, till the construction of Wehdeh dam between 2008 and 2015. As a result, about 40 dams have been built within the Yarmouk basin, 32 of them in the Syrian part, 1 shared between Jordan and Syria, 4 built by Israel in the Occupied Golan, and 3 occupied in Jordan with storage capacities of 206, 110, 10 and 3.1 MCM, respectively (Zeitoun et al., 2019).

The Wehdeh Dam and the Adassiyeh Diversion Weir are two of the major infrastructure projects that applied within the Yarmouk tributary basin and that have a big impact on the flow shared between the three countries. Wehdeh dam was constructed based on the agreement between Jordan and Syria in 1987 and after the increased pressure from Israel on Jordan to secure more water (at least 25 MCM/y for the farmers of the Yarmouk triangle) due to the intensification in water usage from the Syrian part. However, the dam was completed in 2006 after 3 years of construction. On the other hand, Adassiyeh Diversion Weir was a result of the peace treaty between Jordan and Israel in 1994 that serves to divert all flows that bypass and are not diverted into the KAC flow by gravity into the Yarmoukim Reservoir in Israel for Yarmouk Triangle use (Zeitoun & Elaydi, 2019).

Though of the many projects that have been applied on the Yarmouk River, but the flow is decreasing. Most of the dams did not reach their full capacity and others severe from pollution due to high withdrawals for irrigation purposes and waste water. Some of these dams are out of service (ETANA, 2015). So, many cultivated areas lost their water source or they are irrigated by polluted water. Moreover, the river flow has been declining due to many factors such as precipitation decrease, construction of dams and high abstraction from both surface and groundwater from the farmers in both countries (Avisse et al., 2020).

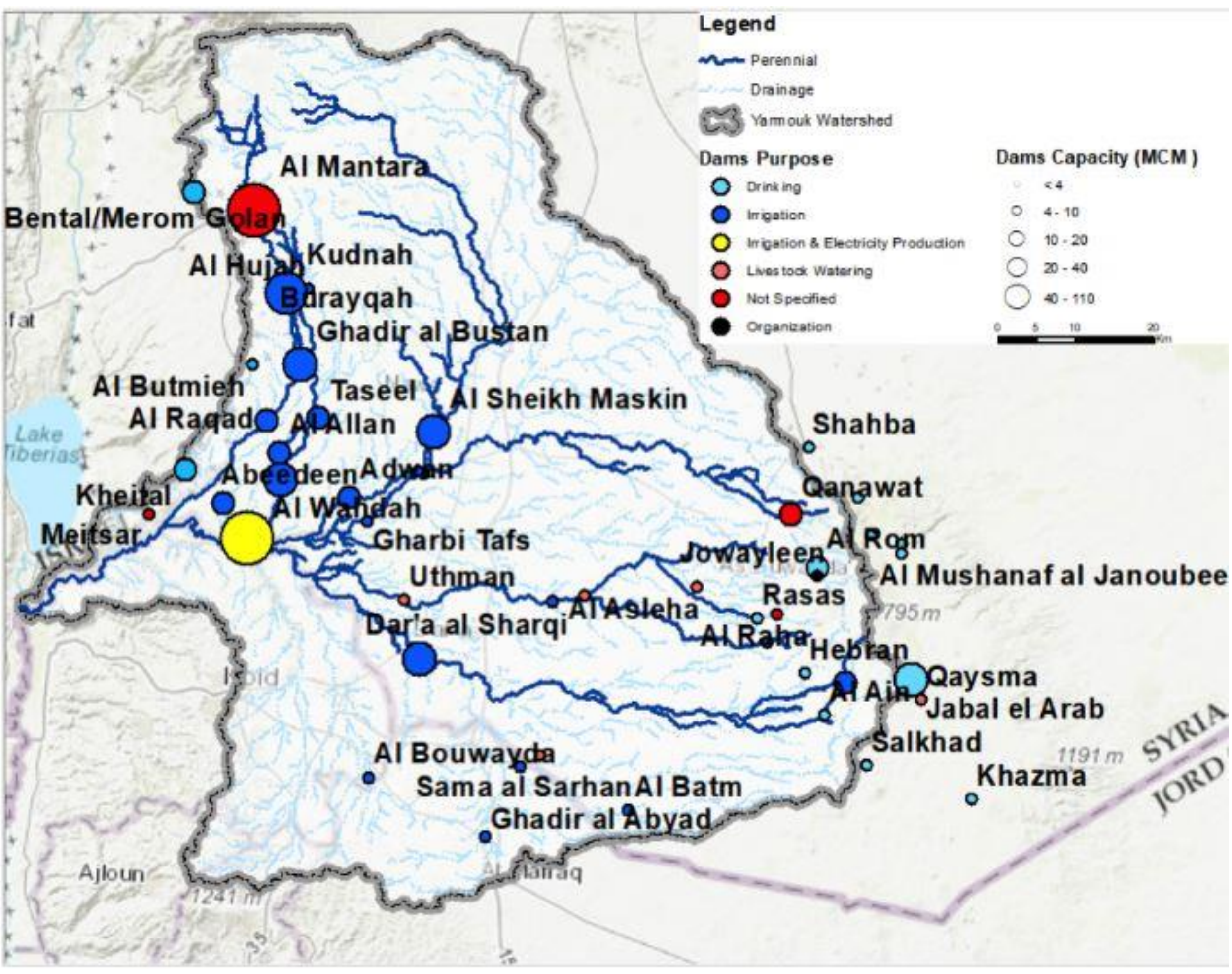


Figure 7: Distribution of dams over the Yarmouk tributary basin. Source: UEA (2018)

3.6.2 Ground water

The three countries that share water resources in the Yarmouk tributary basin characterized by their dependence on cultivation, where the irrigated area from surface and groundwater is estimated by this project to be about 38,114 ha. Many villages in both Jordan and Syria such as Dera'a, Quneitra and Irbid have developed the cultivation of irrigated crops which consumes in 2009 about 175.6 MCM/year from groundwater and 187.8 MCM/year from surface water. Note that, the exact groundwater abstraction from wells is not available officially specially for the Syrian part, then it was estimated according to crop water requirement. This agricultural development mainly at Jabal Al Arab and Hauran Plateau and the increased need for domestic water lead to digging legal and illegal wells both in Syria and Jordan that estimated to be around 16,800 wells where most of them are located in the Syrian part at Dera'a governorate. However, Orient study (2011) listed that the upper and lower basalt aquifer shows recharged from precipitation and inflow from northern regions and the south-eastern constant head boundary. Note that this estimation based on a model for groundwater inflow and demand for Yarmouk basin.

JVA data shows that the number of exploited wells and the amount of groundwater extracted has been increased between 2009 and 2015. However, after crisis many wells became out of service due to lack of maintenance or no fuel found to operate or decrease in irrigated areas within the basin. This severe groundwater withdrawals from licensed and non-licensed wells lead to depletion of springs and consuming the groundwater without any renewable water supply given (ETANA, 2015).

As a result, groundwater as a resource is suffering from high abstraction rates via the huge number of wells located all over Yarmouk for irrigation needs mainly. In addition to that, many wells for drinking purposes dry due to water table decrease. As well as, it suffers from pollution due to digging wells and waste water leakage.

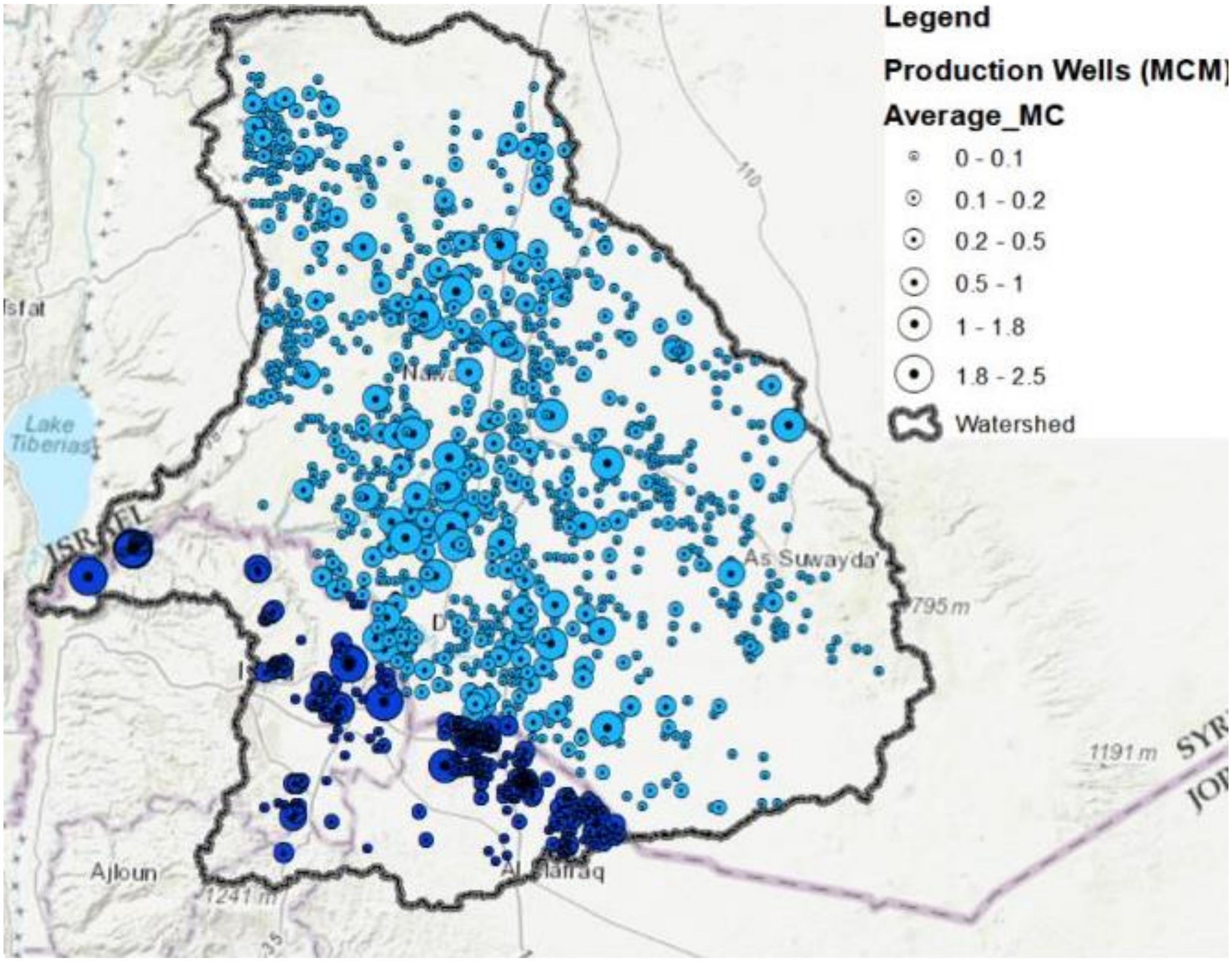


Figure 8: Wells distribution over Yarmouk tributary basin and their production in (MCM). Source: UEA (2018)

4. Methodology

To fully understand the Yarmouk Tributary Basin and release the water accounting plus sheets, it was necessary to compute many products from different satellites. Precipitation and Evapotranspiration are two main inputs for this project, so they were downloaded from different satellites over 38 year period in order to compare between them. However, our account year is 2009, and all the products and the WA+ sheets were released for this year. This part will show all the inputs that were used in this project and the methods by which they computed.

4.1 Precipitation

4.1.1 Satellite product Comparison

Precipitation is one of the essential input parameters for Water Accounting Plus and occupies a great part of the inflow to Yarmouk basin. However, detecting such an important data is very difficult in a big and shared basin like Yarmouk. Rainfall gauge data was not available for this study due to the lack of in situ gauges management and maintenance where many stations become out of service, inequitable distribution and temporal variability of these stations over the whole basin which obstruct the accurate detection of rainfall, moreover, neither Syria nor Jordan provides such official data for a long term. Thus estimating rainfall data using remote sensing was the solution. Many previous water accounting plus projects on Laitani River (Fao & IHE-Delft, 2019) ,Awash River (Sensing & Water, 2020) and Koshi River basin (Khatakho & Alluaibi, 2016) used precipitation data estimated from remote sensing as an input for their frameworks. There are many precipitation data products that can be collected freely and characterizes by different spatial and temporal resolutions. These products estimate rainfall based on two main types of satellite: Geostationary satellites and Polar-orbiting satellites (Barrett & Beaumont, 1994), however, some of them depend on combined estimation results of the two satellites. Geostationary Satellite estimates rainfall rates from the top of cloud using infra-red and visible imagers that provide a high spatial and variable temporal resolution, while Polar-Orbiting Satellite uses microwave imagery that proves its ability to detect actual precipitation within and below the clouds (Asadullah et al., 2008). Many studies and projects have been performed previously that talk about the performance, advantages and disadvantages of them (Asadullah et al., 2008; Joyce et al., 2004; Levizzani et al., 2002; Liu, 2016; McShane et al., 2017; Prakash et al., 2016).

CHIRPS, TRMM, GPM tend to estimate precipitation depending on different methodologies. However, the decision for selecting a satellite data was taken after viewing several researches that test these products and validate their performance (Asadullah et al., 2008; Katsanos et al., 2016), then choose the most fit satellite product for this project. It is found that the Tropical Rainfall Measuring Mission (TRMM) a well product that provides precipitation data based on precipitation radar, microwave imager, visible and infra-red scanner (VIRS) and lightning image sensor with 0.25° spatial resolution and different temporal resolutions (Karimi, 2014). It's freely available from 1998 to April 2015. However, GPM the Global Precipitation Measurement released in March 2015 with spatial resolution 0.1° which is better than that of TRMM and 30 min temporal resolution, it's also based on microwave imager and dual-frequency precipitation radar (Bolvin et al., 2018). CMORPH another product that provides precipitation at a spatial resolution of 0.25° and 3hr temporal resolution, it is based on IR not for rainfall estimates but for rain clouds only. It has seen that TRMM and CMORPH have not been calibrated to gauged data. These products show a less suitable data for this project in comparison with CHIRPS that provides a well precipitation data with a very good resolution of 0.05° and different temporal resolutions. Moreover, the Climate Hazard Group Infra-red precipitation with Station is available for a long term period starting from 80's till present unlike the previous products that provide data for a short period. Regarding the importance of a longer time series in understanding the precipitation trend over YRB, monthly precipitation from the Climate Hazards Group Infra-Red Precipitation with Station (CHIRPS) maps was used for accounting Yarmouk basin. However, CHIRPS is a complete, reliable, up-to-date and 30+ year quasi global rainfall dataset, created by scientists at the USGS Earth Resources Observation and Science (EROS) Center. Monthly raster's have been downloaded from the following website https://data.chc.ucsb.edu/products/CHIRPS-2.0/ from 1981 till 2019 and clipped on Yarmouk basin using GIS software.

4.1.2 BIAS correction with ground stations

CHIRPS precipitation have been validated using gauge rainfall data of different locations in Yarmouk basin, the records of the stations obtained from MOAAR in Syria, JVA in Jordan and ORIENT study. There was a lot of missing data especially that for Jordanian stations and no data obtained after 2014. The data obtained was for 28 stations not equally distributed over the basin, however, only 7 of them showed a good fit and 6 showed a moderate fit. The Bias evaluation results shows that the precipitation in the basin is underestimated due to lack of gauge data in the northwest part of Yarmouk where most of the precipitation accumulates.

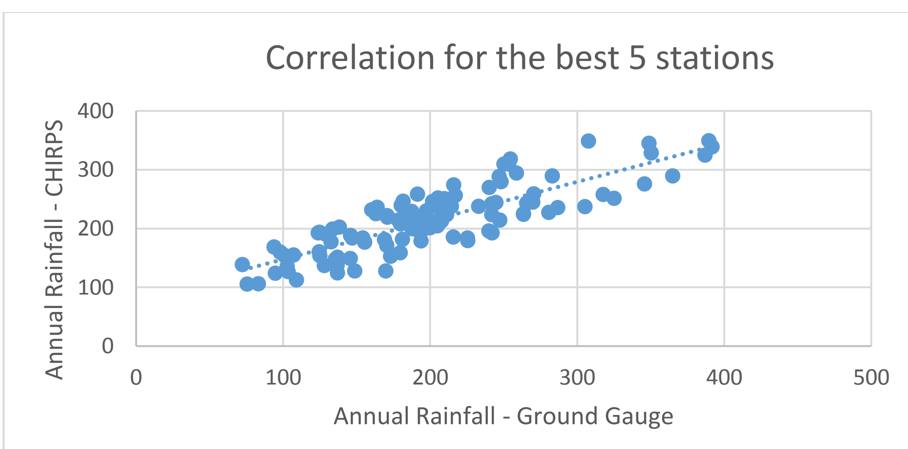


Figure 9: Regression value

4.2 Evapotranspiration:

4.2.1 Actual Evapotranspiration Eta

Water Accounting Plus framework focuses on evapotranspiration as consumptive use of water and refers to depletion process (Karimi, 2014). It is considered an essential parameter and necessary input for most Standard Sheets in order to get results and facilitate a clear understanding of the case study. However, there are many algorithms and methods that estimate this product but the choice would change understanding of the basin, results and management. Previously many methods based on Surface Energy Balance have been developed to estimate ET such as the Surface Energy Balance Algorithm for Land-SEBAL, Mapping Evapotranspiration at High Resolution using Internalized Calibration-METRIC (Allen et al.,2005, 2007), ETWATCH (Wu et al., 2008), SEBALI (Mhawej et al., 2020a, 2020b) and recently the Open source Google Earth Engine-SEBALGEE. These models require many in situ input parameters which is a problem especially in the basins that lacks for local and official data, and this is the case in Yarmouk basin. Many updates and improvements have been performed by specialists to reduce the number of parameters required as the case of SEBALI but still lacks to many libraries and require a specialized software (Mhawej & Faour, 2020). However, the improvement of this model to SEBALGEE performed by Mhawej and Faour (2020) is still not sufficient because it uses satellites with very low resolution and need gap filling process such as Landsat 7 which increase the error while computing results. Then the evapotranspiration product was estimated for this project using remote sensing. A comparison was made between three satellite products of different spatial and temporal resolutions, and the final ET product was estimated from the most accurate satellite to our case study.

