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Causes of Decreasing Water Balances in the Barada Awaj (Damascus) Drainage Basin until the Uprising in Syria

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Abstract

Despite all of the many discrepancies and contradictions in the estimate of the water balance in the Barada Awaj basin, all the research and reports, both local and international, indicate that the basin suffers from water depletion. The agricultural sector is the largest consumer of water, and the area of land irrigated by the basin has risen significantly. Rapid population growth as a result of natural increase and massive immigration to the basin, piratical well-digging without permits, the failure to increase the area of land irrigated by modern methods and a decrease in rainfall and the drought that has affected Syria in general and the Barada Awaj basin in particular, have led to a water shortage in the basin during the first decade of this century.

Keywords

Water Basin, Water Balance, Water Deficit, Surface Water, Ground Water, Legal Wells, Illegal Wells, Irrigation Methods

1. Introduction

In Syria, like in many other countries in the Mideast, there are areas that are rich in water whose population is sparse, and in contrast, there are areas poor in water with a high population density. The Barada Awaj Basin is considered an area poor in water with a high population density. The water available in this basin is less than 5% of the water available in Syria, while the population of the basin is 29.7% of the country's total population [1].

Between 1989 and 1992, groundwater hit a low point between Al-Zabadani and Damascus in the Barada-Awaj Basin. The groundwater level decreased at a rate between 3.1 mm per day, which is 1.1 meter per year, to a rate between 3.3

mm per day which is 1.2 meter per year [2]. Syrian residents of Damascus reported that in 2001, the authorities turned off the water in the taps for 16 hours every day in July from two in the afternoon until six o'clock in the morning of the next day.

The Syrian newspaper *Tishreen* quoted the head of the Water Agency, Ibrahim Abd-Alnur, who said in 2001 that "last week the demand for water was fifteen times greater than the amount available" [3]. According to the report of Mufak Haluf, head of the Damascus Water and Sewage Authority, Syria's capital needs 225 million cubic meters of water per year, but in reality the city receives only 200 million cubic meters. At least 25 million cubic meters of water are lacking, and that amount is likely to rise in the coming years until 2010 in order to fulfill the needs of the city [4]. Recently, he also warned at a conference in Damascus "the city is liable to be without water" and added that "if we do not intervene immediately we are likely to deal with a catastrophe of which we have not seen the like for the last 50 years." The authorities in Syria have taken steps such as developing additional wells and changing pipes in order to prevent leaks. Despite this, Haluf states that disaster is likely to occur if more meaningful steps are not taken. In an interview in the Syrian newspaper *Al-binaa* on July 27 2008, Haluf emphasized that the supply of water from the Al-Figeh Spring, considered to be Damascus' leading supplier of drinking water, was at its lowest in 20 years [5].

On July 20th 2000, the Arabic News Agency reported that "groundwater in Damascus has reached a depth of 150 - 200 meters in comparison to 15 meters in 1985, and the IRIN information agency reported that the head of the Japanese Agency for International Cooperation (JICA) in Syria Mr. Kazuhide Nagasawa said that in the next twenty years the groundwater level of the Barada-Awaj Basin is likely to fall to 400 meters below the surface [4].

The Al-Figeh stream, which is a vital water conduit that flows into the Barada River, is running dry. Shibli Shammi, a public health engineer in Damascus University, estimates that "this stream is on the verge of totally drying up." In his article "Towards a Water Strategy in Syria", Shammi emphasizes that only 65% - 70% of the total water resources in the Damascus region can be used (namely, 550 - 595 million cubic meters of water per year). He estimates that the water reserves of Damascus will be sufficient for the next two years, and those in the Zabadani catchment basin for four years [6].

2. Background

The surface of the basin is estimated at approximately 8596 square km, located in the southwestern part of Syria (see **Figure 1**). In the mountainous western portion of the basin, the climate is Mediterranean, and the central and eastern parts are semi-arid. Average yearly rainfall in the basin is 267 mm, and the amount of water collected in a year of average humidity reaches 2295 million cubic meters. The average volume of yearly water sources in the basin is 850 million

