Why all (Urban) Hydrology is Social Hydrology? Evidence from Bangalore, India

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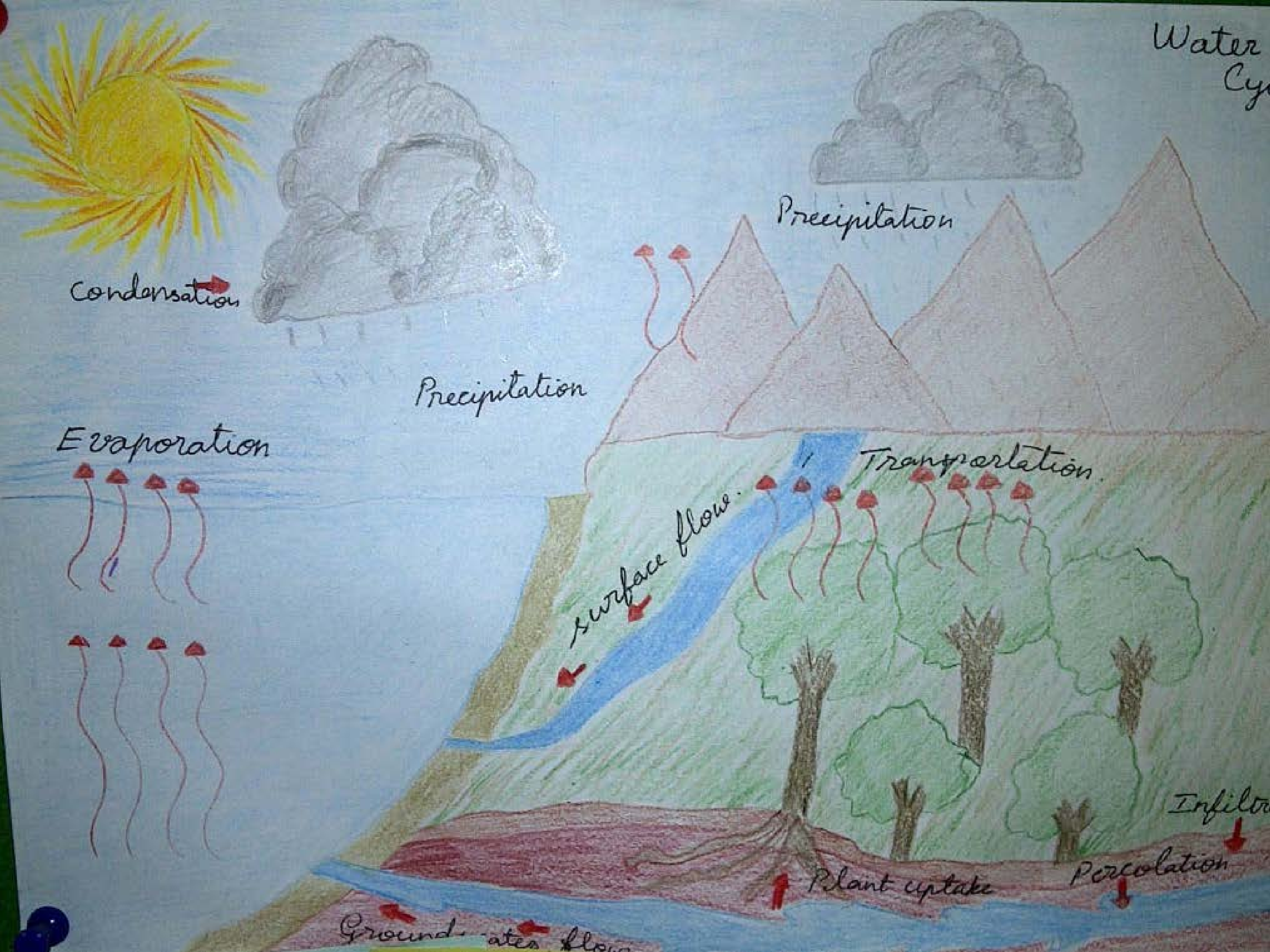
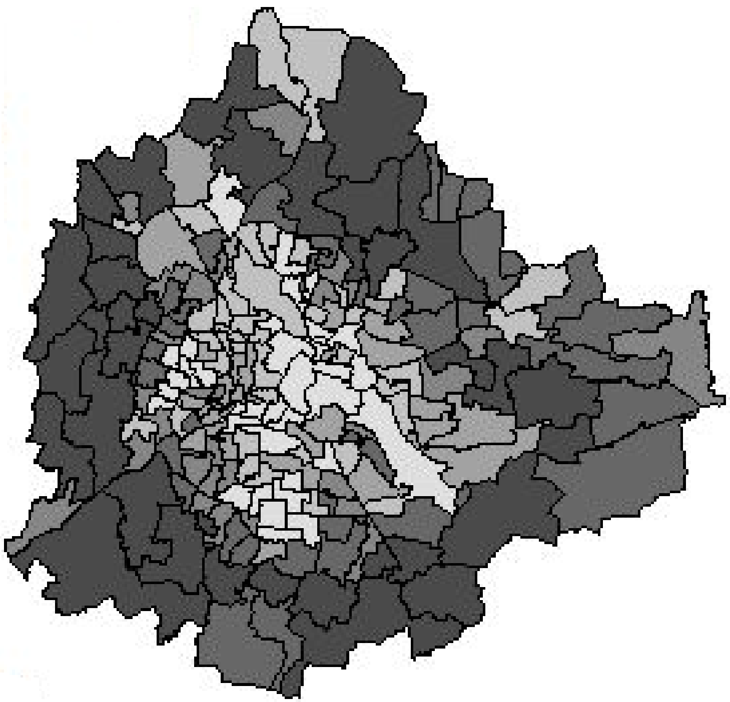
October 29th 2014

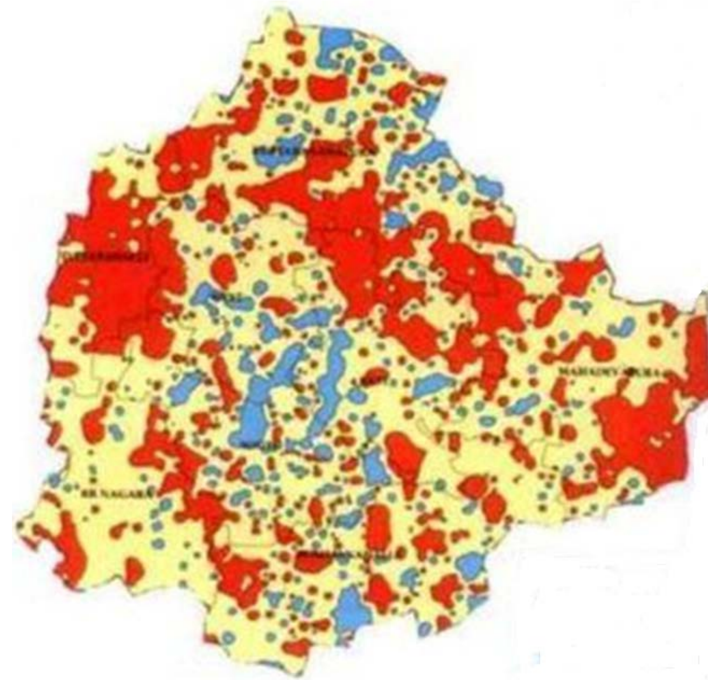

Water
Cy
Condensation
Precipitation
Precipitation
Evaporation
Transportation.
surface flow.
Infilt
Plant uptake
Percolation
Groundwater flow

Social Hydrology in Bangalore 101

- Bangalore, Background Drivers:
  – (Short-term) average rainfall: 850 mm
  – City Area: ~ 700 Sq. Km
  – Total rainfall: **1630 MLD** (million liters a day)
- Bangalore, Anthropogenic Drivers:
  – Surface water import: **1400 MLD** (85% of rainfall)
  – Groundwater extraction: ??
  – "Artificial" recharge rates: ??

Metabolic Urbanism: What do we not see on these maps?





Bangalore (like any other city) is a living organism

- This is from my nephew's 1st grade science book
  - Living things breathe
  - Living things need food
  - Living things excrete
  - Living things grow (usually only for a part of their lives)
  - Living things die

The Problem

- We understand a lot about Bangalore's circulatory system
  - The flow of rupee and (especially) dollar through the city.
  - The circulatory system is what economics and business is interested in.
- However, what about the digestive system?
  - What does Bangalore consume?
  - What does Bangalore excrete?

What are these metabolic flows?

- Food (Organic waste and sewerage)
- Energy (air pollution)
- Water (BWS**S**B)
- Metals and plastic (recyclable waste)

- Metabolic flows share a two-way relationship with the circulatory system

Three ways to characterize metabolism

- Social Justice
  – How are the flows distributed between different people in the city?
- Ecological sustainability
  – What volume of flow is sustainable?
- Economic Efficiency
  – How are the flows distributed between different activities in the city?

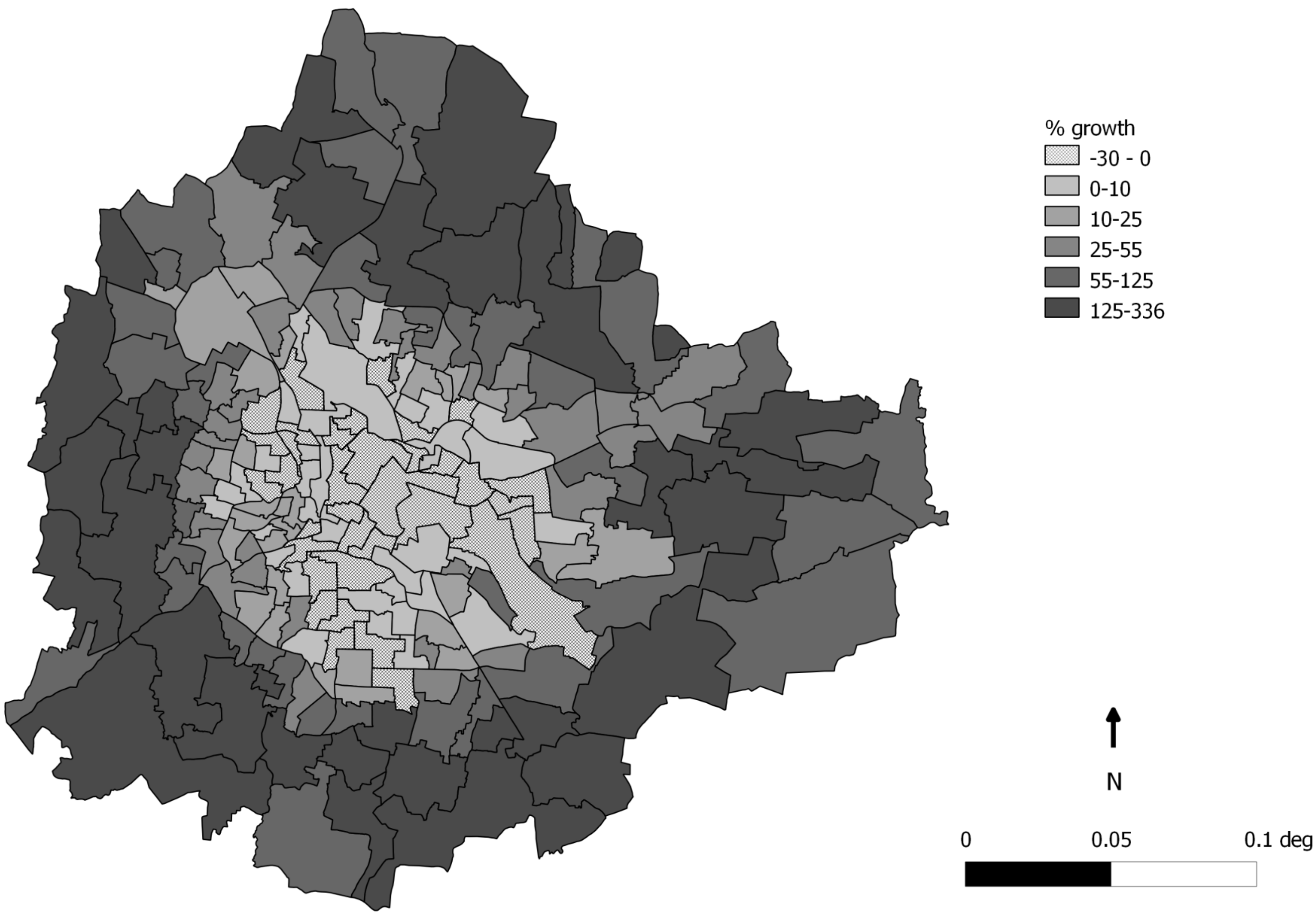
- Bangalore as a living organism is sick and unhealthy on all three counts
  - The political economy of distribution is fraught with inequities on multiple dimensions
  - Most metabolic flows are not physically sustainable
  - The flows are often not economically efficient either

How has the city grown?

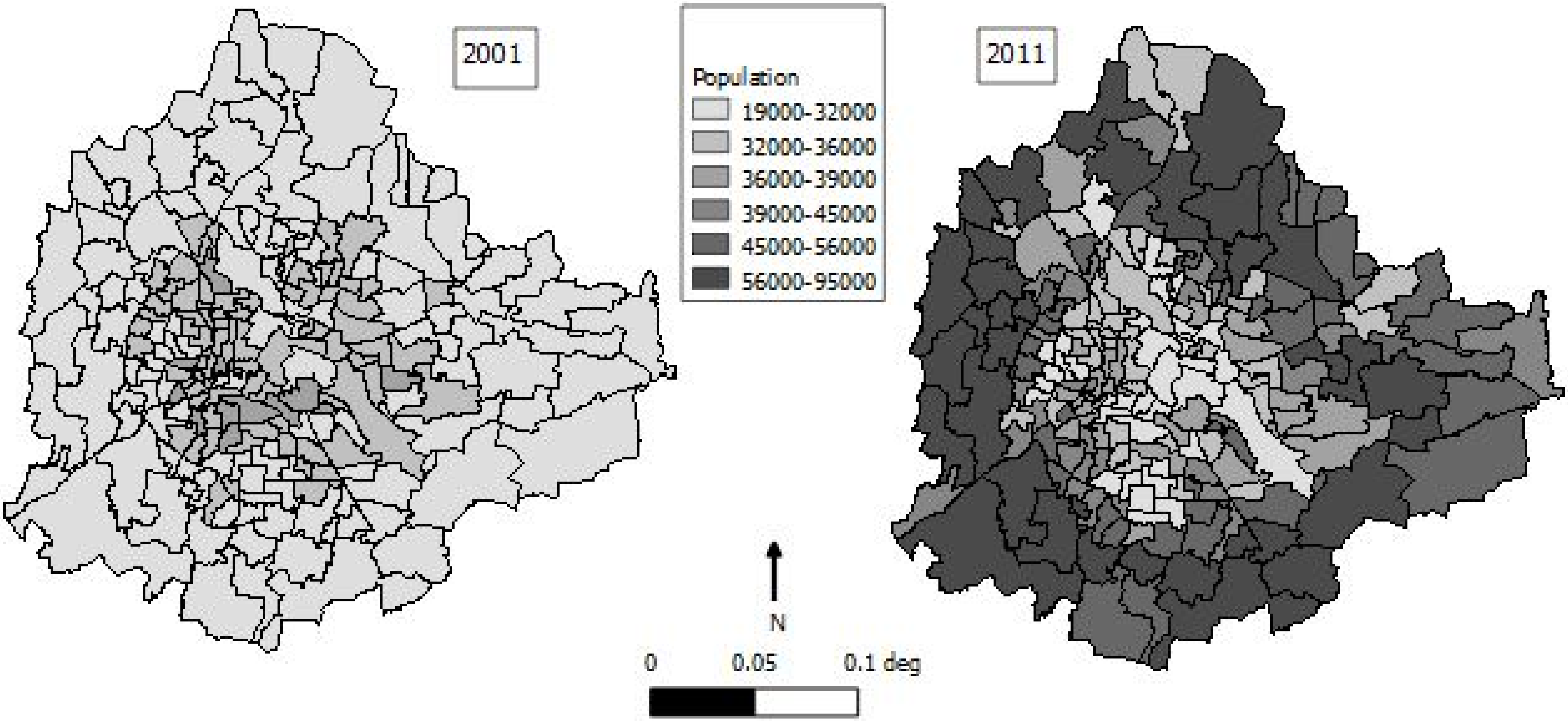
Year	Population (million)	Density (persons per sq. km)	Built-up area (% urban footprint)
1971	1.7	9,465	20%
1981	2.9	7,990	26%
1991	4.1	9,997	39%
2001	5.7	11,545	69%
2011	8.5	12,142	*Na*
2014	~ 9.3	~ 13,280	~75%

