Food-water-energy for Urban Sustainable Environments in Pune, India

A. Jain Figueroa presenting on behalf of the FUSE Team:

This work is supported in part by the National Science Foundation under grant ICER/EAR-1829999 to Stanford University as part of the Belmont Forum – Sustainable Urbanisation Global Initiative (SUGI)/Food-Water-Energy Nexus theme. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.
### Partner Organizations

<table>
<thead>
<tr>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>STANFORD UNIVERSITY</td>
</tr>
<tr>
<td>NSF</td>
</tr>
</tbody>
</table>

### Funding Organization

<table>
<thead>
<tr>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
</tr>
</tbody>
</table>

### Local Partners & Stakeholders

<table>
<thead>
<tr>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Institute for Applied Systems Analysis (IIASA)</td>
</tr>
<tr>
<td>OFSE Austrian Foundation for Development Research</td>
</tr>
<tr>
<td>Federal Ministry of Education and Research</td>
</tr>
<tr>
<td>CEE Centre for Environment Education</td>
</tr>
<tr>
<td>Gokhale Institute of Politics and Economics</td>
</tr>
</tbody>
</table>

---

**Who are we?**

fuse.stanford.edu

**Sponsors**

- BELMONT FORUM
  - Sustainable Urbanisation Global Initiative (SUGI)
- UFZ HELMHOLTZ Centre for Environmental Research
- HSHHOLZ Centre for Environmental Research

---

+ Many Others
The Team

Stanford, US
Hydro, Food, Agent Model
Steve
Anjuli
Hassaan

IIASA, Austria
Hydro, Agro, Climate
Roz
Ju Young
Mikhail
Taher

UFZ, Leipzig, Germany
Economics, Energy, Urban Sociology, Agent Model
Bernd
Christian
Raphael
Yuanzao

ÖFSE, Vienna, Austria
SLLs, Stakeholder Engagement
Erik
Heinrich
Sigrun
Annegret
Christopher
Joni
Karin
Ines
Hannes

In India during Jan 2020
Project Goals

Produce solutions for urban-FWE challenges through participatory model building

Study Areas

Pune, India
FEW Drivers: Urbanization and Climate Change

Based on Assumptions of Representative Concentration Pathways (RCP) for greenhouse gases and Shared Socio-economic Pathways (SSP) for economic growth

Scenario matrix = RCP x SSP

Downscaled To Local Scale

Global CO2 equivalent (ppm)

India Population (million)

India GDP (billion US$ 2005 PPP)
Nexus Drivers: Urbanization and Climate Change

**Nexus Challenges:** Vulnerabilities created by

- Increasing population demands (urbanization)
- Changing resource base (climate change)

Pune Metro population (millions):

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>2.6</td>
</tr>
<tr>
<td>1990</td>
<td>4.2</td>
</tr>
<tr>
<td>2000</td>
<td>5.7</td>
</tr>
<tr>
<td>2015</td>
<td>8.4</td>
</tr>
<tr>
<td>2050</td>
<td>11</td>
</tr>
</tbody>
</table>
Pune Nexus Challenge Example: Urbanization x Temperature

# Days Temperature Exceeds 37 C

Population density

Vulnerability Metric:
Number of people (millions) experiencing max temp >37 C for X number of days.

Changing the frequency and impact of heat waves has implications for cooling (energy, water) and crops (food)
Identifying FEW Challenges

- Intermittency of water and energy supply
- Sectoral competition for water and energy
- Climate-change impacts
- Political economy histories
- Governance systems
- Infrastructure decay

Quantifying Vulnerabilities
Co-Creation Approach - FUSE Process Steps:

1. Get stakeholder ideas about future challenges
   - Experts add ideas and propose solutions

2. FUSE team develops a policy-evaluation model incorporating all ideas

3. Get stakeholder responses to policy-evaluation results
Narrative Development Process

Sustainability Living Labs (SLL) Co-Creation Process

Challenges → Model Design → Vulnerability Metrics

Solutions → Scenarios → Narratives

Interventions
Conceptualizing the Nexus Model

**Agent Network Module**
Tests policy decisions by institutions and managers to supply resources

**Agriculture Module**
Determines the crop type, crop area extent, and water quantity demanded by crop and source

**Urban Module**
Determines urban extent, population density, and urban resources demands

**Water Module**
Uses climate forcing to calculate available water based on land-use
Climate
Climate Forecasting

Global RCP → Ensemble General Circulation Models (GCM) → Regional Climate Model (RCM) → Downscale And Bias Correct → Force Basin Hydrologic Model

GHG Trajectory as radiative forcing

Coarse spatial resolution of GSM Calls for RCM

Statistical Downscaling to bias Correct (Ekstrom et al 2015)

Input into water module
Water
The Community Water Model (CWatM)

- Open-source
- Process-based hydrological model
- Connected grid of cells
- Daily water fluxes
- 1km resolution
Bhima River Basin
• 7 districts
• 43 Talukas
• 55 reservoirs

Nira River Sub Basin
• 2 districts (Pune, Satara)
• 8 Talukas
• 5 Reservoirs
• 1 Urban area
• Command Areas
• Canals

Preliminary results of CWATM
River discharge

- Kinematic Wave Routing
- Main output for calibration at various gauges
- Last gauge, Sarati, integrates the full basin and is used to calibrate with 10 years of observations.
- View monsoon and ephemeral rivers

Two Monsoonal Pulses showing river discharge (m3/s), from July 1996
Evapotranspiration

- Sugarcane, sorghum, and rice are currently included in the model.
- First estimates of the specific region: No data to benchmark with.

