Hydrology of the Jordan River Basin
**Introduction**

*The Jordan River Basin*

The Jordan River is a transboundary river with a catchment area of 18,300 square kilometers.\(^1\) The Jordan River and its tributaries, the Yarmouk, Banias, Hasbani, and Dan River are shared between more than two riparian nations, which makes the task of managing and distributing the water between the riparian countries complicated. The Jordan River today is a damaged river, with sub-standard water quality, and very little inflow into the Dead Sea. The region is under a great hydric stress, there is a need to promote cooperation between all riparian countries and achieve an equitable distribution of water, increase inflows into the Dead Sea and further support the peace process in the region.

The countries located in the Jordan River Basin are: Jordan, Lebanon, Syria, Palestine (West Bank) and Israel (see Figure-1)

Calculating the drainage area of each catchment within the Jordan River Basin and then the volume of water available for run off is an important task. This will show how much each country is contributing to the watershed. Yearly average precipitation data will be obtained in order to calculate the potential runoff in each country’s subwatershed.

*The Dead Sea*

The Dead Sea is a closed sea with no outlet except by evaporation. In the past, the evaporation losses were replenished by an inflow of fresh water from the Jordan River and its tributaries. Today, the Jordan River only discharge about 200 Mm\(^3\)/year. Consequently, the water level has

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declined in recent years to 403 m below sea level, almost 10 m lower than its historical equilibrium level of 1930.\textsuperscript{2}

Figure-1 Riparian countries of the Jordan River Basin

The decline in the Dead Sea level is due to a negative water balance of the lake, evaporation greatly exceeds the inflow. An attempt to calculate the water balance of the

Dead Sea will be performed using GIS and see if the result is the same as the literature which estimates the decrease in the level of the Sea to 1m/year.\textsuperscript{3}

**Watershed delineation**

The first step was to download world basins shape files from Hydrosheds (http://hydrosheds.cr.usgs.gov/)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image.png}
\caption{World’s watersheds}
\end{figure}

Hydrosheds stands for Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales. It was developed by the Conservation Science Program of World Wildlife Fund (WWF). The data sources used to generate Hydrosheds are high resolution elevation data obtained from NASA’s Shuttle Radar Topography Mission (SRTM). We can zoom in to the area

of interest and download 3sec Void-filled DEM, 3sec drainage directions and 15 sec shape files of drainage basins.

![HydroSHEDS Download Site](image)

**Figure-3 Hydrosheds DEM area**

The 15 sec shape files will be useful only to extract the Dead Sea Basin, the resolution being 15 sec, the Jordan River Basin was not represented in the shape files. The next step was to dissolve the Dead Sea Basin using the technique used in exercise 2. Because the drainage directions were already provided from Hydrosheds, we can start to delineate the watershed using the drainage directions instead of starting from the raw DEM. I kept encountering errors when I started with the DEM because of the particular fact that the Jordan River is below sea level. Starting South of Lake Tiberias and extending to the Red Sea, the Jordan Valley altitude varies from 200 meters to 400 meters below sea level! (See Figure-4)

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4 [http://www.ce.utexas.edu/prof/maidment/giswr2010/Ex2/Ex2_2010.htm](http://www.ce.utexas.edu/prof/maidment/giswr2010/Ex2/Ex2_2010.htm)

The drainage directions (15sec DEM).

![Drainage directions from Hydrosheeds](image)

**Figure-5 Drainage directions from Hydrosheeds**

This is why the shape file of the Dead Sea was useful:

1- Data management tools, under raster click raster processing then clip
2- Select the flow direction DEM as input raster, the output extent is the dead sea basin

![Image of a software interface for clipping raster data](image1.png)

Figure-6

3- The result is a clipped flow direction DEM that extent a little bit beyond the dead Sea watershed

![Image of the Dead Sea basin overlaying the flow direction DEM](image2.png)

Figure-7 The Dead Sea basin overlaying the flow direction DEM.
The DEM was clipped in order to speed up the calculation time and projected to Jordan JTM. After following the steps of Exercise 4\(^6\), we isolate the Watershed; the outlet of the Jordan River is the Dead Sea.

