Coupled Human-Natural Systems Analysis of Water Security Under Climate and Population Change in Jordan

Mashreq Waters Knowledge Series

Steven Gorelick, Stanford University

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Jordan Water Project and the FUSE Project

**Goal:** To develop a tool to evaluate policies aimed at freshwater vulnerability reduction through effective interventions

**History:**
- 20 hydrologists, engineers, programmers, earth scientists, remote sensors, economists, and other social scientists
- 52,000 hours (~25 year effort)

Yoon et al., A coupled human–natural system analysis of freshwater security under climate and population change, 2021, Proceedings of the National Academy of Sciences, April 6, 2021 118 (14) e2020431118; [https://www.pnas.org/content/118/14/e2020431118](https://www.pnas.org/content/118/14/e2020431118)
Why Jordan?

Among water-poorest countries
Intermittent and inefficient supply
Major climate change impacts
Transboundary water problems
Groundwater declining 1 m per year
Refugees
Disi Pipeline

Transboundary Groundwater

Disi Aquifer Water Pipeline
325 km to Amman
Remote Sensing Estimation of Saudi Arabian Pumping

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<tr>
<th>Year</th>
<th>Water Use</th>
<th>Crop</th>
<th>Water Use</th>
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<td>Wheat</td>
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<td>2007</td>
<td>800 MCM</td>
<td>Alfalfa</td>
<td>18%</td>
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<tr>
<td>2014</td>
<td>1000 MCM</td>
<td>F &amp; V</td>
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<table>
<thead>
<tr>
<th>Crop</th>
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<tbody>
<tr>
<td>Wheat</td>
<td>25%</td>
<td>16%</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>20%</td>
<td>18%</td>
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<tr>
<td>Fruit &amp; Veg.</td>
<td>27%</td>
<td>13%</td>
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<td>Olives</td>
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<tr>
<td>Palm Dates</td>
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<td>14%</td>
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<tr>
<td>Dates</td>
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Growing Water Demand

Syrian Refugees Entering Jordan

Syrian War Refugee Crisis

Transboundary Surface Water

Growing Water Demand
Syrian War – Farming Decline

- We use remote sensing, hydrologic simulation, and data from Jordan to estimate river flow impacts on Jordan.
- We also developed a basin-scale rainfall runoff model to simulate flows into Jordan from Syria.
Temperature deviation from 1980-2010

Precipitation deviation from historical baseline: RCP8.5

Climate Scenario Component
Annual flow to Jordan under different land-use and climate scenarios

Flow
(million cubic meters per year)

War Begins

Moderate Climate Change and Less Syrian water use (> water to Jordan)

Extreme Climate Change and Greater Syrian water use (< water to Jordan)
Red Sea Desalination Project
Not Implemented

- Desalinated water to 178 km pipeline
- Pumped 230m uphill
- Brine down to 420m below sea level

Non-Revenue Water – NRW = Water Loss (NRW = 50%) types:
1) “Physical loss” = pipe leaks
2) “Administrative loss” = not charged / stolen
Policy Evaluation Model

**Goal:** To develop a tool to evaluate policies aimed at freshwater vulnerability reduction through effective interventions.

**Approach:** Coupled Human-Water Systems Model
**Shared Socio-Economic Pathways (SSPs)**

- 5 global scenarios
- developed for the IPCC’s 5th Assessment Report
- Jordan-specific projections

**Representative Concentration Pathways**

- **RCP 4.5** – radiative forcing stabilizes at 4.5 W/m² by reducing GHG emissions
- **RCP 8.5** – highest GHG emissions
Interventions

**Baseline:** No additional interventions

**Demand Management:** 2x tariff on large consumers 50% Reduction in theft

**Ag to urban:** 25% transfer of GW from ag to urban

**Enhanced Supply:** Add Desalination 50% Physical Water Loss Reduction

**Do Everything:** All projects, Desalination Physical + Administrative NRW 50% Reduction Double Price on Higher Consumers Reduce Supply Duration Disparity, Transfer 25% of Agricultural Well Water to City

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**Scenarios**

**Optimistic**
Moderate Climate RCP 4.5
More flow from Syria
Modest population growth

**Drier Climate**
Severe Climate RCP 8.5
Less flow from Syria
Modest population growth

**Population Growth**
Moderate Climate RCP 4.5
More flow from Syria
Greater population growth

**Crisis**
Severe climate RCP 8.5
Greater population growth
Less flow from Syria
New wave of refugees in 2030
Set of Results – projecting to 2100