⚠️ Data Gap: Crop-specific land use in time.

Reservoir Operations

- Reservoirs distribute water to those within their command area.
- Reservoirs can leak along their canal distribution networks, recharging groundwater.

⚠️ Data Gap: Reservoir operating decisions. Reservoir Inflow and Outflow necessary but not sufficient
Groundwater

Depth to groundwater

- Groundwater pumping is simulated within each cell to satisfy remaining water demands
- Reservoirs recharge groundwater by leaking along their canal networks

⚠️ Data Gap: Depths to bedrock, groundwater storage
Urban
Urban Growth Forecasting

Estimate population
How many people?
Based on different population projections (downscaled SSPs)

Correlate with built-up area
Translate pop. to built up area
Integrate spatial and temporal aspects of urban growth

Project future urban land use change
Where will the people go?
Use the cellular automata model, SLEUTH to find likelihood of urban development

Mitigation Difficulty
Adaptation Difficulty

Logistic regression

\[ f(x) = \frac{L}{1 + e^{-k(x-x_0)}} \]
Nexus Extension of SLEUTH model

Water, Food and Slums

**Water influenced urbanization**
- Use river locations as attractor, similar to road gravity

**Agriculture influenced urbanization**
- Use agricultural profitability as resistance parameter

**Slum-specific**
- Capture slum particularities in adapted CA model

(adapted from Clarke, 2018)
Preliminary results of SLEUTH+

- Historical PMRDA (1975-2015):
  - 3-fold population boom (2.6 to 8.4 M)
  - 8-fold built-up expansion (47 to 384 km²)

- Built up area is displacing agricultural land and ag land is moving to forests and shrubland

- Water influence is decreasing (saturation effect or roads preceding?)

- Slums grow but not as fast as total built up rate
Preliminary results of Urban Forecast

• Urbanized forecast to reach 50.5% in 2055 (35.8% in 2015)
  • Compact growth, infill, ribbon development, slower than past
Urban Consumer Model for FEW Resources

1. Demand Estimation

2. Resource Supply Curve
   “Tiered supply curve” for resources that have limited supply hours (Klassert et al., 2015, based Srinivasan et al., 2010)

3. Can infer unmeasured prices
Urban Demand Estimation

**Survey Instruments**
- HH Consumer Expenditure Survey Type 1, 2
  - NSS 68, 2011-2012
  - NSS 66, 2009-2010
- Indian Human Development Survey
  - I (2005)
  - II (2011-2012)
- FUSE Pilot Survey

**Main Insight:** Importance of energy-water nexus at HH level

- 95% of households in Urban MH receive <10 hours piped water supply per day.
  - > 95% of these consider this availability adequate.
- 83% of 101 households receive less than 7 hours daily piped water supply.
- 82% of 95 households receive one per day piped water for 3.4 hours.
- 37 of 93 households spend time to secure water (waiting, walking, collecting).
- 98% of 93 households receive 24 hour electricity supply.

• Slums consume less water and have lower electricity demand
• HH size affects water demand, electricity and LPG demand
• HH with water storage tend to have higher electricity demand
• Water consumption positively correlated to HH LPG demand
• Increase in LPG consumption and water storage results in more water demand
Urban Demand Estimation

Village-level data available on:

• Well type
• Household size
• Monthly expenditure (income proxy)
• Education, literacy and school access
• Rural/ urban
• Distance to cities
• Businesses employee number
• Electricity supply

⚠️ Data Gap: missing unit level data for nexus-related studies
FUSE Household Survey to Collect Data

**Pilot** May-June 2019
Pune and Pimpri-Chinchwad
112 door-to-door interviews
- urban, formal, slums
- Local language
- 300 + questions

**Full** Jan 2020
Households (n=2000)
Cooperation with Gokhale
Prep, Train, Test, Implement
Commercial (n= 250)
Anonymous in-person interview (no taping)
Structured, quantitative (~40min)
In Marathi
In Pune Metro and surrounding area
Using WB App Survey Solution
FUSE Household Survey Example Questions

**Water**

9 water sources: piped, tanker, private well, public well, canned water jar, bottle water, rainwater, pond, other

3 seasons: winter, summer, monsoon

1. water source(s) and percentage used in past year
2. months you think are water-scarce?
3. monthly water consumption?
4. water storage equipment?
5. Water payment type and amount