4.2.2 Satellite products

Evapotranspiration is evaluated using different remote sensing products to estimate water consumption for Yarmouk basin. Three products were selected: WAPOR, NTSG-MODI6A2 and NASA-MOD16A2.

4.2.2.1 WAPOR

The open access database provides a set of data components collected from different remote sensing satellites at three levels: Level 1 (250m), Level 2 (100m) and Level 3 (30m). It provides the final products over decadal of 10 days or month or year in mm/day from 2009 till present. Actual Evapotranspiration and Interception product estimated by WAPOR as the sum of total evaporation from soil with the transpiration from plant canopy and interception from plants leaves (FAO, 2018c). WAPOR calculate Eta using many inputs such as solar radiation, soil moisture stress, NDVI, surface albedo and precipitation derived from the Proba-V satellite where the presence of clouds affects the resolution of the final product (FAO, 2018c). These parameters are used by WAPOR as inputs for Penman-Equation derived by FAO that estimates ET products based on ET-Look model. However, this database does not provide new data for users, only limited products with specific locations are available, also it does not provide data before 2009.

4.2.2.2 MODI6A2

MOD16A2 the global 8-day evapotranspiration dataset provides the actual evaporation from ground surfaces and transpiration from plant surfaces at daily basis and different spatial resolutions, the data is found by TERRA or Aqua satellite platform (S. Running et al., 2017). The algorithm depends on many meteorological inputs such as air temperature, solar radiation, humidity and others that used as parameters in Penman-Monteith equation to estimate the final ET. There are two collections of MODIS data: collection 5 and collection 6 that are released by NSTG website http://www.ntsg.umt.edu/project/mod16#data-product and USGS LP DAAC https://lpdaac.usgs.gov/dataset_discovery/modis respectively.

4.3 Reference, Crop and Incremental Evapotranspiration

Several evapotranspiration products applied to Yarmouk basin for more understanding of the current case especially that concerning the irrigated agricultural sector and crop water requirement. It's found that FAO review the methodologies and update the procedures to calculate ET products (Anderson & French, 2019). First FAO defined three products of evapotranspiration that we are interested by in this project, the Reference Evapotranspiration ET0 refers to that of a reference surface mainly grass reference crop. However, Crop Evapotranspiration (ETc) represents evapotranspiration from well-watered cropped areas. Whereas ET Incremental accounts for evapotranspiration at Managed category for irrigated areas. It is described as the evapotranspiration that originates from withdrawals from surface and groundwater that used for irrigation purposes.

ET0 defined as the reference evapotranspiration from a hypothetical reference crop (FAO, 2018b). ET0 can be estimated based on the FAO 56 Penman-Monteith equation (Offices & Search, 2014), but the input data for this equation were not available for the account year 2009. In this study Reference ET data was obtained for 2009 from the open access data base WAPOR with a 20 Km spatial resolution and monthly temporal resolution then GIS software has been used to resample, scale and prepare the final output used by this project. Many studies use remote sensing to detect the reference evapotranspiration due to local data scarce. However, WAPOR apply the Penman-Monteith equation by FAO to produce ET0 data using both weather data and solar radiation. This component is an intermediate step in our work to evaluate the Crop Evapotranspiration that will be used to detect irrigated crop locations also to estimate the Incremental Evapotranspiration.

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

However Crop Evapotranspiration obtained by using a formula listed by FAO. According to (ICC) ET0 when derived from remote sensing should be multiplied by a correction factor Kr (Anderson & French, 2019).

$$ETc = ET0 \times Kc \times Kr$$

Incremental ET has been calculated in this project for managed category. This product is needed in the standard sheets for water accounting framework. ETinc is also calculated through formula defined by FAO:

$$ETinc = ETc - Eta$$

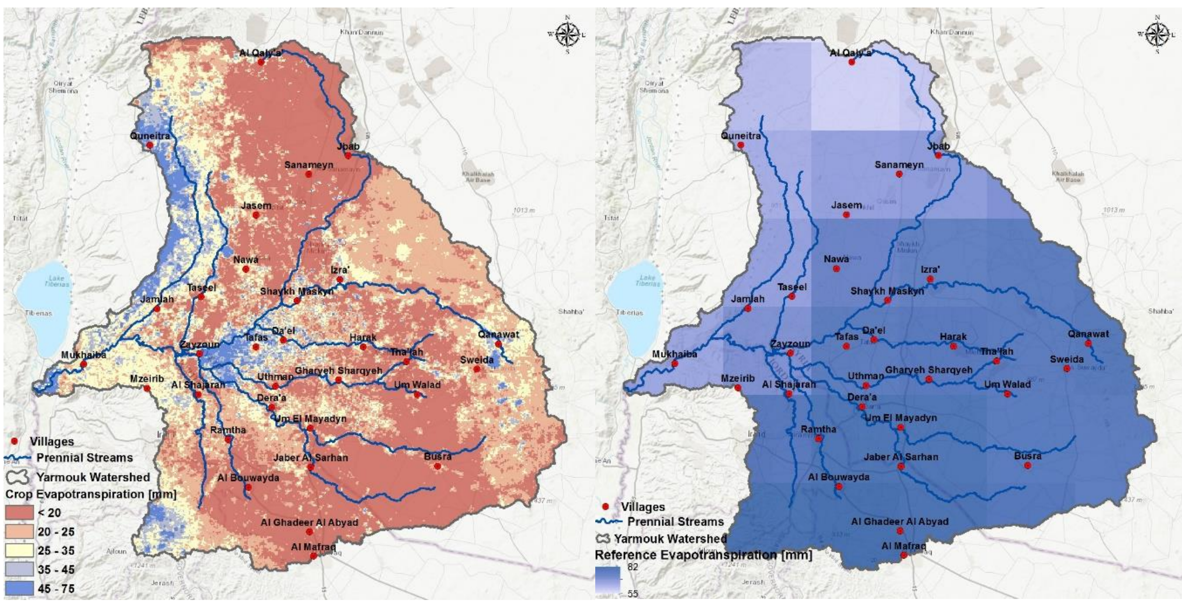


Figure 10: Reference and Crop Evapotranspiration derived by WAPOR in Yarmouk basin for January 2009

4.4 Evaporation, Transpiration and Interception

Through water accounting plus framework, evapotranspiration is divided into three components E, T and I within the Evapotranspiration Sheet in order to differentiate between beneficial and non-beneficial water consumption. WAPOR version 1 level 2 provides freely Evaporation, Transpiration and Interception data from 2009 till present on a decadal basis in mm/day at a 100 m resolution. It uses Penman-Monteith equation based on ETLook model to calculate E and T, this equation requires a several input data components, while some of them have limitations as the optical satellite data that would be affected by clouds and others that suffer from lower resolutions which affect the result of E and T. Regardless of these limitations, E and T were estimated from WAPOR to avoid the multi-errors released by many satellites. The three components reflect evaporation concept but from different locations, T describes the evaporation from plant canopy while I reveals to direct evaporation from leaves, however, E reflects that from soil surface. The required data for this project were downloaded from the open data portal WAPOR every decade (10 days) then clipped on Yarmouk basin and summed to obtain monthly and yearly data set using GIS software.

4.5 NDVI

The Normalized Difference Vegetation Index is an important factor for detection of vegetation and essential for separating irrigated from rain-fed areas and understanding the performance and growth of crops and trees found in Yarmouk basin. NDVI values used in this study was obtained by using remote sensing. However, there was multi of remote sensing products that estimate NDVI values but the problem was that not all of them was available from 2009 (account year), according to data availability regarding account year, three products have been selected compared but only one product used to estimate NDVI values in Yarmouk basin.

Landsat 7 ETM+ collection 1 images were downloaded monthly from USGS for year 2009, each image has 16-day cycle so monthly NDVI values were the average of 2-3 images. These images were at 30 m spatial resolution and consists of 8 bands, however, NDVI values obtained from Red and NIR bands (Irish, 2000).

Landsat 7 images suffer from data gaps which create a big problem in this project because the values obtained will be not accurate enough to rely our analysis on them (Irish, 2000). However, after downloading Landsat 7 images, GIS-gap filling tool was used to fill the missing values but this tool increased the percentage of error in the final values and the final maps show underestimation of the NDVI values of the features in comparison to the NDVI ranges specified by FAO.

SPOT 5, another remote sensing product that estimates NDVI was trialed and shows a very good and accurate results. It was launched in 2002 and provides images at 5 m spatial resolution, the obtained NDVI maps for Yarmouk basin was very use full but the only obstacle was that SPOT 5 is not freely available, due to this reason the only available month for our study was May-2009 which was not enough to build our analysis on.

The Terra Moderate Resolution Imaging Spectro-radiometer (MODIS) version 6 was another choice to estimate NDVI maps for Yarmouk basin at spatial resolution 250 m. Two images of 16-days period downloaded from USGS for each month and the average was taken to obtain the final values. Although the images do not have a good resolution in comparison with the previous products but it was the only one available for this study and gives a good NDVI maps that are used for detection of vegetation areas and building estimation on the irrigation ones.

$$\text{NDVI} = \frac{Red-NIR}{Red+NIR}$$

4.6 Irrigated/Rain-fed Area Classification

Water Accounting Plus Sheets link water depletion processes and withdrawals to all sectors found in the study area especially the agricultural sector. To study this link it was necessary to classify these sectors and group them into categories, but this step cannot be completed without differentiating between irrigated and rain-fed areas. There are many methods to separate irrigated and rain-fed areas have been done before and performed at many basin scales (Ambika et al., 2016; Wu & De Pauw, 2011). In this study we perform many methods to detect irrigated areas using remote sensing and then choose the most accurate one. However, the problem was that no official statistics derived by ministry of agriculture of both countries Jordan and Syria.

After detection the crop type for each region and specifying the irrigation months, it was easier to separate irrigated areas from rain-fed ones. Two methods have been performed to detect the locations of irrigated areas and derive maps using remote sensing. First method depends on studying NDVI trend for crop types in each governorate over their irrigation months and detect the threshold of NDVI. However, as listed in the previous paragraph that there were three products of NDVI but in this project MOD13Q1 images have been taken to compute NDVI values for the whole basin.

NDVI images have been prepared for all months of year 2009 over Yarmouk basin by the aid of GIS software and clipped on every crop type and trees, then converted to points in order to draw a curve that reflects the threshold of NDVI on the turning point as shown in Figure 11. All the crops that have NDVI value greater than the threshold is considered as irrigated.

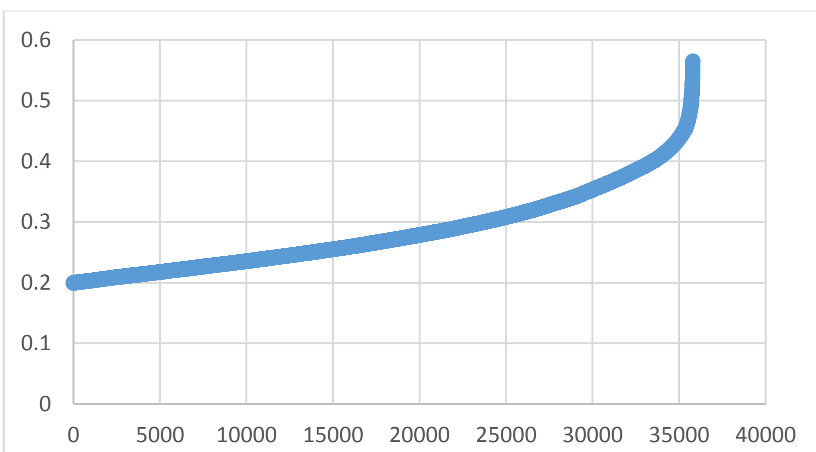


Figure 11: NDVI threshold for a specific crop type

Another method have been used based on Transpiration product that obtained from WAPOR database. This method shows more accuracy than the previous one and the irrigated maps have been derived based on it. Transpiration images obtained for the whole basin and clipped on crops and trees to study each class alone, then the threshold have been calculated for irrigation months and all the crops that have transpiration greater than the threshold are considered irrigated. A trend line performed for every crops and trees at all governorates separately because each governorate includes a specific crop type and different irrigation months. As obvious Dera'a depends on winter wheat plantation, it shows a greater irrigated area during April which is in reality the irrigated month. (Figure 12)

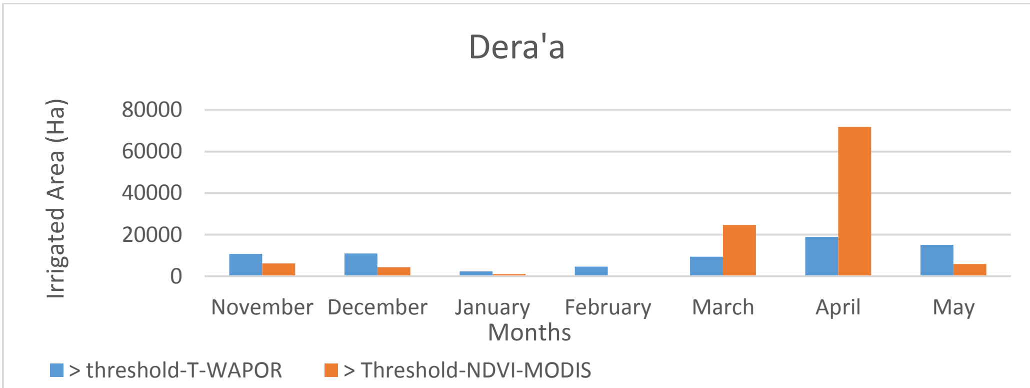


Figure 12: Trend line for irrigated area in Dera'a based on transpiration method

However, a combined analysis for all types and over each governorate has been performed based on the two methods to validate the results obtained. For example in Irbid governorate, a trend line have been performed for irrigated area for vines based on transpiration analysis shows that vines are mostly irrigated during July month. In parallel the NDVI line shows an increase in the post month which reflects the growth of vines after irrigation. (Figure 13)

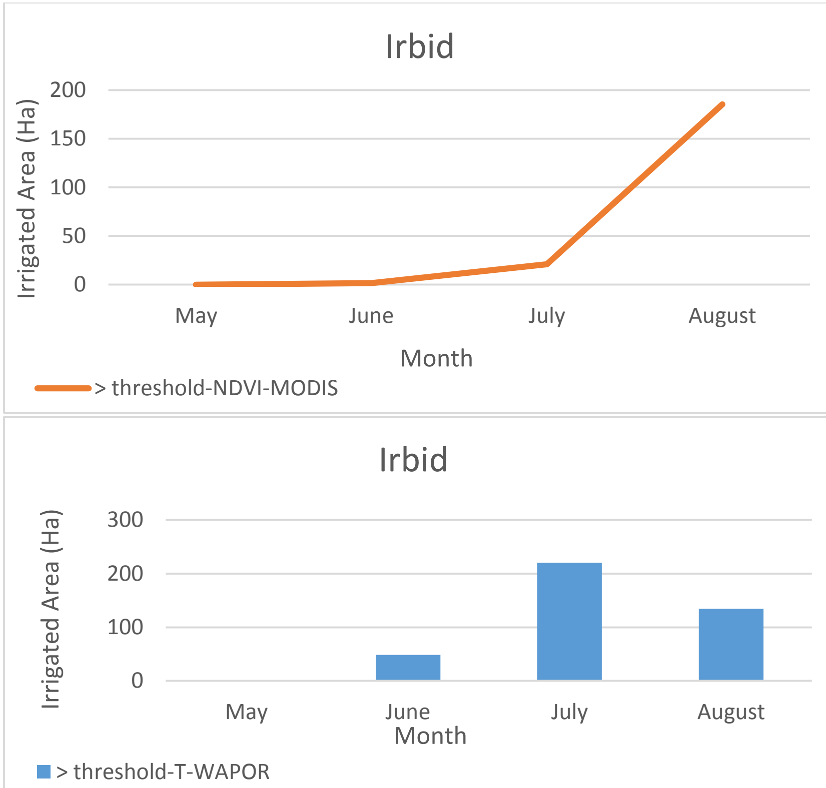


Figure 13: Trend line of irrigated area in Irbid based on NDVI and transpiration analysis

4.7 Biomass Production

Biomass product for 2009 was computed from WAPOR portal. WAPOR provides two season per a year. The images for two season during 2009 were downloaded at 100 m resolution and clipped over the Yarmouk basin by the aid of GIS software. The final images derived by WAPOR from Proba-V satellite. The biomass that used in this project represent the sum of the above-ground dry matter produced during the growing season.

4.8 Land Cover/Land Use:

To complete the water accounting plus sheets, it was necessary to detect all features found in Yarmouk basin, classify them into classes and group these classes in 4 main categories: “Modified category”, “Managed category”, “Utilized category” and “Protected category”. First LUC map was performed using ESRI base maps of GEOEYE (2011) at 50 cm resolution and scale 1:20,000. The obtained map revealed by 11 main classes: crops, fruit trees, olives, vines, bare land, forest, urban zone, green houses, water bodies, surface flow and dams (UEA, 2018).

