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Factors Affecting the Discharge Rate of the Streams – Case Study; Damour River Basin, Lebanon

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Authors' contributions

This work was carried out in collaboration among all authors. Author KK designed the study, wrote the protocol and wrote the first draft of the manuscript, managed the literature searches, analysis of the study. Author FK assisted the work of the first author and author NA managed the experimental process, statistical analysis and performed image processing and contributed to the first draft of manuscript. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

The distribution of precipitation on runoff, evapotranspiration and groundwater recharge and the change of this distribution in response to human activities plays rather important role in the availability of water resources, especially in areas of Mediterranean climate. This study used data on the discharge obtained from six gauging stations along the Damour River and its tributaries, and rates of precipitation obtained from rain gauges located in Beirut belonging to LMS. The study used these data to evaluate the relationship between the precipitation and streams discharge, and to assess the ratios of runoff, evapotranspiration and infiltration. The study came up with the following conclusions: The rates of runoff and groundwater discharge for the whole Damour river basin could reach 70%, and the remaining 30% go mostly to evapotranspiration and submarine springs fed from this basin. The lag time between maximum rainfall and peak discharge of streams ranges between one and three month(s), and the longest lag time is exhibited by es Safa spring discharge.

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High relief areas play a major role in shortening the lag time between maximum rainfall and peak discharge. The timing factor of precipitation events is rather significant and causes great differences in the ratios of discharge throughout the wet season. Finally, the runoff ratio is affected by the following factors: Underlying rocks, snow cover, steepness of the slope, vegetation cover, and timing of precipitation.

Keywords: Discharge; infiltration; precipitation; runoff; water balance; Damour basin.

1. INTRODUCTION

The shortage in water resources has become a major problem on the national, regional and international levels. Water demand in the Middle East region continues to increase due to high growth in the population, rise in the standards of living, scarce water resources and inadequate climatic changes. Although Lebanon is not considered as water deficient country and water is not a pressing issue as the case in many other Middle Eastern countries. Yet, due to the reasons mentioned above, Lebanon will suffer from water deficiencies in the forthcoming decades. The only source of water in Lebanon is the precipitation. The distribution of precipitation on runoff, evapotranspiration and groundwater recharge and the change of this distribution in response to human activities plays rather important role in the availability of water resources. The aim of this study was mainly to evaluate the relationship between the precipitation and streams discharge, and to assess the ratios of runoff, evapotranspiration and infiltration. The application of the methodology used in this study to all other Lebanese river basins will make a significant contribution towards assessing water balance for the whole country. This study used data on the discharge obtained from six gaging stations along the Damour River and its tributaries, and rates of precipitation obtained from rain gauges located in Beirut belonging to the Lebanese meteorological Services (LMS).

2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

To understand the relationship between the precipitation and rivers discharge, it is important to review the factors that affect this discharge. These factors include: climatic effects, vegetation cover, and timing of precipitation, topography, geological setting and human effects.

2.1 Climatic Effects

Climatic changes are known to affect severely on water resources across the world. [1] Indicated that in the last quarter of the past century annual mean air temperature, precipitation and runoff have showed increasing trends. On the other hand, [2] concluded that the principal climatic changes in Lebanon lead to significant changes in water volume, such as a decline in the discharge of rivers ranging from 10 to 30%, and a decrease in the runoff ranging from 10 to 20% [2]. Generally, the climatic effects are caused mainly by precipitation and temperature. The precipitation rate is generally an important factor that affects the quantity of discharge. However, the way, by which precipitation occurs, plays a crucial role in this quantity. For example, heavy (frequent and intensive) rains tend to decrease the infiltration and evapotranspiration and thus cause more water to reach the stream (runoff). The type of precipitation may affect the discharge of a stream. If the precipitation occurs as snowfalls, then the discharge decreases [3]. In Lebanon, most of the discharge occurs during winter. This is because almost all of the precipitation occurs in the period November-April and falls mostly as rain ending up in the drainage system. On the other hand, the discharge of water, as snow melt, during summer months is very low as most of the snow melts during spring.

The temperature, on the other hand, plays an important role in evapotranspiration and snowmelt. In summer, high temperatures increase the evapotranspiration which leads to the reduction of the discharge. But in areas of higher latitudes than the Mediterranean region, precipitation also occurs in summer and most of the snow cover of mountainous areas melts during this period due to high temperatures. These two factors significantly increase the discharge.

2.2 Topography and Vegetation Cover

If the slope of the streams channel is steep, then the water is likely to move down faster, increasing its flow speed [4]. Steep slopes lead rain water to flow on the surface, as runoff, more likely than infiltrating to the ground or evaporating. On the other hand, gentler slopes slow-down the flow of water and hence, rainwater infiltrate into the ground or evaporate more likely than running off.

The vegetation cover can reduce the discharge rate. Plants can simply provide a physical barrier to surface runoff, reducing its speed, which increases evapotranspiration and infiltration, and therefore slowing down the rate of runoff [5]. On the other hand, it has been indicated that after the immediate application of straw mulch the runoff has decreased by one order of magnitude [6].

2.3 Timing of Precipitation

The time/season of the year of the occurrence of the precipitation is one of the important factors affecting river discharge. In Lebanon, at the beginning of the rainy season (November-April), the temperature of the soil and rocks near surface is relatively high and the level of water table is low. These factors cause the evaporation of much of the rainwater and infiltration of some of it to groundwater aquifers, which reduce the discharge. Later on in December-March period, the soil temperature decreases and the groundwater aquifers become saturated, so much of rainwater goes to stream runoff.

2.4 Geological Setting

The type of rock and soil outcropping in watersheds has a crucial role in the infiltration of rain water and snowmelt. Massive non fractured igneous, metamorphic and carbonate rocks have generally very low porosity and permeability, and therefore do not lead to the infiltration of water. Sandstones may cause moderate infiltration of water into groundwater aquifers. Shale and marls have very low permeability and do not lead to the infiltration of water [7]. Fractured rocks especially carbonates may have the highest capacities in water infiltration [8]. Moreover, the presence of fault systems may increase the capacity of water infiltration [9].

2.5 Human Effects

Human activities have important effects on the discharge of streams. The activities that affect significantly the discharge and runoff are: urbanization, deforestation, forest fires and land use, and groundwater exploitation.

The used materials, with which the cities are built, such as asphalt and concrete, are almost impermeable and considerably reduce infiltration and increase runoff. The artificial impervious surfaces can cause higher discharge of streams in urbanized drainage basins, because of higher amounts of surface runoff [10].

Clearing the vegetation cover, especially forests, means that rain water would have lower chances to saturate the ground. Hence, surface runoff will increase and consequently the discharge increases. Forest fires, which are mostly anthropogenic, lead to a decrease in water infiltration and an increase in runoff of rainfall and snowmelt [11,12].

Arid barren lands that are covered with rocks and vegetation may reduce the discharge. However, if the land is used in agriculture the discharge increases because the amount of water infiltration decreases and then the discharge increases. Similarly, overgrazing contributes to the increased discharge as it reduces the amount of herbs, which normally increase evaporation and infiltration [10]. In agricultural fields, the method of plowing has an effect on the discharge. Contour plowing reduces discharge, as it creates horizontally oriented furrows, which prevents the flow of water and reduces runoff. On the other hand, the trampling effect of the animals compacts the soil thereby reducing infiltration and generating surface runoff. Moreover, [13]. concluded that herbicide treated lands had higher runoff ratios compared to other lands.