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\(^6\) [http://www.ce.utexas.edu/prof/maidment/giswr2010/Ex4/Ex42010.htm](http://www.ce.utexas.edu/prof/maidment/giswr2010/Ex4/Ex42010.htm)
If we define the streams based on the same flow accumulation threshold as the exercise we get the following:

Figure-10 Streams using the raster calculation of Exercise 4
This is not good enough, some of the Jordan River tributaries are missing, including the Hasbani River that flow from Lebanon. The raster calculation should be modified:

![Raster formula](image)

Figure-11 Raster formula

\[(\text{fac} > 900) \& (\text{wshed} > 0)\] The result will be a raster representing the streams delineated in the Jordan River Basin. The Hasbani River is well defined.

![Result after modifying the equation](image)

Figure-12 Result after modifying the equation
Now we have the Jordan River Basin!

Figure-13 The Jordan River Basin delineated on Arc Map 10

The online topographic basemap provided by Bing was very useful to verify that we got all the Streams in the watershed.
Using calculate areas, under spatial statistics we input the feature class to be the basin created (catchpoly) and the output are Areas.

The total area of the Jordan River Basin is about 18,260,826,477 m\(^2\) which is about 18,261 km\(^2\).

This is consistent with the literature that estimates the basin area to be about 18,300 km\(^2\). The Basin was accurately delineated.

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Subwatersheds for each country

In order to isolate the catchments of each country, each 77 catchment was selected one by one. Then we export and save it as a new polygon feature, in order to separate each catchment and know exactly the ones that are part of two countries.

For example, the Hasbani River basin shown below.

The river source is in Lebanon. However, part of the catchment is in Lebanon and part of it in Israel. The Hasbani River from Lebanon is one of the main inflow to the Jordan River. The other is the Dan River of Israel.

Figure-16 Hasbani River Basin
**Identify the location of each catchment**

Using the editor toolbar, each subbasin was identified and given the name of each country it belongs too. The Bing online basemap was used to determine in which country each subbasin was located.

We create a new field name countries.

![Figure-18](image)

We start naming each 77 subbasin by the name of each country; if a catchment is located within 2 countries we give it the name of both countries. (We used the same name as the features previously shown on figure 17).

![Figure-19](image)
<table>
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<th>Value2</th>
<th>Value3</th>
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</table>

Figure-20

Figure-21 Catchments
Precipitation Data

Precipitation data was obtained from the Water Systems Analysis Group, University of New Hampshire. The data was downloaded from GIS online as a raster. The raster represents long term (1950-2000) average annual precipitation for the globe (mm/yr) on a 0.5 X 0.5 global grid.

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9 http://app.databasin.org/app/pages/datasetPage.jsp?id=a5915100b8ac47db8dcee9839e838a2c
The raster is projected and clipped

Figure-23 Zoom in of the precipitation raster
Resample under raster processing

Zonal statistics as table to find the mean precipitation for each catchment

Figure-24

Figure-25
We have the mean precipitation for each subwatershed, we can see how much it contributes to the total Jordan River Basin.

Results

32 subwatershed were located in two different countries. The editor toolbar was used to draw polygons for each subwatershed in order to estimate the area of the two parts in each country. As seen in this figure below, this catchment has a part in Israel and a part in Jordan.
Figure-28 Histogram of the volume (million cubic meters) available for run off

Figure-29 Pi chart showing the contribution of each catchment in percent
The total precipitation in the Jordan portion of the Jordan River Basin was about 2091 Mm³/year. When compared with a study done by the French Regional Mission for Water and Agriculture, the values were close; the literature estimates the total precipitation to be 2200 Mm³/year on the Jordan part of the Basin.\textsuperscript{10} This shows that the analysis done on GIS was acceptable, but lack of precision because of the low resolution of the data and the lack of precipitation stations.