Water Accounting Plus framework mainly studies water resources and how they are depleted, however, land classes affect these depletion processes (Karimi, 2014). So, it was very important to study how water is depleted and regulated over the 4 main categories. The distribution of classes over the 4 categories was after detection of irrigated and rain-fed areas. Modified Land use category refers to land that modified by human and includes rain-fed crops, rain-fed olives, rain-fed fruit trees and rain-fed vines, however, the Managed water use category includes the irrigated features in addition to dams and urban zones and green houses and all the classes that manipulated by infrastructure. These two categories highlights the distribution of irrigated/rain-fed crops all over the basin that reflects water consumption sources and allow the differentiation between landscape ET and incremental ET. Whereas, Utilized land use category includes all other features such as bare land, forests, water bodies and surface water that has little interference by man. This project only includes 3 categories since no protected areas were able to be detected by remote sensing to specify there locations and areas.

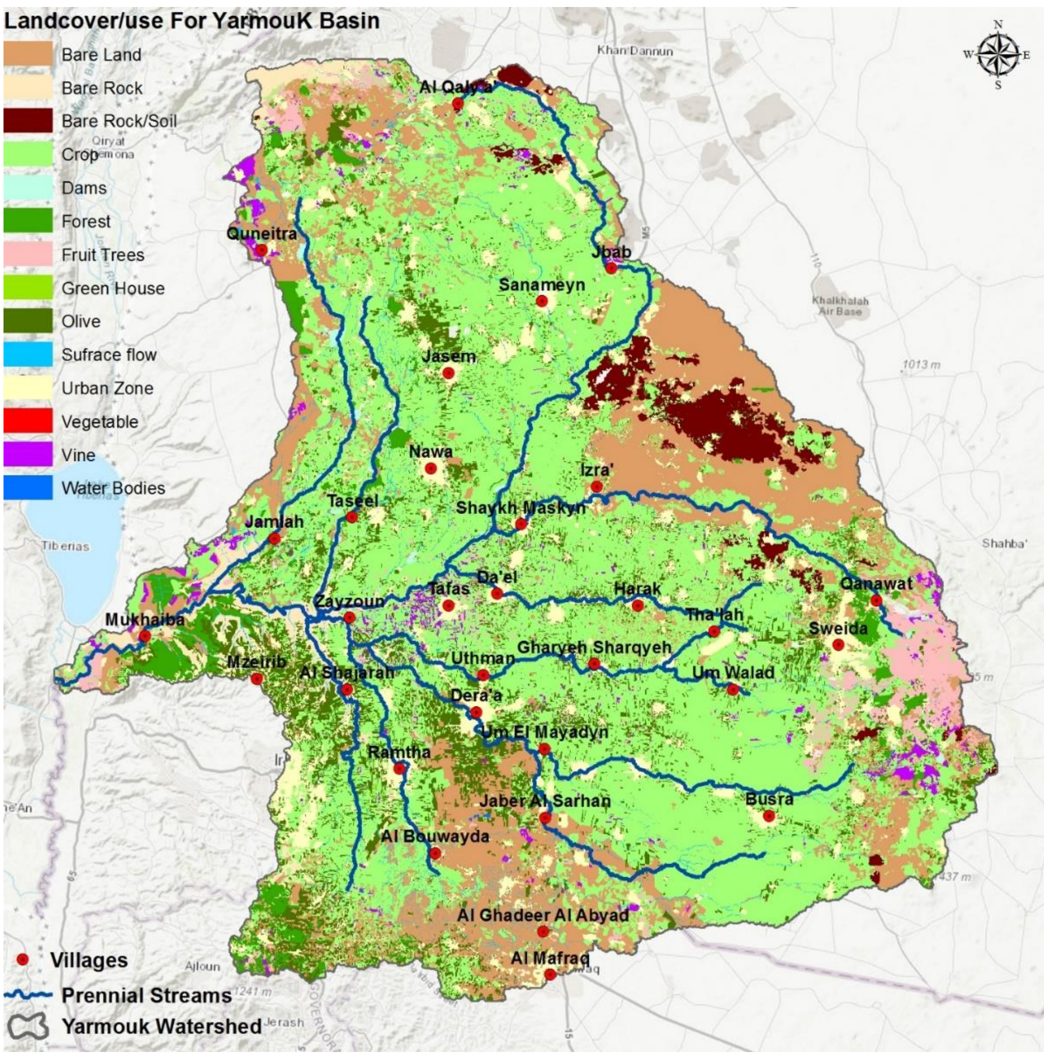


Figure 14 Land cover/Land use for Yarmouk basin in year 2011

4.9 Water Accounting Plus Sheets – Analytical framework

4.9.1 Resource Base Sheet

Resource base sheet gives an overview on water volumes and how they are depleted or exploited within the basin studied, also about the inflows and outflows. It provides a general information on exploitable, avialable, reserved, utilized, utilizable, manageable and unmanageable flows at river basin scale. ET is divided in this sheet into landscape ET and incremental ET.

Among (Figure 15) the inflows are presented including precipitation, surface and groundwater that flows toward the basin from outside, this is what we call it Gross inflow. However, Net inflow includes gross inflow and water storage changes, ground water, snow and glacier melt over a certain period.

Landscape ET and exploitable water are discussed within the sheet diagram. It represents ET that originates from rainfall over the four land use categories and its known as grean water. Exploitable water defined as blue water that is not evaporated and avialable for downstream use and withdrawals. But not all the exploitable water is available as part of it is reserved to meet the commited, navigational and enviromental flow requirements, the another part is non-utilizable such as flood water. However, the avialable water is divided into utilized flow and utilizable outflow. Utilized flow is the depleted water mainly by incremental ET that originates from natural and manmade withdrawals, it also includes the water that flows to sinks or unavialable due to contamination. The another part of avialable water is known as utilizable outflow which represent the amout of water that can be used.

At the end of the sheet depleted water is presented as total ET plus flows to sinks, however, outflow accounts for water that leaves the basin through surface water and ground water.

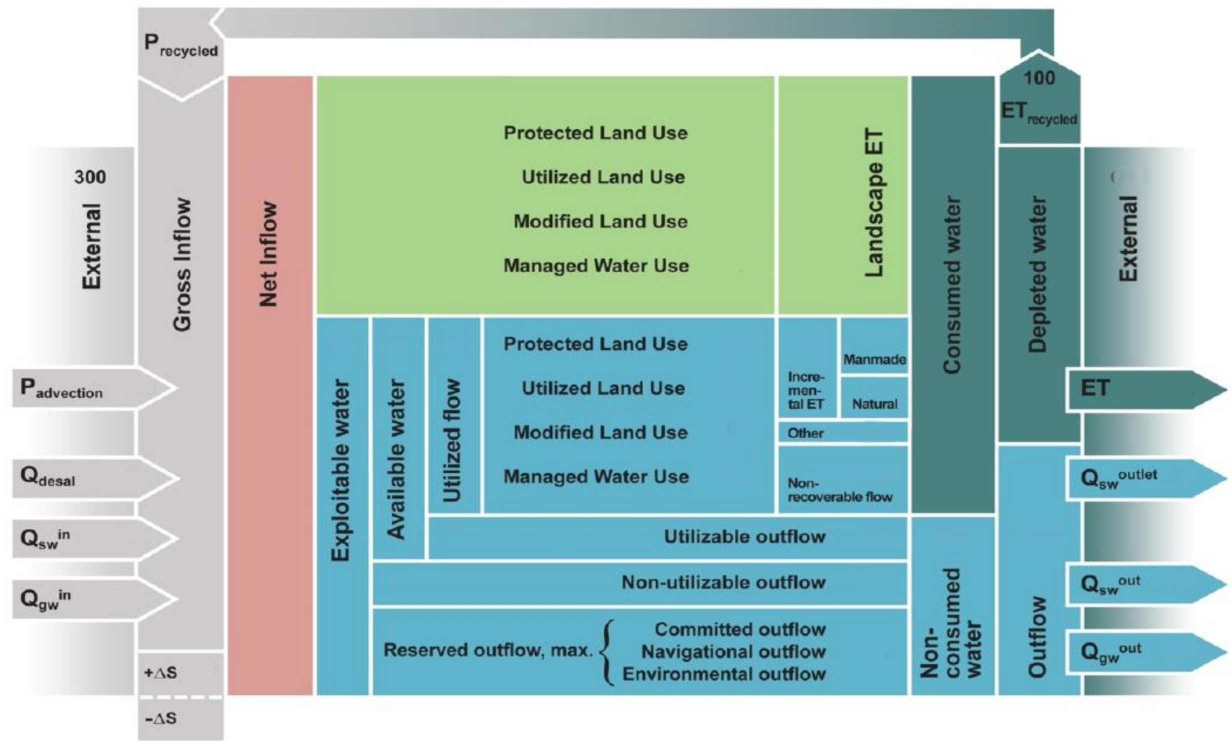


Figure 15: Resource Base Sheet (Km^3/yr)

4.9.2 Evapotranspiration Sheet

ET processes are described in this sheet and divided over all land use types which reflects the water consumption quantity of each category seperately and the impact of the land use planning on consumptive use. Evapotranspiration sheet breaksdown ET into Evaporation, Transpiration and Interception.The second part of the sheet evaluates the benefits from water use, and relates water consumption to beneficial and non-beneficial ET. However, the user defines the definition of beneficial and non-beneficial ET.

Most of E originates from soil moisture and water bodies such as reservoirs which considered as non-beneficial ET, however E collected from natural water sufaces that aims for fishing, buffering floods.. are refered as beneficial. In this thesis we consider E as non-beneficial. Transpiration is the transfer of water vapor from the stomata of plants and it's considered as non-beneficial except that in cropland. However, interception evaporation from wet leaves and canopies is mainly tracked as non-beneficial except for some cases when interception considered as important for temperature regulation, but in this thesis it's totally considered as non-beneficial.

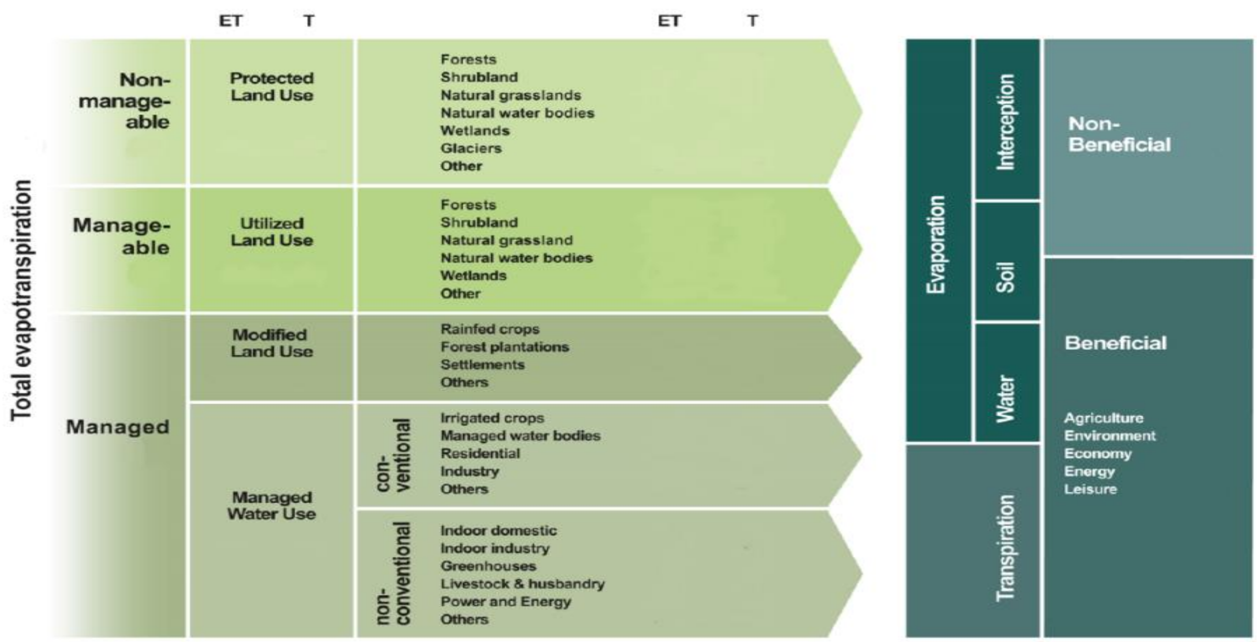


Figure 16: Evapotranspiration Sheet (Km^3/yr)

4.9.3 Agricultural Sheet

Agricultural sheet is divided into two parts. Part 1 (Figure 17): Agricultural water consumption (km3/yr) ; Part 2 (Figure 18): Land productivity (kg/ha/yr) and Water productivity (kg/m3). The Agricultural Services sheet overall provides a summary of agricultural water use and its productivity, both under rain-fed and irrigated conditions. It also it computes crop water productivity (kg/m3).

The objective of this sheet is to achieve sustainable food security and to indicate the possibilities for saving water in agriculture, by allocating water to irrigation, maintaining rain-fed production systems and shifting from irrigated to rain-fed crops through modifying land use planning.

Crop

	Cereals	Non-cereals: Root / tuber crops	Non-cereals: Leguminous crops	Non-cereals: Sugar crops	Non-cereals: Merged	Fruit & vegetables: Vegetables & melons	Fruit & vegetables: Fruits & nuts	Fruit & vegetables: Merged	Oil-seeds	Feed crops	Beverage crops	Other crops	Agricultural water consumption 4.05
ET rainfed	0.67	-	-	-	-	-	-	-	-	-	-	-	0.67
ET from rainfall irrigated	1.09	-	0.02	-	-	0.04	0.15	-	-	-	-	-	1.30
Incremental ET irrigated	1.04	-	0.07	-	-	0.74	0.23	-	-	-	-	-	2.08
Total ET irrigated	2.13	-	0.09	-	-	0.78	0.38	-	-	-	-	-	3.38

Non-crop

	Fish (Aquaculture)	Timber	
ET rainfed	-	-	-
ET from rainfall irrigated	-	-	-
Incremental ET irrigated	-	-	-
Total ET irrigated	-	-	-

Figure 17: Agricultural Water Consumption (Km^3/yr)

Crop

		Cereals	Non-cereals: Root / tuber crops	Non-cereals: Leguminous crops	Non-cereals: Sugar crops	Non-cereals: Merged	Fruit & vegetables: Vegetables & melons	Fruit & vegetables: Fruits & nuts	Fruit & vegetables: Merged	Oil-seeds	Feed crops	Beverage crops	Other crops
Land productivity	Yield rainfed	906	-	-	-	-	-	-	-	-	-	-	-
	Yield from rainfall (irrigated)	320	-	600	-	-	47	2200	-	-	-	-	-
	Incremental yield (irrigated)	1286	-	139	-	-	8636	5659	-	-	-	-	-
	Total yield (irrigated)	1606	-	739	-	-	8683	7849	-	-	-	-	-
Water productivity	WP rainfed	0.45	-	-	-	-	-	-	-	-	-	-	-
	WP from rainfall (irrigated)	0.32	-	0.67	-	-	0.44	1.43	-	-	-	-	-
	Incremental WP (irrigated)	0.65	-	1.23	-	-	8.19	2.37	-	-	-	-	-
	Total WP (irrigated)	0.52	-	0.73	-	-	7.48	1.98	-	-	-	-	-

Non-crop

		Livestock: Meat	Livestock: Milk	Fish (Aquaculture)	Timber
Land productivity	Yield rainfed	-	-	-	-
	Yield from rainfall (irrigated)	-	-	-	-
	Incremental yield (irrigated)	-	-	-	-
	Total yield (irrigated)	-	-	-	-
Water productivity	WP rainfed	-	-	-	-
	WP from rainfall (irrigated)	-	-	-	-
	Incremental WP (irrigated)	-	-	-	-
	Total WP (irrigated)	-	-	-	-

Figure 18: Land Productivity (Kg/ha/yr) and Water Productivity (Kg/m^3)

5. Results and discussion

5.1 Precipitation

Studying the precipitation within the Yarmouk basin over years shows approximately a constant trend line from 1981 till 2019 . Moreover, it reflects the change in rates over the regions within the basin when it studied at a one year scale. That explains the direct effect of this variation on the diversity of agricultural practices between the villages in Yarmouk basin.

5.1.1 Annual Precipitation: 1981-2019

A trend line has been performed over a period of 38 years showing the variation of annual precipitation for Yarmouk basin (Figure 19). The basin annual precipitation varied from 296 mm/year in 1981 to 402 mm/year in 2019 with an average 309 mm/year for this period. Yarmouk basin received an annual precipitation 365 mm/year during 2009 which is greater than the mean of the whole period, this shows that 2009 is a wet year. However, as it is clear that every several years, one year appears to be a drought year such as 1989, 1995, 1999, 2014 and 2017.This variability in rainfall has an impact on the agricultural pattern and water resources within the basin.