Drilling of water wells and taping of groundwater aquifers significantly affect the discharge. For example, the discharge of Abou Ali river has declined about 16% during the period 1974-1986 (with some interruptions due to the Lebanese civil war) compared to the period 1948-1968, while the precipitation has dropped for only 1%. This decline in the discharge is mostly due to the overexploitation of ground water aquifers [14].

3. DAMOUR RIVER BASIN

3.1 Location and Areal Extent

The Damour River basin is located a few tens of kilometers southeast of Beirut. It lies along the northwestern flank of the Barouk Mountain. The basin covers an area of about 290 km^2 (Fig. 1). The basin is bounded from the north by the upper part of Beirut river basin. From the east, the basin is bounded by the Mount Lebanon water divide, which demarks the boundary between the Litani river basin, to the east, and

Mount Lebanon river basins, to the west. From the south and southeast, it is bounded by the Awali river basin. From the west, the basin is bordered along short stretch by the Mediterranean Sea in the area of river mouth and it is bounded to the north and south of the mouth area by small basins of intermittent streams that flow after rainy and rarely snowy storms [15].

3.2 Geomorphology

The altitude of Damour river basin ranges from 0 m at sea level (river mouth), to 1980 m above sea level at the top of the highest hill of the Barouk Mountain. The tributaries of Damour River have carved deep valleys, and canyons along some of its stretches, with very steep slopes and some cliffs along many of stream sides. The depth of the valley may exceed 700 m in many places [15]. The relief is very high in many places. For example, the altitude jumps from 450 m of elevation at the Abou Zebli electric power plant to 930 m in Kfar Niss over a lateral distance of one kilometer. Moreover, there are many cliffs reaching heights of 60 m [15].

3.3 Geology

Almost all Mesozoic formations known in Lebanon are outcropping in the area of Damour river basin. The Jurassic successions (J_4-J_7) especially carbonates underlay an appreciable area of the eastern part of the basin, east of es Safa spring (Fig. 2). These are made up of massive fractured and karstified carbonates [16, 8]. Hydrogeologically, these rocks are characterized by very high infiltration rate of about 42% (UNDP, 1970). Upper Jurassic successions outcrop in a narrow patch about 8 km long and 1 km wide at the bottom of the valley from Jisr el Qadi downstream (Fig. 2). These rocks form 50-60 meters-high cliffs to both sides of the valley in this area [17].

Most of the area of the basin is underlain by lower Cretaceous rock successions (C_1-C_3) especially in central and northern parts of the basin (Fig. 2). These successions include: the Chouf sandstones (made up mostly of slightly lithified sand); the Abieh formation (made up mostly of sandy argillaceous limestone, claystone and shale); the Mdairej limestone (made up mostly of fractured massive limestone); and the Hammana marl (made up mostly of marl interbedded with fractured limestone beds). Except for Mdairej limestone, which is cliffy and does not outcrop over large areas, these formations have very low to moderate infiltration rates (3-13%) [17].

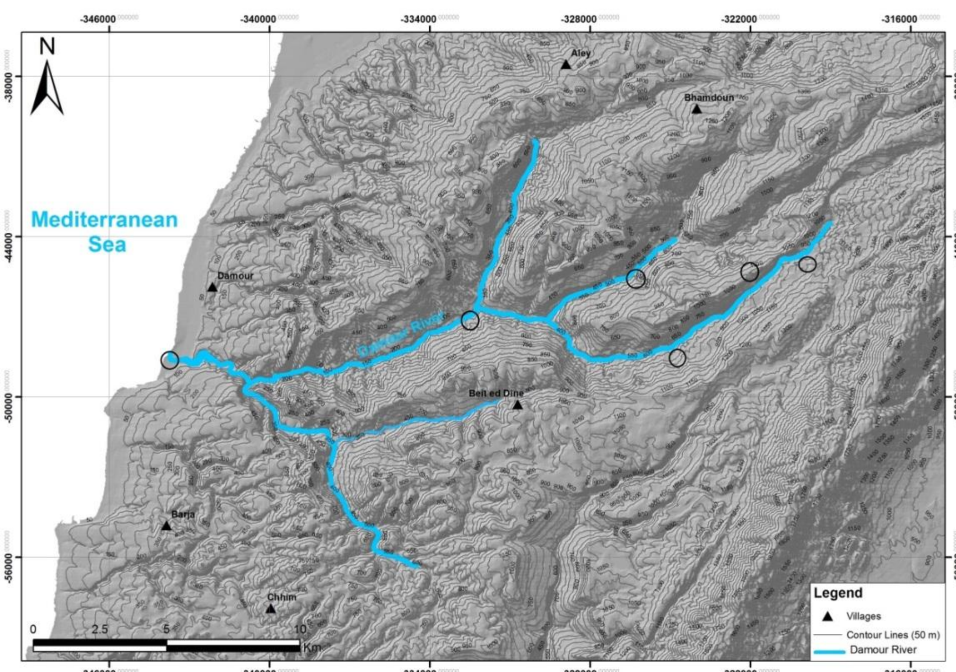

Fig. 1. The Topographic map of Damour river basin (Adapted from [15])

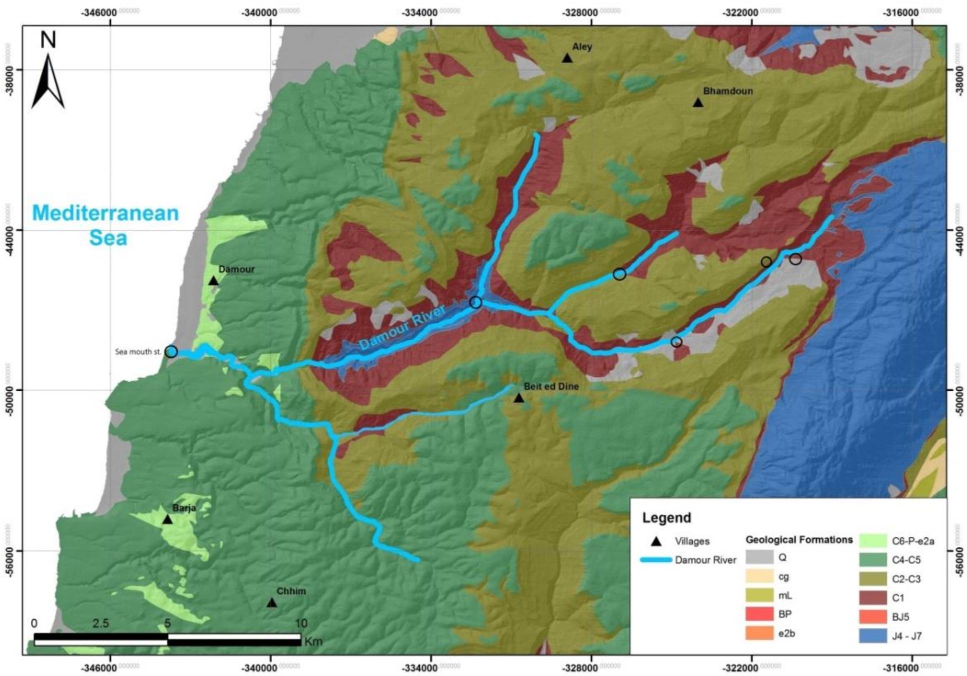

Fig. 2. The Geologic map of Damour river basin (Adapted from [16])

The Sannine limestone (C_4) is made up mostly of fractured thin and thick bedded limestone with chert geodes and bands at different levels. These rocks outcrop in many areas, especially in the southern part of the basin. Hydrogeologically, these rocks are characterized by the highest infiltration rates reaching in some places 49%. The outcrops of Maameltain formation (C_5) are not widely found in the area of the Damour River basin. The outcropping areas of The Chekka marl (C_6) are localized east of the river mouth, these rocks are characterized by very low infiltration rates. Finally, the basin is also underlain by Quaternary landslide deposits (cg) covering an area of about 10 km^2 scattered in many places along the steep slopes of basin's valleys (Fig. 2). These deposits are characterized by low to moderate infiltration rates.

