Quantifying ecosystem services in the Western Mountain Aquifer using the Soil & Water Assessment Tool

Key findings

- We quantify three ecosystem services in the watershed of the Western Mountain Aquifer: water flow, food provisioning, and erosion regulation.
- The average index value of the water flow provisioning services is 0.11, indicating low streamflow in both the karst and non-karst zones.
- Food provisioning services in the watershed have an index value of 0.31, considering primary field crops and orchards.
- Erosion regulation services in the watershed are high with an average index value of 0.78.

Motivation

Karst aquifers provide various ecosystem services, such as supplying freshwater to populations and for agricultural irrigation (which contributes to drinking water and food security). Their management is a challenge, especially in the Mediterranean climate, where groundwater recharge and flow dynamics are incredibly variable throughout the year. In view of rapid climate change and high population growth, the Western Mountain Aquifer (WMA) in Israel and the West Bank is particularly vulnerable. The high domestic and agricultural water demand increases the pressure on groundwater resources, while predicted climate change reduces groundwater recharge due to decreasing precipitation and increasing evapotranspiration. This study quantifies ecosystem services in the WMA. With changing input values, we can use our modeling approach to estimate the effects of changing climatic (precipitation and temperature) and management factors (changes in land use and irrigation water consumption) in scenario analyses.

Methodology

Prediction of future changes in ecosystem services requires model analyses of the current system. In this study, the Soil & Water Assessment Tool (SWAT) was used to quantify ecosystem services for the WMA. The SWAT model (Arnold et al., 1998) was developed for an area of 9,000 square kilometers. Basic data sets were used for the construction of the model and includes topographic data, land cover data, soil characteristics, and agricultural data as well as meteorological time series (Table 1). In the WMA, precipitation varies from 150 mm in the southern to 500 mm in the norther part. The model was calibrated with stream discharge data. Due to karstic and non-karstic zones and multiple rivers in the watershed, calibration was performed at multiple sites in the model area. The output of the calibrated model was then used to quantify ecosystem services according to the 'Index' approach (Logsdon & Chaubey, 2013). The model's monthly output of river discharge, yearly sediment yield, and yearly biomass and crop yield were used to derive three ecosystem services indices: water flow index (WFI), erosion regulation index (ERI), and food provisioning index (FPI). All indices have unitless values between 0 and 1, where ecosystem services are lowest at 0 and highest at 1.

Index calculation

In this study, ecosystem services are quantified using the 'Index' approach (Logsdon & Chaubey, 2013). The WFI is calculated by considering monthly average flow (m^3/s), the long-term environmental flow (5% of the average flow), and the number of times the flow is less than the environmental flow. The ERI is calculated by the yearly total erosion rate (ton/ha) of each sub-basin compared to the allowable erosion rate (mean of the erosion rates for the watershed). The FPI is calculated by summing the food provisioning quantity provided by all crops divided by all crops' total biomass.

MedWater – Sustainable management of politically and economically highly relevant water resources in hydraulically, climatically, and ecologically dynamic carbonate aquifers of the Mediterranean.
Funding code: 02WGR1428A

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Table 1: SWAT input data sets for model development

Data	Spatial Resolution	Year	Source
DEM	30 m	2019	SRTM
Land-use map	30 m	2005-2016	UBAY based on Hamaraag and IMA
Soil map	250 m	1970	Ravikovitch (1970)
Soil profile	20 soil classes	-	The Soils of Israel by Singer (2007)
Crop management	12 individual crops	2012	FAO
Daily Weather	IMS: 118 precipitation stations, 25 temperature stations & NCEP: 30km grid	2000 - 2017	IMS, NCEP

SRTM = Shuttle Radar Topography Mission, IMA: Israel Ministry of Agriculture, FAO = Food and Agriculture Organization, IMS: Israel Meteorological Services, NCEP: National Centre for Environmental Prediction