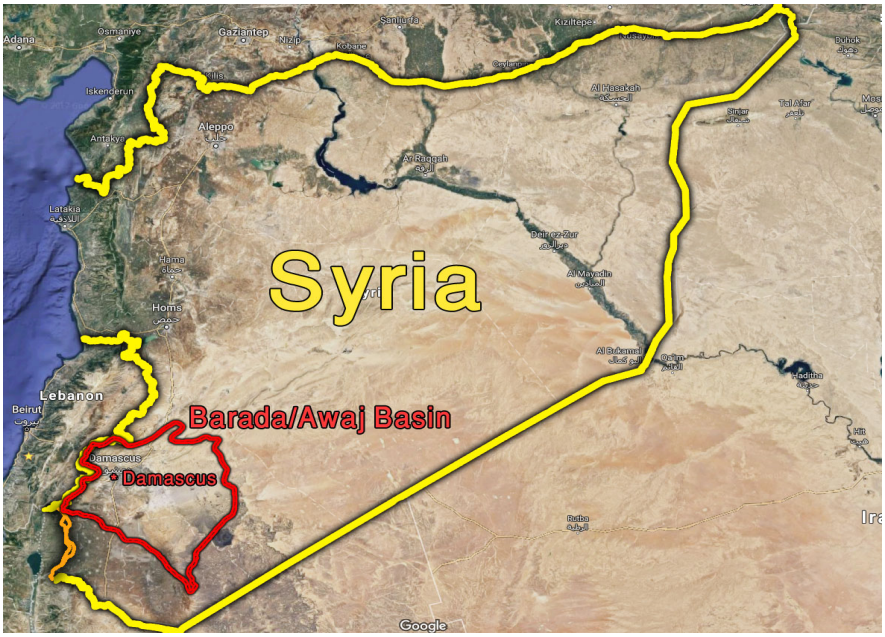

Figure 1. Areal map of Syria and Barada-Awaj basin (prepared by the author).

cubic meters, while the major portion of water sources is located in the mountainous area of the basin [7].

The direction of the flow of surface water in the basin moves from the mountainous portion to the Damascus Plain, with silt that comes with the water from the mountains.

Groundwater—the basin is divided into 21 secondary hydrologic basins. Most of the Barada-Awaj water sources are from groundwater that surface as streams from seasonal springs. Their average flow is 18.9 cubic meters per second, namely 595 million cubic meters per year. The rest of the groundwater sources, whose annual average amount is estimated at 243 million cubic meters, collect in water-bearing layers (water layers) and are used through wells.

Surface water-rainfall-creates streams in seasonal wadis. Six dams have been built in a number of the wadis with a total catchment capacity of approximately 788 million cubic meters. In addition, a significant portion of runoff and melted snow reach the Barada-Awaj rivers. The average amount of surface water, related to the amount of rain and snowfall, reaches 12 million cubic meters per year.

As a result of tectonic activity, volcanic and erosive events that took place during the Mesozoic Era, a number of fold structures were formed, among them the mountains facing Lebanon that reach a height of 2466 meters above sea level, the Hermon Mountains, reaching 2814 meters, the Palmyrides that reach 1308 meters and Jebel Alarab-Aldruz at 1790 meters [8] [9] [10] [11] [14].

The elevation of the area, referred to as "the Damascus Ghotta Basin" sprawls over the plain and central area between the fold mountains mentioned before. The height of the area is from 710 meters at the foot of Mount Qassyoun to 588 meters in the area of the Al-Higaneh Lake (see **Figure 2**).

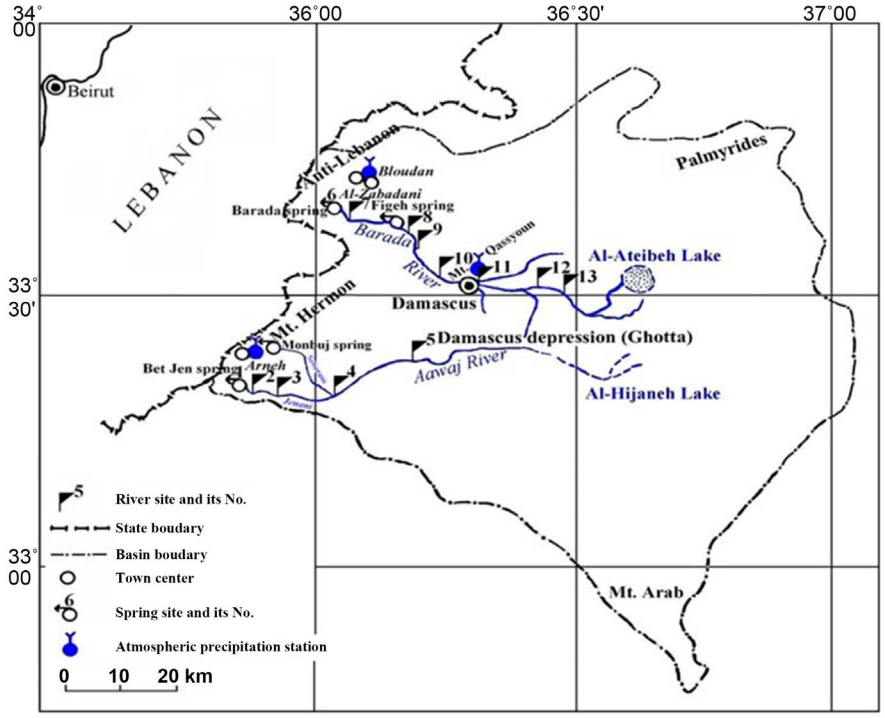

Figure 2. Barada and Awaj rivers location in basin [14].