3.4 Vegetation Cover

Fig. 3 shows that the vegetation cover is widely varying in the basin quantitatively and qualitatively. The natural vegetation cover is thickest in the Multaqa en Nahrain area, where oak trees cover almost completely the ground over large areas, both in the bottom of the valley and along the slopes. This cover becomes less dense moving upstream (Fig. 3). The natural vegetation cover is negligible or nonexistent on the plateaus, ridges and hills. These areas, which make up about 2/3 the area of the basin, have been urbanized extensively.

3.5 Precipitation

Similar to other areas of Mount Lebanon, the precipitation rates increase with altitude. It rises from about 900 mm/yr in the mouth area, to more than 1500 mm/yr in the higher parts of the basin along the ridge of the Barouk Mountain (Fig. 4). From the pluviometric map of Lebanon, it has been estimated that the average precipitation rate for the whole basin is about 1230 mm/yr (Fig. 4). In this study, the data on precipitation was taken from Beirut International Airport (BIA) station and the Golf station, which belong to the Lebanese meteorological Services (LMS). Once the rate of precipitation in Beirut over a period of 118 years (1876-1993) was 890 mm/yr [18], and the average precipitation rate for the whole basin is about 1230 mm/yr (Fig. 4). The current values of precipitation for Beirut stations were multiplied by a factor of 1.38, which is the product of the ratio of rates 1230 and 890 mm/yr.

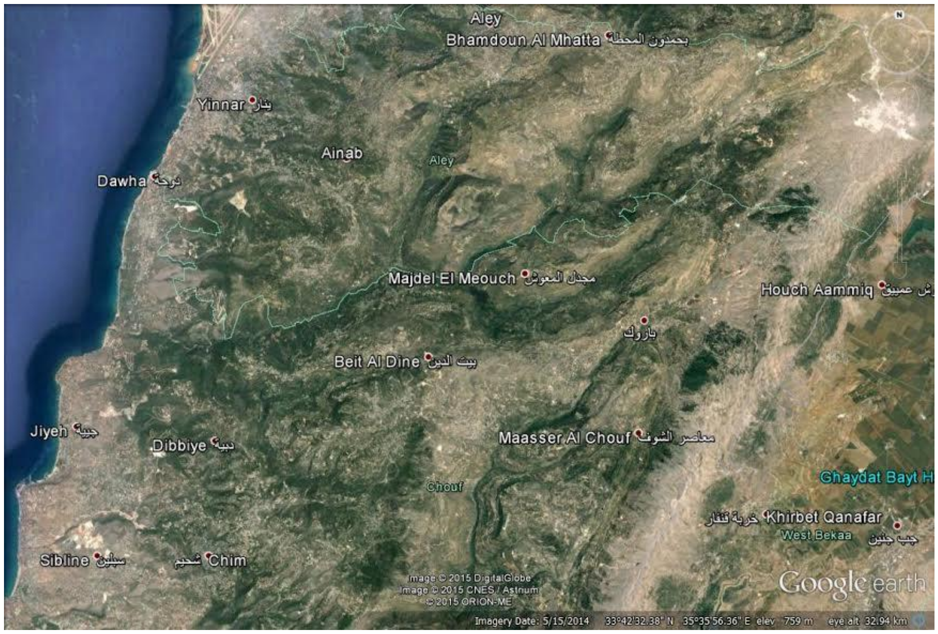

Fig. 3. A Satellite imagery of the area of Damour river basin [19]

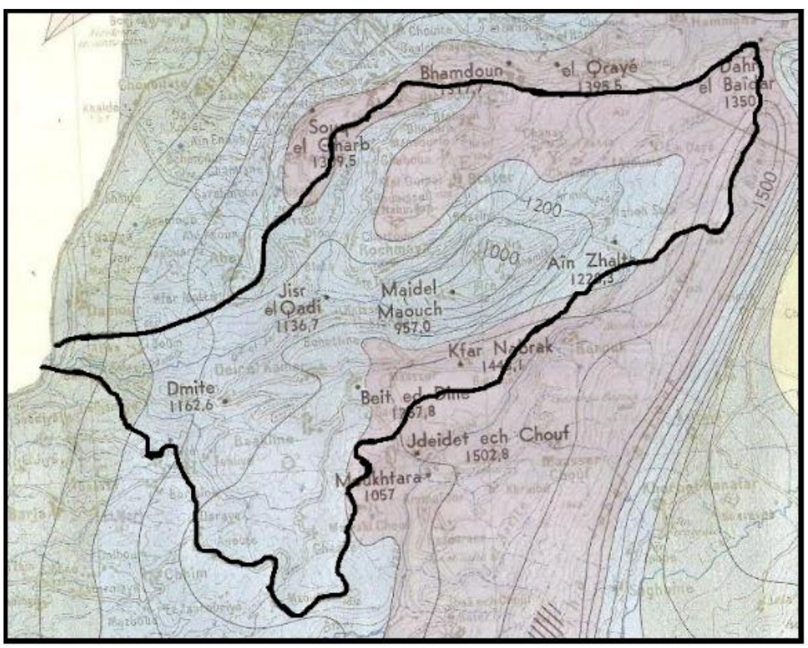

Fig. 4. The pluviometric map of Damour river basin [20]. Contour lines represent hundreds of millimeters of precipitation

4. METHODOLOGY

4.1 Data and Basin Characteristics

The discharge data used in the study was obtained from six gauging stations in the Damour river basin. Table 1 shows the names, the periods of record, the stream or spring measured and whether the record is monthly or daily. The data for each season does not coincide with calendar years, but it starts in September and ends in August of the following year. For example, the data for the year 2004 starts in September 2003 and ends in August 2004.

Fig. 5. Shows the areal extent of the sub-basins included in the Damour river basin and the location of gauging stations (green circles). The distribution of gauging stations, except for the es Safa spring and Jisr el Qadi, makes the assessment of the discharge of different tributaries flowing in the Damour river basin difficult and not accurate. For example, the location of Wadi es Sitt station is not at the end of Naher es Safa stream where it merges into the Abou Zebli stream (Fig. 5). Similarly, the Rechmaya gauging station is located along the Abou Zebli stream and not at its end before it meets with Naher el Ghabon stream (Fig. 5). This station records the water flows of both Abou Zebli stream and es Safa canal. So, to obtain the discharge rate of Abou Zebli stream, upstream the station, the discharge of es Safa canal must be subtracted from the discharge recorded at Rechmaya gauging station. Moreover, the diversion of water in es Safa canal from Naher es Safa stream sub-basin to Abou Zebli sub-basin makes the assessment of the discharge of this sub-basin, upstream Wadi es Sitt station more difficult. To solve this problem, the discharge of this sub-basin, could be obtained by summing up the discharge at both es Safa canal and Wadi es Sitt stations. The respective subtraction and addition to obtain the discharge of Abou Zebli and Naher es Safa streams, faces some problems in accuracy during dry season, as some of the water between the outflow of es Safa canal and the Rechmaya station might be lost on evaporation, irrigation and infiltration.