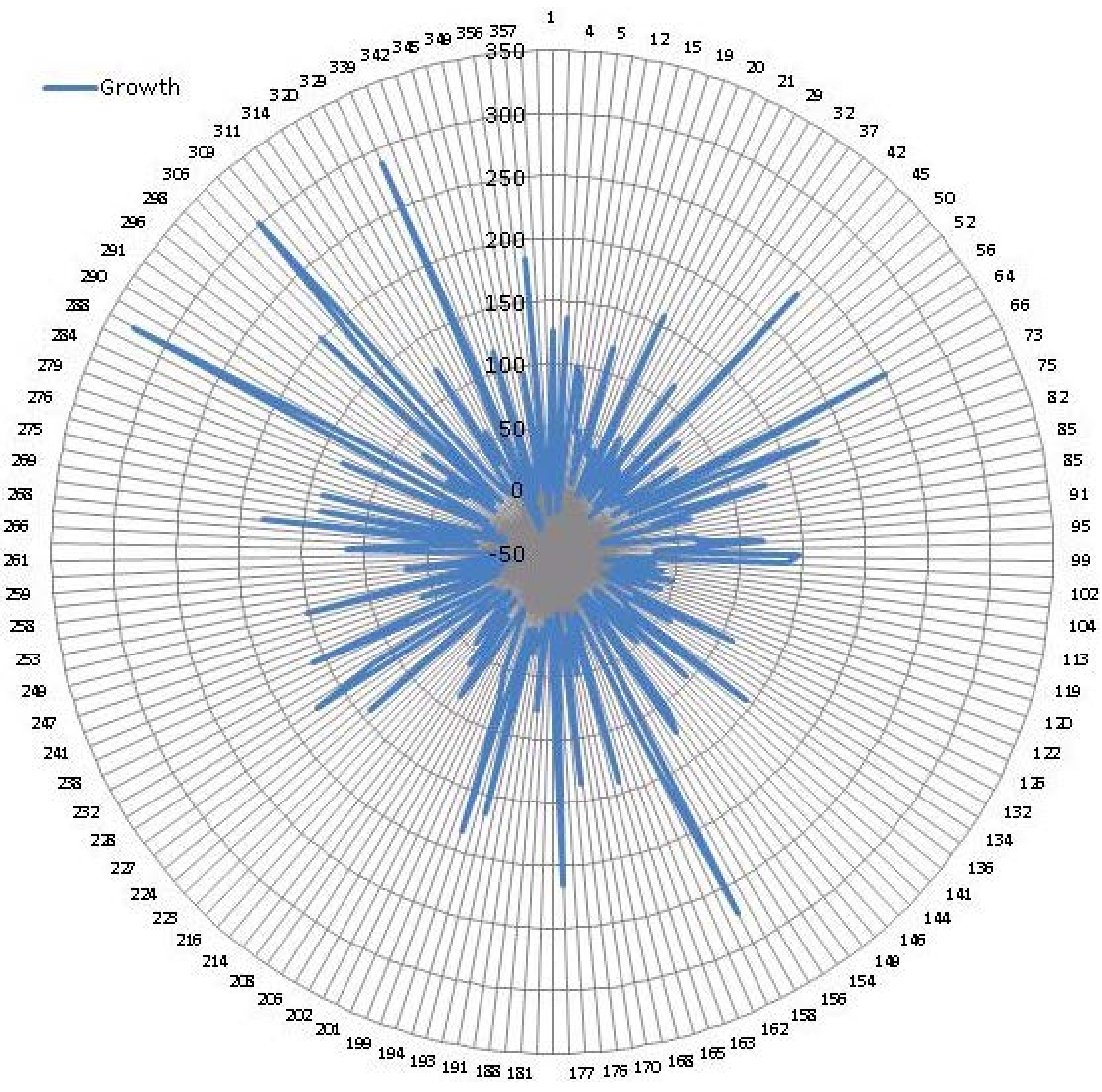
Sources: Census (2011); Iyer et al (2007); Mehta et al (2013)

Where has the city grown?

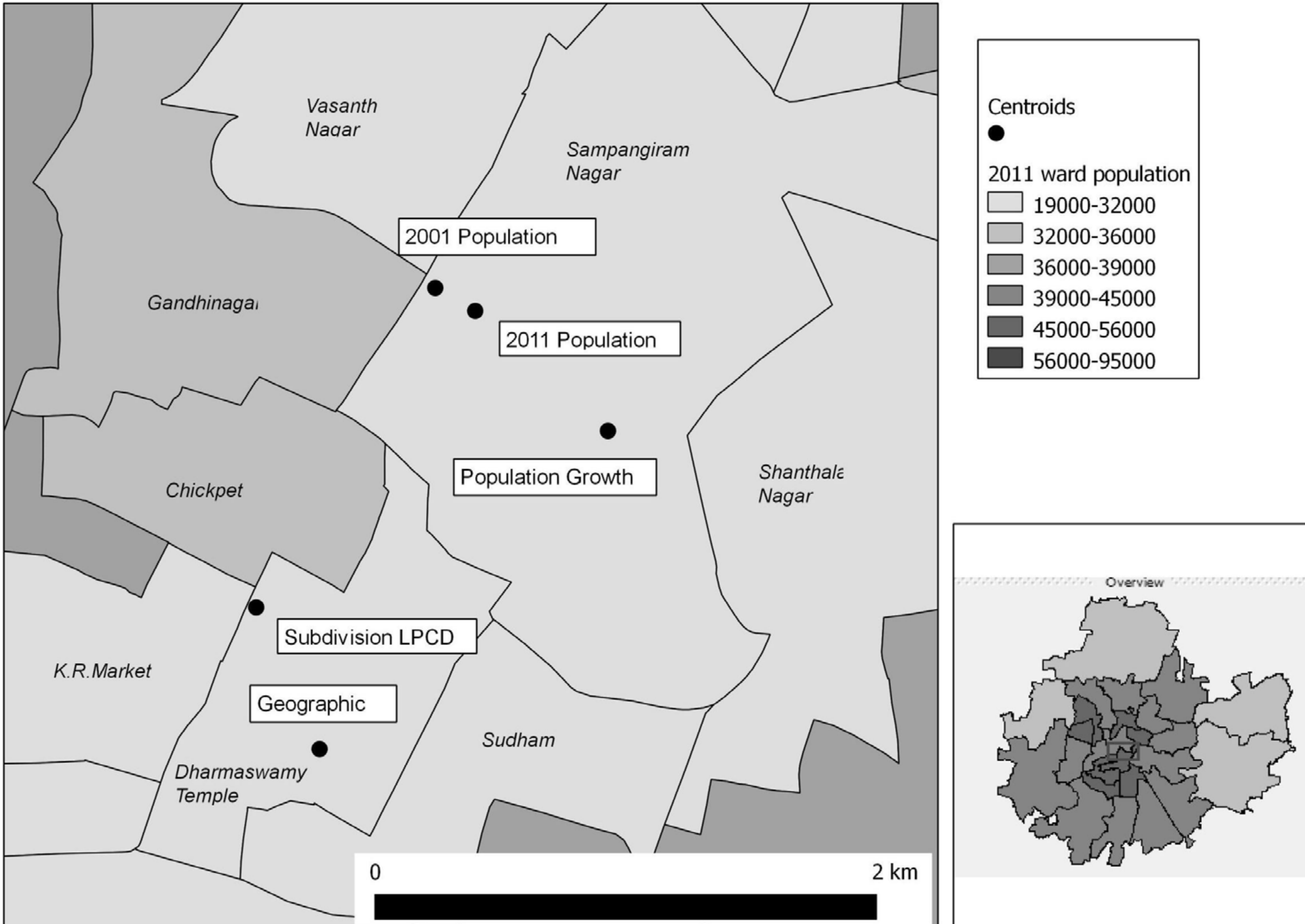


Where has the city grown?

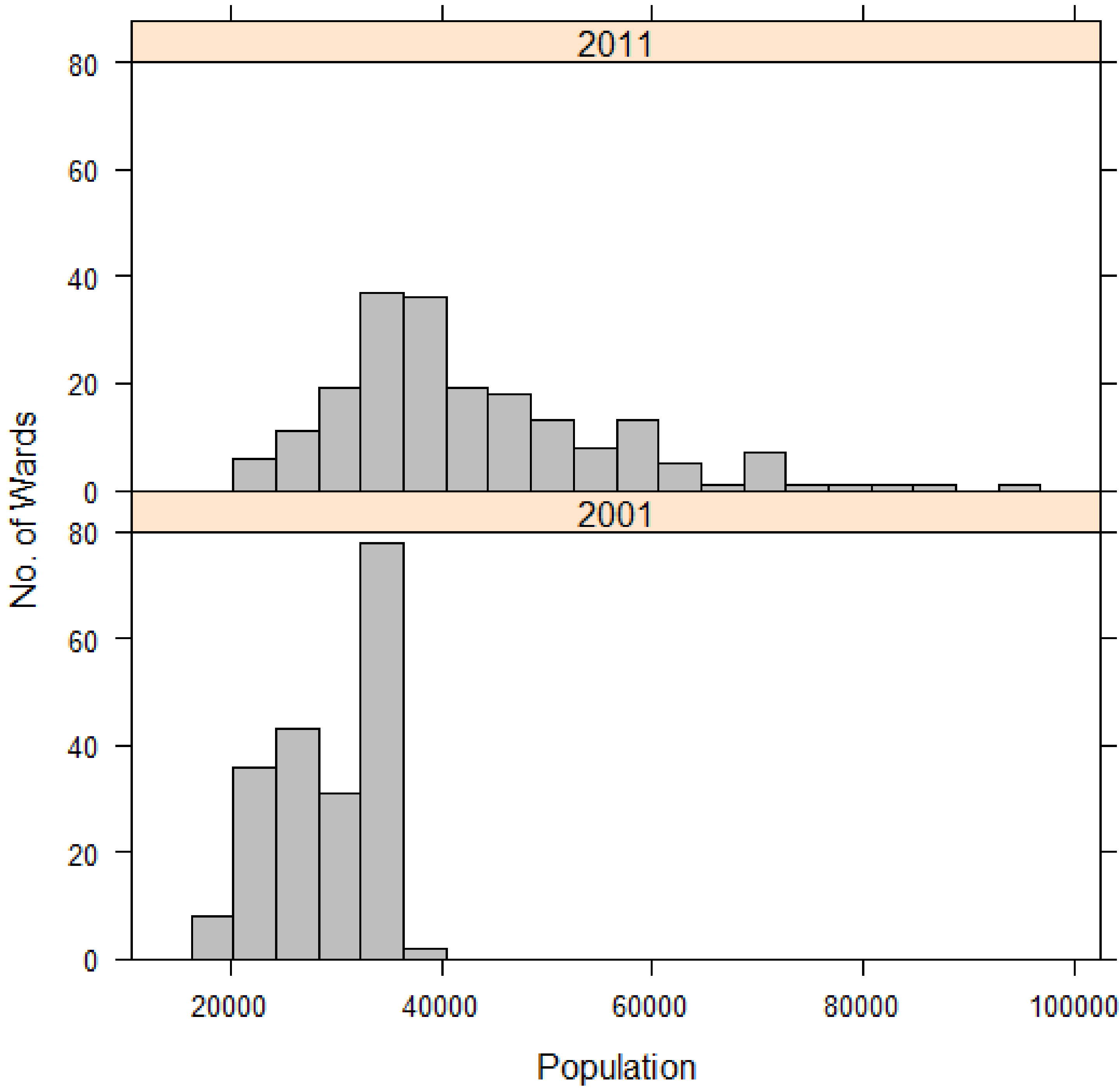


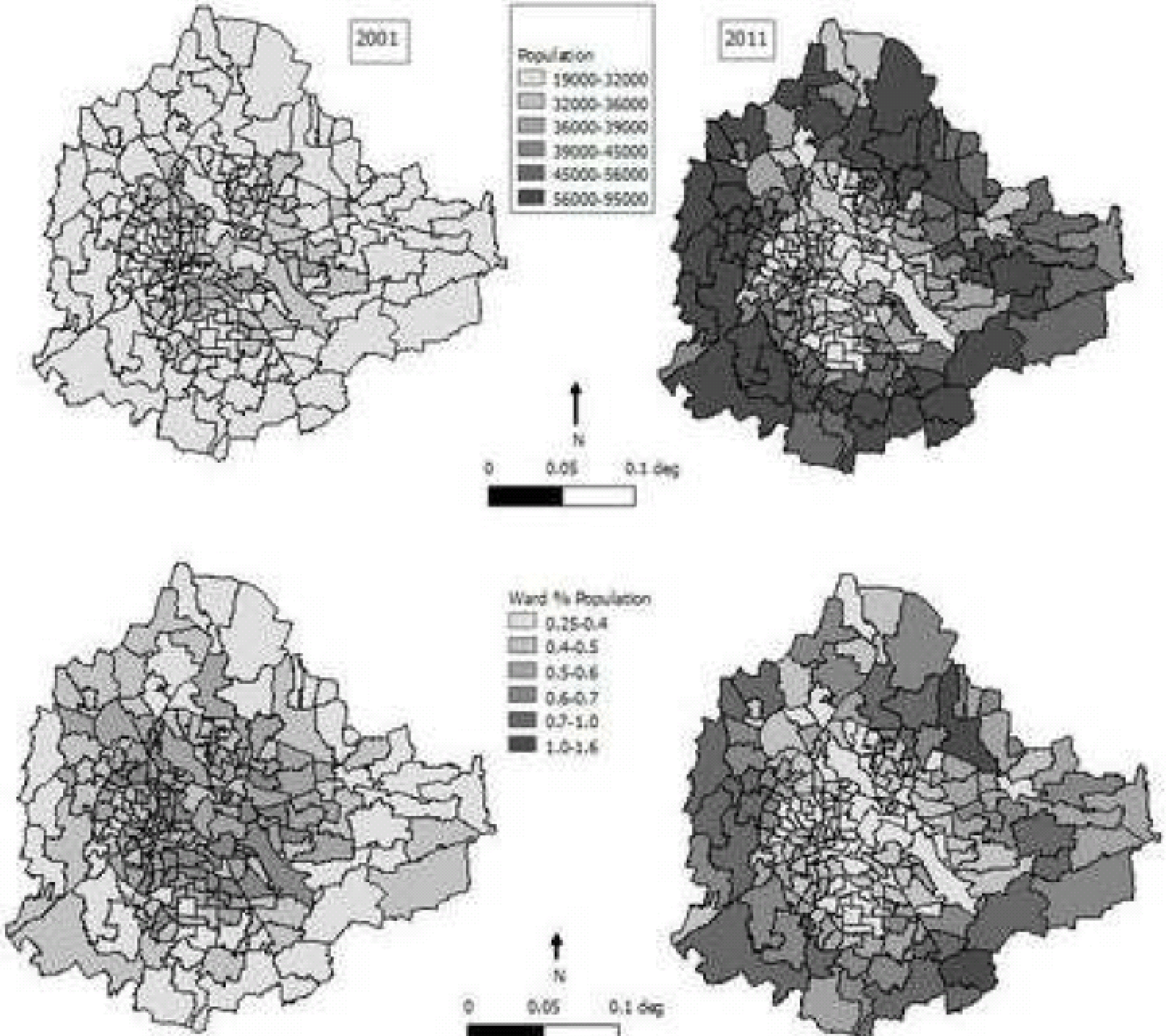


Growth
350
300
250
200
150
100
50
0
-50

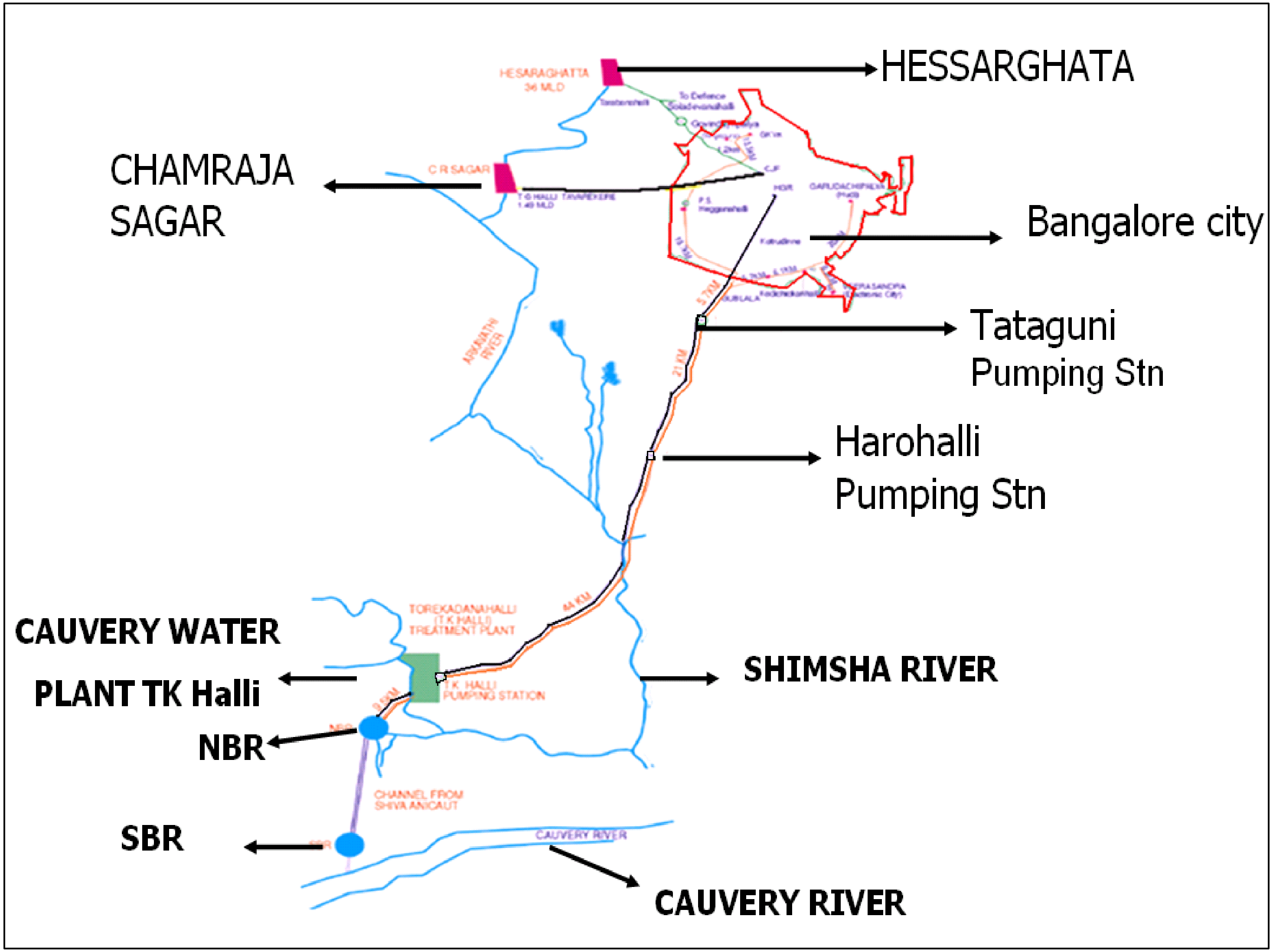


Vasanth Nagar
Sampangiram Nagar
Gandhinagar
Chickpet
Shanthala Nagar
K.R.Market
Sudham
Dharmaswamy Temple
2001 Population
2011 Population
Population Growth
Subdivision LPCD
Geographic
0
2 km
Centroids
2011 ward population
19000-32000
32000-36000
36000-39000
39000-45000
45000-56000
56000-95000
Overview

