The coupled social-hydrology of Bangalore city, India

Muddu Sekhar[1], Vishal K. Mehta[2*], Eric Kemp-Bendict[2], Deepak Malghan[3], Sören Gebbert[4]

[1]Indian Institute of Science, [2]Stockholm Environment Institute, [3]Indian Institute of Management, [4]Thünen Institute of Agricultural Climate Research

*corresponding author: vishal.mehta@sei-us.org

AGU December 2012, San Francisco # H23F-1459

Problem

- India is rapidly urbanizing. Its urban population of 370 million exceeds the total population of all countries except China.
- Utility water services are extremely poor; no Indian city receives 24x7 water supply[1].
- Water is consumed from many sources: surface, private groundwater self-supply, tankers, bottled water.
- Cities are tightly coupled social-ecological systems. The pattern of water supply and consumption is dynamically linked with hydrology[2,3].
- Scientific understanding of this dynamic inter-linkage is crucial to sustainable urban water management and policy.

Goals

To develop a robust urban water balance for science-based comprehensive planning. The first phase focuses on the domestic (residential) water sector.

Methods

Data Collection: Spatial and temporal data on population and utility water supply, from government agencies.

Modeling: Lumped and distributed groundwater models of the city under natural and modified (existing) conditions.

Acknowledgements

Financial research support from the Swedish International Development Cooperation Agency (Sida), and the Ministry of Urban Development (GoI) is gratefully acknowledged. We thank Rimi Goswamy, BWSSB and BBMP for data support.

References

[1] Srinivasan, V., Gorelick, S.M., and Goulder, L. (2010). "A hydrologic-economic modeling approach for analysis of urban water supply dynamics in Chennai, India." *Water Resources Research*, 46(7),W07540.

[2] House-Peters, L.A., and Chang, H. (2011). "Urban water demand modeling: Review of concepts, methods, and organizing principles", *Water Resources Research*, 47(5), W05401.

[3] Kim, Y.Y., Lee, K.K., and Sung, I. (2001). "Urbanization and the groundwater budget, metropolitan Seoul area, Korea." *Hydrogeology Journal*, 9(4), 401-412.

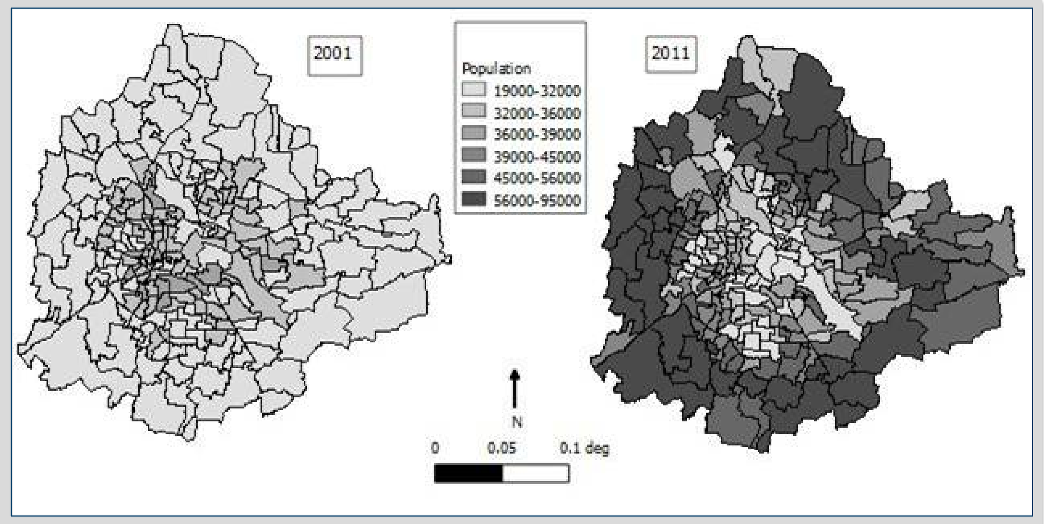
[4] Hegde, G.V. and Chandra, K.C.S. (2012). "Resource availability for water supply to Bangalore city, Karnataka", *Current Science*, 102(8), 1102-1104.

[5] Neteler, M., and Mitasova, H. (2008). *Open source GIS: A Grass GIS Approach*, Springer, New York.