It is worth noting that the stream hydrographs addressed in this study for the discharge of Abou Zebli (57 km^2) and es Safa sub-basins (46.2 km^2), does not include the discharge of areas located downstream Rechmaya (15.7 km^2) and Wadi es Sitt stations (17.4 km^2). The discharge of these areas could be obtained together with the discharge of Naher el Ghabon sub-basin (44.4 km^2) by subtracting both the discharge recorded at Rechmaya and Wadi es Sitt stations from the discharge recorded at Jisr el Qadi station (Fig. 5). This discharge will be addressed as the discharge of the Naher el Ghabon sub-basin. Similarly, the discharge of Naher el Hammam stream, which draws its waters from the streams of Naher ej Jahliye and Wadi Deir sub-basins (76.3 km^2), could be obtained by the subtraction of the discharge recorded at Jisr el Qadi station from the discharge recorded at Sea Mouth station. However, this will also include the discharge of the areas located between Jisr el Qadi and sea mouth (32.8 km^2), see Fig. 5. The result of subtraction will be addressed as the discharge of Naher el Hammam stream. So, in this study, the data obtained for Naher el Ghabon and Naher el Hammam streams are not precise, as the values of their discharge also include the discharge of small areas that are not parts of these two sub-basins. The precipitation rates for each of the sub-basins were estimated from the pluviometric map (Fig. 4). This rate was 1275 mm/yr for es Safa and Abou Zebli sub-basins, 1250 mm/yr for Naher el Ghabon sub-basin, 1175 mm/yr for Naher el Hammam sub-basin. So, the multiplication factors for these sub-basins were 1.43, 1.40 and 1.32, respectively.

4.2 Data Manipulation and Presentation

In this study, the relationship between the precipitation and discharge of the main streams of Damour basin has been studied on a yearly, monthly and daily basis. Moreover, the data were processed on a storm -basis, and the studied storms could last from one to 13 days.

Table 1. Description of gauging stations in the Damour River Basin

Station name	Periods of record	Spring or stream measured	Type of record
es Safa spring	2004-2014	es Safa spring	Monthly
es Safa canal	2002-2012	Water flow carried to Abou Zebli hydroelectric plant	Monthly
Wadi es Sitt	2001-2014	Tributary of Wadi es Sitt valley	Daily
Rechmaya	2001-2010	Abou Zebli stream + es Safa Canal	Daily
Jisr el Qadi	2002-2014	Flow at Rechmaya and Wadi Sitt stations + Naher el Ghabon stream	Daily
Sea Mouth	2001-2014	Flow at Jisr el Qadi station + Naher el Jahlieh stream	Daily

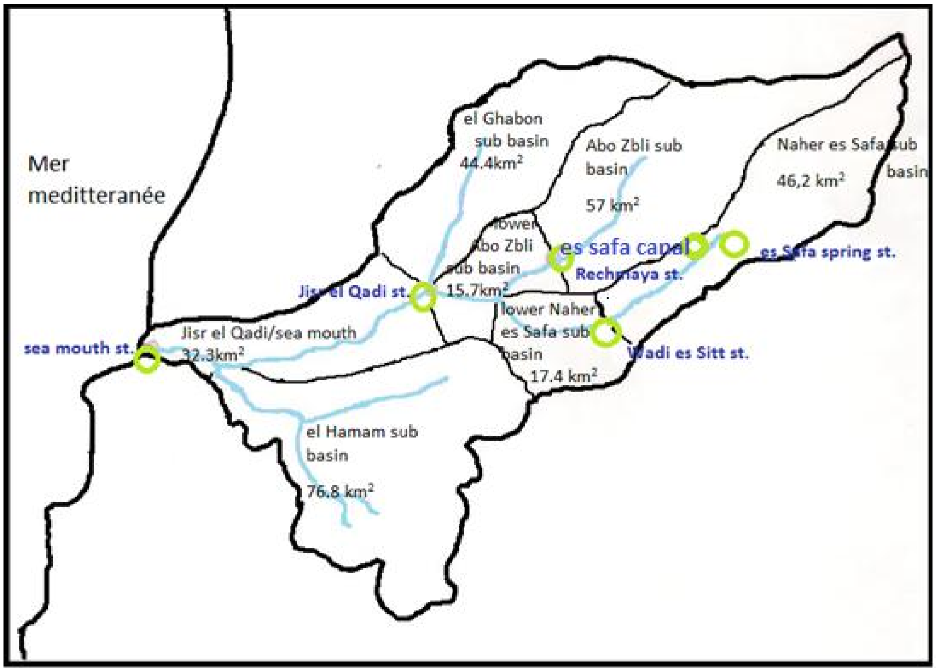

Fig. 5. Map of the sub-basins of Damour river basin

Yearly stream hydrographs were constructed to show whether there is a direct relationship between the precipitation and all streams, the discharges of which are recorded. These hydrographs could give a general idea on the dependency of discharge on the precipitation for many streams presented on a single diagram. Moreover, the water budget for the whole basin has been calculated, based on the discharge data at the sea mouth gauging station D_{sm} (Table 3). This calculation covered the period 2004-2011. The precipitation rates of El Horsh station in Beirut P_h were converted to basin-values P_b by multiplying them by the factor 1.38, as it has been mentioned above:

$$Pb = Ph \times 1.38$$

Then, the precipitated water P_y in the basin for each year has been calculated by multiplying the yearly precipitation rates for the basin P_b (in meters) by the area of the basin in square meter 290,000,000 m^2. The ratio of runoff and springs discharge (infiltration) R_{ri} has been calculated by dividing the yearly river discharge at the sea mouth station D_{sm} over the precipitated water P_y:

$$Rri = \frac{Dsm}{Py}$$

The ratio of evapotranspiration has been calculated by subtracting the proportions of runoff and infiltration from one hundred: $Re = 100 - Rri$

Monthly stream hydrographs were constructed separately for es Safa spring, and Abou Zebli and Naher es Safa sub-basins, and the whole Damour river basin recorded at the sea mouth station. For each of these stream flows, monthly stream hydrographs were constructed for the year 2008, during which the rates of precipitation were almost average over the period of available data. The goal of this study is to show the lag period between the maximum rainfall and peak discharge of streams. In other words, how approximately long does it take for water to infiltrate into the groundwater and exit to the surface again?

Daily stream hydrographs were constructed for the stream at the sea mouth station, at Jisr el Qadi station and for Naher es Safa and Naher Abou Zebli streams together by summing up the daily stream hydrographs of Rechmaya and Wadi es Sitt stations. This addition was performed because there is no daily record for es Safa canal station to separate between Naher es Safa and Abou Zebli streams. The daily stream hydrograph for es Safa spring was not constructed because its gauging station like es

Safa canal does not provide a daily record of the discharge (Table 1). The hydrographs have been constructed for the period November 2001-February 2002. The period covered by the hydrographs was only 4 months, and not for the whole wet season, because the bar graphs would not clearly show the relationship between the precipitation and the discharge. The rainy season 2001/2002 was chosen because, this is the latest year of data available for daily record of the BIA station and the earliest year of data for all discharge stations that provide a daily record. The reason for building these hydrographs was to show the effect of precipitation on the runoff from several hours to several days, and to show that this effect widely varies between the beginning and end of the rainy season.