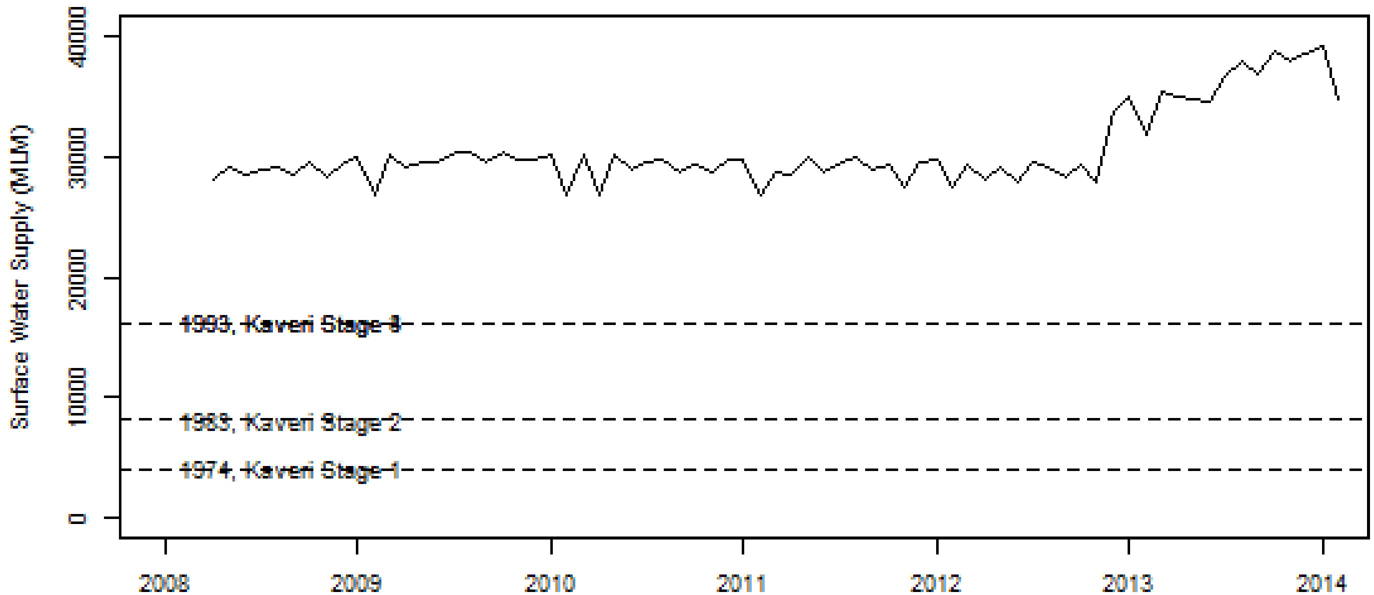

2011
2001
80
60
40
20
0
No. of Wards
20000
40000
60000
80000
100000
Population


2001
2011
Population
19000-32000
32000-36000
36000-39000
39000-45000
45000-56000
56000-95000
N
0
0.05
0.1 deg
Ward % Population
0.25-0.4
0.4-0.5
0.5-0.6
0.6-0.7
0.7-1.0
1.0-1.6
N
0
0.05
0.1 deg

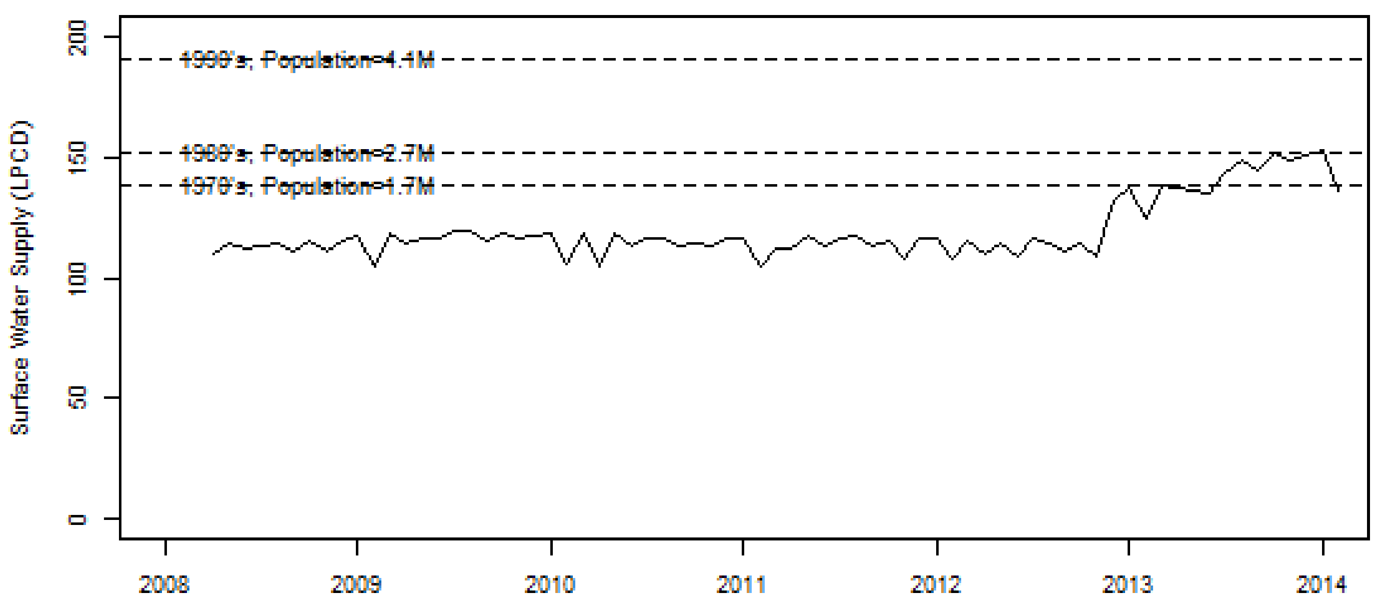
Surface Water Supply



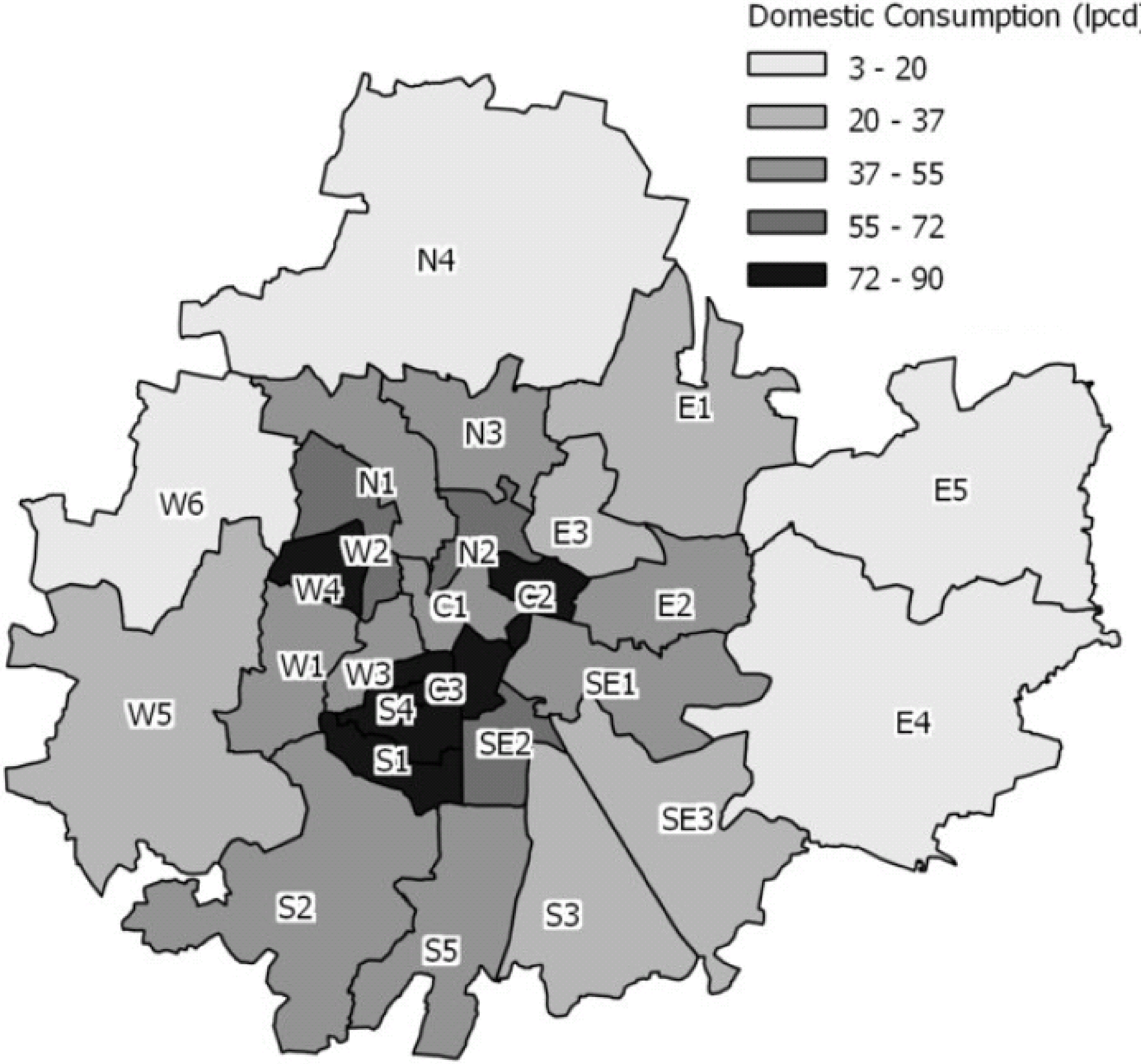
Source: BWSSB



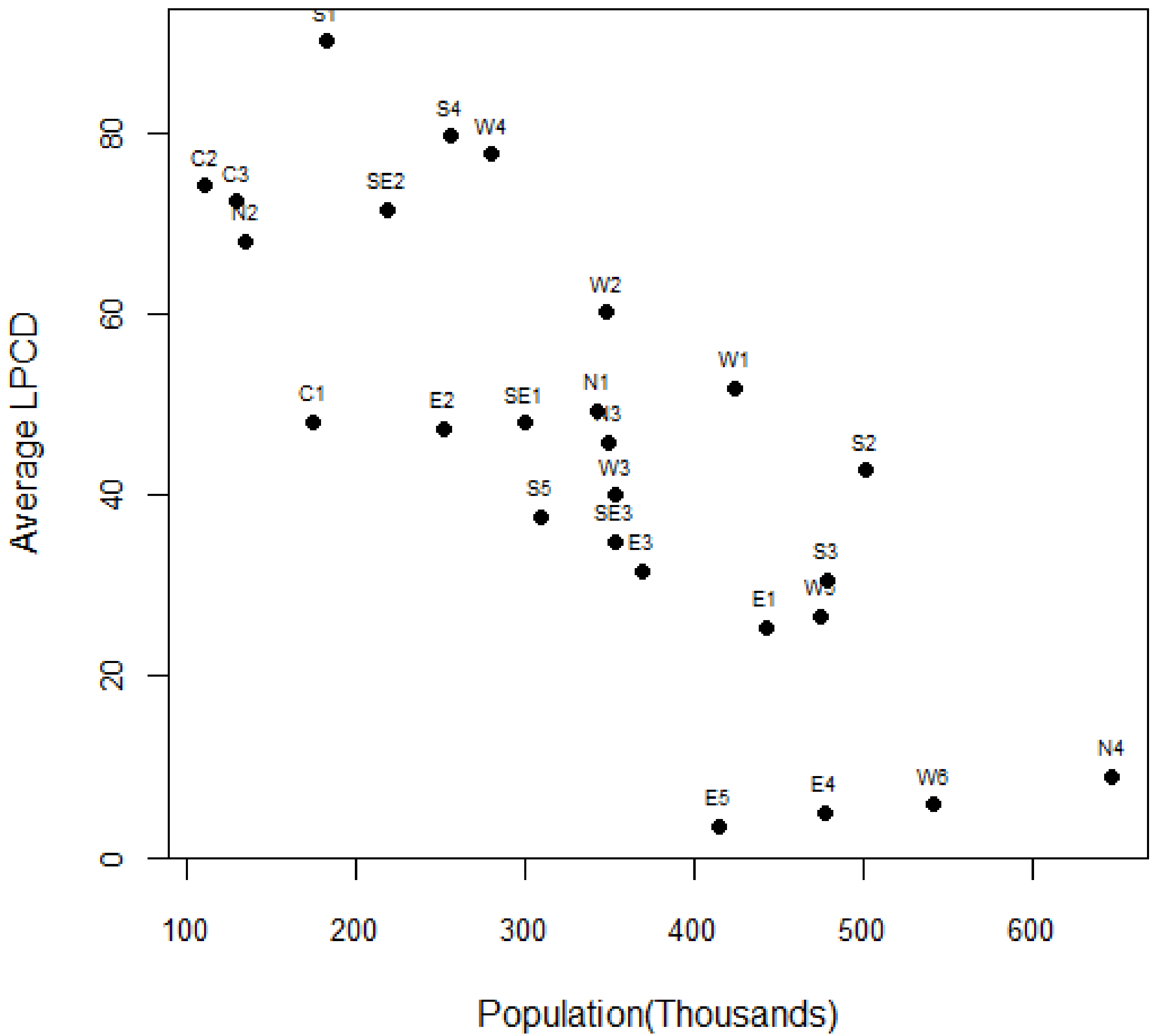
Surface Water Supply (MLM)
0
10000
20000
30000
40000
1993, Kaveri Stage 3
1983, Kaveri Stage 2
1974, Kaveri Stage 1
2008
2009
2010
2011
2012
2013
2014



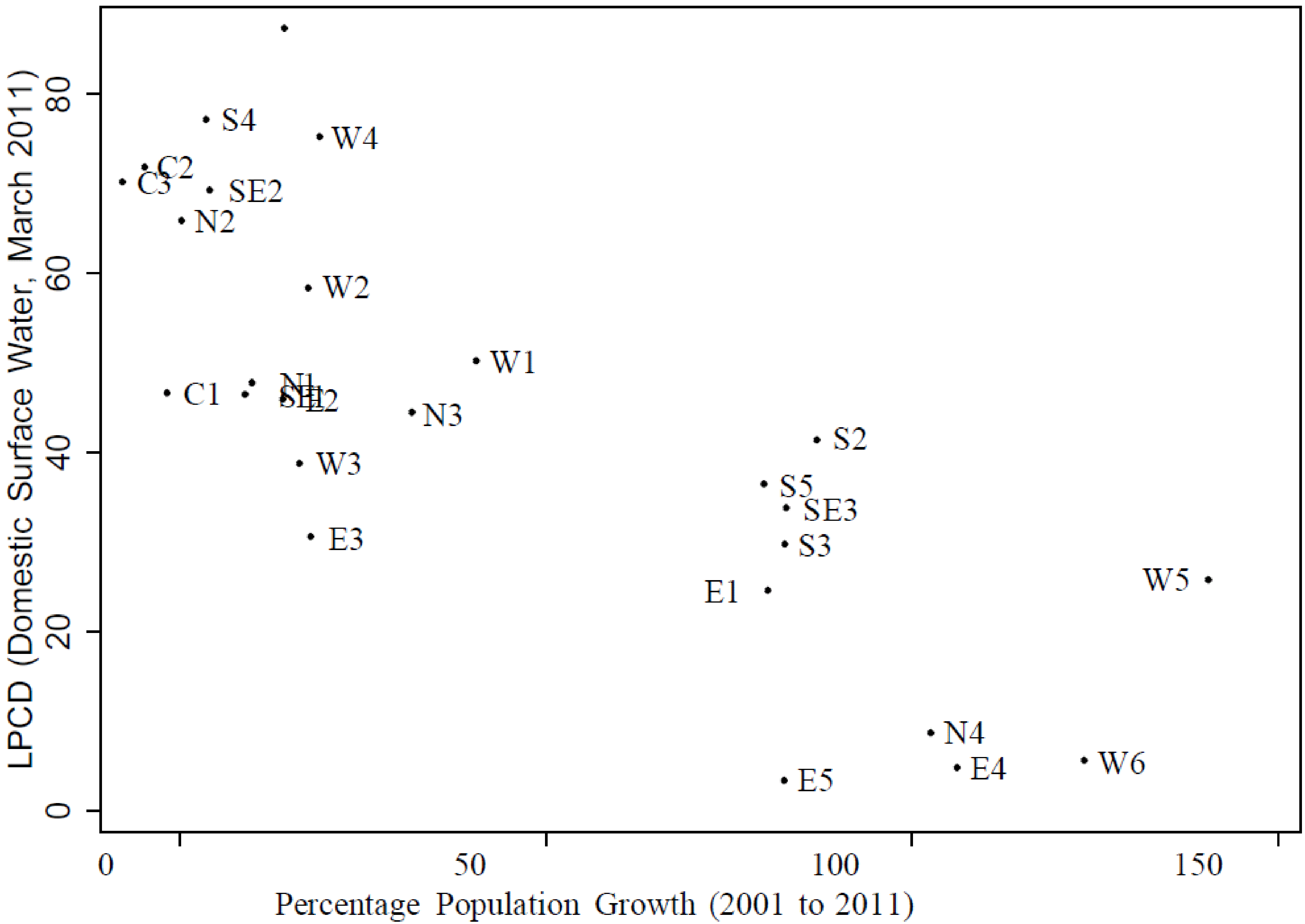
Surface Water Supply (LPCD)
0
50
100
150
200
1990's, Population=4.1M
1980's, Population=2.7M
1970's, Population=1.7M
2008
2009
2010
2011
2012
2013
2014