The Damascus Basin's climate is Mediterranean; the winter is slightly rainy with temperatures between 10˚C and 15˚C and the summer is hot and dry with temperatures of 25˚C - 27˚C [10] [12]. At an elevation of 1500 - 2000 meters, the temperature is likely to fall to −0˚C, and in the summer season it can reach as high as 42˚C. The average yearly temperatures from east to west range between 16˚C - 17˚C in elevations less than 1000 meters, and from 4˚C - 5˚C in elevations of up to 2800 meters. Relative humidity is essentially connected to temperature variations so that 60% - 70% humidity prevails during the rainy months of January and February, while the humidity decreases to 24% - 50% as recorded in July and August [12]. Rainfall occurs only in the rainy season, between November and May, and the larger part, between 55% and 60% during December and February. Snow falls mainly in the mountainous areas. The amount of precipitation as one moves east and ranges between 1500 - 1800 millimeters in the Mount Hermon area, and 90 millimeters near Lakes Al-Hijaneh and Al-Ateibeh [13].

The hydrological characteristics of the Damascus Basin are mainly influenced by climatic variations, topography, geo-morphology, geology and ecological conditions of the area. The drainage network on the mountain slopes is quite dense, and completely disappears in the flat lowlands in the south and south eastern part of the basin. Besides the pumping of groundwater, the two rivers are the main sources of water in the area—the Barada and Awaj Rivers.

2.1. Barada River

The length of the Barada reaches 65 km with the area of the basin at 2400 square

km, and this is the main river flowing through the Damascus Basin. The river is fed by the Barada Springs that are in the middle of Wadi Zabedani (before the Al-Figeh Springs join it, whose average flow reaches 7.71 cubic meters per second). The river flows south in silt and sediment, in a narrow channel whose width ranges between 5 - 10 meters, changing its stream through a deep and narrow wadi called Wadi Barada. At the point where it crosses the Al-Figeh Springs, the river receives a huge amount of water, making up 50% of its total volume, especially during flood season. The Barada River continues to flow into the capital, Damascus, and there it divides into various irrigation canals that crisscross cultivated land in the plains area called "Damascus Ghotta". Occasionally the water from the river reaches the Ateibeh Lake [14]. The average annual flow of the river is 3.1 cubic meters of water per second, but as it leaves the mountainous region, the annual flow reaches 14 cubic meters per second, equaling 98 million cubic meters per year [15].

2.2. The Al-Awaj River

This is the second most important river in the Damascus Basin. This river is characterized by an annual flow regime. The length of the river reaches approximately 91 km and the surface area of the basin is 1480 square km. The river is fed by two streams, Jenani and Sebarani, which are fed by a large number of springs on the slopes of Mount Hermon (see **Figure 2**). In the course of its flow to the Damascus Ghotta, the river loses a significant part of its water as a result of usage, and its flow seldom reaches the Al-Hijaneh Lake. Its average annual flow under normal circumstances is 4.7 cubic meters of water per second, however in the past decade its flow decreased to 2.2 cubic meters per second, which is 70 million cubic meters per year. The river flows into the Al-Hijaneh Lake only in rainy seasons.

2.3. Population

The size of the Damascus Basin's population according to the 2000 data has been estimated to be 3.6 million inhabitants, constituting 21% of the total population of all of Syria. In 2010 the Basin's estimated population was 4.4 million, making up 21% of all of Syria as well. The population of Damascus was 14.9 million residents in 2000 and approximately 1.7 million in 2010 [16]. The percentage of natural increase ranges between 1.68% in Damascus and 4.48% in other parts of the Basin.

The principle economic activities in the Basin are services, industry and agriculture. The employment level in the Basin is somewhat higher than the national average, especially in Damascus. The number of employed persons in the Basin is estimated at 176,116, not counting those employed in the government or military sector, Most of the workforce is involved in services, and they make up 68% of the employed persons in the Basin. This number is close to the national estimate, which is 65%. The employed persons in the industrial sector number ap-

proximately 27.5%, while the national estimate is 26%. The agricultural sector makes up 4.5%, in contrast with the national estimate of 9% [17].

3. The Water Crisis in the Basin

The Barada-Awaj Basin is considered to be one of the basins confronting the challenge of water resources, and includes the highest percentage of population and density in comparison with other basins in Syria (nearly 23% of the total population of Syria and a population density of 670 inhabitants per km square [18], which has led and will lead to an increase in water usage for human activity. On the other hand, the basin is considered closed, with great differences in temperature and amounts of precipitation between the eastern and western sides of the basin, and the repeated drought seasons that visited the basin only increased the pressure on its water sources.