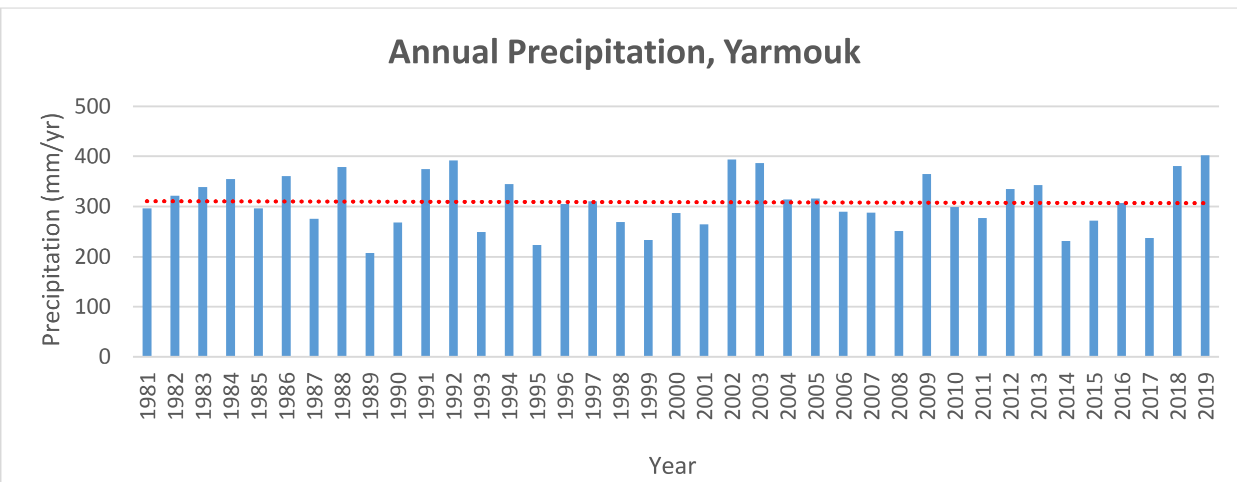


Figure 19: Annual Precipitation estimated from CHIRPS in Yarmouk basin for a period of 38 years (from 1981 till 2019)

As it is clear in the precipitation map (Figure 20) that most of the rain accumulated in the western side of the Yarmouk basin especially at the north-west part up to Quneitra and Golan. This region receives a yearly average precipitation about 1000 mm/yr in year 2009. However, the eastern cities in the basin such as Al Sweida and Al Bouwayda in the southern ones receive the lowest rainfall rates. The distribution of precipitation in Yarmouk basin according to CHIRPS shows declining in rainfall amounts when moving in the direction of Jordan toward the south. While, this inequitable distribution of rain over the villages affect there agricultural pattern in a way many villages like Mafraq and Al Sweida that receives little amount of rain over the year focus on rain-fed agriculture.

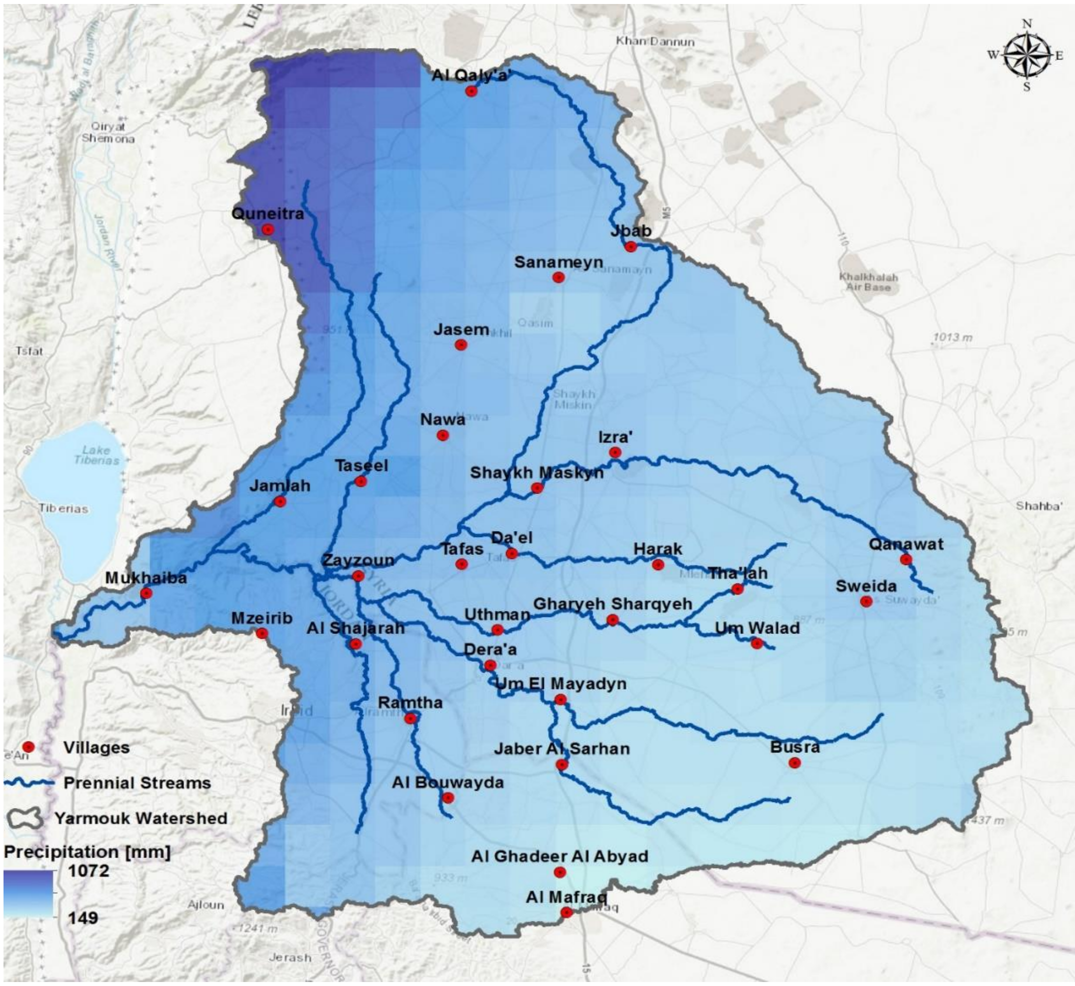


Figure 20: Annual Precipitation map computed from CHIRPS for Yarmouk basin in 2009

5.1.2 Monthly Precipitation - 2009

Figure 21 shows the variation of monthly precipitation during the account year of this project (2009). As it is clear that Yarmouk basin characterizes by two main seasons over the year, winter and summer season. During the summer season that it last from April till September, little to no rain recorded, Yarmouk receives during this season in 2009 an average 19 mm/year. The winter season during 2009 received an average 345 mm/year starting from October till March, where it reaches the top during February (101 mm/year). However, most of the villages in the Yarmouk basin such as Dera'a, Sweida and Irbid depend on agriculture during both seasons which highlights the importance of redistribution of water through natural and artificial storage.

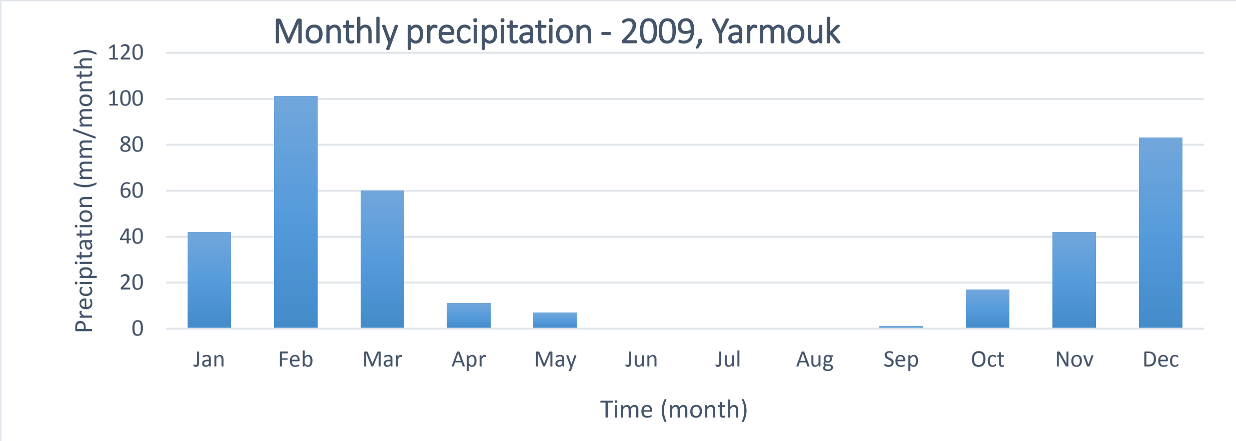


Figure 21: Monthly Precipitation estimated from CHIRPS in Yarmouk basin for 2009

5.2 Actual Evapotranspiration

5.2.1 Comparison results between MODIS satellite products

Although the two collections estimated on the same methodology and provide an improved cloud cleaning technique, but NASA and NTSG MODIS products show a big difference. Before testing the two products on Yarmouk basin a review have been made on the characteristics of each collection. It is found that NASA MOD16A2 product depends on a daily BRDF Albedo input and three dynamic land cover datasets, while that of NTSG relies on a static land cover and a 16-day BRDF Albedo input (S. W. Running et al., 2019). As listed before that the two datasets depends on many meteorological data as inputs for their algorithm to estimate ET, but they rely on different data sources where NTSG uses MERRA version3 created by GMAO/NASA, in contrary NASA uses near real time surface weather data released by GEOS-5. Moreover, NASA provides MOD16A2 collection with an 0.5 Km resolution which is better than that of NTSG of 1 km resolution (S. W. Running et al., 2019). However, the two products have been tested and applied to Yarmouk basin, as shown in Figure 22 they give different values for each year and different pattern over a period lasts from 2009 till 2014, note that the comparison stops at 2014 because NTSG data is invalid after that date. The main reason that stands behind not using NTSG dataset is that the latest stops renewing and improving the product from 2014 which obstruct the estimating of a real and accurate ET data as well as it is not available. At the level of MODIS satellite it was preferable to use the updated version (from USGS) that provide data for a long period which permit a good comparison with other satellite products and help in showing the trend of such important input (ET) within the Yarmouk basin over a selected period. A graph has been released that shows the trend of the two versions of MODIS satellite over a period from 2009 till 2014. The difference is clear between the two data sets in the annual values and in the trend over years, by which the annual evapotranspiration in the account year (2009) was 125 mm/year and 179 mm/year estimated by MODIS-USGS and MODIS-NTSG data sets respectively.

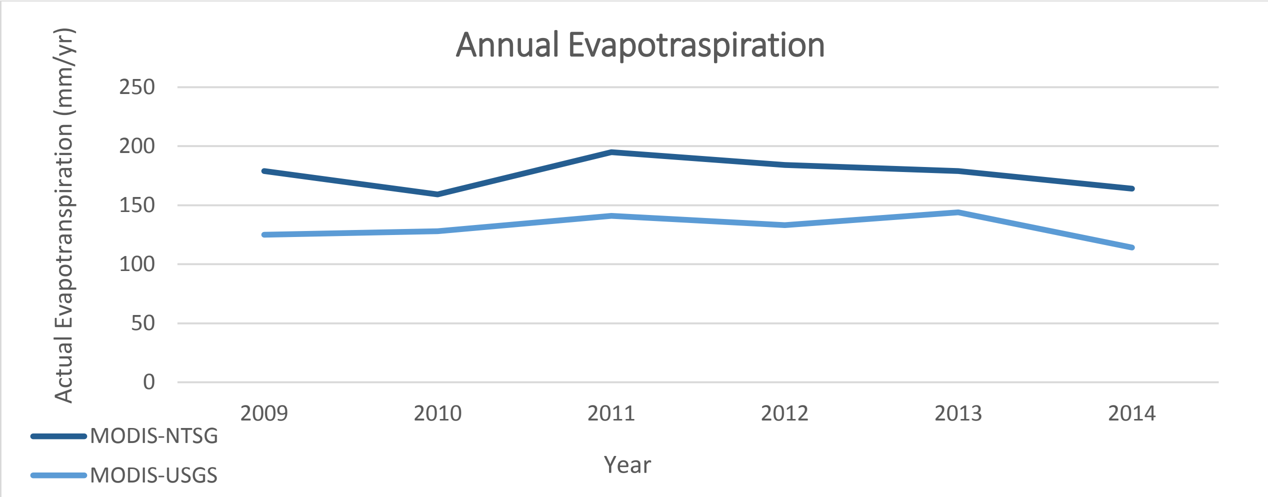


Figure 22: MODIS products trend line between 2009 and 2014

5.2.2 Comparison between WAPOR and MODIS products

Another comparison made between WAPOR and USGS-MODIS ET products to decide which data will be used for accounting Yarmouk basin. MODIS shows a less reliable values than that provided by WAPOR, and as shown in Figure 23 the distribution of ET over the Yarmouk basin differs. Moreover, MODIS does not reflect the total evapotranspiration over the basin where many pixels have no data due to low resolution for non-vegetated regions while WAPOR provides values for the whole basin without any exception. Furthermore, MODIS final values underestimated the evapotranspiration over the whole basin in comparison to WAPOR values and note that this appears also when WAPOR applied on the parts where MODIS provides data especially in 2009 the account year as shown in Figure 24.

WAPOR provides a good time series enough to build an overview of its performance and accuracy, moreover, it works on a strong model to estimate ET. As well as, many products such as transpiration, evaporation and interception have been used also from WAPOR for this project that would show compatibility in the results without confusing the work by many errors from different products. For these reasons ET data estimated by WAPOR have been used in this project as an inputs for the standard sheets in order to well understand depletion processes in Yarmouk basin.

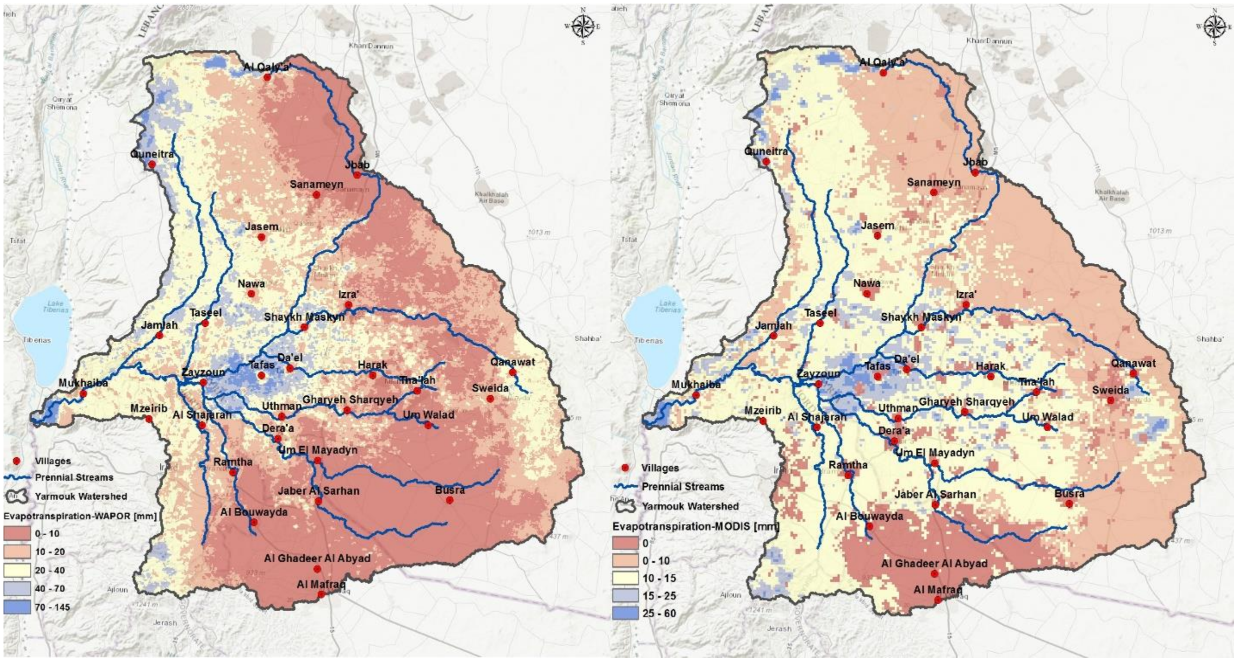


Figure 23: WAPOR and MOD16 Evapotranspiration distribution maps for Yarmouk Basin in year 2009

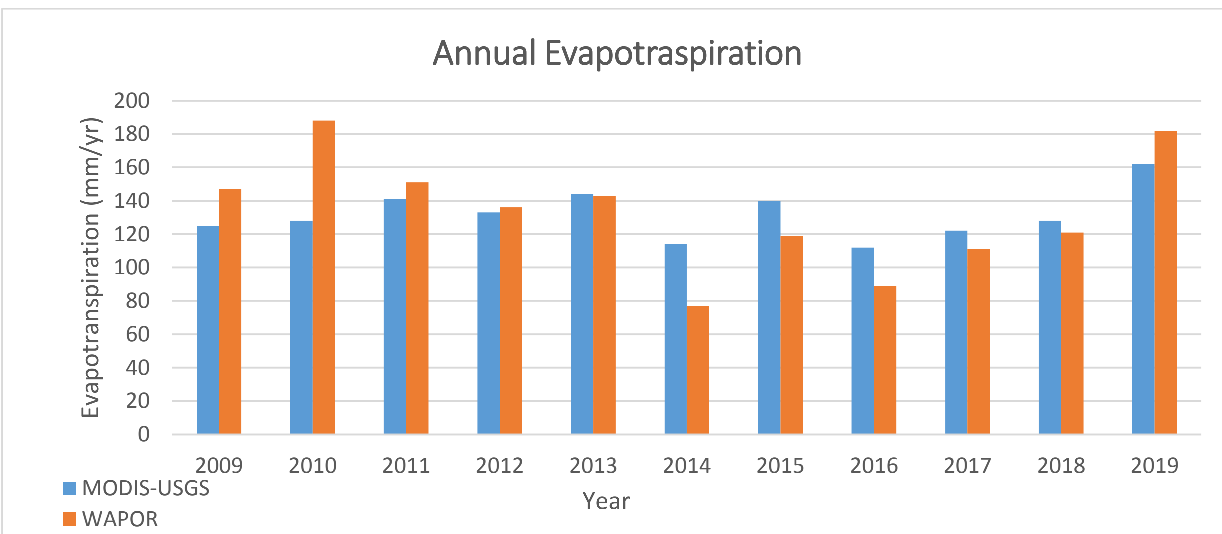


Figure 24: WAPOR and MODIS-USGS Annual Actual Evapotranspiration over a period between 2009 and 2019

The depletion processes within the Yarmouk basin for 2009 was estimated from WAPOR. As shown in Figure 25 the actual evapotranspiration for August-2009 differs over the diverse classes within the basin. Most of the evapotranspiration occurs at the west of Dera'a, Quneitra, Golan, and a small part of Irbid where most of the crops occur, this reflects mainly the presence of irrigated crops and trees in the summer season. At the other regions where we have bare lands and urban zones the satellite gives low or no evapotranspiration. So, from this map we can understand more about the depletion processes over each class, note that this map was an example on a month during the account year, however, for each month an evapotranspiration map was computed to show the depletion processes all over the year.