Domestic Consumption (lpcd)
3 - 20
20 - 37
37 - 55
55 - 72
72 - 90
N4
N3
N1
N2
E1
E5
E3
E2
E4
W6
W2
W4
W1
W3
W5
C1
C2
C3
S4
S1
S2
S5
S3
SE1
SE2
SE3

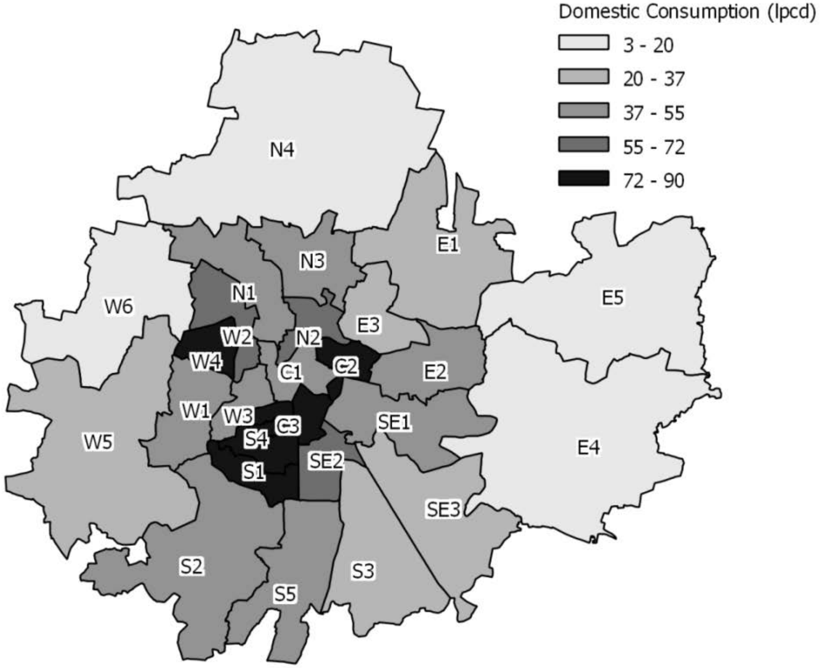

N4
N3
E1
N1
W6
E5
W2
N2
E3
W4
C1
C2
E2
W1
W3
SE1
C3
W5
S4
E4
S1
SE2
SE3
S2
S3
S5
1:225000
Wards
Domestic consumption (lpcd)
1 - 3
3 - 20
20 - 37
37 - 55
55 - 72
72 - 90
90 - 107
N-2
N-1
NE-3
E-1
NW-3
C-3
E-3
NW-1
NE-1
NE-2
C-2
NW-2
C-1
SE-2
W-2
E-3
E-2
W-1
SW-1
SE-1
SW-3
SE-3
SW-4
W-3
SW-2
S-3
S-1
S-4
S-2

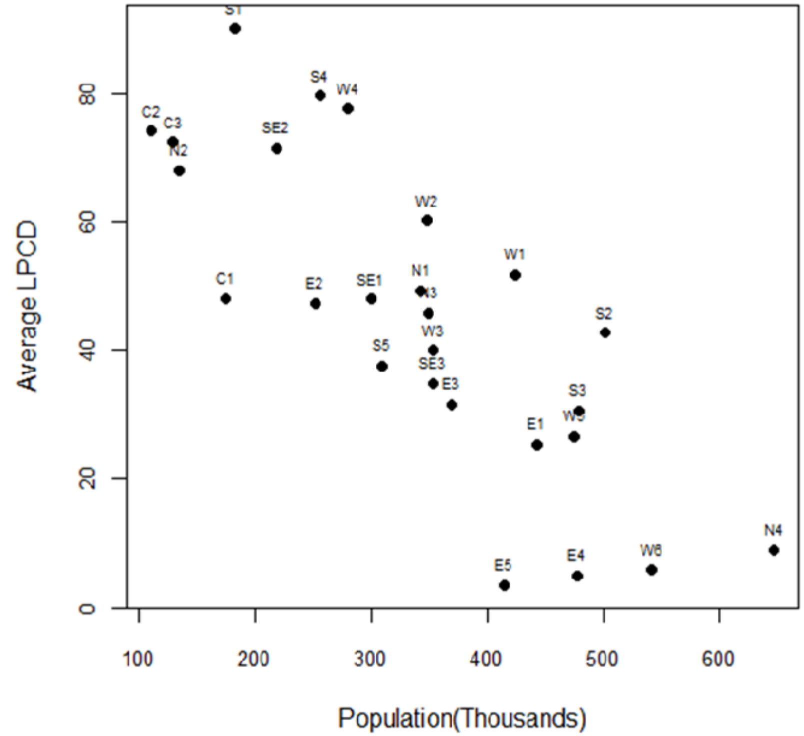


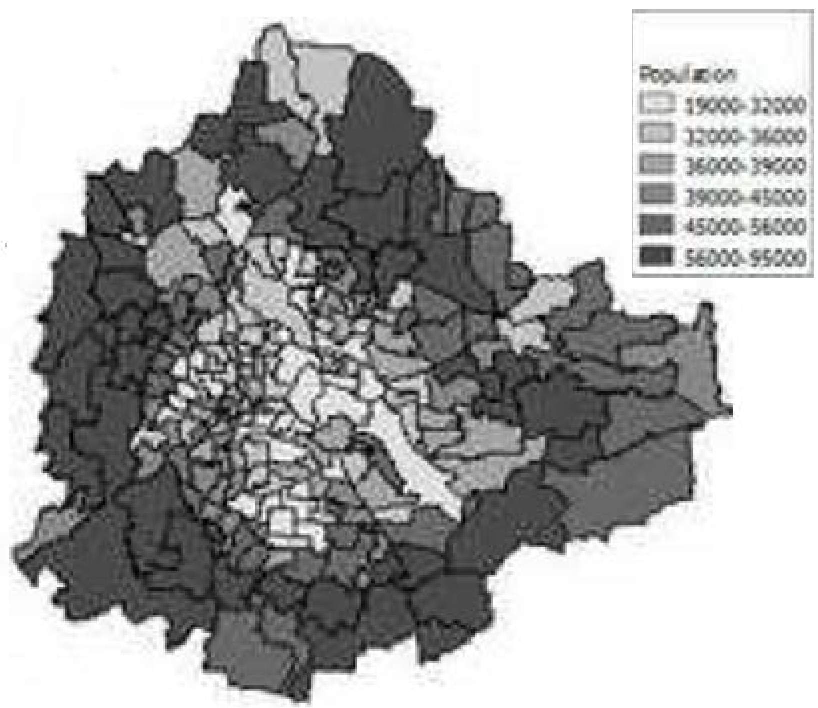
Average LPCD
Population(Thousands)
0
20
40
60
80
100
200
300
400
500
600
S1
S4
W4
C2
C3
N2
SE2
W2
W1
C1
E2
SE1
N1
N3
S2
W3
S5
SE3
E3
S3
W5
E1
N4
E5
E4
W6

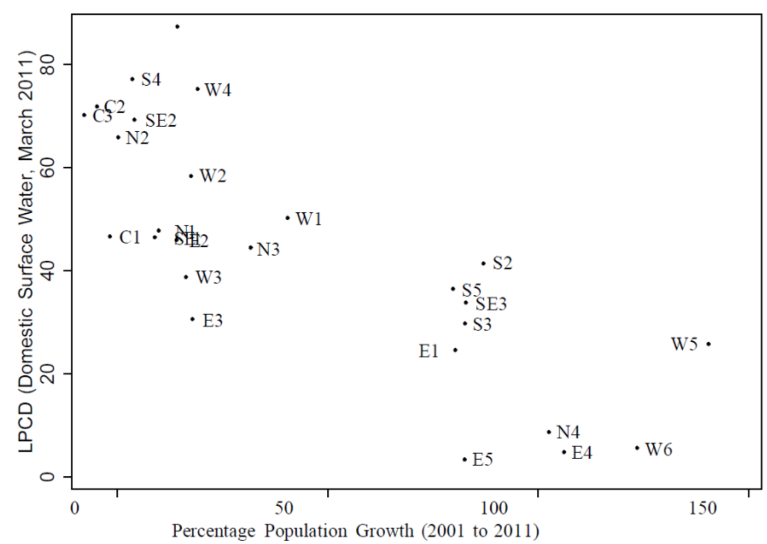


LPCD (Domestic Surface Water, March 2011)
Percentage Population Growth (2001 to 2011)
0
20
40
60
80
0
50
100
150
S4
W4
C2
C3
SE2
N2
W2
W1
C1
N1
SE1
E2
N3
S2
W3
S5
SE3
E3
S3
W5
E1
N4
E4
W6
E5

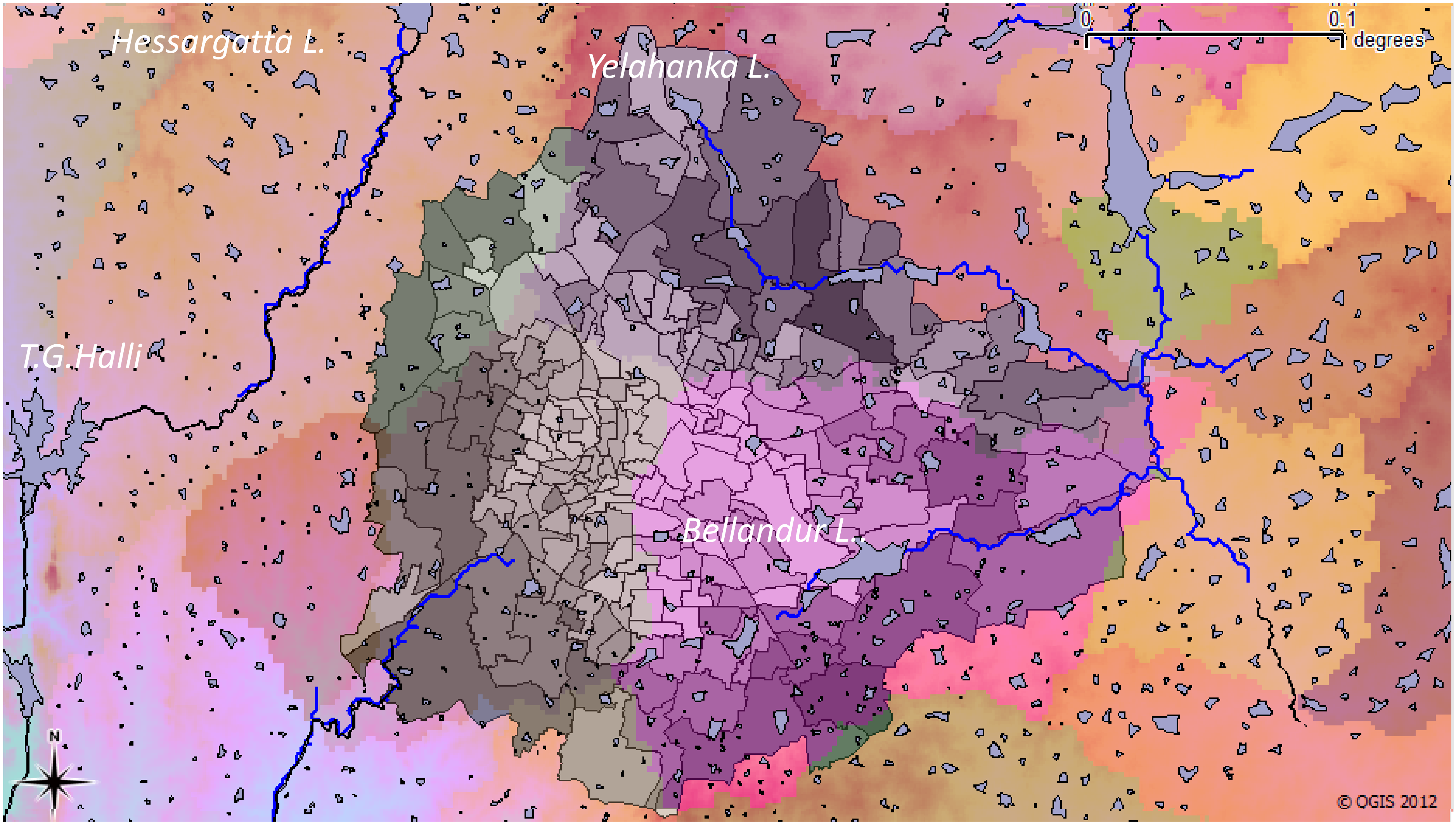

Domestic Consumption (lpcd)
3 - 20
20 - 37
37 - 55
55 - 72
72 - 90
N4
N3
N1
N2
E1
E5
E3
E2
E4
W6
W2
W4
C1
C2
W1
W3
C3
S4
S1
SE1
SE2
SE3
W5
S2
S5
S3


Average LPCD
Population(Thousands)
0
20
40
60
80
100
200
300
400
500
600
S1
S4
W4
C2
C3
N2
SE2
W2
C1
E2
SE1
N1
W1
S5
W3
SE3
E3
S2
S3
E1
E5
E4
W6
N4


Population
19000-32000
32000-36000
36000-39000
39000-45000
45000-56000
56000-95000

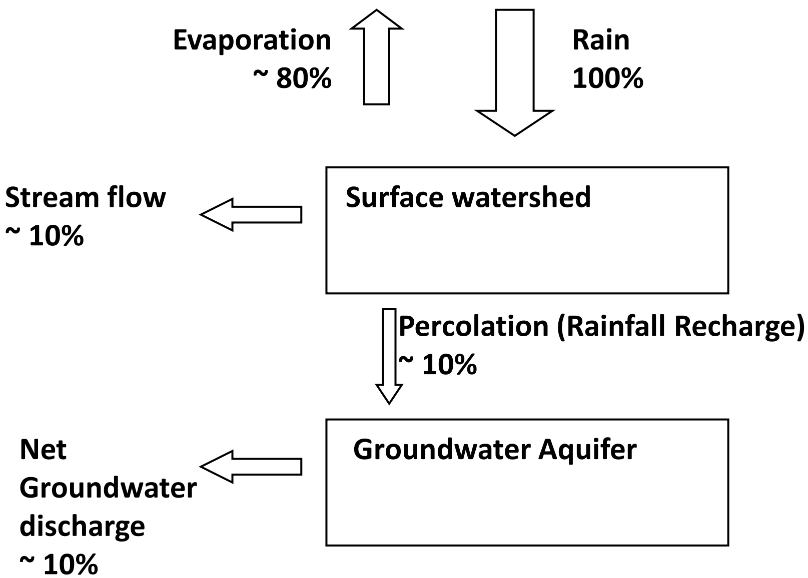

LPCD (Domestic Surface Water, March 2011)
Percentage Population Growth (2001 to 2011)
0
20
40
60
80
0
50
100
150
S4
W4
C2
C3
SE2
N2
W2
W1
C1
N1
SE1
E2
N3
W3
E3
S2
S5
SE3
S3
E1
W5
N4
E4
W6
E5