A study done by JICA shows that Syria must invest billions of dollars in order to prevent a grave water crisis in Damascus. In 2004 the Japanese government funded the renovation of the water piping of Damascus costing 50 million dollars, and it plans to continue to invest a total sum of 5 billion dollars in projects transferring water from the Euphrates River to Damascus [19].

There are many contradictions in evaluating the declarations and balances published by the various Syrian government offices and international agencies in everything having to do with water resources and their use in the drainage basin of the Barada-Awaj River region.

A report presented by Al-Shammi in his lecture and later quoted in [20] showed that the water balance in the Barada-Awaj Basin for 1995 was balanced, meaning that the amount of water pumped equaled the amount that was restored afterwards. Later, on August 6, 2001, the report of the International Bank in the department of Syria's Ministry of Irrigation, quoted the 1997 JICA study. This report shows the water balance with a deficit of approximately 450 million cubic meters of water [2]. Likewise, Varela-Ortega and Sagardoy, who quoted the data of the Syrian Ministry of Agriculture (MOI) in their research, speak about the deficit of 311 million cubic meters of water.

On the other hand, a report issued by the Syrian Ministry of Irrigation (MOI) in 2001, titled "Strategic Works in the Irrigation Ministry" reflects a different picture. That report shows that the water balance of the catchment basin of the Barada-Awaj Rivers stood at minus 762 million cubic meters of water in 2001, after the dry weather conditions continued for another two years consecutively [21].

However, Kaisi Ali, in his article "Syrian Arab Republic Report" shows the water deficit in the Damascus Basin to be 423 million cubic meters [22]. Subsequently Mourad and Berndtsson 2012, showed the deficit to be 212 million cubic meters for 2008 [23]. **Table 1** summarizes the differences between the various sources and compares percentages of water use for agricultural needs in the total water use in the various reports and studies.

Table 1. Water balance in Barada-Awaj basin according to various reports and studies.

	Alshami [6] & Gareth [20]	World Bank Report [2]	Varela-Ortega and Sagardoy [24]	Syria'MOI [21]	Kaisi Ali [22]	Mourad & Berndtsson [23]
Available Water						
Resources			452	452		
Wastewater Return			257	384		
Agriculture Drainage Return			568	120		
Total	1097	900	1277	956	714	836
Water Use						
Irrigation	748	920	1207	1200	786	675
Domestic	275	390	298	379	269	340
Industry	67	40	77	133	76	33
Evaporation Loss	6		5	5	6	
Total	1096	1350	1588	1717	1137	1048
Water Balance	0	−450	−311	−762	−423	−212

As can be seen from Table 1, the agricultural sector is the principle consumer of water in the Damascus region, and this is reflected b all the data that are reported in the research and various reports. The deficit in the water balance ranges between 212 million cubic meters and 782 million cubic meters. The groundwater level descends becomes lower each day by 3.1 mm (1.1 meters per year). As a result, the level of groundwater between Al-Zabadani and the Damascus region has dwindled, with especially sharp descents between 1989-1992 [2]. This downward trend continued after 1992 as well, and especially in areas closest to the capital (See Figure 3).

If the over-pumping of water continues, mainly farmers who depend on rainwater will remain in the area, and others will have to abandon it. This situation is likely to create a real need to transfer water from other basins to the affected areas.

This sort of condition does not only characterize the Damascus region and its surroundings. The Syrian Ministry of Irrigation has declared that "all drainage basins in Syria, with the exception of the Euphrates and the coast, have suffered from a large water deficit due to the adoption of irrigation with surface water or expanding this method of irrigation." [21].

3.1. Fluctuations in the Irrigated Area of the Basin

The Syrian Ministry of Irrigation acknowledges the overuse of water in agriculture. On August 16 2000 the ministry proclaimed the very ambitious and optimistic goal of modernizing irrigation methods. Likewise, a decision was made to reduce consumption per hectare to 7000 cubic meters of water within four years [21]). The area irrigated in the Damascus region and its surroundings has been reduced in the last six decades from 86,000 hectares in 1955 to 61,000 hectares in 2010 (See Table 2).