Results

Figure 1 shows average index values for water flow (WFI), food provisioning (FPI), and erosion regulation (ERI) for the WMA. Figure 2 shows the spatial distribution of the indices for individual sub-basins. Due to high evapotranspiration and natural infiltration to the deep aquifer, river discharge is low, explaining the relatively low water flow index of 0.11. Of the entire watershed area, 19% is barren land, mostly in the southern part; 17% are urban areas. 35% of the watershed area is used for food production, mostly field crops (winter wheat, herbs, potatoes, cucumbers, watermelons etc.) and orchards (olives, apples, citrus, etc.). Field crops and orchards in the watershed provide a yearly average index value of 0.31 for food provisioning services during the simulation period. This means 31% of the biomass of all harvested crops is used as food. The calculated erosion regulation index is 0.78 in the watershed during the simulation period, which means that soil erosion is below the maximum erosion rate for 78% of the time. The ERI varies throughout the watershed, which needs further investigation considering land use and slope classes.

Application

Our results can assist policymakers with a better understanding and management of regional water and food resources. However, the model results presented here are not yet entirely reliable because of low model performance with flow calibration. Flow calibration in the karstic zone is not satisfactory yet because of frequently occurring low river flows, leading to rivers drying out. Additionally, we have noticed a discrepancy between the precipitation and flow data. Therefore, we are going to perform a multi-variable calibration with evapotranspiration data from MODIS and annual recharge. The parameterized model will be used to investigate the impacts of climate (RCP4.5), land use, and water management changes on ecosystem services until 2050.

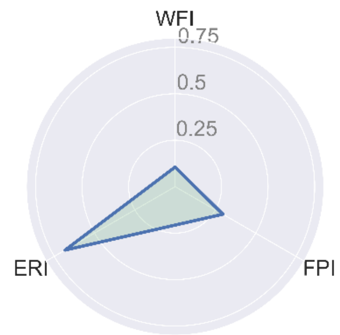

Figure 1: Water flow (WFI), erosion regulation (ERI), and food provisioning (FPI) indices for the Western Mountain Aquifer

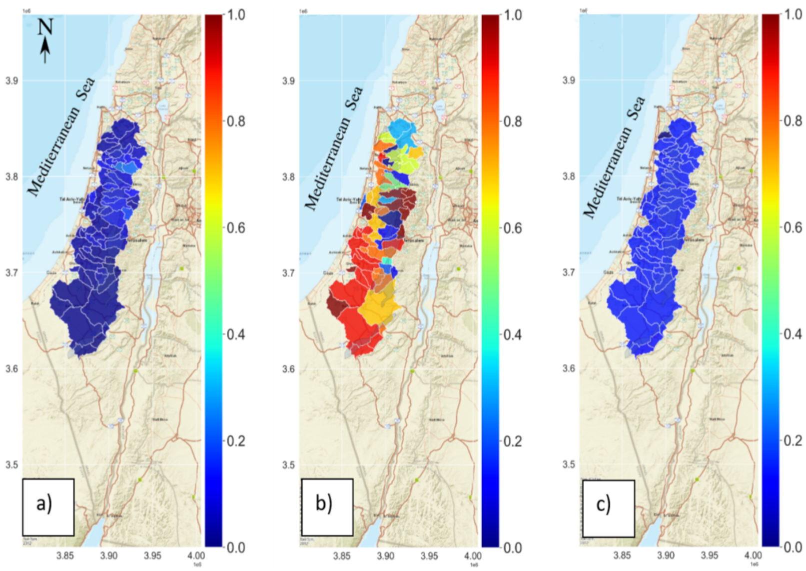

Figure 2: Distribution of a) food provisioning (FPI), b) erosion regulation, and c) water flow (WFI) index values on the sub-basin level

References

Arnold, J.G., Srinivasan, R., Muttiah, R.S., & Williams, J.R. (1998). Large area hydrologic modeling and assessment part I: Model development. *Journal of the American Water Resources Association, 34*(1), 73-89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

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