**Energy (Kerosene, LPG, Electricity)**

1. payment in Rs/month by season
2. price in rs/liter per season
3. quantity consumed per month in L/mo by season
4. from where (shop, market, other)

**Economics**

1. Living space in sq. ft
2. Number and type of appliances
3. Monthly income for all members Rs/month
4. Home ownership

**Food**

1. Percent of HH income used for food?
2. How much do you spend on food per month? in Rs/month
3. Seasonal variation in food expenses?
4. Ration card Type?
5. What factors influence food purchase decisions from most important to least (nutrient content, calorie, taste and texture, prestige, availability, safety, region of production)
Additional FUSE Activities in Pune

**Water Diaries**
- 50 household document water collection and use for a week
- Focus on locations with high herterogeneity in water access

**In-depth household interviews**
- 20 households concerning water collection, storage, usage behaviors

**Small Tanker Operator Survey**
- 20 structured interviews with tanker operators to understand cost, pricing, business
- Semi-structured expert interviews

**‘Clicker Study’**
- Estimate tanker volume market by counting tanker trucks passing by strategic observation points

**Migration Interview**
Agricultural
Optimization and Machine Learning for Farmer Decisions

Farmer Decision: Optimization method using positive math programming (PMP) to select a crop --- Requires parameter calibration to observation

Unsupervised land classification

Data Gap: **spatial** crop maps with which to validate; price and cost info.
Agent Network
Agent
Network
Module

Inflow

Reservoir

Water Department
How much outflow?

Irrigation Ministry
Water distribution to Irrigation nodes

Sugarcane
Irrigation Demand

Sugarcane
Irrigation Demand

Rice
Irrigation Demand

Ministry/Department Priorities coded
Policy Change Tests
Ex: sugarcane weight (to reflect support)
Ex: spatial/regional weight
Ex: flood protection operating rule
Ex: additional capacity/infrastructure
Conceptualizing the Nexus Model

Agent Network Module
Tests policy decisions by institutions and managers to supply resources

Agriculture Module
Determines the crop type, crop area extent, and water quantity demanded by crop and source

Urban Module
Determines urban extent, population density, and urban resources demands

Water Module
Uses climate forcing to calculate available water based on land-use

*Energy Module Not Yet Shown
Data Needs
Some General Data Needs

**Urban**
- Actual urban water and energy use spatially by sector and time
- Focus on historical time series by spatial units
- Aggregate water use by cities (PMC, PCMC, PMRDA, MIDC)
- Piped distribution network map
- Water and energy supply system capacities and supply duration by ward or distribution zone
- Big consumers and changes in use
- Urban flood information

**Agricultural**
- Observed land use (crop specific and in time, months)
- Observed crop yield (Production and Area)
- Crop prices at higher resolution than state
- Production Costs (spatial or higher resolution than state)
  - land costs
  - input costs (labor,
  - Water costs (surface water and groundwater)
- Irrigation water used (amount and source)
- Historical drought information

**Water**
- Ujjani inflow for recent years
- Water audit spreadsheets for more years
- Water allocation rules among crops or within ag
- Annual water withdrawals
- Monthly water supplies
- Reservoir operating rules
- IMD Soil Moisture and Evapotranspiration
- Evaporation station locations
- 38 gauge River Discharge Daily 1980-2019*
- 55 Reservoir Daily Inflow, Level, Storage, Discharge from Flood Control Cell Sheets*
- Water Accounting Sheets for missing 44 Reservoirs and longer time for all*
- Reservoir Top bottom and Crest*
- Irrigation water use
- Ground level and pumping*
- Flood Control Levels (FCL)*

* Some obtained previously, need missing years/locations to fill data gaps
Exploring Potential Policy Interventions for Pune

**Climate**
- Climate policy
  - Mitigation/Adaptation to Extremes
  - Green Infrastructure

**Water**
- Governance
  - Enforcement of the existing regulations
  - Basin-wide economic optimization
  - Transferable water entitlement system
- Supply
  - Distribution Rules
  - Additional infrastructure
  - Local solutions RW harvesting
- Demand
  - Restructuring of water tariff system
  - Reduce non-revenue water

**Agriculture/Food**
- Sugar sector
  - Removal of sugar price supports
  - Sugarcane use for biofuel production

**Irrigation**
- Adoption of new irrigation technology
- Water reallocation to priority crops

**Urbanization**
- Urban policy
  - Planned Development

**Energy**
- Energy policy
  - Biofuel and Solar PV adoption
  - Capacity expansion
Preliminary Insights

- **Nexus focus** – model and quantify the benefits of overcoming silo thinking
- **Co-creation** – stakeholders aware of challenges
- **Evaluation** – limited capacity to assess policy solutions
- **Stakeholders** - Eager for systems approach
- **Data acquisition** – difficult, top down
- **Pune** – civil society – pro-active and lower expectation of government
Questions/ Comments