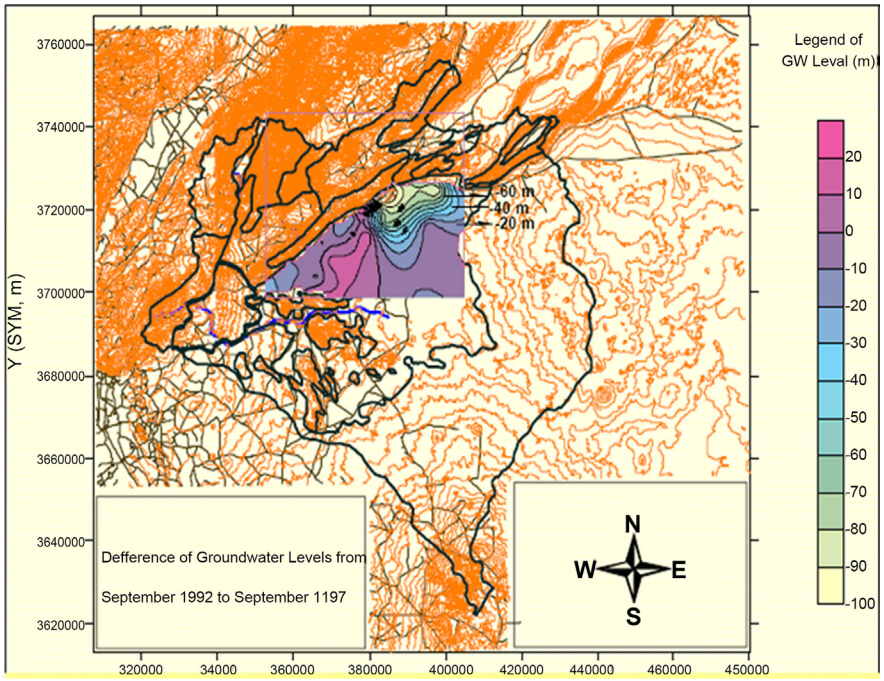

Figure 3. Differences in levels of groundwater in Barada-Awaj basin between 1992-1997 [25].

Table 2. Irrigated area in Barada-Awaj basin in various years (1000 hectares).

Year	Irrigated area	Year	Irrigated area
1955	86	1990	75
1961	72	1995	75
1966	64	1998	75
1970	68	2000	71
1973	87	2005	81
1979	74	2010	61
1984	79		

Source: [26].

The data refers to the district of Damascus and its rural surroundings.

During this period a number of fluctuations occurred in the size of the area 86,000 hectares in 1955, 72,000 hectares in 1961, 64,000 hectares in 1966, 68,000 hectares in 1970. 87,000 hectares in 1973, 74,000 hectares in 1979, 79,000 hectares in 1984, 75,000 hectares in 1990-1998, 71,000 hectares in 2000, 81,000 hectares in 2005 and 61,000 hectares in 2010 [26].

3.2. The Decrease in Flow of the Al-Figeh and Barada Springs

The available water in the area comes from the Al-Figeh Spring and 26 other smaller springs (a spring, in this context, has more than 10 liters of water flowing per second). Syrian statistics show that the amount of water flowing from the Al-Figeh Spring has decreased in the past 35 years. W. Mualla, the chairman of

the engineering department of Damascus University, offered an explanation connecting the dramatically decreased flow of the spring with pumping during drought years. The water authorities in Damascus began pumping in 1981 with the assumption that the amount of water would be returned from the aquifer during the dry season. From 1965 to 1974 the average flow was 7.4 cubic meters of water per second, and between the years 1975-1984, this decreased to 7.3 cubic meters. In 1985-1994 the flow decreased further to 7 cubic meters, and from 1995-2008, there was an additional decrease to 5.7 cubic meters. In 2009 the flow reached only 5.42, and in 2010 a low point of 4.8 cubic meters of water per second [16]. This shows a decrease of 35% between 1965 and 2010. This continuous downward trend is likely to be dangerous and can point to the end of the groundwater supply.

It is possible to claim that the irrigation water pumped from the Al-Figeh Spring constitutes half or more of this non-replenishing reservoir. The World Bank report shows that "a great low is developing in the groundwater between the Zabedani region and Damascus in the Barad-Awaj Basin [2]. In order to maintain balance in the basin, there is a need to reduce pumping in general and for irrigation in particular. This lack of balance has been worsening during periods of drought. The amount of rainfall falling on the basin in 2000 was 59% of the average yearly rainfall, and the year before it was 16% [21].

However, the average flow of the Barada Spring is much less than that of the Al-Figeh Spring, and stands at 3.12 cubic meter per second. A minimal flow of 0.32 cubic meter per second was recorded in January 2000, and a maximum of 4.12 cubic meter per second in the winter of 1991-92 [27].

This data, presented in a report titled (Climate changes and its impact on water sector, Mathematical modeling, Damascus, Syria, In Arabic) with the support of UNDP, in 2008, shows a clear rise in flow in the winter of 2002-03 that reached 7 cubic meters per second. Nevertheless, a drastic decrease of flow occurred in the winter of 2006-07, of 1 cubic meter, and estimates show a further reduction of flow by 0.5 cubic meters per second after 2010 [28].

3.3. Groundwater and the High Percentage of Unauthorized Wells in the Damascus Region and Its Rural Surroundings

The waters of the Barada River and the Al-Figeh Springs do not provide enough water for the needs of Damascus and its surrounding rural areas. These could be fulfilled for Damascus and its suburbs alone, but not for other areas. In the Ghotta plain there are seven main wells, dug by the Damascus Water Supply and Sewage Authority (DAWSSA), and in other areas more than 1000 secondary wells have been dug which provided approximately 30 million cubic meters of water [29].