Biophysical links

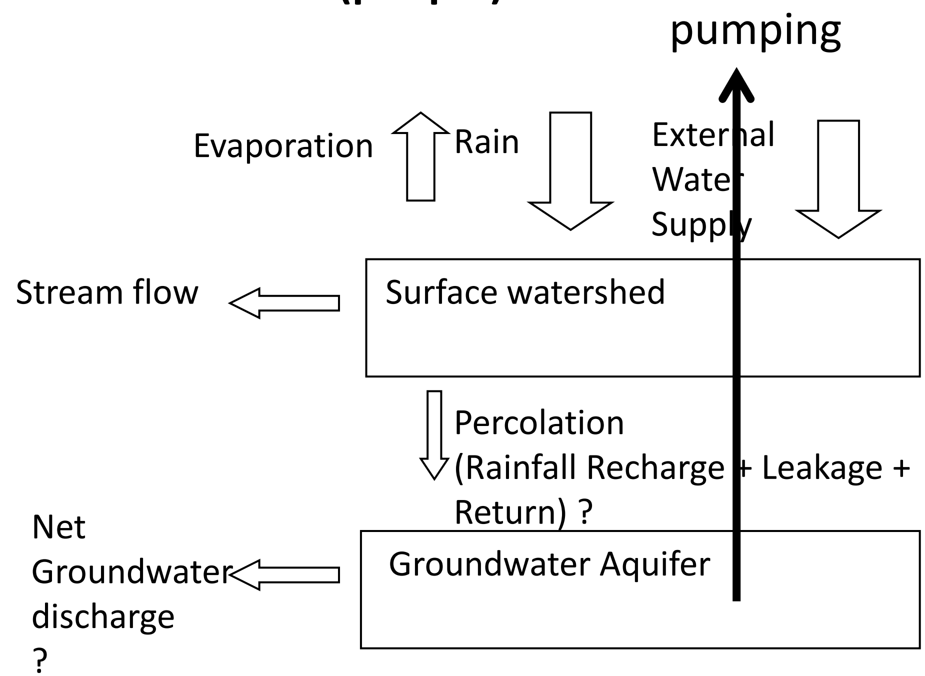


The water balance: people + ecosystem

Natural state (no people)



Altered state (people)



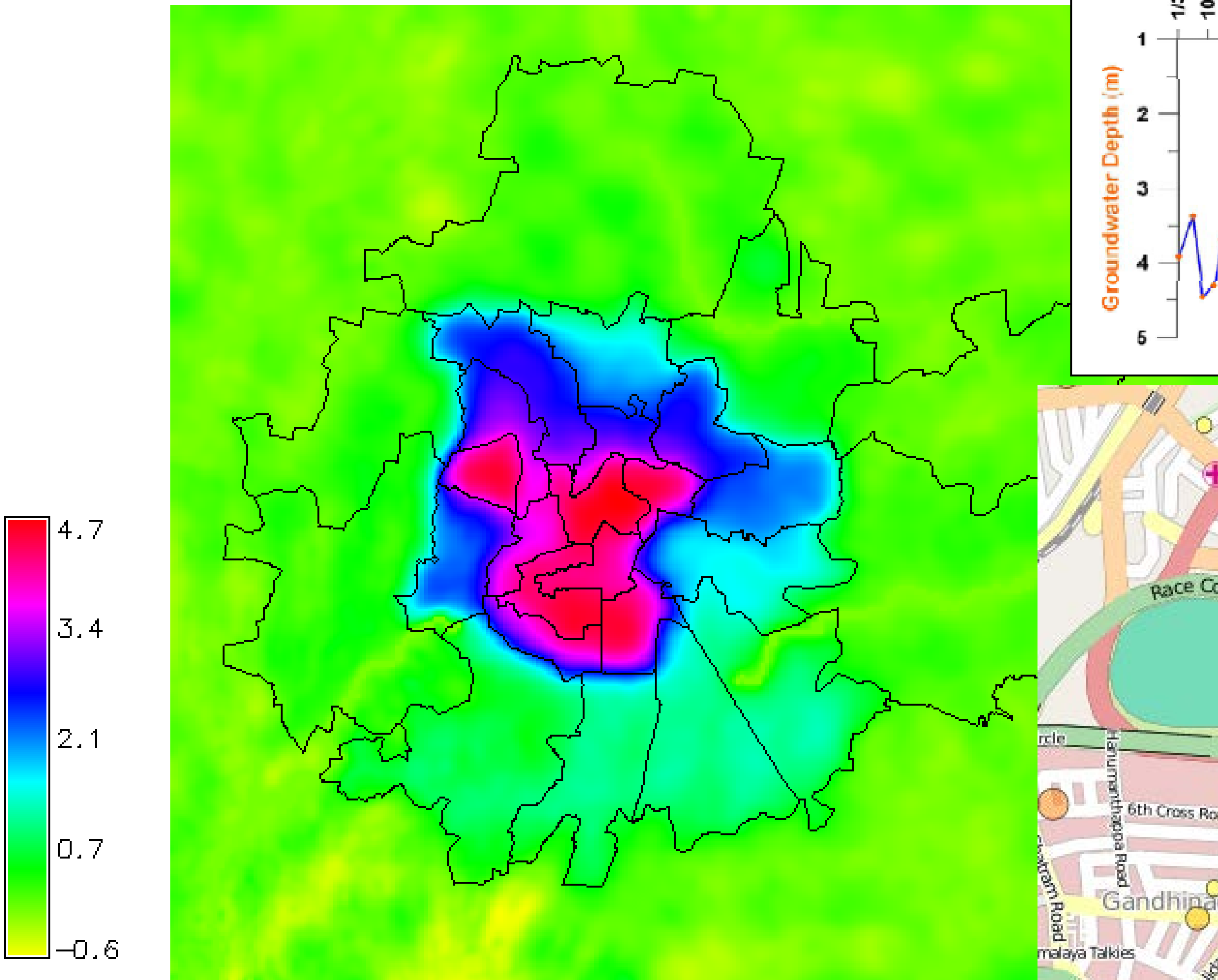
Biophysical impact: groundwater

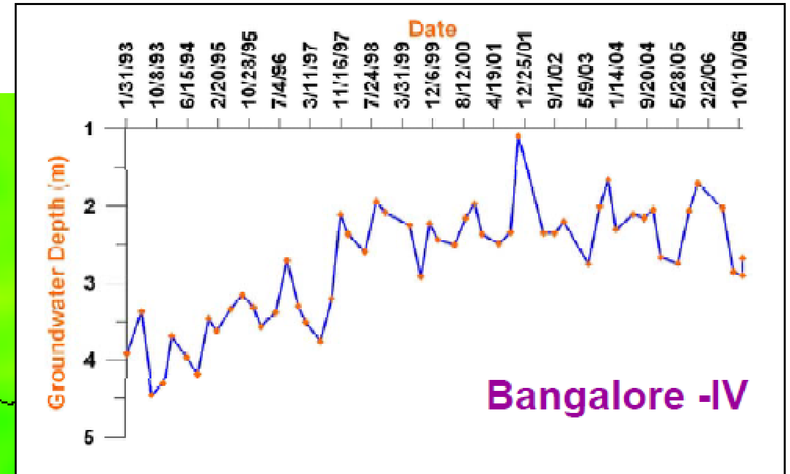
Plausible recharge scenarios: city as one unit

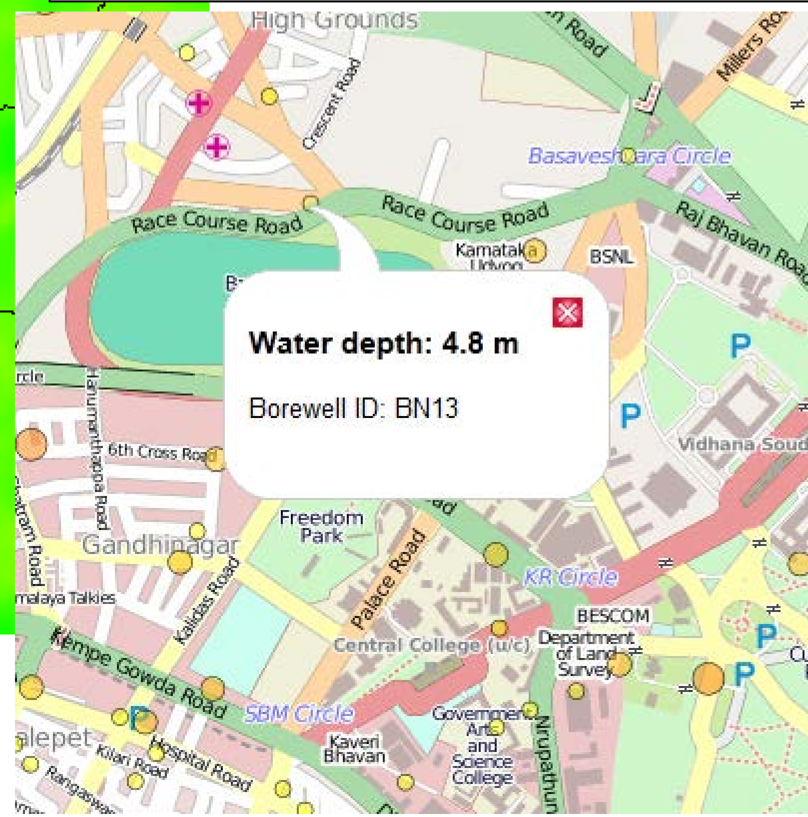
Mm/y	Natural	Natural + Leakage	Natural + Leakage + Return flow
Rainfall recharge	63	63	63
Piped supply Leakage (30%)		140	140
Net pumping (150lpcd –Domestic)		- 360	-360
Return Flow (30% of domestic consumption)			138
Net recharge	***63***	***-157***	***-19***

human-biophysical feedbacks

Plausible change in groundwater head

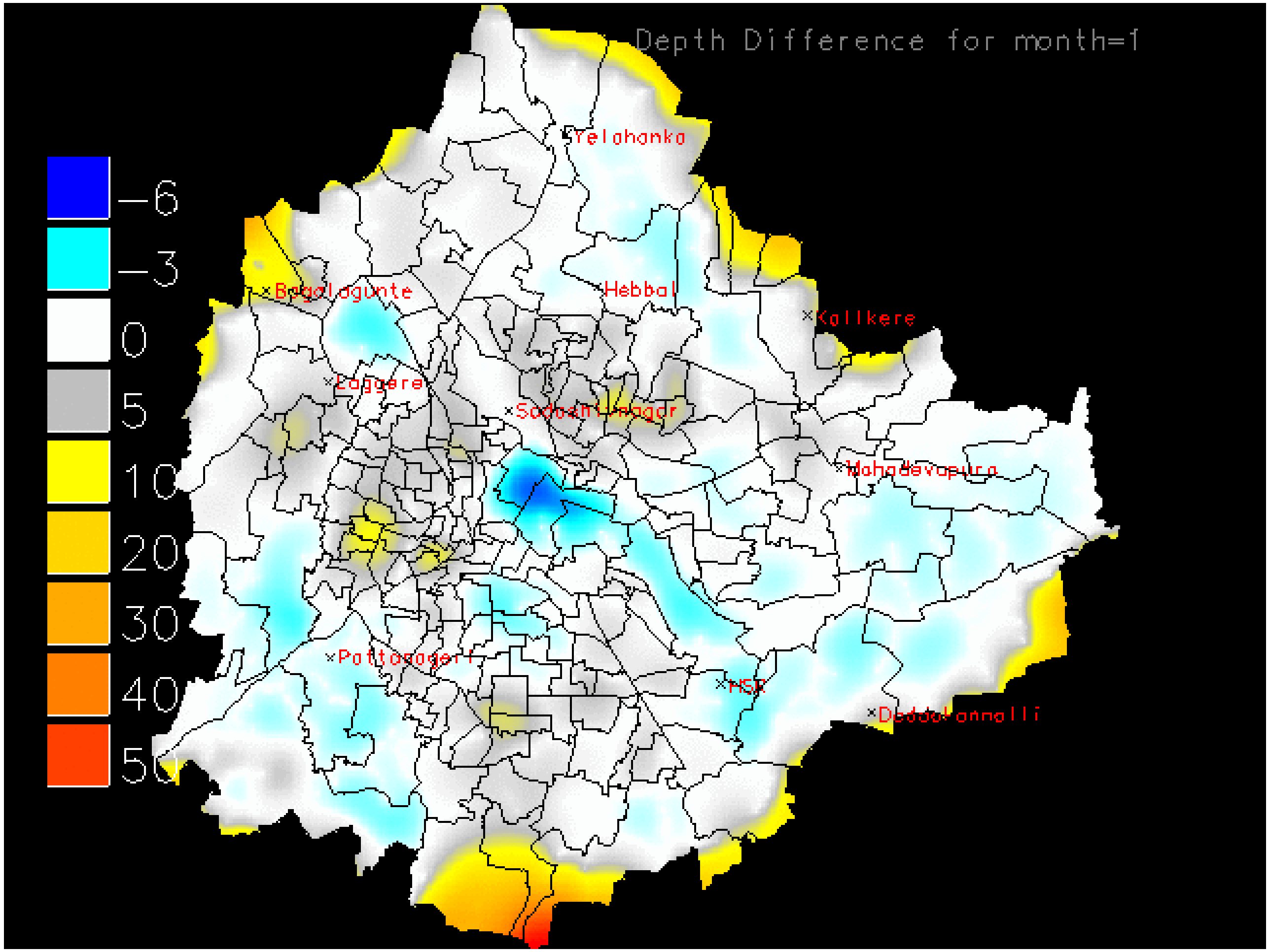






human-biophysical feedbacks

Plausible change in groundwater DEPTH; MONTHLY ANIMATION



Human-biophysical feedbacks: water quality

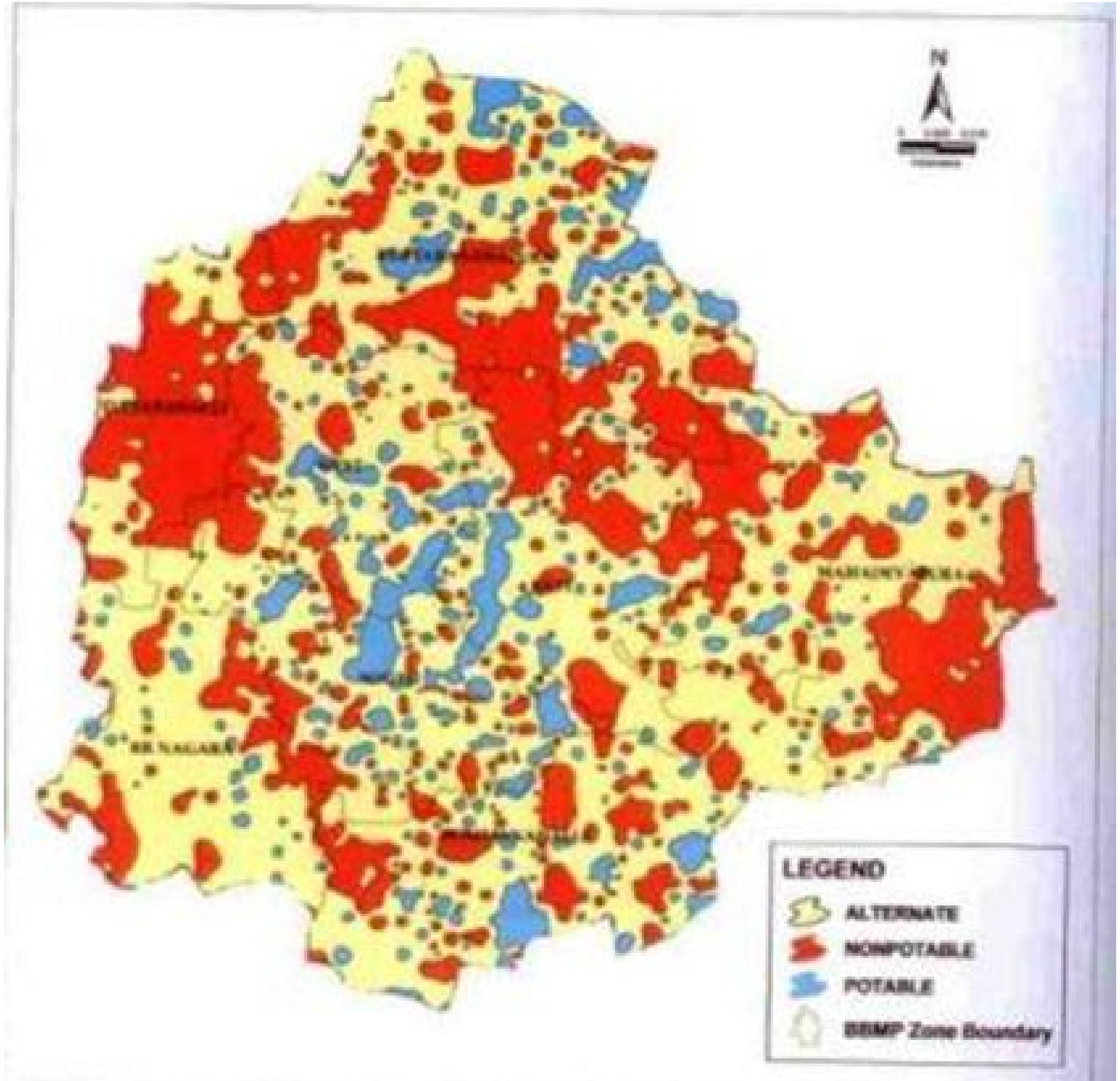
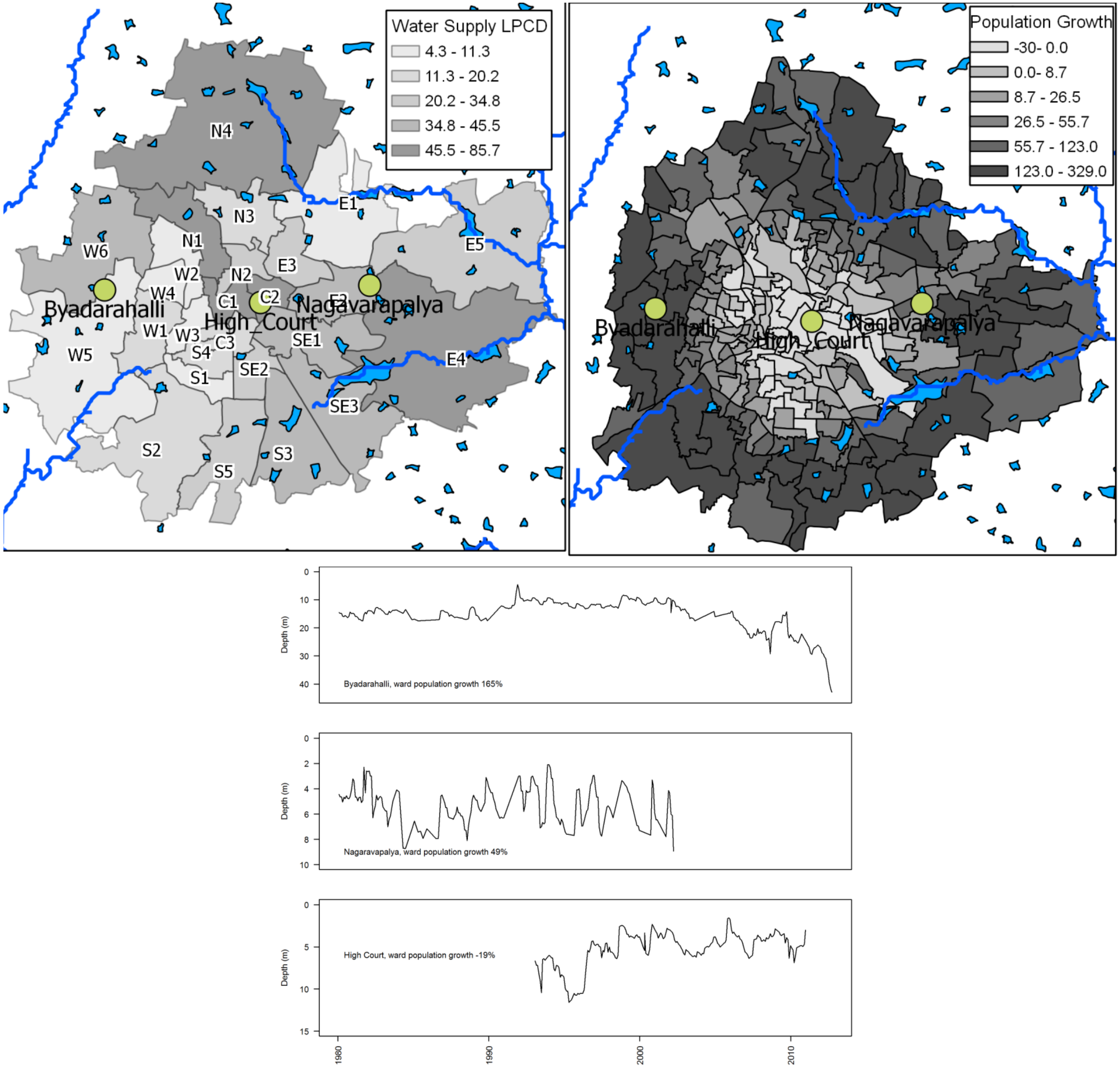
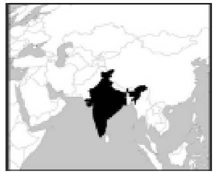