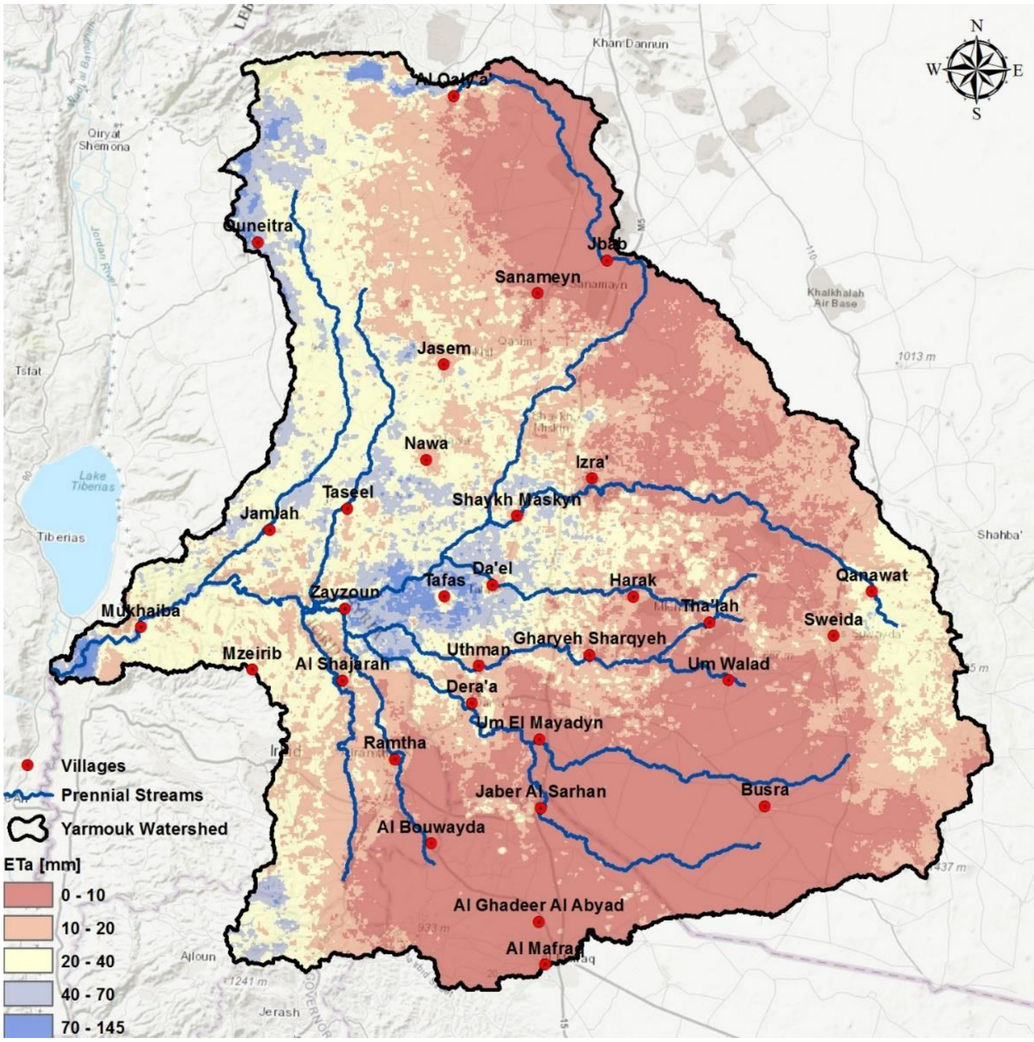


Figure 25: Actual Evapotranspiration map computed from WAPOR for Yarmouk basin during August-2009

After computing the precipitation and actual evapotranspiration for the Yarmouk basin, it was calculated the difference between the two components over the months during the account year 2009 in order to quantify the water shortage during summer season. Figure 26 shows that precipitation exceeds evapotranspiration in the winter season whereas we have shortage in the summer season starting from April till October. This reflects the need for another sources of water during this period to cover the irrigation requirements specially in the regions that recieves low precipitation rates during the winter season. However, this need justify the presence of dams and wells all over the Yarmouk basin to cover water shortage.

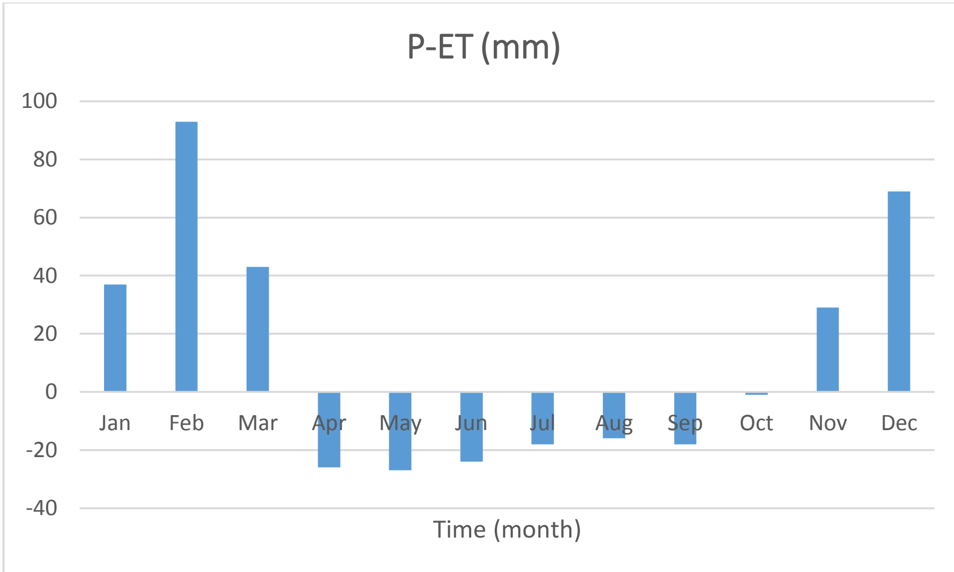


Figure 26: Difference between precipitation (CHIRPS) and evapotranspiration (WAPOR) over the months

5.3 Reference Evapotranspiration

The monthly reference evapotranspiration images was downloaded from WAPOR portal and then summed up using GIS software to get annual refence evapotranspiration map for the account year (2009) as shown in Figure 27. This map gives one value for each 250 m2 within the Yarmouk basin, the relatively low resolution of ET WAPOR map (250 m2) will increase the marge of error taking into consideration the diversity of land use classes and the absence of ground measurements at the study area region.

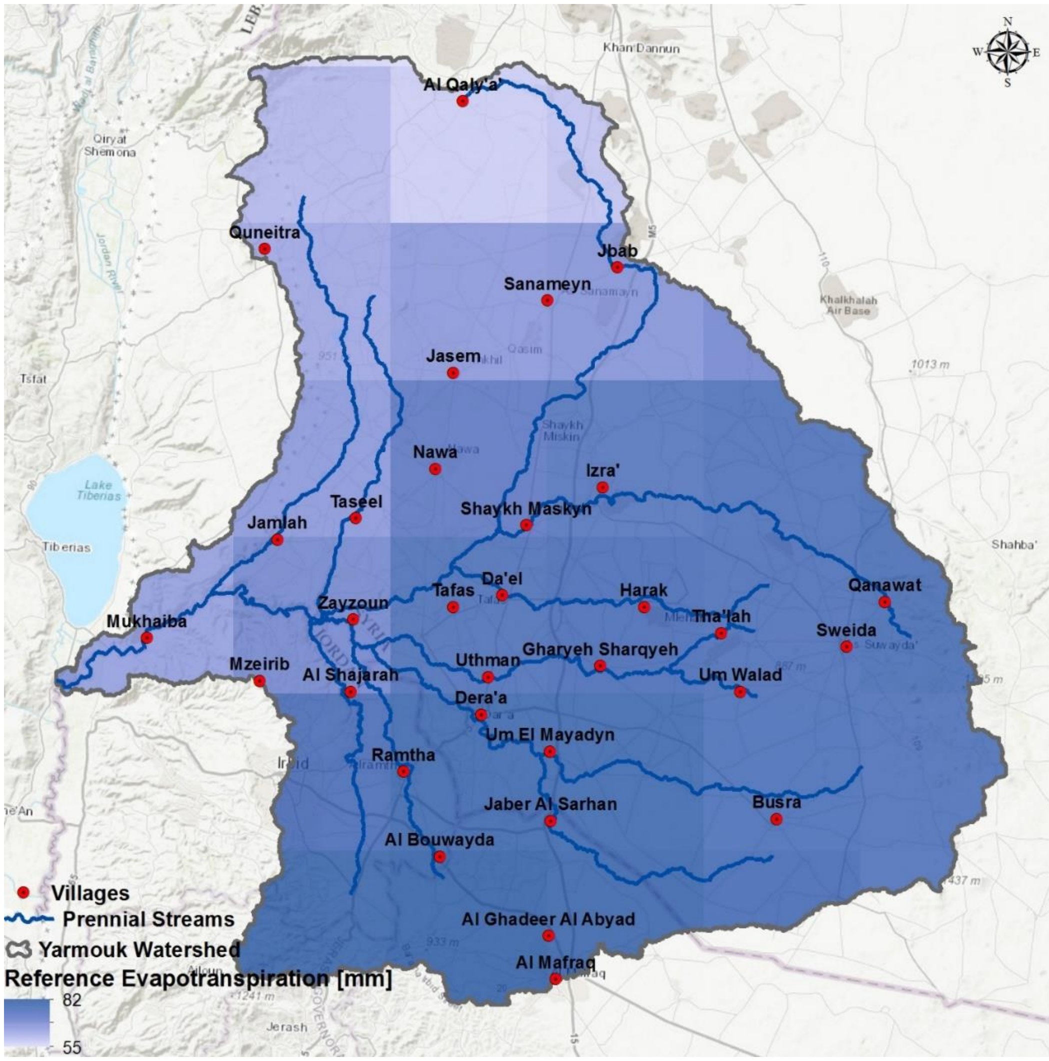


Figure 27: Reference Evapotranspiration map computed from WAPOR for Yarmouk basin in 2009

5.4 Crop Evapotranspiration

Crop evapotranspiration map was released using GIS software based on the reference evapotranspiration one and other factors that derived from NDVI maps. Monthly maps were prepared for the account year (2009) in order to compute the incremental evapotranspiration, Figure 28 shows the distribution of crop evapotranspiration over the land classes within the Yarmouk basin it is very similar to that derived by the actual evapotranspiration map. However, for each land class ETinc was computed to complete the WA+ sheets.

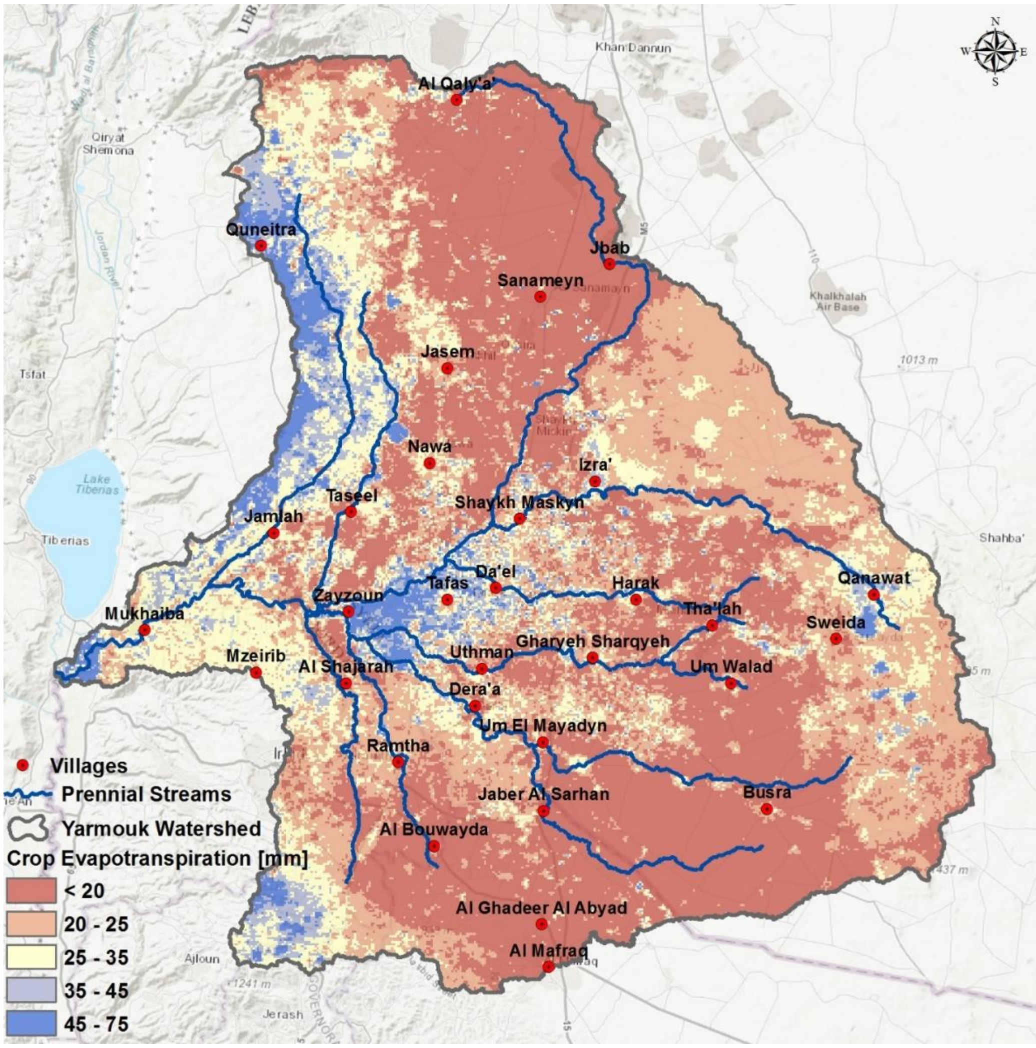


Figure 28: Crop Evapotranspiration map computed from WAPOR for Yarmouk basin in 2009

5.5 Landscape and Utilized Evapotranspiration

In this project it was required to separate evapotranspiration into landscape and utilized, landscape ET that originates from precipitation and utilized ET that originates from surface and groundwater withdrawals. As it is clear that Yarmouk basin recieves the main precipitation during winter season that lasts from November till March, whereas there is little to no precipitation during the summer season that lasts from April till October. Then, the utilized ET will occur mainly during the months where we have shortage as the difference between precipitation and the total actual evapotranspiration, whereas, landscape is considered the total evapotranspiration during the winter season. The two components were calculated for each land use category in MCM/Year. It was shown that most of the utilized ET is depleted within the Managed and Modified land use categories, mainly by crops and trees.

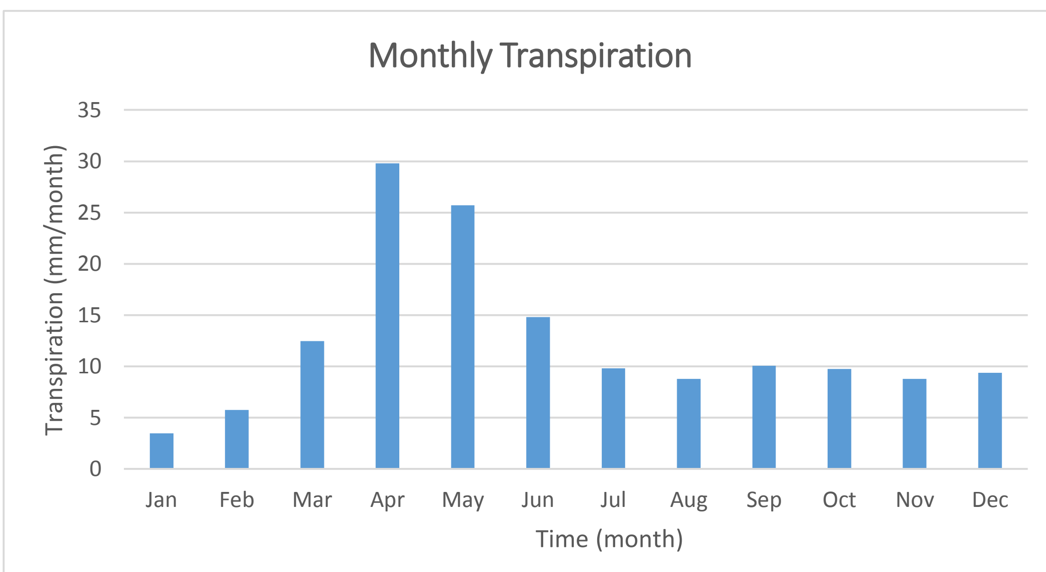
Table 2: Landscape and Utilized Evapotranspiration for each category during 2009 in MCM/year

Category	Landscape-ET (MCM)	Utilized-ET (MCM)
Managed	158.66	211.91
Modified	209.34	288.77
Utilized	367.94	248.88

5.6 Evaporation, Transpiration and Interception

It was required to separate evapotranspiration components to study them on all land use classes. As it is mentioned before that Transpiration, Evaporation and Interception images were downloaded from WAPOR portal. Transpiration was studied monthly over Yarmouk basin, where table shows the variation of transpiration rates during the account year (2009). It was shown that April, May and June accounted for the highest transpiration rates, this was seen to be very logical, these months match the growing period of the crops and trees found within the Yarmouk basin. Wheat and barley are the popular crop types at Dera'a, Quneitra, Golan and Irbid, during April before harvasting at May, these crops will be at the last stage of growing where it consumes water (Zhang & Oweis, 1999). This was shown by both Table 3 and Figure 29, transpiration map gives the highest values within these regions in addition it was clear in the table that April accounted for the highest transpiration during 2009. However, both months (May-June) reflects the production period for most of the fruit trees, vines and olives within the Yarmouk basin.