In 2005, the Syrian government demanded that farmers obtain permits for their extant wells. This step was taken in light of the government's annual plan. The intention of the plan was to enable farmers to take loans from the central bank for agricultural tasks and to repay the loans after the harvest. Most of the

users did not request permits due to the difficulty of proving ownership of the plots and wells. By 2008, among the 222,000 wells in Syria, only 41% were authorized. In areas such as the Damascus *Rif*, the city's rural district, Aleppo and Dir-Alzur, the percentage of unauthorized wells was more than two thirds greater than the general number of wells.

Likewise, the continuing droughts in the last three years have caused the groundwater level in the wells to deepen from 90 - 100 meters to 120 - 150 meters. This makes it necessary to invest more time and money into pumping water or to dry out wells completely [30].

Unauthorized wells that were dug in the Barada-Awaj basin caused a decrease in groundwater. These wells were dug mostly for irrigation, and the majority, numbering in the thousands, were dug between 2000 and 2005.

A large part of the increase in water use is connected to the irrigation of wheat, cotton, citrus and sugar-beet fields. The price of pumping this water was subsidized by the government, therefore it did not influence the general yield production [31]. Irrigation is a strategy that can make agriculture more secure in arid areas such as Syria. Data show that crop and produce yields resulting from irrigation can reach five times that of those watered by precipitation alone [32]. The accelerated rate of growth in irrigated areas comes from the need to supply agricultural produce, and reliance on groundwater sources as well as surface water. The use of groundwater, especially for irrigation, rose dramatically in all of Syria from 0.6 million hectares in the middle of the 1980's to 1.2 million hectares by the end of the 1990's, which caused a large portion of the agricultural fields to change from being watered by rain to those watered by irrigation [33].

The high percentage of unauthorized wells in the Damascus area can be explained by lesser effectiveness in law enforcement in the capital as compared to other places. The concentration of army officers, ruling-party functionaries, and other members of the governing elite is the guilty factor here. Many of these individuals own country houses where they spend their weekends. Agriculture has become a form of investment in order to supply fruits, vegetables and poultry for the big city, which has grown quickly. Digging wells requires a permit that must be renewed every ten years. The price of irrigation is based on the size of the plot, and not on the quantity (volume) of the water necessary. Members of the stronger class violate this law [34].

Mualla and Salman, in their 2002 article based on the Syrian Agricultural Ministry data, reported that approximately 16,425 unauthorized wells exist in Syria, making up 25% of the unauthorized wells that existed in 1998. Since August 2000, only 2367 illegal wells, which make up 11% of the illegal wells in 1998 in the Damascus area, were made legal in that period (see **Table 3**).

3.4. The Great Population Increase in Damascus and Its Rural Surroundings

The water deficit in the Damascus area is due to rapid population growth since

Table 3. Licensed and unlicensed wells in damascus and its rural basin compared to all basins in Syria.

Year	Damascus and its Rural Basin				All Syrian Basins			
	Licensed Wells	Unlicensed Wells	Total	%	Licensed Wells	Unlicensed Wells	Total	%
1982	NA	NA	12,000		NA	NA	NA	
1998	3315	22,169	25,484	87	73,779	66,120	139,899	47
2000	3516	27,558	31,074	89	73,834	64,168	138,002	46
2005	7753	38,883	46,636	83	86,030	116,244	202,274	57
2010	13,715	43,246	56,961	76	98,884	130,997	229,881	57

Source: [26].

Table 4. Population growth and density in the basin between 1948-2011.

Year	Population (1000)	Density Cap/km^2
1948	437,000	50
1960	704,000	81
1981	1,681,533	195
1989	3,855,000	451
2008	5,000,000	582
2011	5,780,000	670

Source: [18].

the 1950's. The situation has worsened even more because of the water management policy that was instituted over the course of decades. Table 4 shows the development of population growth and density in the Barada-Awaj Basin between 1948 and 2011. From the table, one can clearly see an increase of 13 times the original number of inhabitants, and the consequent increase in population density, which in turn led to the decrease in available water per person annually, from 188 cube in 2000 to 147 cube in 2011 [18].

The population in Syria numbered 3.3 million inhabitants at the end of 1948, and 20.8 million at the end of 2010, while the population in the Barada-Awaj Basin numbered 437,000 in 1948 and grew to 5,780,000 in 2011.

The growth rate of the Syria's population from the end of the 1940's to the end of the last decade reached 630%, while the rate of increase in the Barada-Awaj Basin in the same period reached 1320%. The population increase in the Barada-Awaj Basin was double that of the total in Syria in that period.