The processing of data on storm basis was carried out to assess the ratio of runoff R of the precipitated water in a storm, and how does it vary in space and time domains. 11 storms were studied and processed, 4 in 2000/2001 rainy season and 7 in 2001/2002 rainy season. It was not possible to process the storms that occurred in later years as the daily data on precipitation is available up to 2002 rainy season. The studied storms were chosen to be widely separated from other storms in time to avoid their effects on each other. The daily precipitation rates obtained from BIA station were converted to the Damour basin rates by multiplying the Beirut rates by a factor of 1.38. The amount of precipitated water P on the basin or sub-basin was calculated in cubic meters by multiplying the rate of precipitation (in meter) during the storm by the area of the basin or sub-basin (in square meter). The rates of stream discharge caused by the storm D_{st}, were calculated by subtracting the rates of discharge during the days of the storm and the following days D_{as} minus the rate of discharge one day before the storm D_{bs}:

$$\mathrm{Dst} = Das - Dbs$$

In other words, D_{st} is the rate of discharge caused only by the storm, and does not include the base flow discharge. The amounts of discharged waters by streams, caused by the storm, each day D_d was calculated by multiplying excess discharge D_{st} by 86400, which is the number of seconds in a day, as the discharge rate is provided in cubic meters per seconds. The total amount of discharged water by the stream caused by the storm D_t, was calculated by summing up the discharged waters D_d of all days considered. The percentage of run off R was calculated by the following equation:

$$R = \frac{\mathrm{Dt}}{P} * 100$$

It is worth noting that the data for the Rechmaya and Wadi es Sitt stations were summed up together. So, the upper Abou Zebli and es Safa sub-basins were treated as one sub-basin due to the lack of daily data for es Safa canal, which transfers waters from es Safa sub-basin to Abou Zebli sub-basin. Table 2 shows the calculation of the discharge Dt of the Damour river basin, which was caused only by the storm that occurred on 13-15/12/2000 excluding the base-flow discharge.

Table 2. The discharge D_t of the Damour river basin upon the storm of 13-15/12/2000

Date	Discharge rates of the river Dbs and Das (m3/sec)	Discharge rates caused only by the storm Dst (m3)	Discharged water caused only by the storm each day Dd, (m3)
12/12/2000 one day before the storm	0.424	NA	NA
13/12/2000	7.767	7.343	634435
14/12/2000	5.039	4.615	398736
15/12/2000	3.031	2.607	225245
16/12/2000	1.986	1.562	134957
17/12/2000	1.551	1.127	97373
18/12/2000	1.338	0.914	78970
19/12/2000	1.507	1.083	93571
Total amount of discharged water D_t, (m^3)	NA	NA	1663287

5. RESULTS AND DISCUSSION

5.1 Yearly Analysis

Fig. 6 shows an approximate mimic relationship between the yearly discharge of Damour basin streams and the precipitation. The precipitation values were converted from Beirut rates to the basin rates. The data of discharge and precipitation for all years look to be mimic, except for the year 2006. In this year, the precipitation rate jumps from 1101 mm in 2005 to 1243 mm in 2006, whereas the discharge of most streams drop significantly. However, the yearly discharge of es Safa spring exhibit perfect match with the precipitation. The period between 2007 and 2010 shows a clearer mimic relationship than the earlier period. The discrepancy of the 2006 rate probably could be due to a lower precipitation rates in the basin than in Beirut.

Table 3 shows the water budget of the whole Damour river basin for the period 2004-2011, it shows that the average ratio of runoff and infiltration (groundwater discharge) is about 61% of the precipitated water. This means that the ratio of evapotranspiration is about 39%. The ratios of runoff and infiltration are erratic and do not strongly support the theoretical assumptions, which hypothesize high ratios in rainy years and low ratios in dry years.

Moreover, water consumption in the basin is not included in the table, because of the lack of accuracy on its values. However, the domestic use in the basin is estimated to be 25000 m^3/day or 9.125 $M.m^3$/yr. Meanwhile, water consumption on irrigation cannot be accurately estimated as it could vary highly, depending on the rates of precipitation in the basin. Therefore, it is not irrational to assume that it ranges between 7 and 15 $M.m^3$/yr. Hence, the total water consumption in the basin could range between 16 and 24 $M.m^3$/yr, and this amount makes up about 10% of the Damour river discharge. Then, the proportions of runoff and springs discharge are actually about 70%, higher for about 10% than the 60% given in Table 3. [17] estimated that the rate of infiltration for large part of the Damour basin, except for the slopes of Barouk mountain, is 25%. If an infiltration rate of 30% is applied to the whole basin then the runoff rate would be 70-30=40%. Similarly, if ater consumption is included in the table, then the ratio of evapotranspiration would be only about 30%. Reseaches have suggested that the overall rate of evapotranspiration for all Lebanon is about 50% [20]. The great difference in evapotranspiration rates between Damour river basin and Lebanon as a whole is due to the fact that Damour river basin is located in Mount Lebanon, which is known to be a wet area, characterized by high precipitation rates and low evapotranspiration ratios.

5.2 Monthly Analysis

Fig. 7 shows the monthly precipitation and hydrographs (discharge) of es Safa spring, for 2008 – almost average precipitation rate. This figure shows that the lag period between the precipitation events and the rise in the discharge of Safa spring is about 2.5 months. Figs. 8 and 9 show the monthly precipitation and hydrographs of Naher es Safa stream and Abou Zebli stream, respectively, for the seasonal year 2008. These two figures show that the lag period for both streams is about 2 months. Fig. 10 shows the

Table 3. The water budget of the Damour river basin

Year	Discharge at sea mouth D_{sm}, M. m^3	Precipitation at Horsh station P_h, m/yr	Average precipitation for the whole basin P_b, m/yr	Precipitated water on the basin P_y, M. m^3	Ratio of runoff and infiltration R_{ri}, %	Ratio of evapo-transpiration R_e,%
2004	190.1	0.654	0.903	261.9	72.6	27.4
2005	255.4	0.796	0.1098	318.4	80.2	19.8
2006	178.6	0.899	0.1241	359.9	49.6	50.4
2007	174.4	0.777	0.1072	310.9	56.1	43.9
2008	115.2	0.699	0.965	279.9	41.2	58.8
2009	199.5	0.811	0.1119	324.5	61.5	38.5
2010	250.9	0.1121	0.1547	448.6	55.9	44.1
2011	263.1	0.939	0.1155	375.8	70.0	30.0
Average	203.4	0.837	0.1155	335.0	60.7	39.3