Figure 23 : Groundwater Quality (drinking) map of Bangalore City (IS 2003, Drinking Water Standards)

Source: CGWB


Water Supply LPCD
4.3 - 11.3
11.3 - 20.2
20.2 - 34.8
34.8 - 45.5
45.5 - 85.7
N4
N3
N1
N2
E1
E2
E3
E4
E5
W1
W2
W3
W4
W5
W6
C1
C2
C3
S1
S2
S3
S4
S5
SE1
SE2
SE3
Byadarahalli
High_Court
Nagavarapalya
Population Growth
-30- 0.0
0.0- 8.7
8.7 - 26.5
26.5 - 55.7
55.7 - 123.0
123.0 - 329.0
Byadarahalli
High_Court
Nagavarapalya
Depth (m)
Byadarahalli, ward population growth 165%
Nagaravapalya, ward population growth 49%
High Court, ward population growth -19%
1980
1990
2000
2010



Slum types and adaptation strategies: identifying policy-relevant differences in Bangalore

ANIRUDH KRISHNA, M S SRIRAM AND PURNIMA PRAKASH

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M S Sriram is Visiting Faculty at the Centre for Public Policy at the Indian Institute of Management, Bangalore. His work investigates access to financial services among the poorer communities. He also works on the institutional architecture for financial inclusion.

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Purnima Prakash is a Research Associate at the Centre for Public Policy at the Indian Institute of Management, Bangalore.

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Acknowledgement: Field investigations for this study were in large part supported by the Jana Urban Foundation (JUF), a not-for-profit company, having its registered office

ABSTRACT An empirical analysis of the lived experiences of more than 2,000 households in different Bangalore slums shows how migration patterns, living conditions, livelihood strategies and prospects for the future vary widely across distinct types of slums that were initially identified from satellite images and studied over a 10-year period. Shocks and responses vary in nature and intensity, and coping and accumulative strategies diverge across slum types. More fine-grained policy analyses that recognize this diversity of slum types will help people deal with shocks and increase resilience more effectively.

KEYWORDS Bangalore / coping strategies / geo-referencing / migration / shocks / slums / slum types / social mobility / urban poverty

I. INTRODUCTION

As slums have continued to expand across Indian cities, official and scholarly attention has grown rapidly in recent years. For the first time, the Census of India 2011 presented separate estimates of the population in slums,(1) and recent reports from other official agencies have also added much-needed knowledge about slums and slum dwellers.(2) Scholarship, which previously focused mostly on rural poverty, has more recently been restoring the balance by looking at poverty in urban slums.

Considerable gaps in knowledge remain, however, with that described below being especially important:

- **Unhelpful typologies and shaky estimates**: There are diverse estimates by government agencies of the number of slums and the size of the slum population, with different views about what constitutes a slum. For example, the National Sample Survey Organization (NSSO) considers a slum to consist of at least 20 households, while the Census of India 2011 sets the threshold at 60–70 households. There are practical implications: in 2009, the Ministry of Housing and Urban Poverty Alleviation estimated, based on the NSSO definition, that 16.5 per cent of the urban population of Karnataka lived in slums; only two years later the census came up with a figure of 12.2 per cent.

  Official agencies also acknowledge only two broad types of slums: officially declared ("notified" or "recognized") slums, and a second omnibus category that includes all other low-income settlements.(3)

PHOTO 1
Example of a blue polygon settlement: Quadrant IV – Tigalarpalya

© Ajay Parikh, 4 August 2013

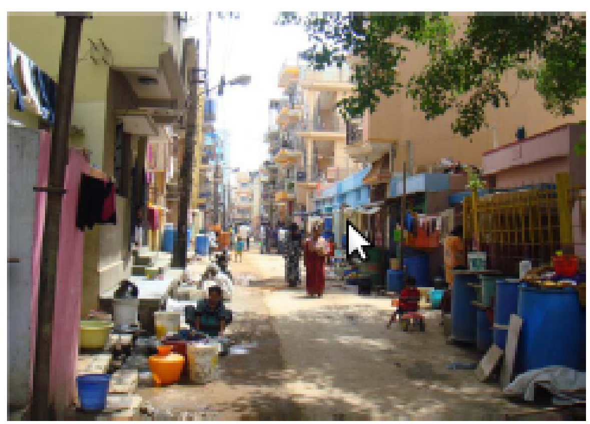

PHOTO 2A
Example of a notified slum: AMM Residency, Siddapura

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PHOTO 2B
Example of a notified slum: Roopen Agrahara

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BANGALORE DOMESTIC WATER SURVEY 2013
ಬೆಂಗಳೂರು ಗೃಹ ಬಳಕೆ ನೀರು ಸಮೀಕ್ಷೆ 2013

HOUSEHOLD QUESTIONNARE

502	Which of these BWSSB/CMC sources do you use? ಬಿಡಬ್ಲ್ಯುಎಸ್‌ಎಸ್‌ಬಿ /ಸಿಎಂಸಿ ಯ ಈ ಯಾವ ಮೂಲಗಳನ್ನು ನೀವು ಬಳಸುತ್ತೀರಿ? MULTIPLE RESPONSES POSSIBLE ಹೆಚ್ಚು ಉತ್ತರಗಳ ಸಾಧ್ಯತೆ	BWSSB PUBLIC TAP/STAND PIPES HAND PUMPS------------------------- 1 ಸಾರ್ವಜನಿಕ ನಲ್ಲಿ/ನಿಂತ ಕೊಳವೆಗಳು/ ಕೈ ಪಂಪ್-ಬಿಡಬ್ಲ್ಯುಎಸ್‌ಎಸ್‌ಬಿ) CMC PUBLIC TAP/STAND PIPES-- 2 CMC ಸಾರ್ವಜನಿಕ ನಲ್ಲಿ/ನಿಂತ ಕೊಳವೆಗಳು BWSSB TANKER LORRIES -- 3 -ಬಿಡಬ್ಲ್ಯುಎಸ್‌ಎಸ್‌ಬಿಯ ಟ್ಯಾಂಕರ್ ಲಾರಿಗಳು) CMC TANKER LORRIES -- 4 CMC ಟ್ಯಾಂಕರ್ ಲಾರಿಗಳು BWSSB PIPED INTO DWELLING ಮನೆಯೊಳಗೇ ಬಿಡಬ್ಲ್ಯುಎಸ್‌ಎಸ್‌ಬಿ ಪೈಪ್ --- 5 BWSSB PIPED TO YARD/PLOT ಅಂಗಳ/ಸೈಟಿಗೆ ಬಿಡಬ್ಲ್ಯುಎಸ್‌ಎಸ್‌ಬಿ ಪೈಪ್ ------ 6 CMC PIPED INTO DWELLINGಮನೆಯೊಳಗೇ ಸಿಎಂಸಿಯ ಪೈಪ್----------- 7 CMC PIPED TO YARD/PLOT ಅಂಗಳ/ಸೈಟಿಗೆ ಸಿಎಂಸಿಯ ಪೈಪ್-------------- 8 BWSSB SUPPLY ALONG WITH WATER FROM OTHER MIXED SOURCES ಬಿಡಬ್ಲ್ಯುಎಸ್‌ಎಸ್‌ಬಿ – ಇತರ ಮಿಶ್ರ ನೀರಿನ ಮೂಲಗಳೊಂದಿಗೆ ---------------------9 CMC SUPPLY ALONG WITH WATER FROM OTHER MIXED SOURCES ಸಿಎಂಸಿ – ಇತರ ಮಿಶ್ರ ನೀರಿನ ಮೂಲಗಳೊಂದಿಗೆ --------------------------------10 DONOT USE BWSSB/ CMC WATER BWSSB ಅಥವ CMC ನೀರನ್ನು ಬಳಸುವುದಿಲ್ಲ --11	IF CODED 5,6,7,8, 9 OR 10 THEN SKIP TO 514 ಕೊಡ್ 5,6,7,8,9 ,ಅಥವ 10 ಆಗಿದ್ದಲ್ಲಿ 514 ಕ್ಕೆ ಹೋಗಿ IF 11 CODED GO TO 525 11 ಕೋಡಾಗಿದ್ದಲ್ಲಿ 525 ಗೆ ಹೋಗಿ

Biophysical impact: Energy and Emissions

Energy consumption from public water supply:

- Pumping from river sources and through the distribution network requires a total of 60 booster pumps, 52 reservoirs in the city 277 and close to 6000 km of pipeline.
- **The total energy consumed is approximately 50 GWH/month**
- Electricity charges alone account for 280 crore rupees annually (~9.2 million USD)
- **~ 450 Kilo-tones CO2 emissions** *(at 0.75 tCO2/MWh)*

Biophysical impact: Energy and Emissions

Energy consumption from only domestic water use?

- ***Public supply ~ 220 GWh (less uncertain)***

- ***Pvt pumping = 164 GWh/y (more uncertain)***

City-wide assumptions for private pumping (probably worst case)

- 150m constant depth
- 65% efficiency of pumping
- 150 lpcd total actual consumption

Visit our online scenario explorer http://www.urbanmetabolism.asia

Biophysical impact: Energy and Emissions

CO2 from domestic water use

Public supply = 165 Kt/yr

Pvt pumping (worst case) = 118 t Co2/yr

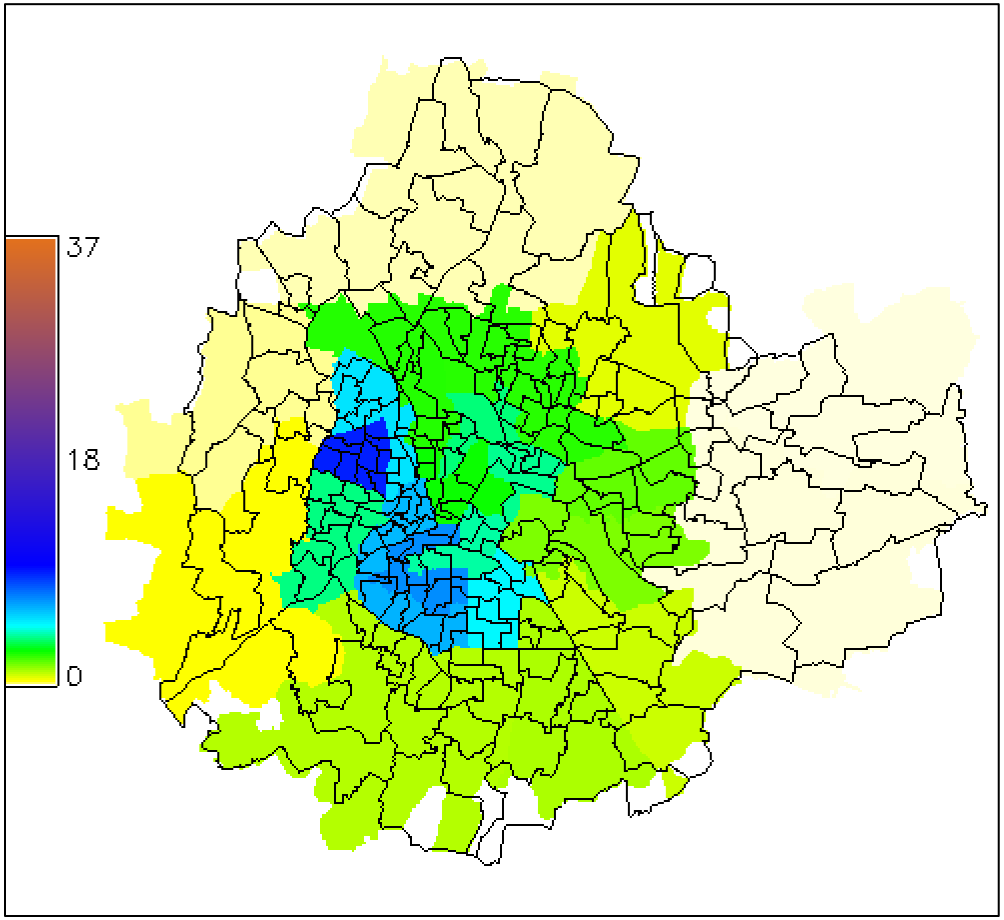
However, private pumping energy and emissions depend heavily on groundwater water depth.