Table 3: Monthly Transpiration estimated from WAPOR for Yarmouk basin in 2009



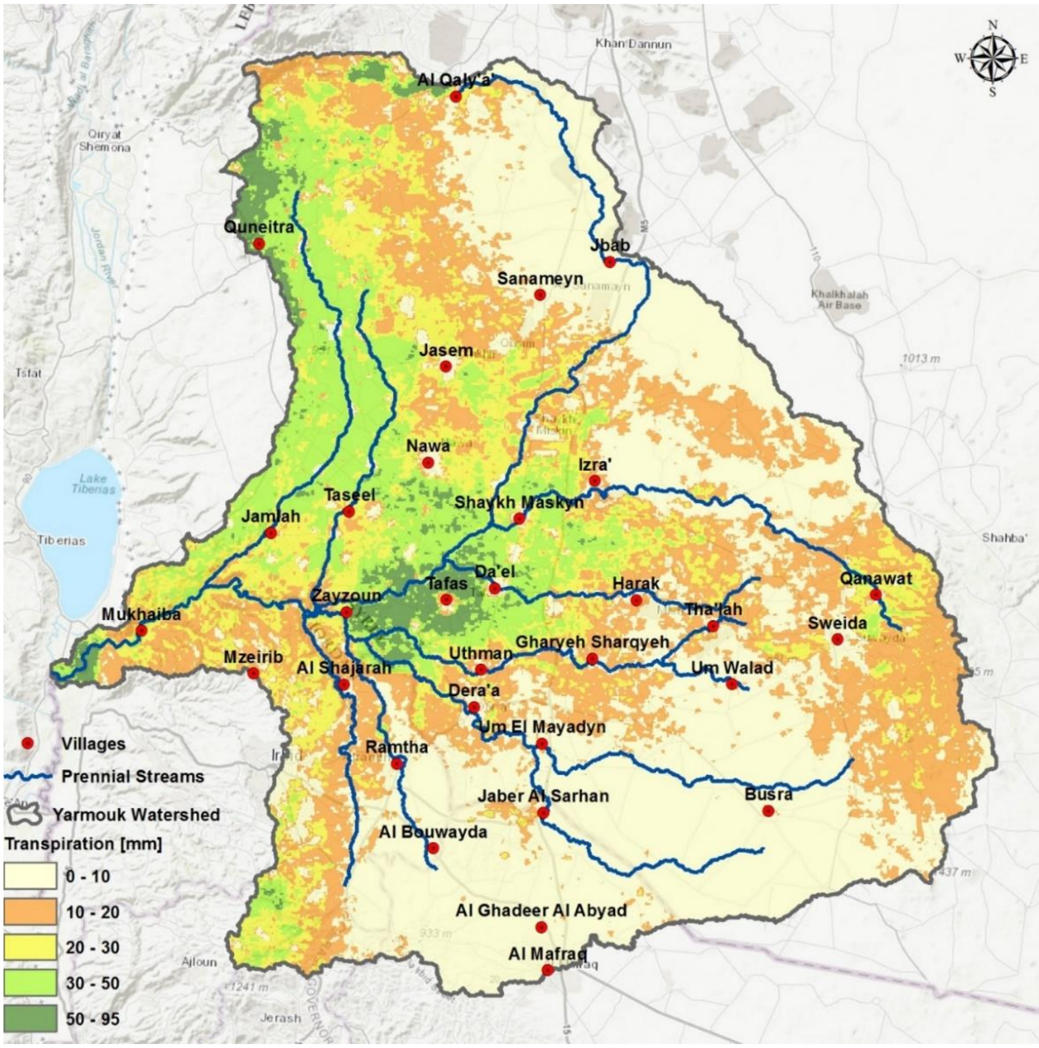


Figure 29: Transpiration map computed from WAPOR for Yarmouk basin in 2009

Figure 30 shows the distribution of evaporation over the whole basin. The map was computed for 2009 but it did not show a big difference in evaporation rates within the basin. However, evaporation mainly occurs over bare lands.

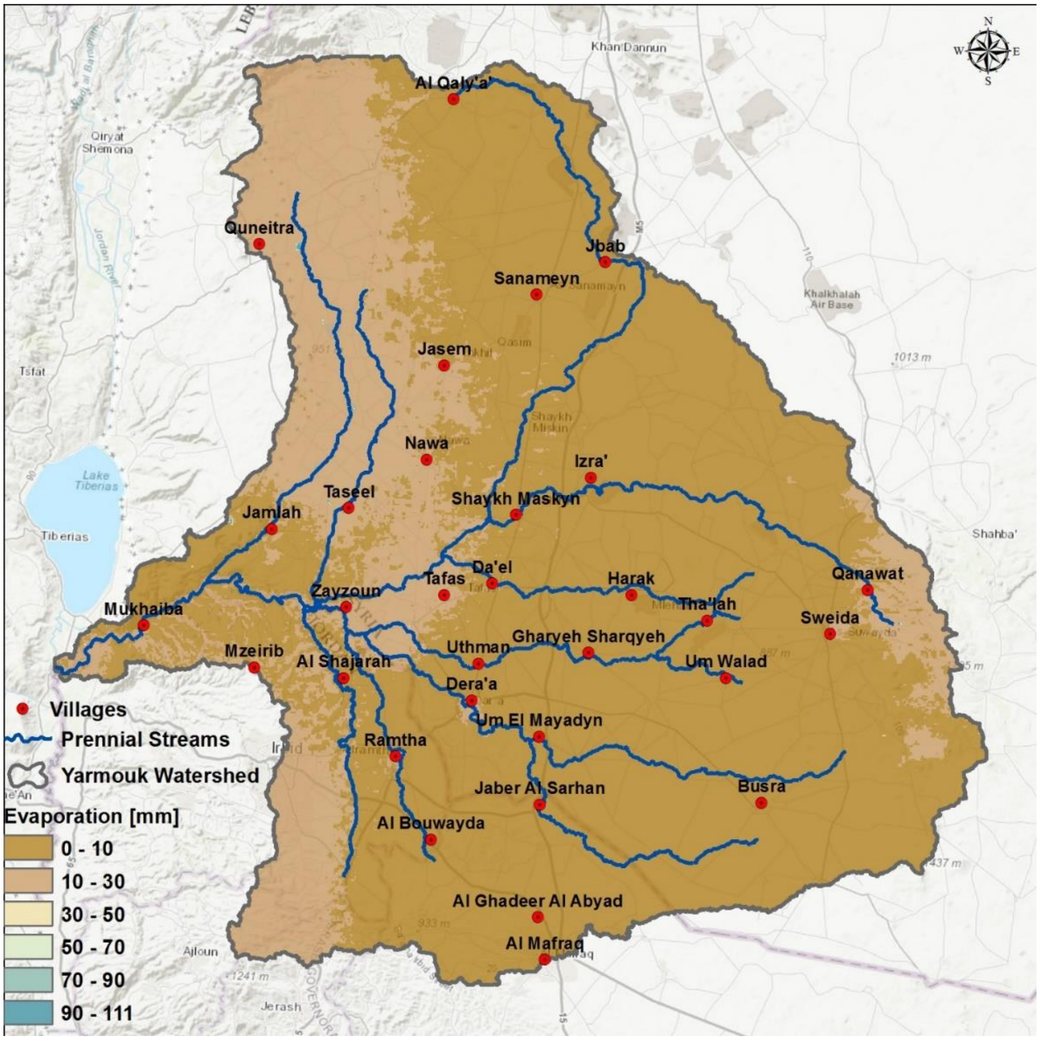


Figure 30: Evaporation map computed from WAPOR for Yarmouk basin in2009

Interception map was computed for year 2009 as it is shown in Figure 31. Most of the interception occurs over the vegetation zones which is explained as logical. The highest interception values match the locations of crops mainly at the west and north-west parts of the Yarmouk basin in Dera'a, Golan, Quneitra. The other parts of the basin accounted for small values of interception mainly over urban zones, water bodies and dams.

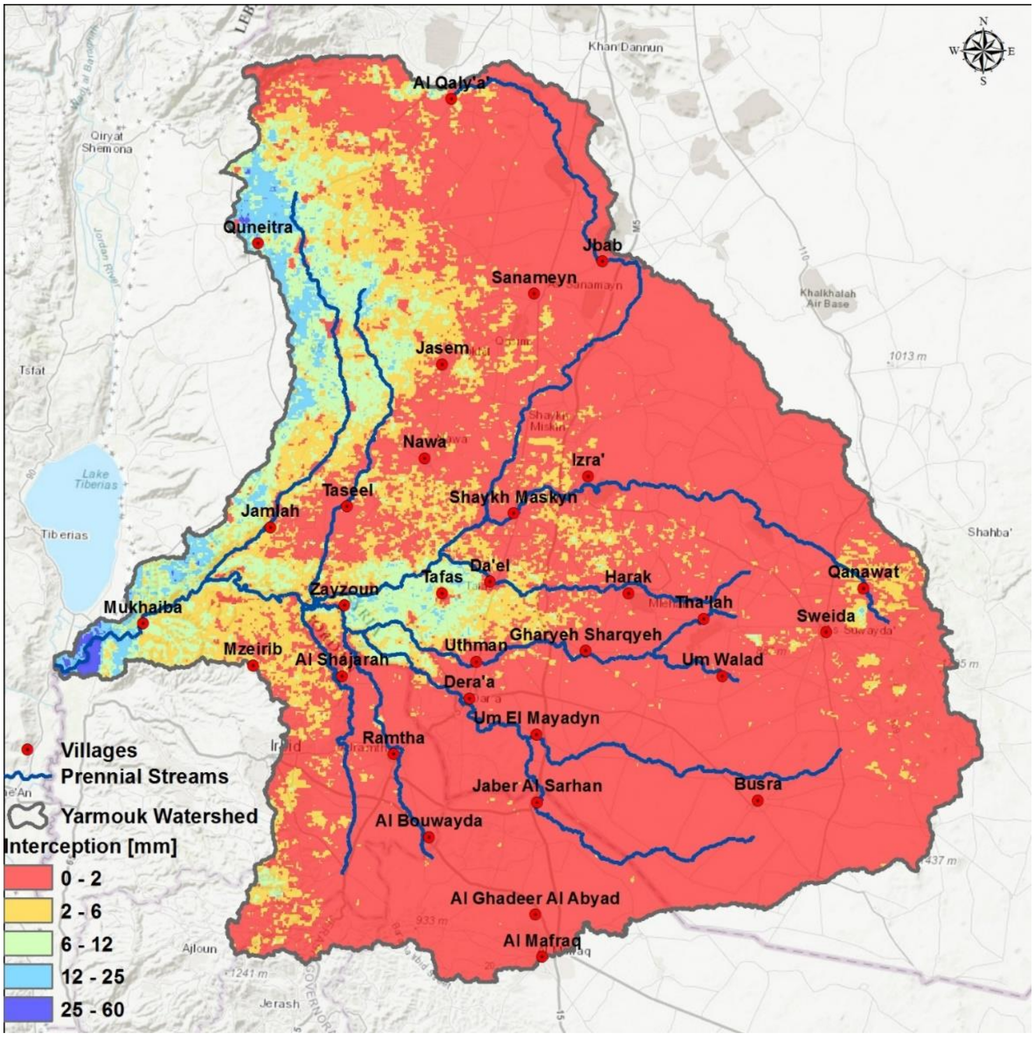


Figure 31: Interception map computed from WAPOR for Yarmouk basin in 2009

Table 4 shows the values of the three components over all land use classes during 2009 within the Yarmouk basin. As it is clear that transpiration occupies the greatest part of the total evapotranspiration, mainly for irrigated and rain-fed crops. As a result, most of the depleted water by evapotranspiration process occurs by the big cultivated sector within the Yarmouk basin.

Table 4: Evaporation, Interception and Transpiration values estimated from WAPOR for each land use class in Yarmouk basin during 2009

Land Use Class	E (MCM/Yr)	I (MCM/Yr)	T (MCM/Yr)
Dams	5.4	0.015	0
Green House	0.26	0.005	0.54
Urban Zone	43.22	0.589	55.25
Bare land	236.93	3.897	380.94
Forest	19.59	0.944	46.3
Water Bodies	9.37	0.332	0

Irrigated Crops	57.22	3.469	186.15
Irrigated Trees	6.2	0.519	27.22
Rain-fed Crops	89.66	3.555	256.39
Rain-fed Trees	81.6	1.955	177.85

5.7 NDVI

NDVI map was computed first from SPOT5 satellite as shown in Figure 32, it shows a realable values for vegetation zones and a good distribution all over the basin. But there were missing parts within the basin by which the avialable images did not cover it. Moreover, the only images obtained were just for May-2009, so it was insufficient to derive analysis and estimate results based only on a one month per year. Then, Landsat7 images were downloaded monthly for the account year 2009 as mentioned before. NDVI map was derived from Landsat satellite for Yarmouk basin, the distribution of NDVI values were less realable, as shown within the map obtained most of the parts give negative values and the vegetation zones indicate low NDVI which is not logical. This result was due to error obtained after gap-filling the map using GIS software, by which Landsat satellite (version-7) provides images that miss data over many pixels and need to be corrected by this tool. As a result, NDVI map for this project was then computed by MOD13 satellite at 250 m resolution. Monthly NDVI maps for the whole year were computed as shown in Figure 33. The map obtained shows a good distribution of NDVI values over the land use classes within the Yarmouk basin, the highest values match the vegetation zones whereas bare lands, water bodies and urban zones occupy for negative values which is very logical.