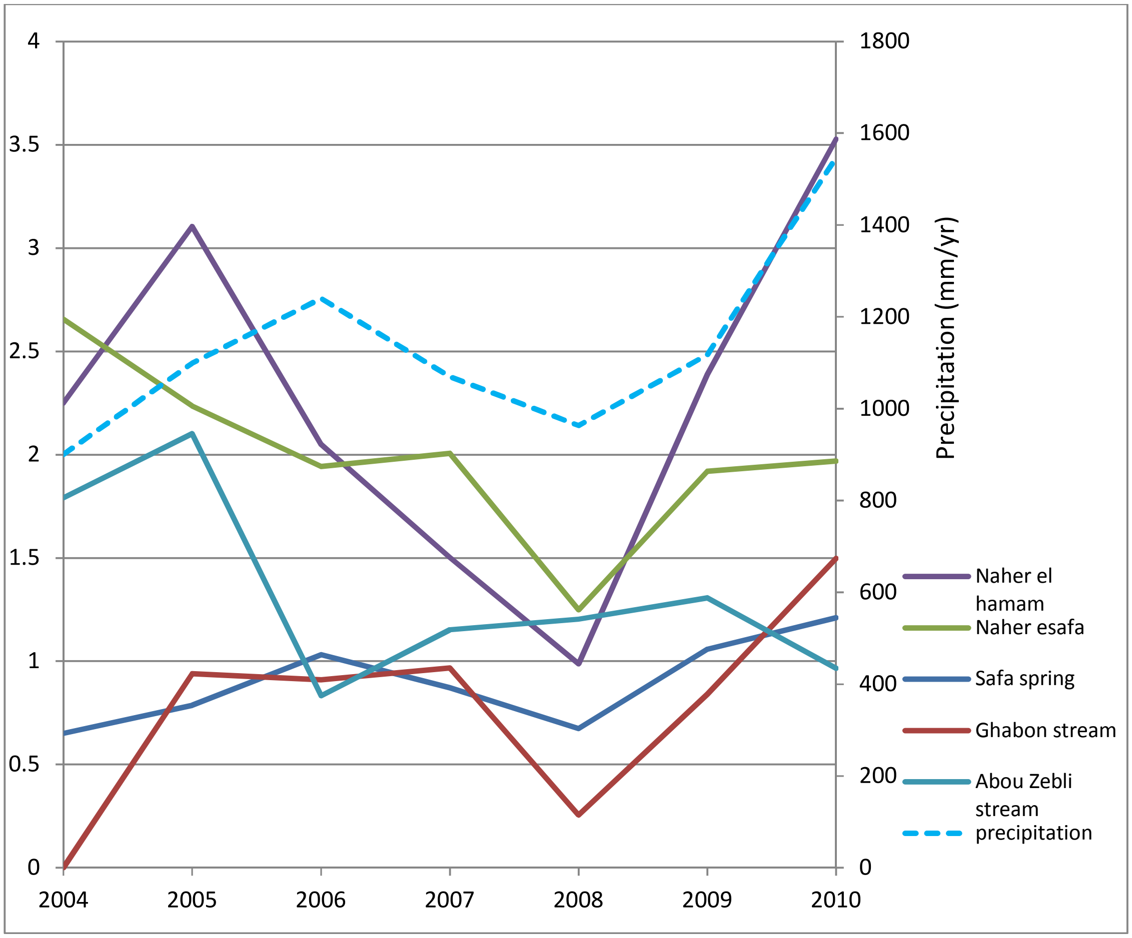

Fig. 6. The yearly precipitation and hydrographs of the streams of Damour river basin

monthly precipitation and hydrograph (discharge) of Damour river (sea mouth) for 2008. This figure shows that the lag period for the Damour river (sea mouth station) is about 1.5 months. The long lag period for es Safa spring is most likely due to the contribution of snowfalls to the discharge of that highly elevated spring (about 950 m). Snow thawing is a slow and a continuous process and it might lengthen the lag period. The lag period at the sea mouth station is shorter than other streams, because the river draws its water from many sources, some of which have steep slopes, especially in the lower part of the Damour river, and the others from shallow seasonal springs, which normally have short lag period.

5.3 Daily Analysis

Fig. 11 shows the daily precipitation and hydrograph (discharge) of Naher es Safa and Abou Zebli streams, for the period November 1st, 2001 – February 28th, 2002 rainy season. Fig. 12 shows the daily precipitation and hydrograph (discharge) of Damour river at Jisr el Qadi station, for the same period. Fig. 13 shows the daily precipitation and hydrograph (discharge) of Damour river at sea mouth station, for same the period (November 1st, 2001 – February 28th, 2002 rainy season). Figs. 11-13 show that in the first month of rainy season (November), precipitation events cause only slight increase in the discharge of streams. Moreover, the curve of sea mouth station shows that some precipitation events in November do not cause any flow in the stream channel of the Damour river. This behavior of the relationship between the precipitation and stream discharge is highly affected by evapotranspiration and infiltration to groundwater, which draw a large proportion of the precipitated water. As time progresses, precipitation events cause more and more increase in the discharge (higher runoff) of all streams. The curves show that after January

20th (day 81 on curves) a moderate precipitation event could cause a measurable increase in the discharge of streams, and therefore the rate of runoff. This means that by this time the groundwater aquifers have already been recharged to great extent, and the loss to evapotranspiration is minimized due to the drop in temperatures in this period of the year. Moreover, the curves show that the increase in the discharge of streams drops back to base level a few days after the end of the precipitation event. This fact made it possible to differentiate between discharge increases caused by runoff and the rise of spring discharge, which is addressed in storm-basis analysis.

5.4 Storm-basis Analysis

Table 4 shows the ratio of runoff (in percentages) to the precipitated water upon 11 storms, the dates of which are indicated in column 2. Column 3 in Table 4 shows the amount of precipitation during the storm. Column 4 shows the average daily amount of precipitation during the storms. Columns 5-8 show the ratio, in percentage, of runoff of the precipitated water for the sub-basins of Naher es Safa and Abou Zebli streams together, the whole Damour river basin, the sub-basin of Ghabon stream, and the sub-basin of Naher el Hammam stream. The boxes filled by N.A. are resulted from negative values of the discharge of the sub-basins of Naher el Ghabon and Naher el Hamman streams, as they have been derived from the extraction of the discharge at Rechmaya and Wadi es Sitt stations from the discharge at Jisr el Qadi station, and the extraction of the discharge at Jisr el Qadi station from the discharge at the sea mouth station. These negative values imply great losses of the water, probably on evapotranspiration and infiltration to the ground along the stream between the Rechmaya and Wadi es Sitt stations and Jisr el Qadi station (Ghabon sub-basin), and between Jisr el Qadi station and sea mouth station (Naher el Hammam sub-basin). Table 4 shows that the ratio of runoff of the precipitated water upon 11 storms that occurred in 2000/2001 and 2001/2002 vary significantly, and range from 0.01% up to 61%. The ratios are very low in the beginning of the wet season, and gradually rise through December -March and even April months. This implies that large proportions of the precipitated water through October to mid-December are consumed on evapotranspiration, due to relatively higher temperatures, and recharging groundwater aquifers. The table also shows that runoff ratios of Naher es Safa and Abou Zebli sub-basins are smaller than the ratios of Naher el Ghabon sub-basin. This is most probably due to the fact that large proportions of the precipitated water in the first two sub-basins occur as snowfalls, as they have higher elevations. Moreover, the first two sub-basins are underlain by a higher proportion of highly fractured Jurassic rocks than Naher el Ghabon sub-basin. This means that ground water recharge in Naher es Safa and Abou Zebli sub-basins is higher than in Naher el Ghabon sub-basin. On the other hand, runoff ratios in Naher el Hammam sub-basin are higher than Naher el Ghabon sub-basin. This difference might be due to several factors: such as steep slopes, lower vegetation cover and fewer snowfalls in the first sub-basin compared to the second.