3.5. Failure to Increase the Areas Watered by Modern Irrigation Methods

Agricultural modernization is a complex process whose goal is to achieve fundamental change in the regulations and laws that affect irrigation management, in order to improve water supply service to users. The process includes, among

other things, physical intervention in infrastructures and management, in addition to political and organizational reform in the irrigation infrastructure. The Food and Agriculture Organization (FAO) declared that "modernization in the irrigation system is the technical and management process of upgrading the irrigation program, together with organizational reforms whose purpose is improved exploitation of water sources and their supply to farms and agriculture [35] [36].

At the end of the 1980's, Syria began, with the help of the FAO and United Nations Development Program (UNDP) a project to promote the use of sprinklers ad drip-irrigation, as well as creating balance in agricultural land using laser technology (Improved Management of Water Resources in the Syrian Arab Republic, UNDP/FAO 86015). Later, the Syrian government launched programs to encourage the use of these irrigation technologies by offering low-interest loans that cover about 85% of the cost of sprinklers and drip systems. As a result of the drought that Syria experienced in 1998, these loans grew to 100%.

According to the Syrian government decision No. 2166, the irrigated area will be equipped with modern irrigation technology within the next four years. This means that the area whose surface is 1,149,349 hectares must be equipped with this technical apparatus at a rate of 287,337 annually. The modernization policy aims at decreasing the annual use of water for one hectare from 12,434 cubic meters to 8000 cubic meters. The average amount of water required per hectare according to primitive irrigation methods is estimated at 14,446 cubic meters of water per year. The transition to the use of sprinklers is likely to decrease this quantity to 8920 cubic meters which would be a 38% conservation of water and a 31% increase in annual harvest.

In contrast, transition to the innovative irrigation drip system is likely to reduce water consumption per hectare to 6113 cubic meters, which would be a 58% conservation and a 35% increase in yearly crops [35]. Data from the Syrian agricultural ministry showed that the drip and sprinkler method has already been instituted in approximately 9800 hectares in the Damascus area of 170,000 hectares in all of the country [37].

The area of farmland irrigated by modern methods in the Barada-Awaj Basin rose 33% from 3% in 1998 to 35% in 2009 (see **Table 5**), while at the same time the increase in use of modern irrigation methods rose only 29% in all of Syria, and the number of plots irrigated in the entire country did not rise above 282,000 in 2009. In addition, there were a number of fluctuations in this process, so that in some years the areas irrigated by modern methods decreased, as was the case e.g. in 2001, 2003 and 2006. This data contradicts the government's aspiration to transform 287,000 hectares to modern irrigation each year [29]. It must be remembered that the amount of agricultural land in the Barada-Awaj Basin decreased from 75,000 hectares to 56,000. Likewise, the use of modern methods for only 35% of the farmland there is insufficient for saving water in the Basin.

Table 5. The growth of modern irrigation methods in the Barada/Awaj basin compared to all Syria basins.

Basin	drips	sprinklers	Total land Irrigated by modern methods (1998)	Total Irrigated land (1998)	%	Drips	Sprinklers	Total land Irrigated by modern methods (2009)	Total Irrigated land (2009)	%
Barada/Awaj	1227	893	2120	75,000	3	17,200	2900	20,100	56,000	35
All Syria	8533	80,480	89,003	1,214,000	7	103,000	178,900	281,900	1,239,000	23

Source: [29] cited from [16] [38].

3.6. Decrease in Average Amounts of Rainfall in General, and in the Damascus Basin and Its Sub-Basins

It is expected that the Middle East will experience from 20% - 25% decrease in rainfall by 2050 which will lead to a decrease of up to 23% in the amount of water, and subsequently a decrease of between 30% and 70% in the flow of the rivers in the region.

The average rise in temperatures in the Middle East is likely to be up to 2.5˚C by 2050, which will cause water evaporation [39] [40]. Global climate models (GCMs) have indicated decrease in precipitation in the eastern basin of the Mediterranean: Turkey, Syria, northern Iraq and northeast Iran. Moreover, according to Wasimi [41], Syria is located in an area of the Asiatic Rift which is likely to experience a temperature rise of 0.05 degrees Celsius per year, while at the same time the amount of rainfall will decrease by 1.5 mm.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) in cooperation with BGR and the Stockholm Environmental Institute (SEI) has developed a model for observing the influence of climatic change on groundwater balances. This research model follows the United States Geological Survey Modelflow 2000 which examines the dynamics of underground water and the Stockholm Environmental Institute model WEAP 21 that checks the supply volume and balance of underground water [42]. This new model provided information regarding the climatic behavior over the thirty years that passed between 1961 and 1990, and predicts conditions between 2070 and 2099. This information has been correct regarding 2005-2017 (See **Figure 4**).

Figure 5 shows the annual rainfall for the Damascus district and its environs in all the various agro-climatic areas. One can clearly see from the graph that the amount of rainfall measured at the various stations between 1995 and 2009, with an average amount of 262 mm, were significantly less than the annual average which was 308 mm [44].