Bangalore context

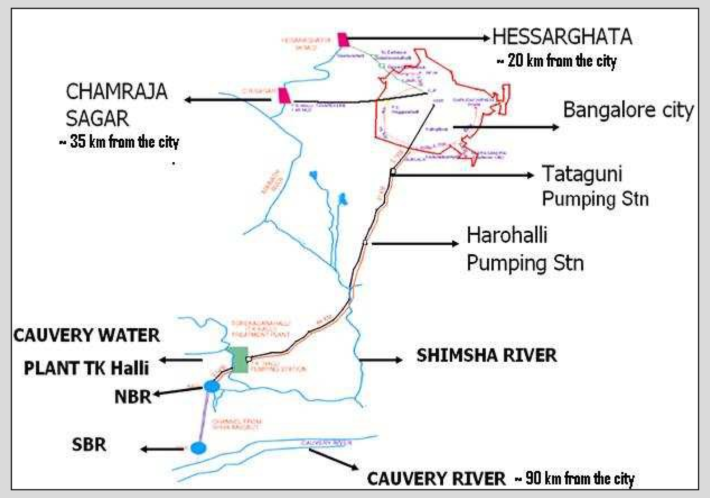
Bangalore Population Growth

Year	Population (million)	Density (per sq km)	Built-up area (% urban footprint)
1971	1.65	9,465	20%
1981	2.92	7,990	26%
1991	4.13	9,997	39%
2001	5.7	11,545	69%
2011	~8.5	12142	*na*



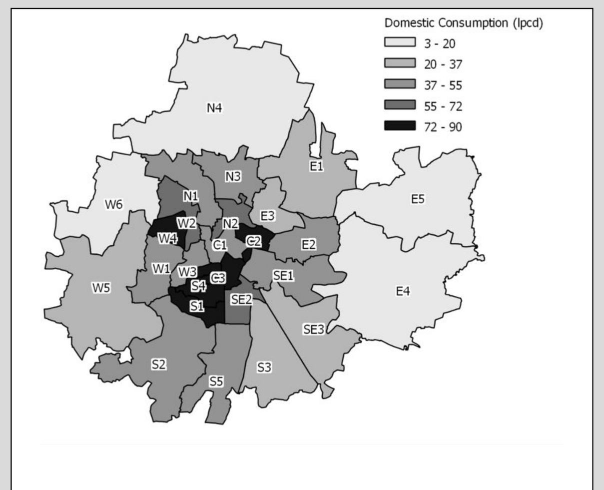
Population growth is highest away from the historic center of the city; precisely in those areas which are least connected to water utility pipelines.