Range of 15kT/yr-118kt/yr

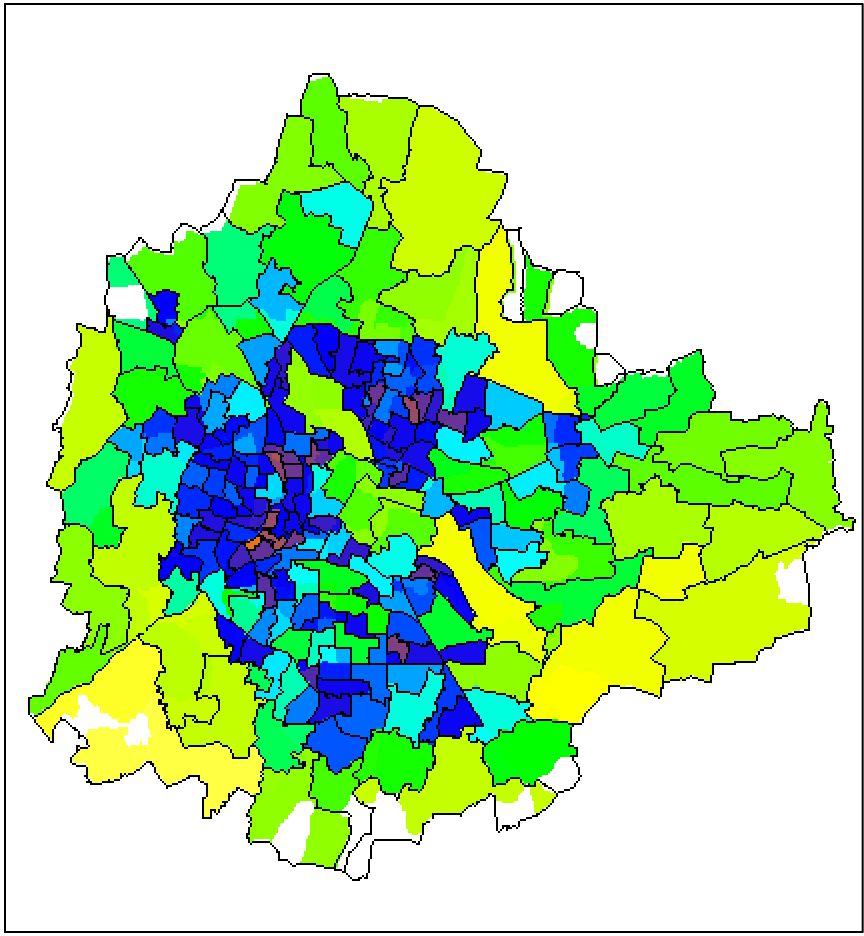
Visit our online scenario explorer http://www.urbanmetabolism.asia

Water: domestic consumption, million liters/year

From public supply

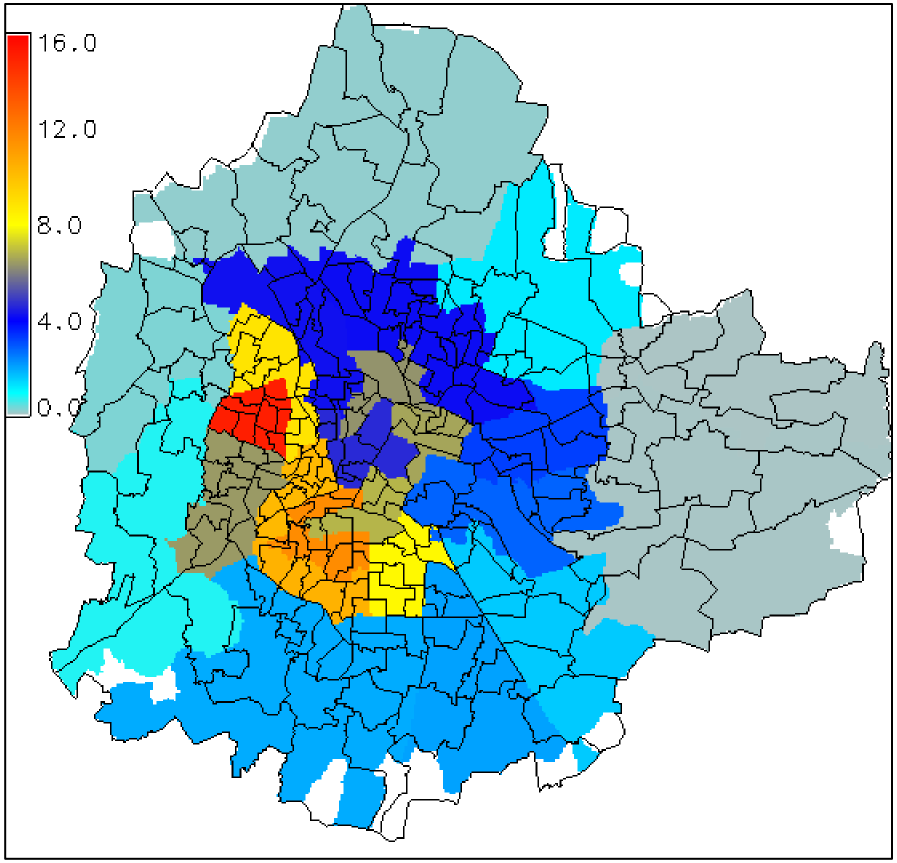


From private self-supply (pumping)

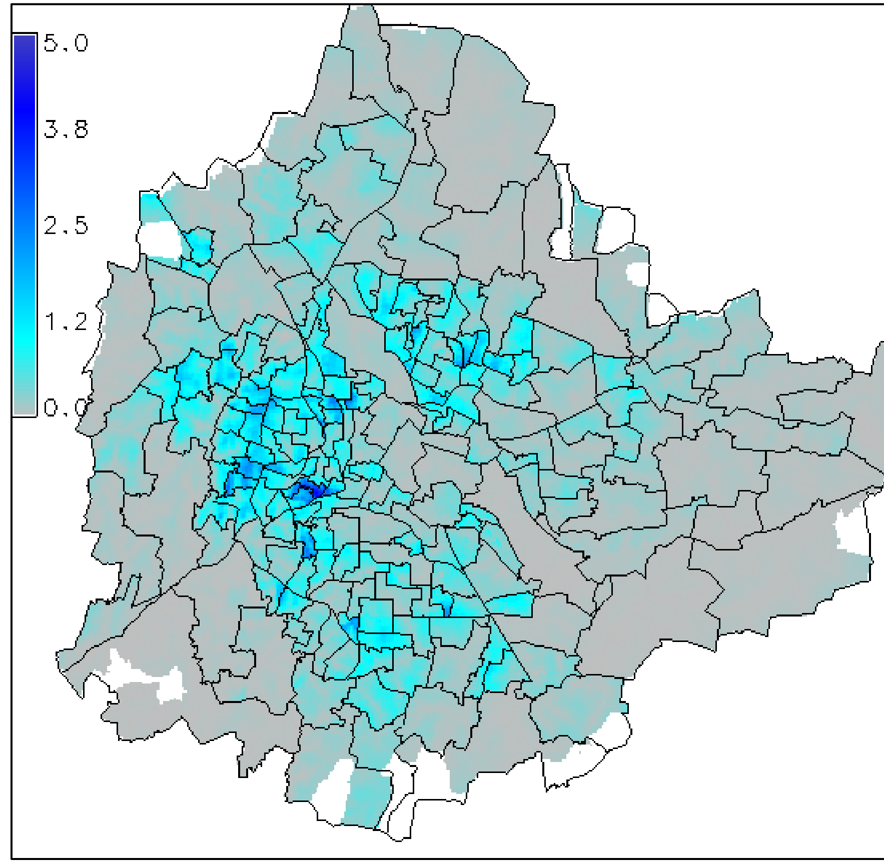


Energy consumption for domestic water supply , MWh/year

From public supply

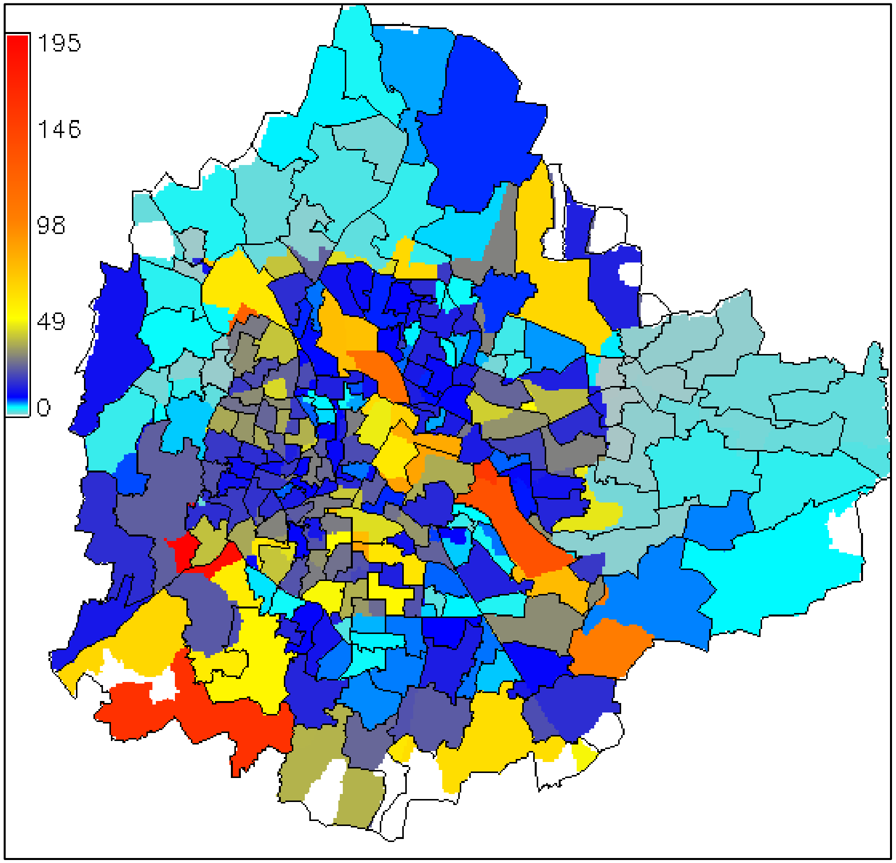


From private self-supply (pumping)

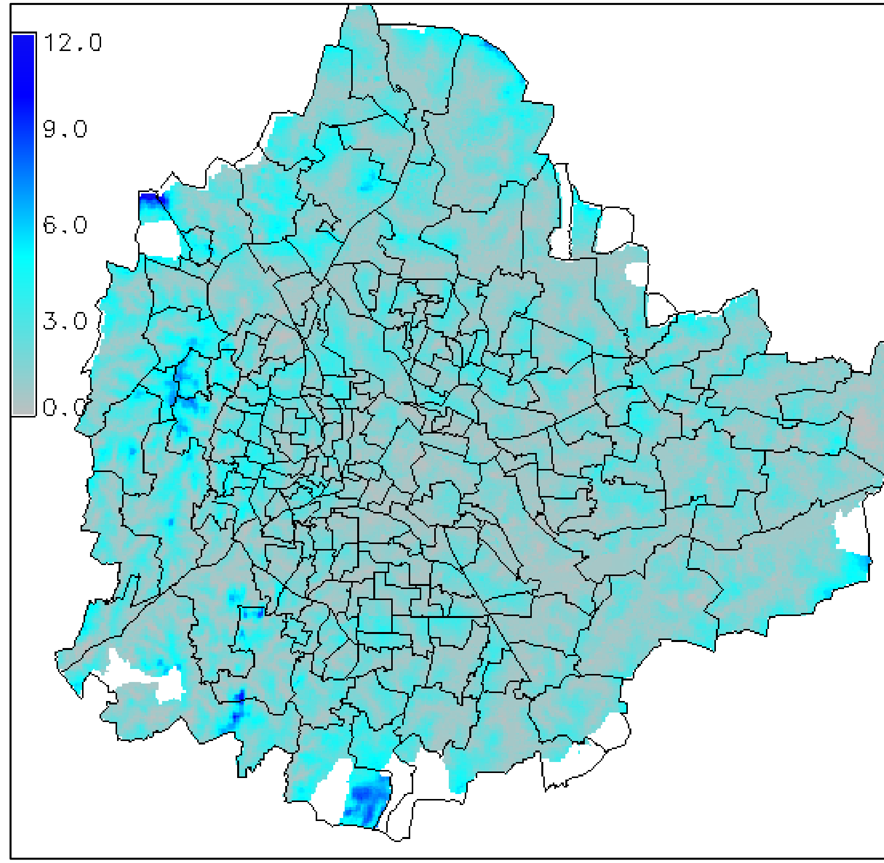


Per Capita CO2 Emissions from domestic water consumption, kg/y

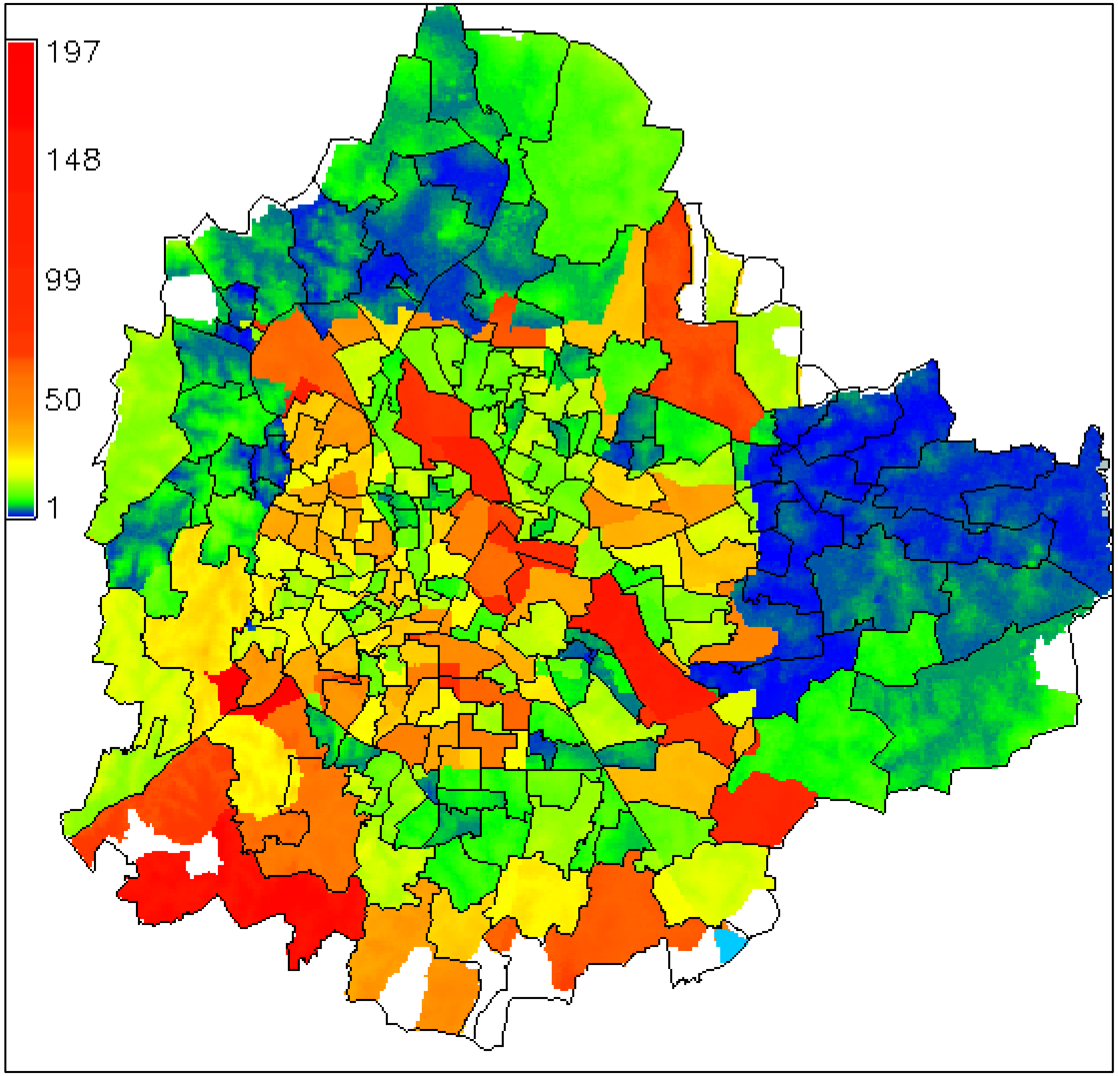
From public supply



From private self-supply (pumping)



Total Per Capita CO_2 Emissions from domestic water consumption, kg/y



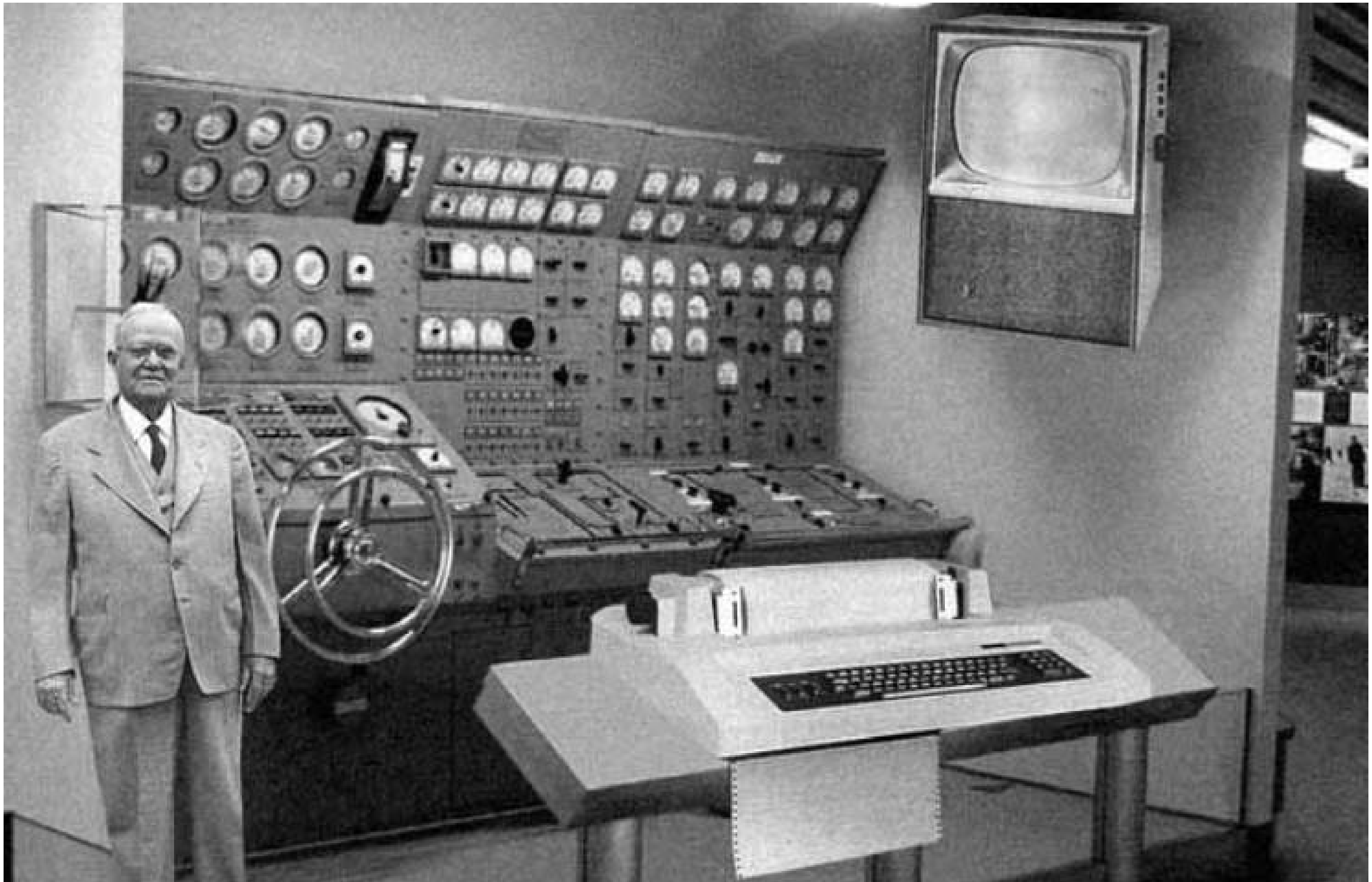
Uncertainties

- Uncertain knowledge today
  - We do not know extraction rates and demand by source, other than piped supply (e.g., tankers, private borewells, local water bodies), or how much is being pumped from what depth
  - We do not know leakage rates from piped supply with certainty
  - We only have partial information about the groundwater level
  - We do not know return flows and consumptive use
- Uncertain futures
  - Changing economic opportunities (high-tech, manufacturing)
  - Growing population and expanding city
  - Changes in the Cauvery and Arkavathy watersheds beyond the city boundaries
  - Attitudes toward “reclaimed water”, PPP arrangements, etc.