4. Conclusions

Up until the 1990's, the water balance in the Barada-Awaj Basin was even; later the balance turned into a deficit with many contradictions in the reports of the amount of water in deficit.

Non-rational use of water resources in the agricultural sector led to a negative

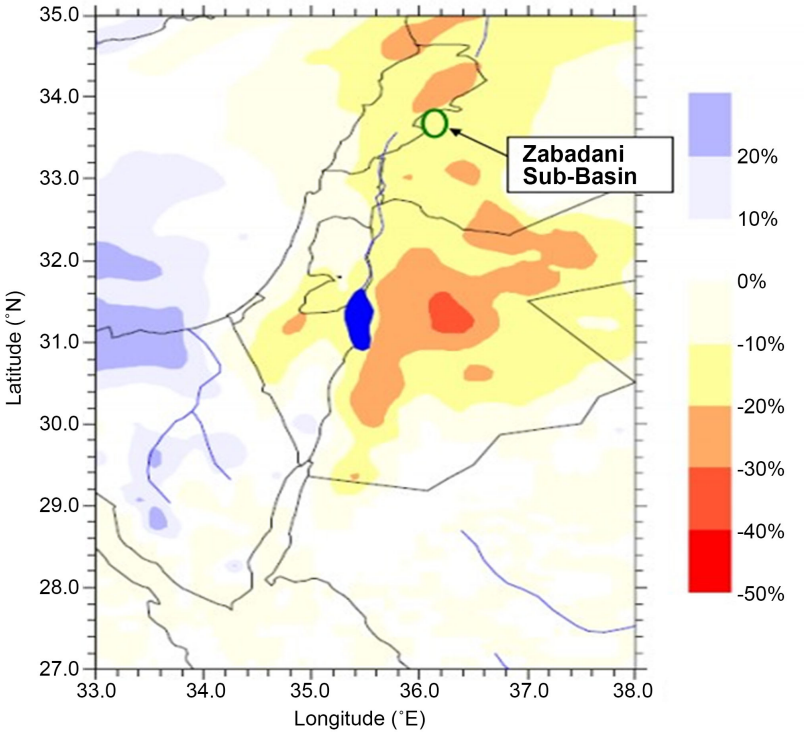

Figure 4. Decreased rainfall in Barada-Awaj basin in general, and in Zabadani sub-basin in particular [28] cited from [43].

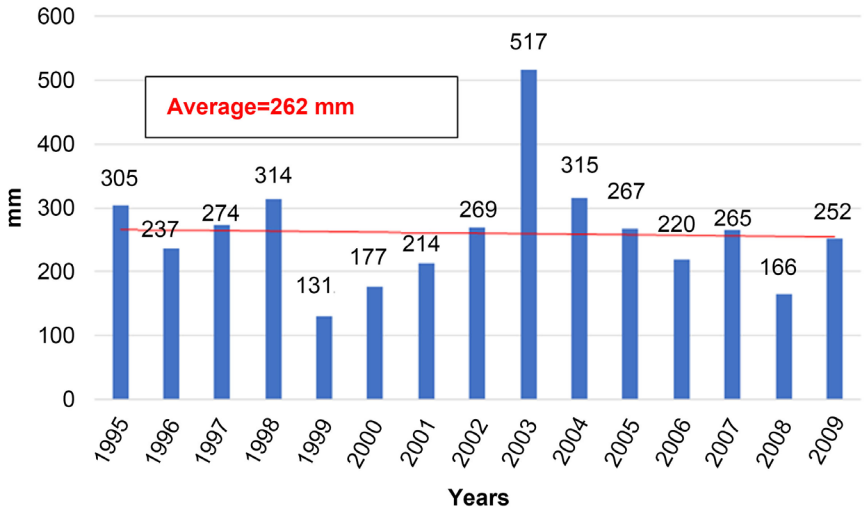

Figure 5. Amounts of precipitation in damascus and its rural basin in various years [26].

influence on this sector. Growing crops on farmland with no consideration regarding the availability of renewable and extant water led to a significant deficit in the Barada-Awaj Basin.

As a result, farmers in Syria must develop skills in the use of innovative irrigation techniques which will lead, as has been explained, to decreasing the use of water and an increase in crop yields. Moreover, the over-pumping from legal and illegal wells led to a significant decrease in underground water levels, changes

in water quality and the drying up of a large number of springs that the government depends upon for water collection for agricultural projects.

Population increase had an influence on the diminution of water sources in this basin. In the period when the area's inhabitants numbered nearly half a million, there was no significant domestic use of water, but when the population reached nearly 6 million, the demand for water became significant and required the use of alternative sources. Finally, the decrease in rainfall in the area and a whole, and in the Barada-Awaj Basin in particular, has caused a substantial decrease in the filling of renewable aquifers.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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