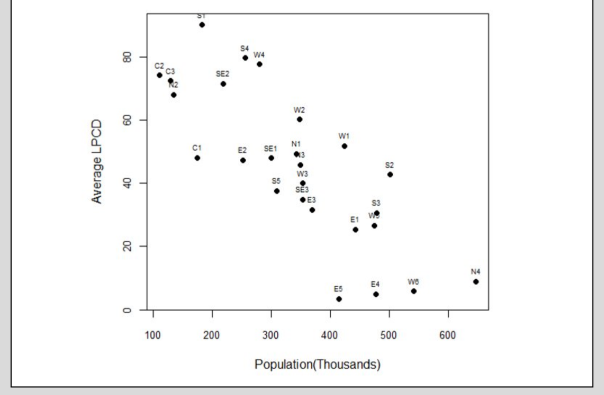
Utility Water Supply

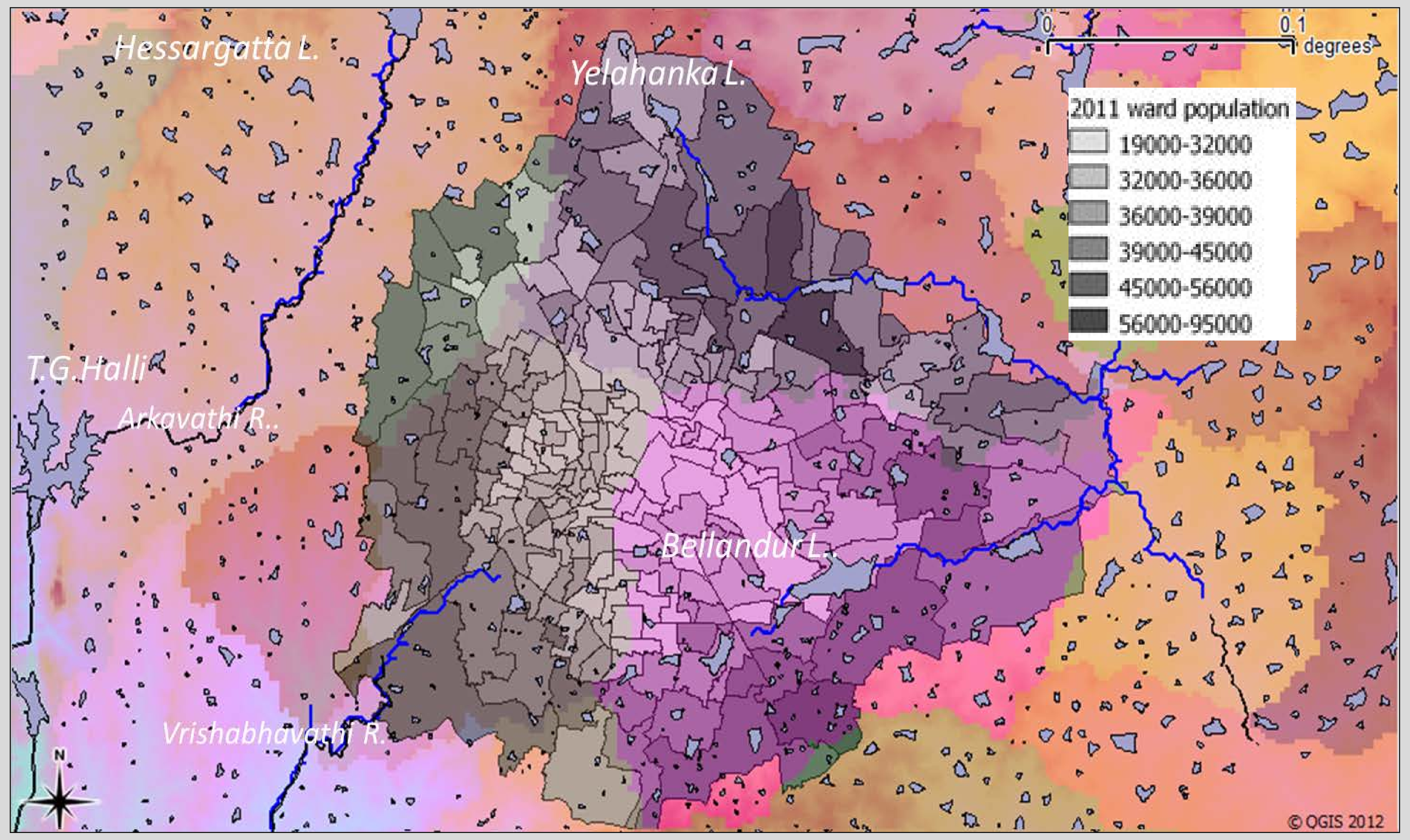


The public utility (BWSSB) supplies 900 MLD from the Cauvery river, 100km away up a 500m gradient. Domestic water consumption. At least 35% leaks through the pipelines. Only about one-third finally reaches the domestic sector.

Our analysis shows that hundreds of thousands of city residents receive less than 50 liters per capita per day (lpcd) from utility piped supply.. Residents use a variety of coping strategies to make up the difference- primarily relying on tankers and private pumping



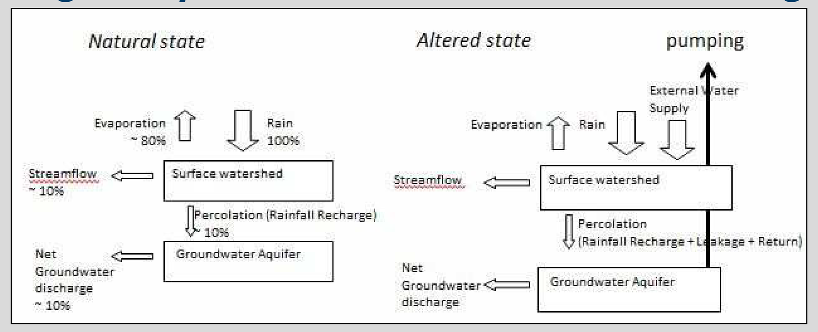




The city as a coupled social-ecological system. *Bangalore ward population is overlaid over terrain, watersheds and hydrography. The city of Bangalore is approximately 700 km2 in area, and lies between latitudes 12°48'- 13° 9'N and longitudes 77° 27' – 77° 47'. The city core is at 930 m amsl, on a divide with a roughly North-South axis. The climate is semi-arid with normal rainfall of 820mm, September being the peak rainfall month. In the past decade, mean annual rainfall has been 937 mm[4]. The city is underlain by Precambrian granite and gneiss, weathered to about 15m, covered by red loamy and gravelly soils. Hard-rock aquifers of this kind are characterized by low hydraulic conductivity and specific yield, because the granite-gneiss complex can only store and transmit water via open fractures. Hence borewell yields are typically very low, compared to alluvial aquifers.*