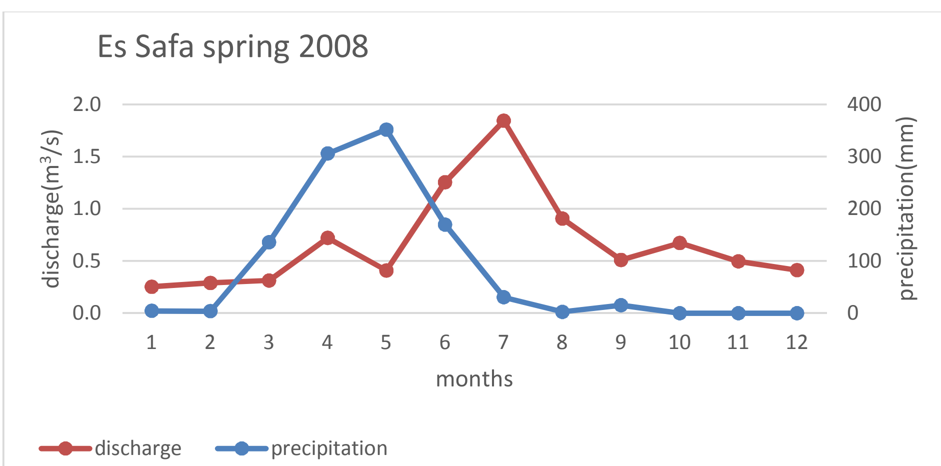

Fig. 7. The monthly precipitation and hydrographs of es Safa spring, for 2008

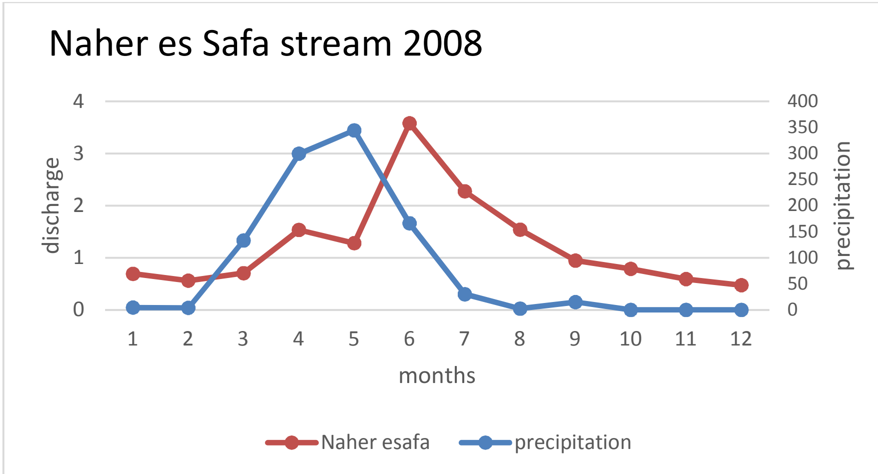

Fig. 8. The monthly precipitation and hydrographs of Naher es Safa stream for 2008

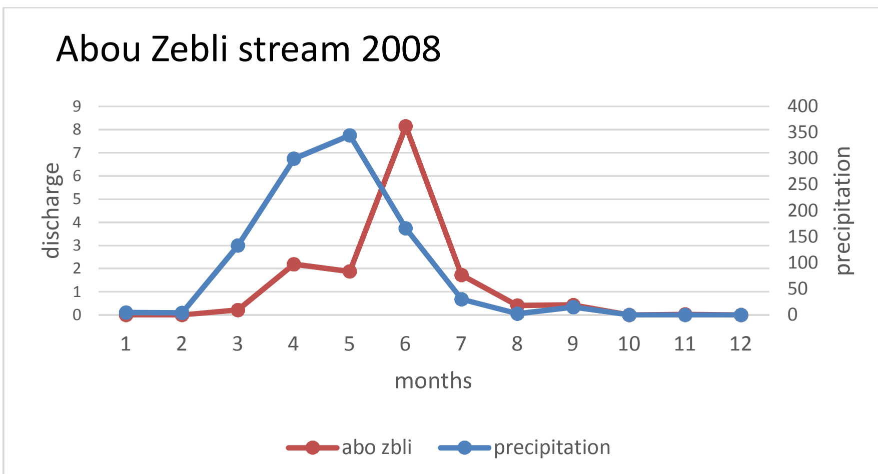

Fig. 9. The monthly precipitation and hydrograph of Abou Zebli stream for 2008

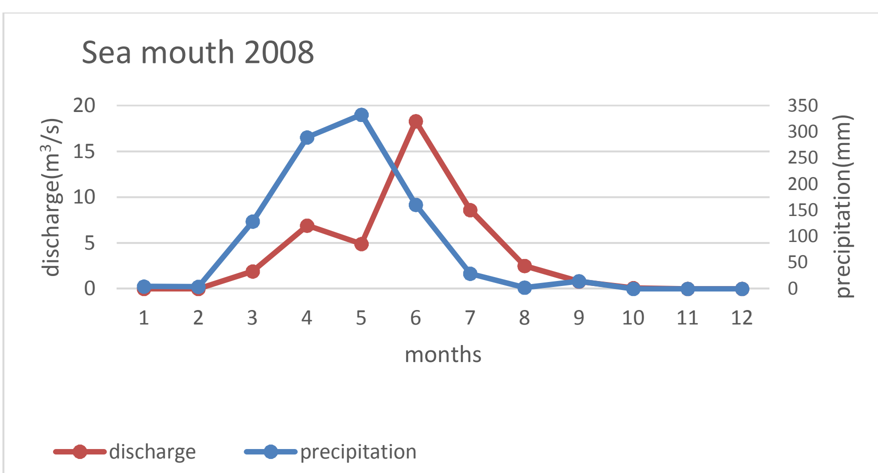

Fig. 10. The monthly precipitation and hydrograph of Damour river (sea mouth) for 2008

Table 4. The ratio of runoff to the precipitation upon storms

Storm N°	Storm date	Total precipitation during the storm, mm	Precipitation per day, mm	Naher es Safa and Abou Zebli streams	Whole basin (sea mouth)	Naher el Ghabon stream	Naher el Hammam stream
1	21-26/10/2000	74.2	14.84	0.38%	0.01%		
2	30/11-1/12/2000	64.22	32.11	0.06%	0.60%		
3	13-15/12/2000	41.34	20.67	23%	13%		
4	14-23/2/2001	157.3	17.4	20.90%	17%		
5	26-31/10/2001	69.16	13.8	2.60%	2%	10%	N.A.
6	26-27/11/2001	61.88	30.94	1.30%	1.60%	5.70%	N.A.
7	19-21/12/2001	56.16	28.08	17.90%	48%	55%	66%
8	3/1/2002	39.26	39.26	4.50%	11.80%	8%	25.50%
9	11-13/2/2002	55.9	27.95	4.60%	18.90%	N.A.	N.A.
10	26-30/3/2002	113.88	28	8.90%	27.70%	24.00%	61%
11	20-22/4/2002	67.34	33.67	3.60%	10.30%	N.A.	23%

