Water Scarcity in the Serbian Danube:
Agricultural land use change and irrigation

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Water Scarcity in the Serbian Danube: Climate Change and Agricultural Land Use
Recurring droughts in the Danube River Basin

August 10-20, 2015

August 10-20, 2022

European Drought Observatory, Combined Drought Indicator v2.2 = f(precipitation, soil moisture, Fraction of Absorbed Photosynthetically Active Radiation)
Europe’s Rivers, Starved by Drought, Reveal Shipwrecks, Relics and Bombs

The Danube River is running so low on water that the wreckage of German warships, sunk in 1944, has resurfaced, posing a danger to local ship traffic.

Wreckage of a World War II German warship in the Danube (Prahovo, Serbia)
A warmer and **drier** Danube (in the growing season)

**Summer precipitation declines of ~15% (2041-2060) compared to 1981-2010 baseline**

Equivalent to a loss of ~1.5 in of rain

**Increase in consecutive dry days**
Global water scarcity in major agricultural regions

Intensifying water scarcity will affect 80% of global cropland by 2050

Evapotranspiration demand outpaces green water (soil moisture) and blue water (surface and groundwater)

Liu et al. (2022) Earth’s Future 10(4)
Serbian Agriculture, Water, and Policy

- **Agricultural sector:**
  - 10% of GDP, employs 21% of population
  - 5 million ha (70-120k ha irrigated)
  - 630,000 farms (most < 10 ha)
  - Maize, wheat, soy, sunflower, sugar beet
  - Complex rotations (3-4 crops)

- **EU accession negotiations (2014-ongoing)**
  - Changing agricultural policy
  - Access to EU single market

- **Danube River Protection Convention**
  - Transboundary water management
  - Sustainable use and protection of resources
  - 14/19 countries are full members (incl. Serbia)
Serbian Agriculture and impact of 2022 drought

### Agricultural sector:
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### 2022 Production

- Maize ↓ 25%
- Soybean ↓ 26%
- Sugar beet ↓ 21%
- Wheat ↑ 10% (wet spring)
- Sunflower ↑ 6%

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1. Statistical Office of the Republic of Serbia; 2. USDA Foreign Agricultural Service
Land and water management choices in a warmer and drier world

The producer
- What to plant? (Markets, yield, weather)
- When should I plant?
- Should I invest in irrigation?

The landscape
- How do these choices change the landscape?
- How do these choices affect water availability?
- Will this change in a warmer world?
Research Questions

**Overall objective:** identify the dominant factors driving agricultural land use change in the Serbian Danube, and their relative influence on water availability

1. Shifts in crop rotations?
   - How do rotations change over time?

2. How is water availability and use changing?
   - 1992-present
   - Future: +1.5°C, +2°C

3. How do farmers respond in their decision-making?
   - Market prices
   - Weather
   - Investment in irrigation infrastructure?

4. How will climate change, water availability, and policy changes influence crop rotation and irrigation investment?
Q1: How do crop rotations change over time?

**Objective:** Create annual crop maps from 1992-2022

- **Landsat Collection 2**
- **Preprocessing** (e.g., clouds, cloud shadow, etc.)
- **Phenology**
- **Field training data & crop maps, 2016-2022 (BioSense Institute)**
- **DeepCropMapping\(^1\) (LSTM) classification**
- **Post-processing (de-speckle - floodfill)**
- **Crop rotation maps (annual, 6 key crops)**

\(^1\)Xu, J., et al. (2020) Remote Sensing of Environment
Q1: How do crop rotations change over time?

2018 preliminary classification (Vojvodina Province, Serbia)

Reference Map (BioSense, 2018)

DeepCropMapping (Landsat 8)
Q1: How do crop rotations change over time?

*Ongoing and future work*

- **Classifier transferability**
  - Annual maps to 1992

- **Improved phenology representation**
  - Not restricted to plant/harvest dates that vary annually and spatially

- **Improved post-processing**
  - Segmentation algorithms
  - SegmentAnything (Meta)
Q2: How is water availability and water use changing?

**Objective:** Quantify and map water scarcity from 1992-present, and at + 2°C

- Process-based, distributed hydrological model
  - Water, N, and P cycles
  - Plant growth – yield estimates (EPIC)

- Daily weather time series
  - *Observed:* EU Copernicus E-OBS (1950-present)
  - *Future:* EURO-CORDEX ensemble (1981-2100)

- Agricultural practices
  - Crop rotations (from Q1 crop maps)
  - Irrigation (amount, frequency, source)

- Calibration and uncertainty analysis
  1. Global Runoff Data Centre discharge
  2. Annual country-level crop yield (RS Statistics)
  3. Remotely-sensed ET(?)

![Image of a tree with water flow pathways and labels such as 'Evaporation and Transpiration', 'Surface Runoff', 'Infiltration into shallow aquifer', 'Evaporation from shallow aquifer', 'Precipitation to shallow aquifer', 'Confining Layer', 'Deep (confined) Aquifer', and 'Evaporation from deep aquifer'.]
Q2: How is water availability and water use changing?

Model input data, parameterization, uncertainty

- 25m DEM
- Harmonized World Soil Database
- Crop maps

Parameterize 2 km grid cells

Simulate daily water balance at each grid cell (1981-2100)

Calibration and uncertainty analysis
Q2: How is water availability and water use changing?

Ongoing and future work

Model evaluation
- Integrate crop rotations
- Calibrate/validate
- Uncertainty analysis

Future climate runs
- EURO-CORDEX regional climate model
- 7 models/ 2 RCPs
- 1981-2100

Average monthly soil water (mm)
Summer 2015-2016

2015

2016
Q3: What climatic, market, and policies influence crop choice and irrigation investment?

**Objective:** quantify how land use and irrigation decisions respond to commodity prices, weather, and socioeconomic trends

**Markov transition matrix:** defines the rotation probabilities between any two crop types

<table>
<thead>
<tr>
<th>Year t Crop</th>
<th>Maize</th>
<th>Soy</th>
<th>Wheat</th>
<th>Other…</th>
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</thead>
<tbody>
<tr>
<td>Maize</td>
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<tr>
<td>Soy</td>
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</tbody>
</table>

- Crop specific switching costs: maize → (wheat is less costly than maize) → wheat
- $\hat{p}_m|c_t=m$ is the estimated probability of maize ($m$) in year $t+1$ IF field was maize in previous year
- Use multivariate regression to generate $\hat{p}_m$ as a function of prices, planting weather, soil, and water availability
Q4: How does a warmer and drier Danube affect water availability ↔ cropping systems?

Objective: quantify future water availability/use and crop rotations in response to climate change
Significance and Impact

- Forecasts of future water scarcity and agricultural productivity/rotational changes

- Climate change impacts on the agricultural sector
  - Inform policy and decision-making related to public irrigation infrastructure and water use

- Does trade policy exacerbates or alleviate water scarcity issues?
  - EU affects prices in Serbia, which affects planting and water scarcity
Thank You!

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