The analysis done on GIS is useful for a rough estimate of subbasin contribution to see each country’s contribution to the total Jordan River Basin. We can see that the largest contribution of all riparian countries is from Jordan. That is why previous water allocation plans in the Basin allocated 56% of the available freshwater to Jordan (see figure 30). One of the plans was the famous Johnston Plan of 1953, which after tough negotiations was rejected by all the stakeholders.\textsuperscript{11}

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For future work, evapotranspiration data and streamflow data could be used with the precipitation volume calculated in order to develop a hydrologic information system that can be used for hydrologic modeling of the basin, including a surface water balance.

**Dead Sea water balance**

The Dead Sea being a closed sea, it has no outlet, evaporation is the only output. The input besides precipitation is the Jordan River inflow, about 200 Mm$^3$ of water per year reaches the Sea.

A shape file for the Dead Sea was created using the editor toolbar, as seen below. This is an approximation of the Dead Sea shape.

![Figure-31](image1.png) ![Figure-32](image2.png)

The area was estimated using GIS, and it was about 621.4 Km$^2$, the literature estimates this number to be 625 Km$^2$.$^{12}$

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Besides inflow from the Jordan River, the most important factor in the calculation of the water balance is the rate of evaporation, which is estimated to range between 1.05 and 2 m/yr. The same precipitation data was used for a rough estimate of the water balance. The total precipitation on the Dead Sea was determined to be approximately 115 Mm$^3$/year.

Currently the water level of the Sea declines by 1m/year. Evaporation greatly exceeds inflow. In the past the Jordan River was the single most important water source to the Dead Sea, discharging 1,200 Mm$^3$ of water per year. The discharge today is 150 to 200 Mm$^3$/year.  

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Figure 34: Dead Sea water balance

**Water balance:**

Average Precipitation + Jordan River Inflow – evaporation = Water deficit

\[
\begin{align*}
200 \times 10^6 \frac{m^3}{yr} + 115 \times 10^6 \frac{m^3}{yr} - 1.5 \times 10^6 \frac{m^3}{yr} \times 621.4 \times 10^6 m^2 &= -617.1 \times 10^6 \frac{m^3}{yr}
\end{align*}
\]

The average decline in water level in one year of the Dead Sea is:

\[
\frac{\text{Volume}}{\text{Area}} = \frac{-617 \times 10^6 m^3}{621.4 \times 10^6 m^2} = -0.998 \frac{m}{\text{year}}
\]

Thus we estimate the decline in the Dead Sea level to be about 1m/year, this is consistent with Ittai Gavrieli and Amos Bein estimations from the Geological Survey of Israel they state: “The rate of water level drop over the last 10 years is about 0.9 m/yr, representing an annual water
deficit of about 600 million cubic meters.” The deficit calculated in this report was 617.1 million cubic meters per year!

**Conclusion and future work**

It is important to recognize the potential of GIS in water resources as a tool for improving water demand management in the implementation of the integrated water resources planning (IWRP) and management (IWRM). The use of GIS in studying the hydrology of the Jordan River Basin enabled calculation of the drainage area of each catchment within the Basin, the volume of water available for runoff and the decline of the water level in the Dead Sea estimated to be about 1m/year. This result is consistent with Ittai Gavrieli and Amos Bein estimations from the Geological Survey of Israel.

The Jordan River today is a damaged river with depletion of its aquifers, sub-standard water quality, severe damage to its ecosystem, and very little inflow into the Dead Sea. The main objective of my work with Dr. McKinney would be to contribute to the promotion of cooperation between all riparian countries of the Jordan River to achieve an equitable distribution of water, rehabilitation of the Jordan River Ecosystem, increased inflows into the Dead Sea and further support for the peace process in the region.

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