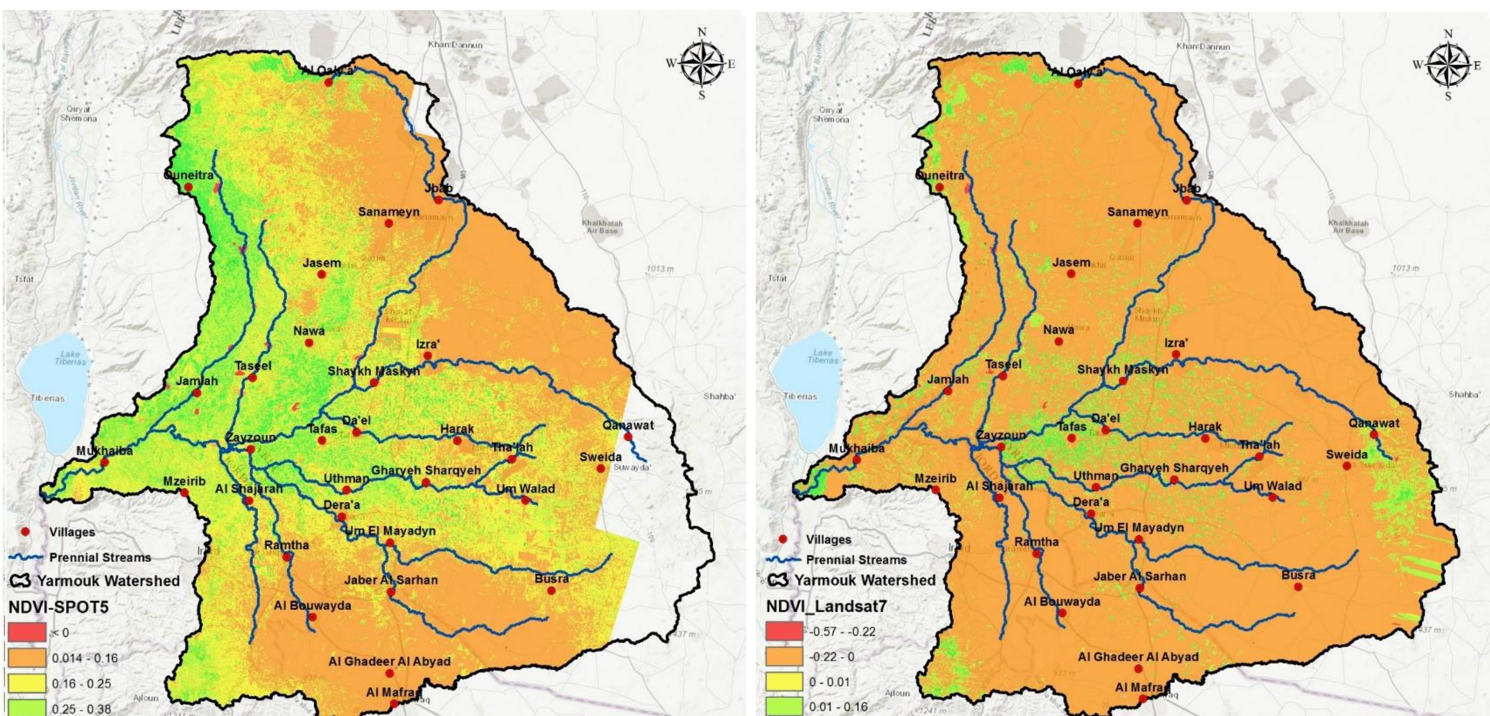


Figure 32: NDVI map derived from SPOT5 and Landsat7 for Yarmouk basin in 2009

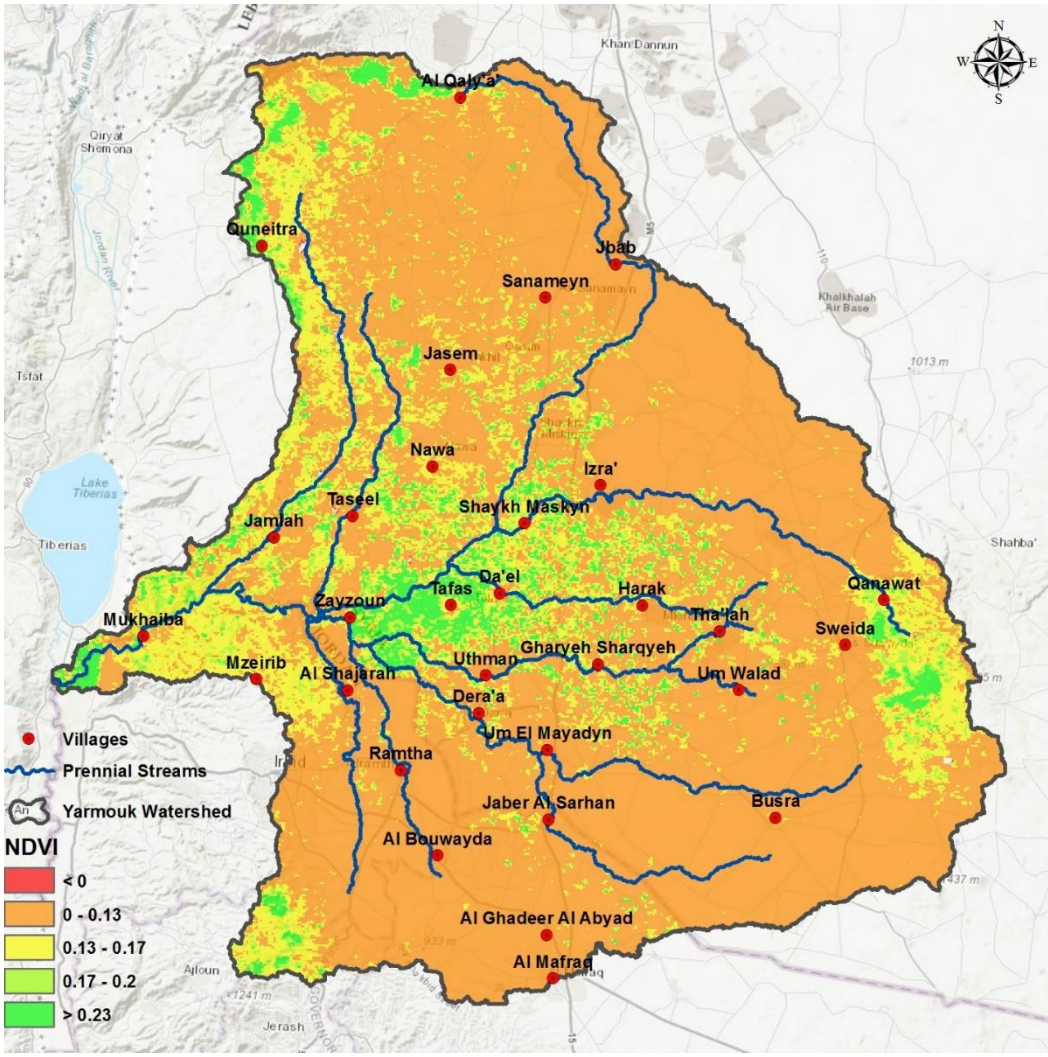


Figure 33: NDVI map derived from MOD13 satellite for Yarmouk basin in 2009

5.8 Biomass production

Biomass production was computed from WAPOR over 2 seasons per year. Table 5 shows the production for each class in irrigated and rain-fed groups. For rain-fed type the biomass was calculated only for the first season which reflects the winter period, by which it is the only period where crops and trees receive water for production. Whereas, for irrigated type the biomass was calculated for both season because they receive water all over the year either from rain or from withdrawals (Fao & IHE-Delft, 2019).However, both irrigated and rain-fed crops show a big production all over the year greater than that for trees. Rain-fed crop production within the

Yarmouk basin is double that for irrigated crops, this due to the large areas of rain-fed crops in comparison to the limited irrigated areas.

Table 5: Biomass production (Kg/ha) for cultivated area in Yarmouk basin during 2009

Type	CLASS	Biomass (Kg/ha)
Rain-fed	Fruit Trees	29,645,452.80
	Olive	70,800,868.80
	Vine	16,476,638.40
	Crop	201,815,193.60
Irrigated	Fruit Trees	5,301,633.60
	Vine	4,749,624
	Olive	11,594,714.40
	Crop	103,516,588.80

5.9 Irrigated/Rain-fed results

First a research has been performed to collect information about the agricultural sector in both countries such as the type of crops in each governorate, crop calendar and the characteristics of these types. It was found that both countries mostly depend on wheat, barley and many vegetables plantation as well as olives, vines and fruit trees (*NAPC*, 2010). Each governorate found to be interested in a specific crop type as shown in Table 6 the plantation for each governorate is specified with its plantation, irrigation and harvest date.

Table 6: Crops types and calendar for most important governorates in Yarmouk basin

Governorate	Type of crop	Plantation date	Irrigation date	Harvest date
Dar'a	Wheat	November	January-March-April	May
	Vegetables	February	April-May-June	July
Quneitra	Protected Tomato	August	Sep-Oct	November
Sweida	Rain-fed Wheat and barley	November	_	May
Rif dimashq	Potato	February	April-May-June	July
Golan	Vegetables	February	April-May-June	July
Irbid	Vegetables	February	April-May-June	July

It was required to separate irrigated from rain-fed crops and trees in order to release a new LUC and compute each input component on every land use class. Monthly NDVI maps derived from MOD13 was used first to detect irrigated crops and trees as listed before. In parallel, Transpiration maps derived from WAPOR also prepared monthly for irrigated areas detection.

For winter crops that are mainly wheat and barley, a trend line performed for each governorate within the Yarmouk basin over a period from the planting month (November) till the harvest one

(May), showing the irrigated area estimated by both methods Figure 34.Both methods show that April contributes for the greatest irrigated area during which crops receive irrigation and this has been showed in the evapotranspiration part where crops release the greatest evapotranspiration rates within this month .However, the irrigated areas that estimated based on NDVI analysis were less than that estimated based on Transpiration method, as well as, they were far from the irrigated areas published by the Ministry Of Agriculture in Syria. Dera'a was takes as a good example to compare between our values and that derived by MOA because this governorate is included totally within the Yarmouk basin but the others are partly included, so it will not be logical to take a percentage on the irrigated areas and compare it. The irrigated area within Dera'a estimated by NDVI method was set to be 71844.57 ha and that estimated by Transpiration method was 18970.44 ha, whereas, the irrigated area estimated by the ministry was 19477 ha. Then it was not logical to have this big irrigated area within Dera'a as estimated by NDVI, this method did not give an accurate results due to the bad resolution of MODIS satellite used. Though, Transpiration maps were of 100 m resolution but they give more fit results that are very close to that of the ministry. As a result, the irrigated area for crops were estimated based on Transpiration method for each governorate mainly during April month and their locations were specified based on Transpiration maps derived from WAPOR where we have high transpiration.

Table 7: Irrigated, Rainfed and fallow area for crops within governorates in 2009

Governorate	Irrigated Area (ha)		Rain-fed Area (ha)	Fallow Area (ha)	Total Area (ha)/LUC-2011
	Winter_Crops	Summer_Vegetables			
Dar'a	18846.46	8349.95	68856.33	131656	219359
Quneitra	8613.34	11267.89	11268	3669	23551
Suweida	0	0	5140.73	46455	51596
Rif dimashq	214.15	873.63	3934.193	12098	16247
Golan	4020.3	922.25	4161.917	566	8748
Irbid	713.41	43.58	7041.21	24287	32085
Mafraq	0	0	27.74	7130	7158
Ajlun	34.14	0	395.86	877	1307
Jarash	0	0	0	373	373
Yarmouk	32442	21457	100826	227113	360424

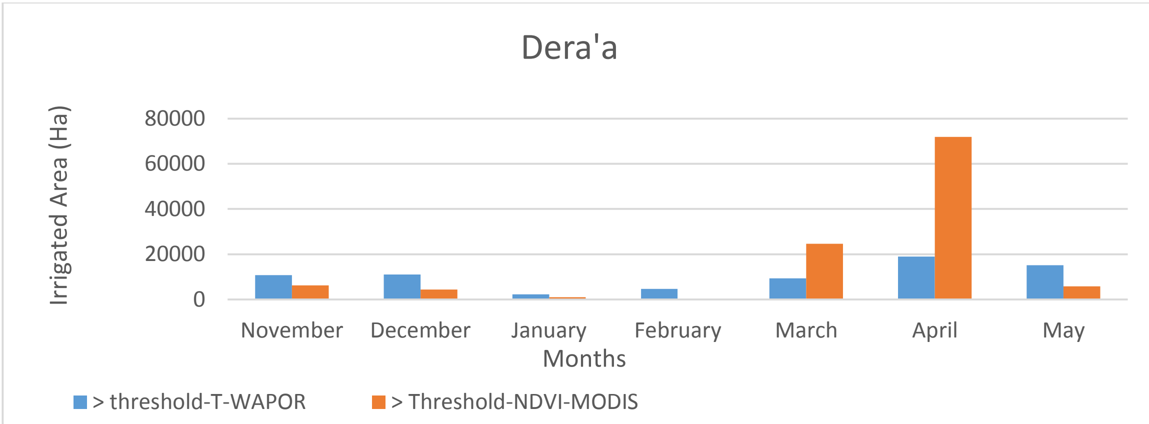


Figure 34: Irrigated area (ha) in crop season within Dera'a

For fruit trees, vines and olives the same methodology used. However, each type in each governorate contributes for a different month during which it receives water for irrigation. It has shown that olives and vines mainly irrigated in May within all governorates, whereas, fruit trees differ between the governorates depending on the fruit type, where Dera'a and Quneitra irrigate their vines during May, in Rifdimashq they irrigate vines during June, in Irbid they irrigate vines during July while in Golan they irrigate vines during August. However, the irrigated area for trees have been estimated based on Transpiration method, on characteristics for each tree type and on irrigation month within each governorate. Their locations also specified on the Transpiration maps where we have high transpiration.

Table 8: Irrigated area (ha) for trees within the governorates in 2009

Type	Governorate	Irrigated Area (ha)	Rainfed Area (ha)
Olives	Dar'a	2909	30356
	Quneitra	153	3244
	Suweida	0	8242
	Rif dimashq	34	773
	Golan	300	275
	Irbid	24	19599
	Mafraq	0	2094
	Ajlun	9	2908
	Jarash	0	338
	Yarmouk	3428	67827
Fruit Trees	Dar'a	285	3132
	Quneitra	10	1812
	Suweida	0	13193
	Rif dimashq	462	1271
	Golan	305	1165

	Irbid	220	768
	Mafraq	0	506
	Ajlun	0	351
	Jarash	0	0
	Yarmouk	1280	22196
Vine	Dar'a	233	3005
	Quneitra	24	395
	Suweida	0	2714
	Rif dimashq	88	559
	Golan	621	2051
	Irbid	0	426
	Mafraq	0	367
	Ajlun	0	153
	Jarash	0	1
	Yarmouk	965	9666

5.10 Irrigation Requirements

Table 9 gives information about surface flow in the main tributaries for the Yarmouk basin, as well as, withdrawals from surface and groundwater. Shallal, Zeidi, Thahab, Hareer, Allan and Raqqad are the main tributaries that constitute the Yarmouk basin. The surface flow was estimated during 2009 for each tributary, but it was difficult to specify the surface runoff for each tributary alone, then it was estimated for the whole basin to be 45.8 MCM/Year. Similarly for the return flow it was given for the Yarmouk basin to be 11 MCM/year from irrigation water, 38 MCM/Year from domestic water and 26 MCM/Year from industrial water.

The irrigated area in the Yarmouk basin during 2009 was 55760 ha, it is irrigated from both surface water from dams and wells found in each tributary. The total irrigated area from dams that found to be in service within 2009 was 10255 ha and the rest was irrigated from wells. The irrigation requirements for each tributary were calculated as shown in Table 9. However the volume used from dams for each tributary were less than the irrigation requirements. Then the rest water requirements were taken from the wells, but the maximum productivity for legal wells was 185.6 MCM/Year for all tributaries. As a result, the irrigation requirement for Yarmouk which is 439 MCM/Year is greater than the withdrawals from dams and legal wells, which confirm the presence of many illegal wells where most of the groundwater is abstracted from.

Table 9: Irrigation Requirements for tributaries within the Yarmouk Basin in 2009

Tributary	Irrigation area (ha)	Irrigation volume (Mm3)	Volume used for irr from dams (MCM)	Wells Volume interval (MCM)	Flow volume (MCM)
Main Outlet	1390.85	11.0	13.49	-	37.5
Shalala	627.54	4.9		-	1.6
Zeidi	746.92	5.9	4.71	0-31.6	21.5
Thahab	2936.89	23.2	0.33	0-24.9	3.8
Hareer	23231.5	183.2	4.35	0-105.2	25.9
Allan	10147.42	80.0	7.42	0-8.5	12.3
Raqqed	16603.57	130.9	5.47	0-15.4	35.2

5.11 Water Accounting Plus Sheets

5.11.1 Resource Base Sheet

The WA+ resource base sheet is represented in Figure 35. It provides an over view on all water resources within the Yarmouk basin in 2009. The net inflow was 3043.1 MCM/Year that mainly originates from precipitation which occupies for 2693 MCM/Year whereas the remaining was derived from both growndwater inflow and surface water storage through many dams in the basin. Due to the lack in guage data and the many contradictions in values, there was a difficulty to estimate the exact surface inflow, however, it was estimated to be 70 MCM/Year.

Landscape ET is defined to be the evapotranspiration that originated from rainfall, and it accounted for 735.9 MCM/Year which is less than the half of the total inflow (26.67%). While the exploitable water was 2307 MCM/Year which constitutes 73.3% of the net inflow. This highlights the problem of the over exploitation from surface and groundwater through the huge number of wells all over the Yarmouk basin. However, most of the rainfall was depleted through the ULU category over the bare lands, water bodies and forests. The remaining landscape ET divided equally on both MLU and MWU mainly over rain-fed and irrigated crops classes.

More than the half of the exploitable water shown to be non-consumed water, 749.6 MCM/Year (34.7%) is utilized within the basin and 1557.4 MCM/Year (65.3%) is transferred out. About 25% of the utilized flow goes for MWU category to irrigate crops and different types of trees, this contributes to the small irrigated areas within the Yarmouk basin where most of the villages depend on rain-fed cearels and fruits. The remaining water distributed on ULU and MLU categories. However, it is shown that ET from exploitable water (288.8 MCM/Year) in the MLU is greater than the landscape ET (209.3 MCM/Year) for the same category and this would reffered to the growing stages of the rain-fed crops. Landscape ET was estimated before the booting stage in rain-fed season but in the summer season the plant became in between booting to maturating stages and this reffer to growing of the plant, then ET at this stage will be greater (Zhang & Oweis, 1999).

The total water that depleted from the basin through evapotranspiration processes was about 1174.9 MCM/Year, while the outlet from Yarmouk basin was 1517 MCM/Year. However, surface outflow was estimated from Adassiyeh station to be 40.6 MCM/Year whereas the groundwater outflow was estimated to be 31.6 MCM/Year.

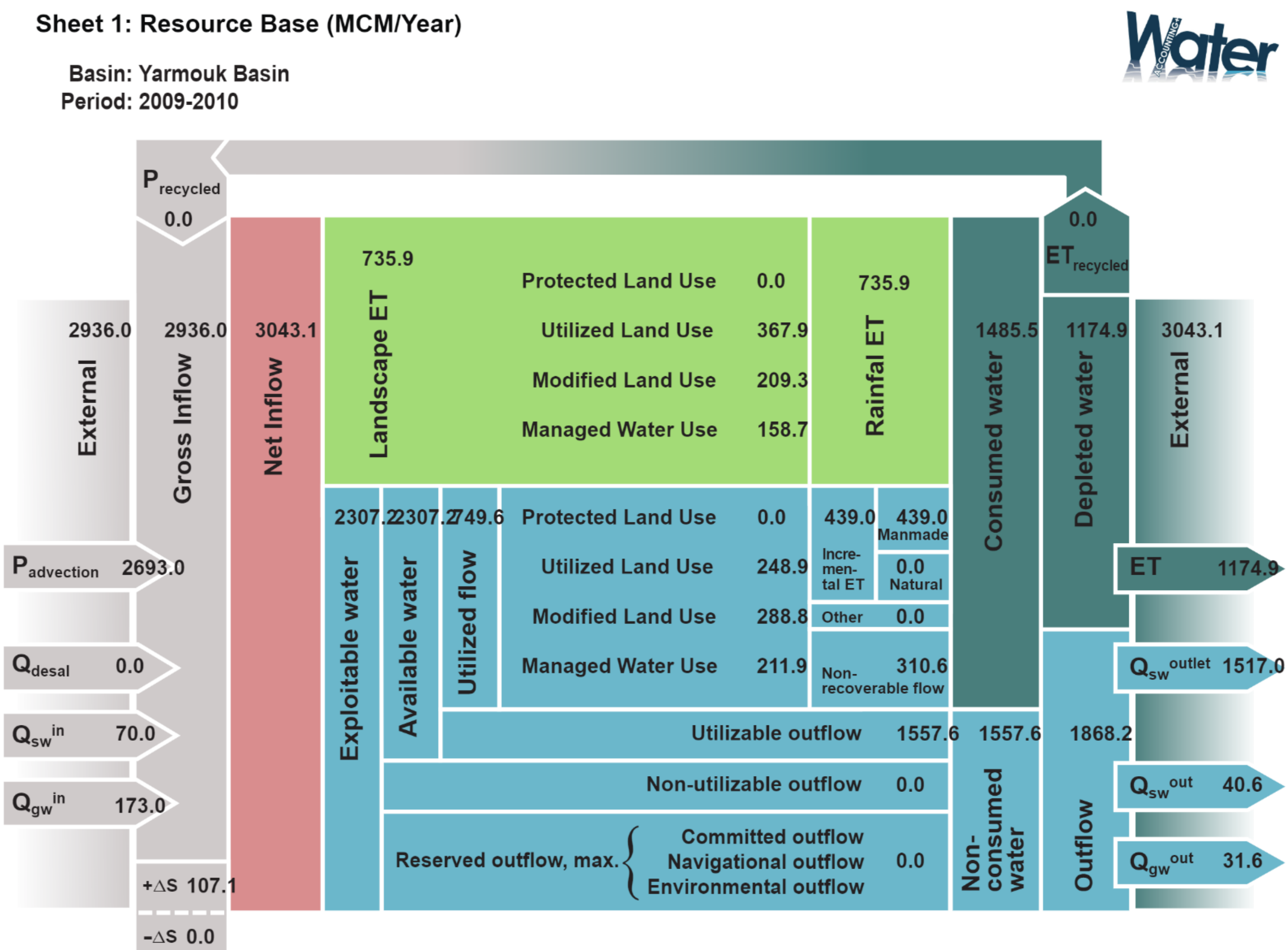


Figure 35: WA+ Resource Base Sheet for Yarmouk basin based on 2009 data expressed in MCM/year.