Lumped model

Thought experiment: the urban water budget



Impact on groundwater recharge depends on the magnitudes of artificial recharge from leakage against abstraction from pumping

Assumptions:

Total water consumed=150 lpcd

$NR = r_{nat} * P$ (1)

$AR = r_{alt} * P + (l * Q_{supply}) + (l_{return} * Q_{cons}) – Q_{pump}$ (2)

Where:

NR = groundwater recharge under natural conditions;

AR = groundwater recharge under altered conditions;

r_{nat} = rainfall recharge factor under natural conditions = 0.07

r_{alt} = rainfall recharge factor under altered conditions = 0.07

P = rainfall; l=leakage factor=0.35; lreturn=0.05

Q_{supply} = BWSSB total water supply ;

Q_{cons} = domestic water consumption;

Q_{pump} = estimated net pumping

Distributed model

A distributed groundwater model was applied to the Bangalore region, using **r.gwflow**, a groundwater module available in GRASS GIS[5]..

The module solves for each cell, the groundwater flow partial differential equation of the form:

$(dh/dt)*S = K_x * (d^2h/dx^2) + K_y * (d^2h/dy^2) + q$ (3)

Where :

h= piezometric head (m);

dt=time step for transient calculations (s);

K_x, K_y=K=hydraulic conductivity in x and y directions respectively (m/s);q=source or sink (m/s);S=specific yield (-)

For hard rock aquifers, K and s are very low. We assumed a fully penetrating, homogeneous unconfined aquifer formulation with parameters K=0.5m/day and S=0.0075. q was set to the net recharge term, estimated spatially from eqn. 1 and 2. Monthly rainfall data for Bangalore were extracted from WMO.

The model was run for at monthly time step using natural and altered state conditions. Differences in the spatial pattern of simulated head were compared.

http://grass.osgeo.org/grass70/manuals/r.gwflow.html

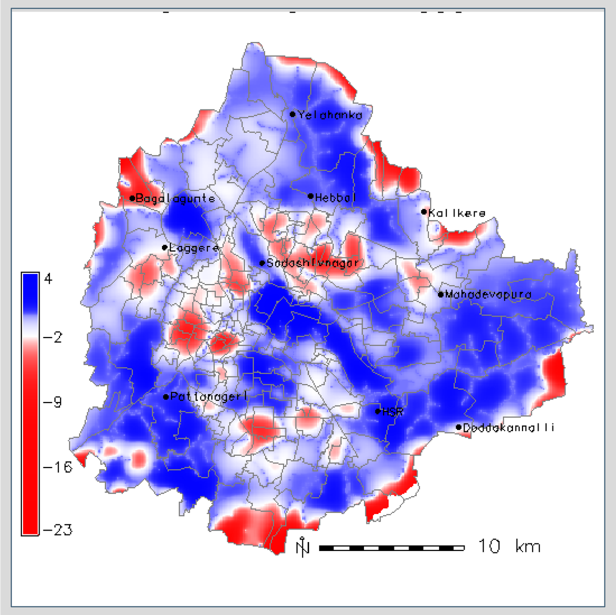
Results

- Domestic water use alone results in an estimated groundwater overdraft of 130%, with pumping exceeding artificial recharge from utility pipelines.
- Large uncertainties arise from knowledge gaps on various portions of the urban water budget.