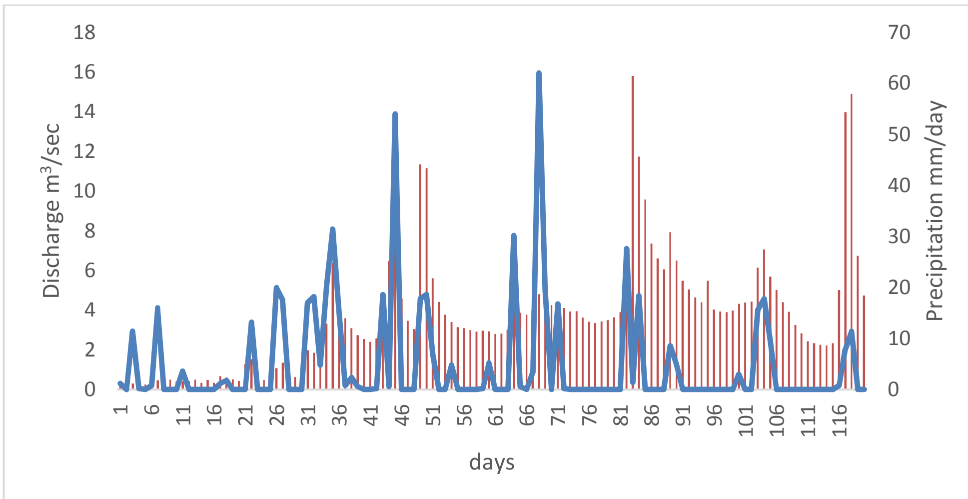

Fig. 11. The daily precipitation and hydrograph of Naher es Safa and Abou Zebli streams

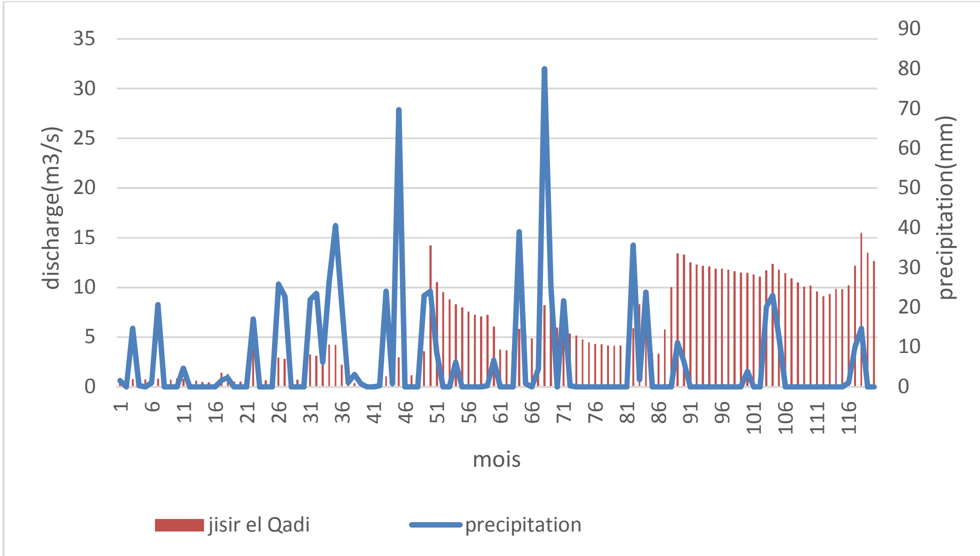

Fig. 12. The daily precipitation and hydrograph of Damour river at Jisr el Qadi station

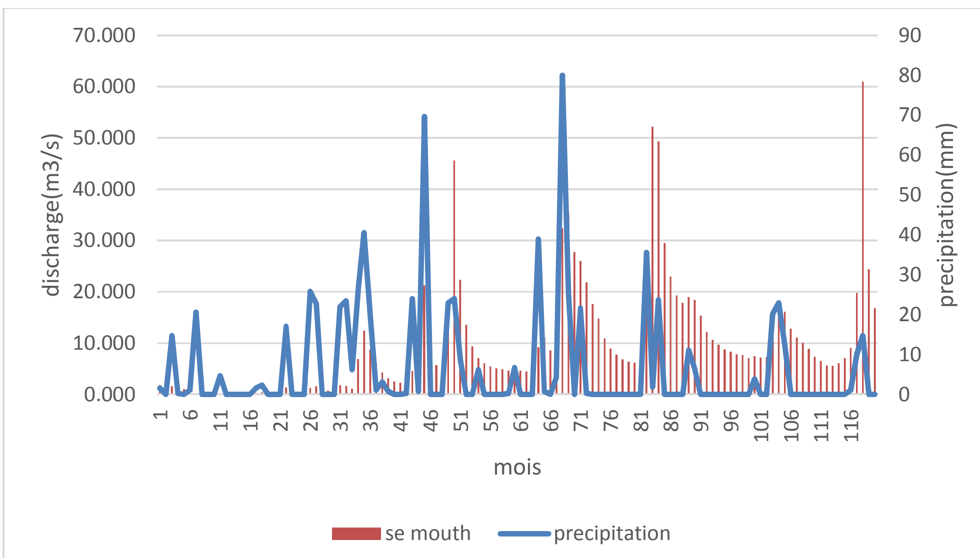

Fig. 13. The daily precipitation and hydrograph of Damour river at sea mouth station

6. CONCLUSIONS

The analysis of the processed and presented data leads to the following conclusions:

- The yearly hydrographs for the streams of Damour river basin show that they are generally mimic with the precipitation, except for the year 2006. However, es Safa spring yearly hydrograph exhibits perfect match with the precipitation.
- The ratio of runoff and groundwater discharge for the whole Damour river basin is about 61% and it might jump to about 70% if the water consumption is included in the water budget. This ratio is much higher than the country's 50% ratio.
- Monthly analysis show that the overall lag period between the rises in precipitation and the discharge of streams ranges between 1.5 and 2.5 months. The longest lag period is exhibited by Safa spring discharge. So, snowfalls play an important role in lengthening the lag period.

- the shortest lag period is exhibited by the hydrographs of the whole Damour river, the high relief in the lower part of this river plays a major role in shortening the lag period between the rises in precipitation and stream discharge.
- In the early period of wet season (October-November), a large proportion of the precipitated water goes to evapotranspiration and infiltration to groundwater. Moreover, the groundwater aquifers become recharged to great extent by the end of January, later on the runoff ratio constitutes most of the precipitated water.
- Daily stream hydrographs show that the discharge of streams caused by rain storms drops back to base-flow values within 3-5 days after the end of rain storms.
- Storm analysis show that runoff ratios vary considerably, from less than 1% during October and November to as high as 66% in Naher el Hammam sub-basin during December.
- Finally, the runoff ratio is affected by the hydrogeologic characteristics of the underlying rocks, the snow cover, the steepness of slope, the vegetation cover, and most importantly the timing of precipitation that is influenced by the temperature and the extent, to which the groundwater aquifers are recharged.

For obtaining better results regarding the relationship between the precipitation and the discharge of streams, and therefore the ratio of runoff, it is highly recommended to:

Install additional gauging stations at the meeting points of the streams of the Damour river, and deploying weather stations to measure daily records of precipitation in different parts of the Damour river basin.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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