5.11.2 Evapotranspiration Sheet

Water Accounting Plus Sheet 2 gives an over view on the water consumption for each land use class within the Yarmouk basin. It provides a separation for evapotranspiration component into Evaporation (E), Transpiration (T) and Interception (I). Moreover, it shows wethier water is depleted in a beneficial or non-beneficial way.

The classes are grouped into four main groups, whereas the Protected Land Use Group is not avialable in this study. Accordingly, only three groups discussed within this sheet. As shown in Figure 36, about 694.1 MCM is depleted within the Utilized Land Use which indicated that a large amount of water is bieng evapotranspirated through bare lands which are listed as others in the sheet and occupied about 89% of the total evapotranspiration of this category, this depletion has no benefit on either agriculture nor environment. However, most of the water is being evapotranspirated through Managed category which includes Modified Land Use and Managed Water Use groups. The amount of depleted water within this category is estimated to be 996.4 MCM as a total separated to 611 MCM for MLU mainly over rain-fed crops that corresponds for 349.6 MCM, and to 385.4 MCM for MWU mainly over irrigated crops that corresponds for 246.8 MCM alone. This depletion through rain-fed and irrigated crops have benefits on both agriculture and environment. However, the trees are listed as others in both groups, about 261.4 MCM were depleted over rain-fed trees , whereas, only 33.9 MCM evapotranspirated by irrigated trees. As a comparison between irrigated and rain-fed cultivation, it was shown that most of the water has been depleted by the rain-fed ones, and this is due to the small area of which irrigated crops occupies. As a total, Transpiration occupies about 66.8% of the total evapotranspiration compared to 32.5% of Evaporation and only 0.7% of Interception.

Water depletion components were divided into beneficial and non-beneficial based on our judgement. All the Evaporation and Interception were assumed to be non-beneficial, whereas, Transpiration was considered beneficial except for grasses in bare lands, urban zones and the floating grasses over the water bodies. As a consequence, 56% of the water is deplted in a Non-beneficial way and only 44% of it deplted beneficial, which is a negative observation of the whole case.

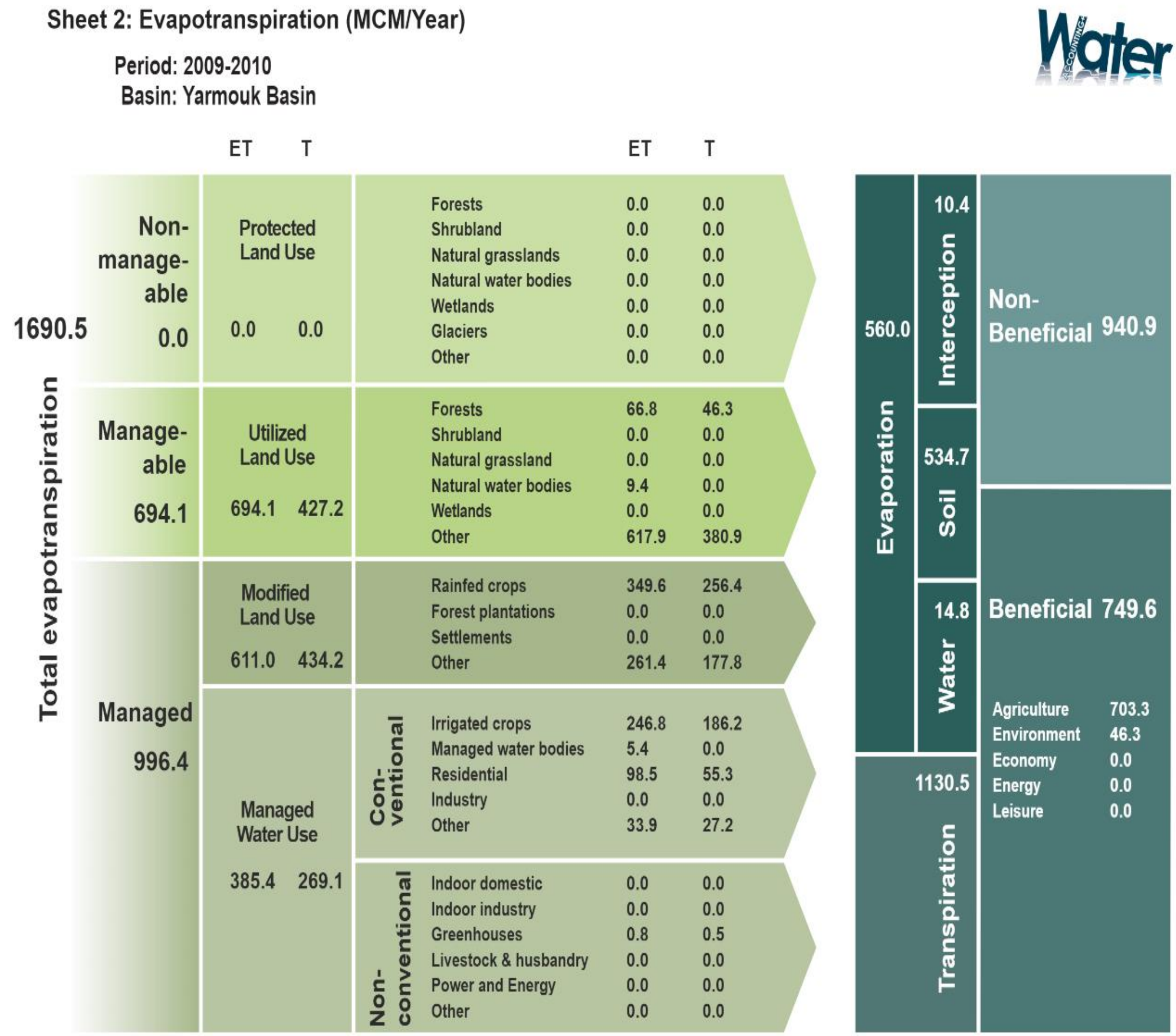


Figure 36: WA+ Evapotranspiration Sheet for Yarmouk basin based on 2009 data expressed in MCM/year.

Table 10: Water depletion by LULC class for the Yarmouk basin in 2009

Land Use Class	Land Use Group	E (MCM/Yr)	T (MCM/Yr)	Evaporation	Transpiration
Dams	MWU	5.4	0	Non-Beneficial	Non-Beneficial
Green House	MWU	0.26	0.54	Non-Beneficial	Beneficial (Agr)
Urban Zone	MWU	43.22	55.25	Non-Beneficial	Non-Beneficial
Bare land	ULU	236.93	380.94	Non-Beneficial	Non-Beneficial
Forest	ULU	19.59	46.3	Non-Beneficial	Beneficial (Env)
Water Bodies	ULU	9.37	0	Non-Beneficial	Non-Beneficial
Irrigated Crops	MWU	57.22	186.15	Non-Beneficial	Beneficial (Agr)
Irrigated Trees	MWU	6.2	27.22	Non-Beneficial	Beneficial (Agr)
Rain-fed Crops	MLU	89.66	256.39	Non-Beneficial	Beneficial (Agr)
Rain-fed Trees	MLU	81.6	177.85	Non-Beneficial	Beneficial (Agr)

5.11.3 Agricultural Sheet

5.11.3.1 Agricultural Sheet – Part 1

This sheet shows water consumption by rain-fed/irrigated crops and other plantings. There is no information on the consumptive water use for non-crops so they were considered negligible. Water consumption over crops through evapotranspiration is considered during crop season only (Fao & IHE-Delft, 2019). For rain-fed category, evapotranspiration is measured only during winter season, the only duration which crops receive water and considered beneficial for growing and producing. While, for irrigated category the crop season was considered the whole year at which crops receive water from either rain or withdrawals. Cearels were considered to be wheat and barley for this project, while fruits were composed of fruit trees and vines.

As shown in Figure 37, the ET consumptive over rain-fed crops during crop season was 75.22 MCM/Year which is less than the total ET during the whole year that estimated by 256.4 MCM/Year. However, the consumptive ET for irrigated crops does not differ from the total ET. Though the irrigated area is less than that of the rain-fed ones but the consumptive water by irrigated crops (201.62 MCM/Year) is greater than that by rain-fed crops (75.22 MCM/Year).

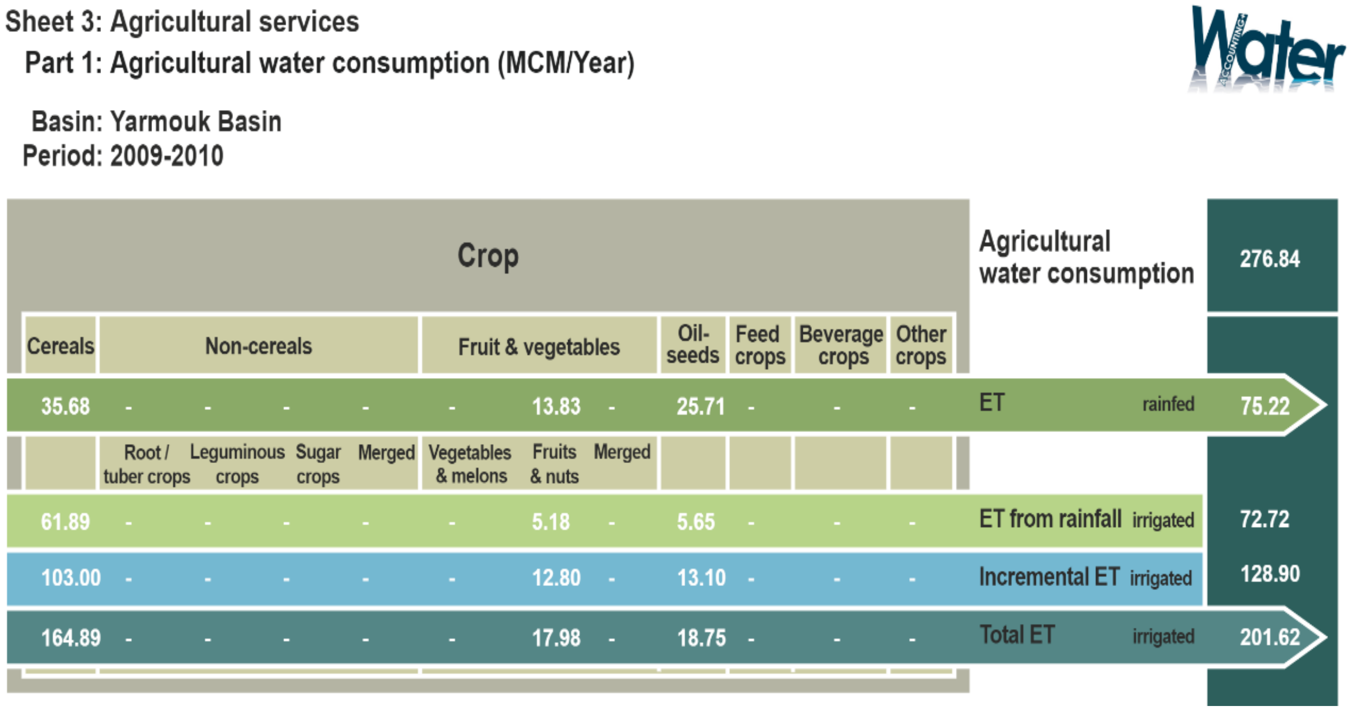


Figure 37: WA+ Agricultural water consumption Sheet for Yarmouk basin based on 2009 data expressed in MCM/year.

5.11.3.2 Agricultural Sheet – Part 2

To compute the crop yield, biomass production (Kg/ha) has been downloaded from WAPOR portal and clipped on Yarmouk basin by the aid of GIS. The yield for rain-fed crops was estimated from the first season during winter, where the crops are receiving water for growing and producing. Whereas, the yield for irrigated crops was estimated all over the year. It has shown in Figure 38 that the yield for rain-fed crops, fruits and olives was 159838, 36529 and 56074 Ton/ha respectively. Which is greater than that for irrigated crops, fruits and olives that were 81985, 7961 and 9183 Ton/ha respectively. This would seen very logical for a reason that the rain-fed area is much greater than the irrigated where most of the villages depend on rain-fed cultivation.

Sheet 3: Agricultural services

Part 2: Land productivity (Ton/Ha) and water productivity (Ton/m3)

Basin: Yarmouk Basin

Period: 2009-2010

	Crop													
	Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops	Other crops		
		Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged						
Land productivity	159838	-	-	-	-	-	36529	-	56074	-	-	-	Yield	rainfed
	-	-	-	-	-	-	-	-	-	-	-	-	Yield from rainfall	irrigated
	-	-	-	-	-	-	-	-	-	-	-	-	Incremental yield	irrigated
	81985	-	-	-	-	-	7961	-	9183	-	-	-	Total yield	irrigated
Water productivity	375.29	-	-	-	-	-	83.91	-	147.92	-	-	-	WP	rainfed
	-	-	-	-	-	-	-	-	-	-	-	-	WP from rainfall	irrigated
	-	-	-	-	-	-	-	-	-	-	-	-	Incremental WP	irrigated
	16.43	-	-	-	-	-	0.99	-	1.68	-	-	-	Total WP	irrigated

Figure 38: WA+ Land productivity (Ton/Ha) and water productivity (Ton/m3) Sheet for Yarmouk basin based on 2009 data

6. Conclusion

Yarmouk Tributary Basin as a shared basin between three important countries prove to be a very complicated case for study due to the many problems that obstruct the understanding and managing it. The basin is facing many challenges that appears in the two ambiguous treaties between the countries that ignore the hydrological characteristics of the basin and show a big contradictory in data, the inefficient infrastructure that push beyond the sustainable limits of the resources, the expanding in irrigated crops area that tension water resources as well as the over water abstraction from dams and wells for agricultural needs mainly.

A water accounting framework has been applied to Yarmouk basin for more understanding the distribution and use of water resources within the basin. Through this framework, all water resources have been discussed, inflows and outflows within the basin shown, depletion processes over all land use classes have been classified, and beneficial and non-beneficial usage of water resources have been separated, as well as, land and water productivity have been computed for every land use class. Most of the input parameters were unavailable locally, so they were derived from remote sensing. Precipitation, Evapotranspiration, Biomass production, NDVI, and Land use/Land cover were computed from satellite images. The basin was studied over an account year 2009 before the Syrian crisis and it is recommended to complete this work over a period after the crisis to show its impact on water resources and agricultural sector within the basin.

The input water resources into the Yarmouk basin constitutes mainly from precipitation that forms about 90%, in addition to surface water and ground water that comes from outside the basin but they form a small portion. The basin receives rain for about 6 months per year which provides a good source for watering many rain-fed agricultural sectors. Though, the Yarmouk basin characterizes by the many dams and infrastructures but the water storage seems to be negligible due to the high abstraction rates from both surface and groundwater.

Half of the water resources showed to be consumed by the multi-sectors within the basin, whereas the other half is not consumed within the basin and it is depleted outside as outflows to form about 1500 MCM during the account year 2009. However, a big part of the water that consumed within the basin is wasted and depleted in a non-beneficial way. About 940.9 MCM were depleted over bare lands and water bodies, which reflects that within the Yarmouk basin water resources have been tensioned and abstracted for no benefit or use. The irrigated sector within the Yarmouk basin in 2009 formed only 8% of the total area, then it forms a small portion that located at the western and north-western parts of the basin mainly in Dera'a, Quneitra, Golan and Irbid. This irrigated part require water for irrigation during the summer season where we have shortage, for the rest period it receives rain which is sufficient for growth. However, the irrigation requirement estimated to be 439 MCM/Year from dams and wells by which 80% of the irrigated area receives water from wells. The irrigation requirement is considered low in comparison to the high abstraction rates from dams and wells mainly, and it doesnot justify the huge number of legal and illegals wells mainly distributed in Syria. The productivity of both rain-fed and irrigated crops have been showed to be good in comparison to their water consumption, where both Syria and Jordan depends on their agricultural sector to cover food needs.

This project was limited by data scarcity from both countries, though they provided some station data but they suffer from contradictory and lacks for continuety. Many inputs were limited by the bad resolution of the avialable satellites. It is recommended for the future to have more accessibility on remote sensing products and continuety in the data to derive a good and more realable analysis and estimations.

After revising all what concerns water resources, future water allocation and an equitable sharing for water resources within the Yarmouk basin is needed. Water treatment plants needed to recover the non-recoverable flow. As well as, groundwater abstraction reduction requires more management by decreasing number of illegal wells.

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