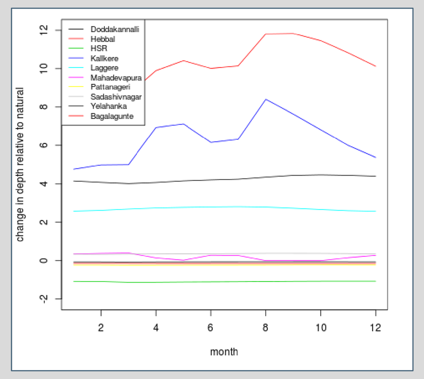
mm/yr	Natural	Altered (no return flows)	Fully altered (return flows)
Rainfall recharge	63	63	63
Piped supply leakage	0	140	140
Net Pumping	0	-360	-360
Return Flow	0	0	138
Net recharge	63	-157	-19

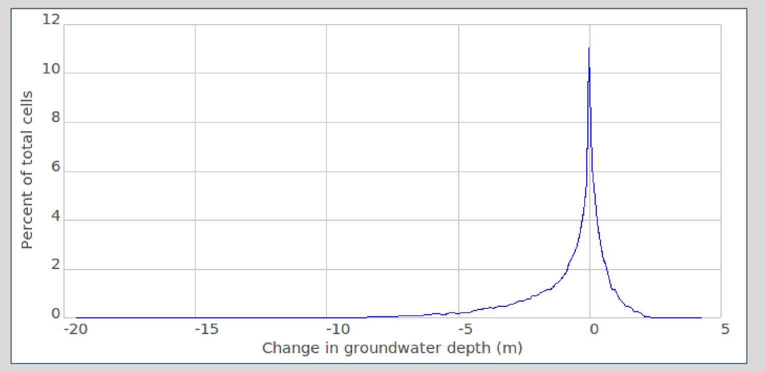
Results

- Large spatial variation in changes in groundwater head from domestic water use alone.
- Modeled changes in groundwater depth are shown below.



Spatial patterns in groundwater impacts reflect a complex interaction of groundwater hydraulics, water supply infrastructure, population density, and socioeconomic drivers of water demand.



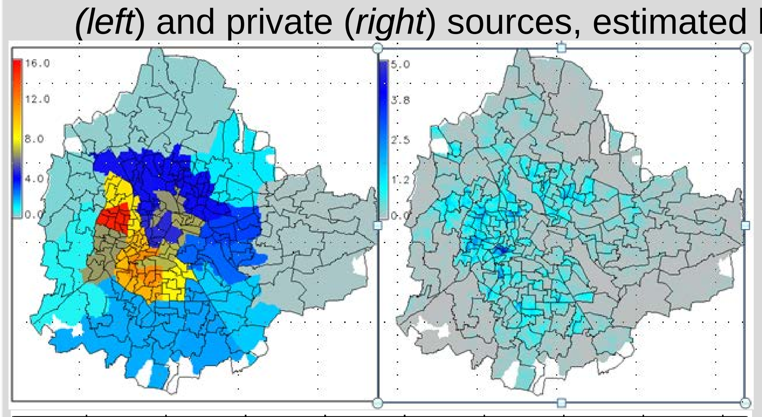


Key challenges

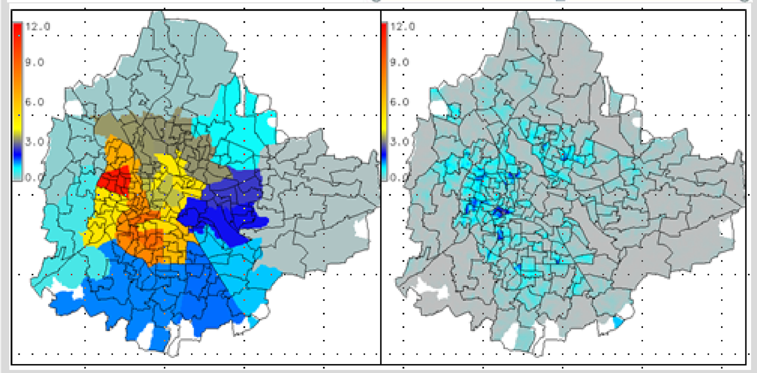
- There is no systematic knowledge of actual water consumption by source and sector for any Indian city.
- There is no knowledge of the groundwater surface at adequate spatial resolution. A very small number of long-term groundwater monitoring stations exist, whereas the number of groundwater extraction wells number anywhere between 200,000-400,000.
- Science-based water policy and management is severely hampered by these knowledge gaps.

Ongoing research

- A household water consumption survey will produce a water demand function.
- Crowdsourcing and citizen science initiatives will be explored to fill in critical knowledge gaps.
- Water-energy nexus of domestic water supply from public (*left*) and private (*right*) sources, estimated below:



Electricity consumption, MWh/year



CO2 emissions, tonnes/year

Electricity and emissions from private pumping are very sensitive to water table depth. These results emphasize the need for data-driven, coupled social-ecological modeling of cities as living systems.