**Water Supply Vulnerability** < 40 liters/person/day

Series of results stratified - 20 **Narratives** - for example

<table>
<thead>
<tr>
<th>Interventions</th>
<th>Baseline</th>
<th>Ag-Urban</th>
<th>Aggressive</th>
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</tbody>
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- Optimistic
- Drier
- Population Growth
- Crisis
Vulnerability Metric
< 40 liter/capita/day

**Scenarios**

**Optimistic**
- Moderate Climate RCP 4.5
- More flow from Syria
- Modest population growth

**Drier Climate**
- Severe Climate RCP 8.5
- Less flow from Syria
- Modest population growth

**Population Growth**
- Moderate Climate RCP 4.5
- More flow from Syria
- Greater population growth

**Crisis**
- Severe climate RCP 8.5
- Greater population growth
- Less flow from Syria
- New wave of refugees in 2030

20 Narratives: each one consists of a Scenario plus an Intervention

**Interventions**
Example Narrative:

- Baseline Intervention
- Optimistic Scenario

**Vulnerability:** Percent of Population Getting < 40 Liters per person per day
Vulnerability Metric
< 40 liter/capita/day

Scenarios

Optimistic
Moderate Climate RCP 4.5
More flow from Syria
Modest population growth

Drier Climate
Severe Climate RCP 8.5
Less flow from Syria
Modest population growth

Population Growth
Moderate Climate RCP 4.5
More flow from Syria
Greater population growth

Crisis
Severe climate RCP 8.5
Greater population growth
Less flow from Syria
New wave of refugees in 2030

Baseline <Demand Ag to City >Supply Aggressive

Income Category
Top 90%
Bottom 10%
**Vulnerability Metric**
< 40 liter/capita/day

**Scenarios**
- Optimistic
  - More flow from Syria
  - Climate RCP 4.5
  - Modest population growth SSP 2
  - Drier Climate
- Climate RCP 8.5
  - Less flow from Syria
  - SSP 2
- Population Growth
  - Climate RCP 4.5
  - More flow from Syria
  - Greater population growth SSP 3
- Severe climate RCP 8.5
  - Greater population growth SSP 3
  - Less flow from Syria

**Baseline**
- All planned projects + Red Sea Desalination
- 50% Physical and Administrative NRW Reduction
- Double water price (for higher tiers)
- Reduce Supply Duration Disparity
- Transfer 25% of Agricultural Well Water to Cities

**Aggressive**
- New wave of refugees in 2030

**Aggressive Action means Do Everything**
- All planned projects + Red Sea Desalination
- 50% Physical and Administrative NRW Reduction
- Double water price (for higher tiers)
- Reduce Supply Duration Disparity
- Transfer 25% of Agricultural Well Water to Cities
Integrated Multi-Agent **Systems Model** of the Food-Water-Energy Nexus

**Urban Modules**
- Climate change
- Energy prices, crop prices, land area

**Riparian Modules**
- Climate change
- Energy prices
- Regulations

**Energy Module**
- Solar farming

**Groundwater Module**
- New supply wells
- Non-Jordan withdrawals

**Agricultural Modules**
- Crop Yield Module
- Regulations, tariffs, subsidies, repairs quotas, enforcement, reallocation
- Non-Jordan withdrawals

**Surface Water Modules**
- Pipeline capacities, new infrastructure
- Climate change

**Institutional Modules**
- Population, land use socioeconomic characteristics

**Environmental Module**
- Regulations

**Legend**

= Narratives

Scenarios
Interventions
Set of Results – projecting to 2100

**Water Supply Vulnerability**  < 40 liters/person/day

**Water Security**  Number of months < 40 liters/person/day

**Economic Well-Being**  Consumer surplus (benefit to consumers)

**Equity**  Gini coefficient of water use (1=disparity in supply, 0= equity)
It’s going to be an uphill climb.
Stanford Hydrology Agent Model
Laval, Canada Risk Analysis Transboundary
UFZ, Leipzig Economics Institutions
Manchester Agriculture and Modelling Platform
Jordan Tech Training Tech Transfer

Special thanks to Jordan’s former Minister of Water and Irrigation

King College Geography