Uncertain Futures: Scenarios

- Evaluate system performance over a range of plausible conditions; different from traditional “design event” approach
- Explicitly recognize that **critical uncertainties**—high-impact and high-uncertainty drivers and events influence the system
- Rely upon two way communication with stakeholders to capture their understanding of the system and the way in which they evaluate competing goals
- Can result in robust decisions—strategies that are least likely to fail across a range of plausible futures

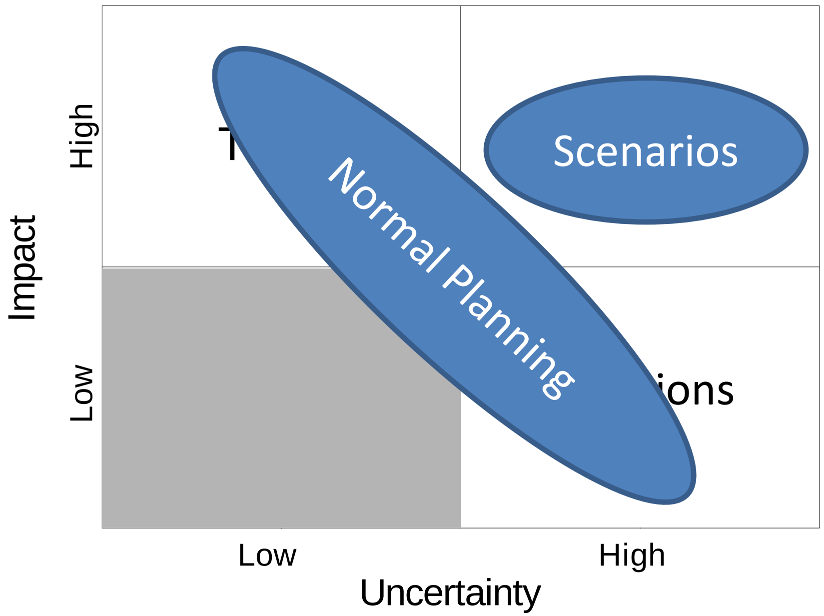
Don't let expectations of the future be dictated by your experience of the present



Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems. With teletype interface and the Fortran language, the computer will be easy to use.

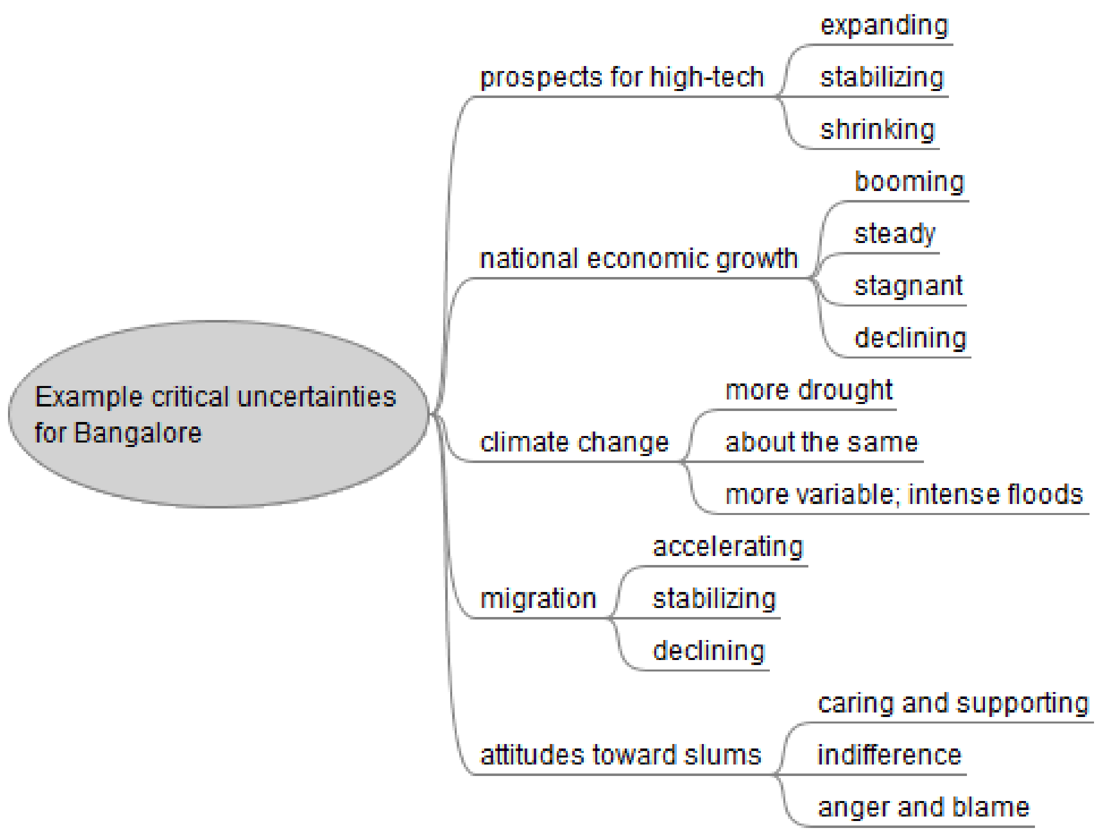
Scenarios vs. Sensitivity Analysis

- Scenarios are distinguished from each other by “critical uncertainties”
- Critical uncertainty:
  - High **uncertainty**
  - High **impact**



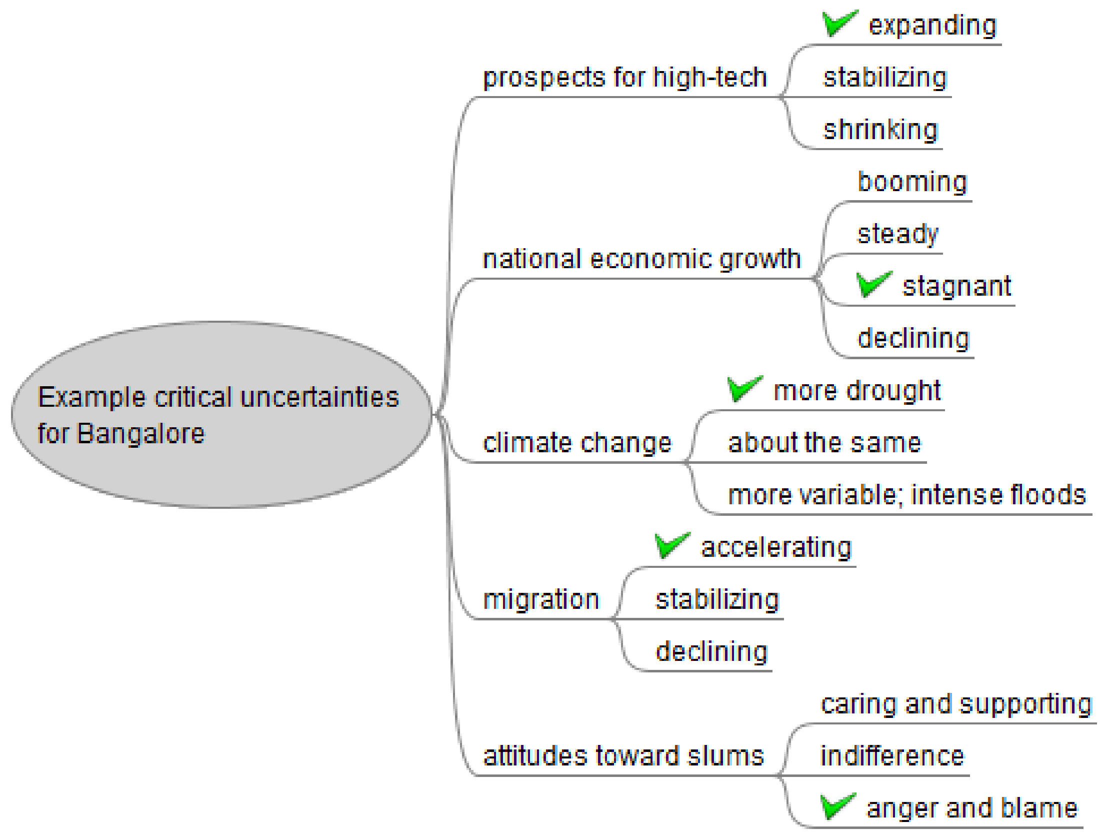
Scenario Possibilities

- A list of possible values for each of the critical uncertainties
  - Typically 2-4 per critical uncertainty
  - Should be distinct possibilities

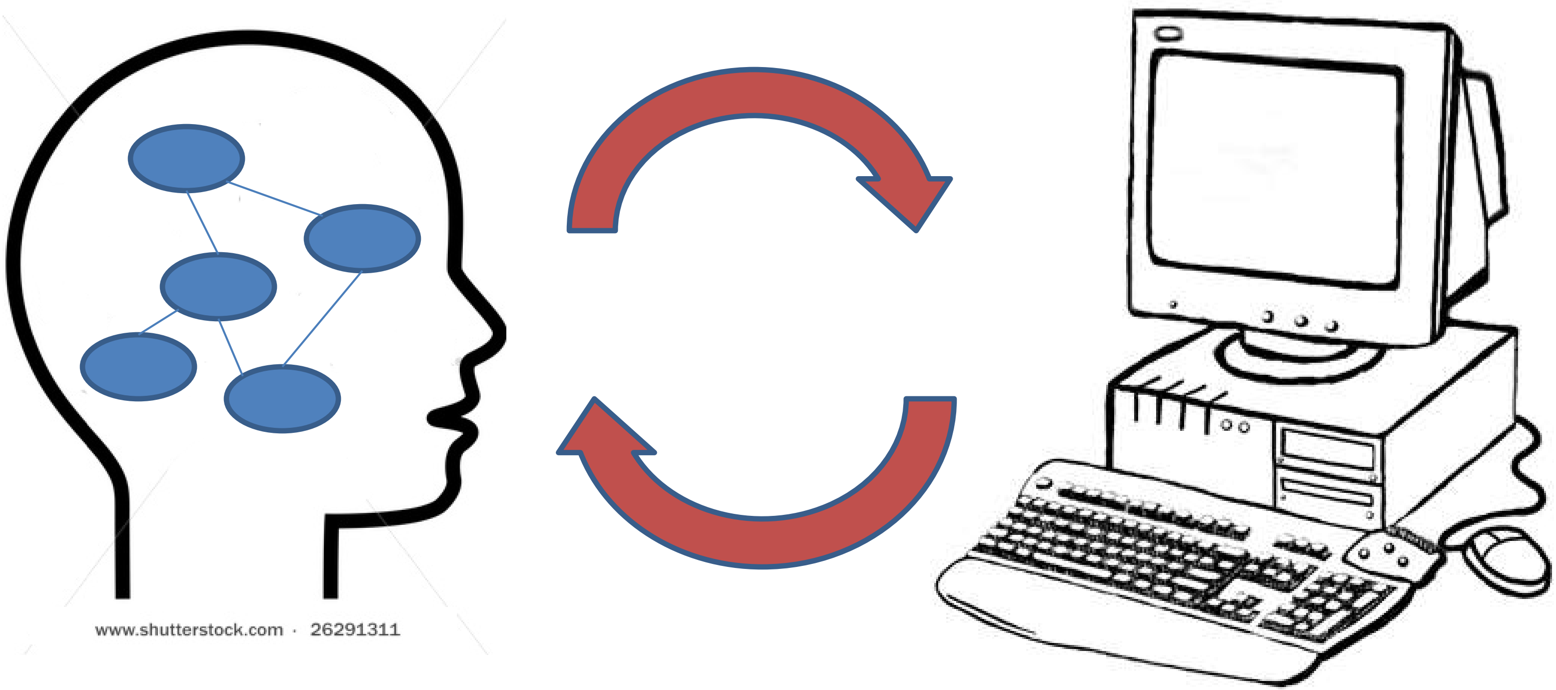


Building a Framework

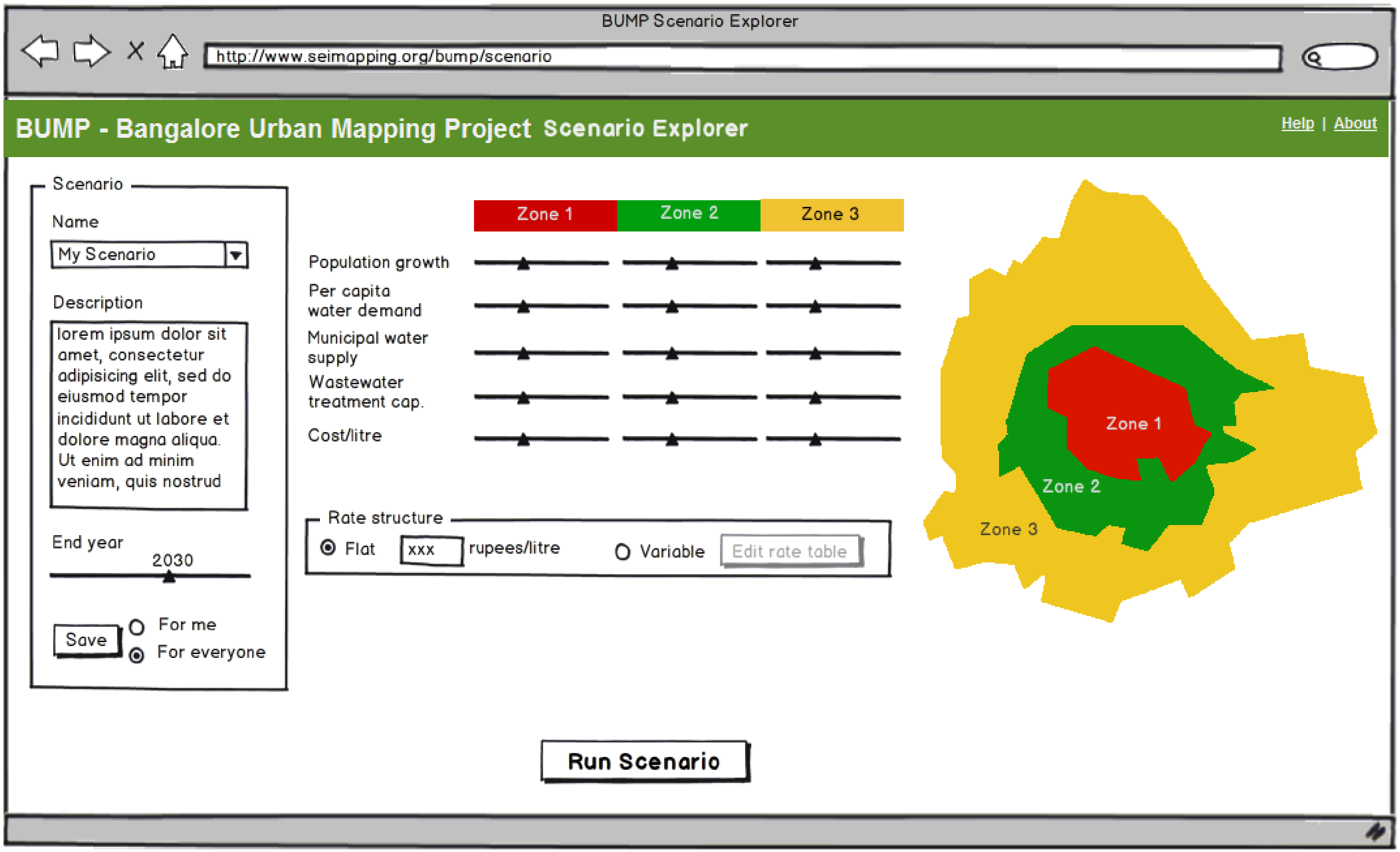
- For each critical uncertainty, choose one possibility
- Each combination of possibilities labels a scenario



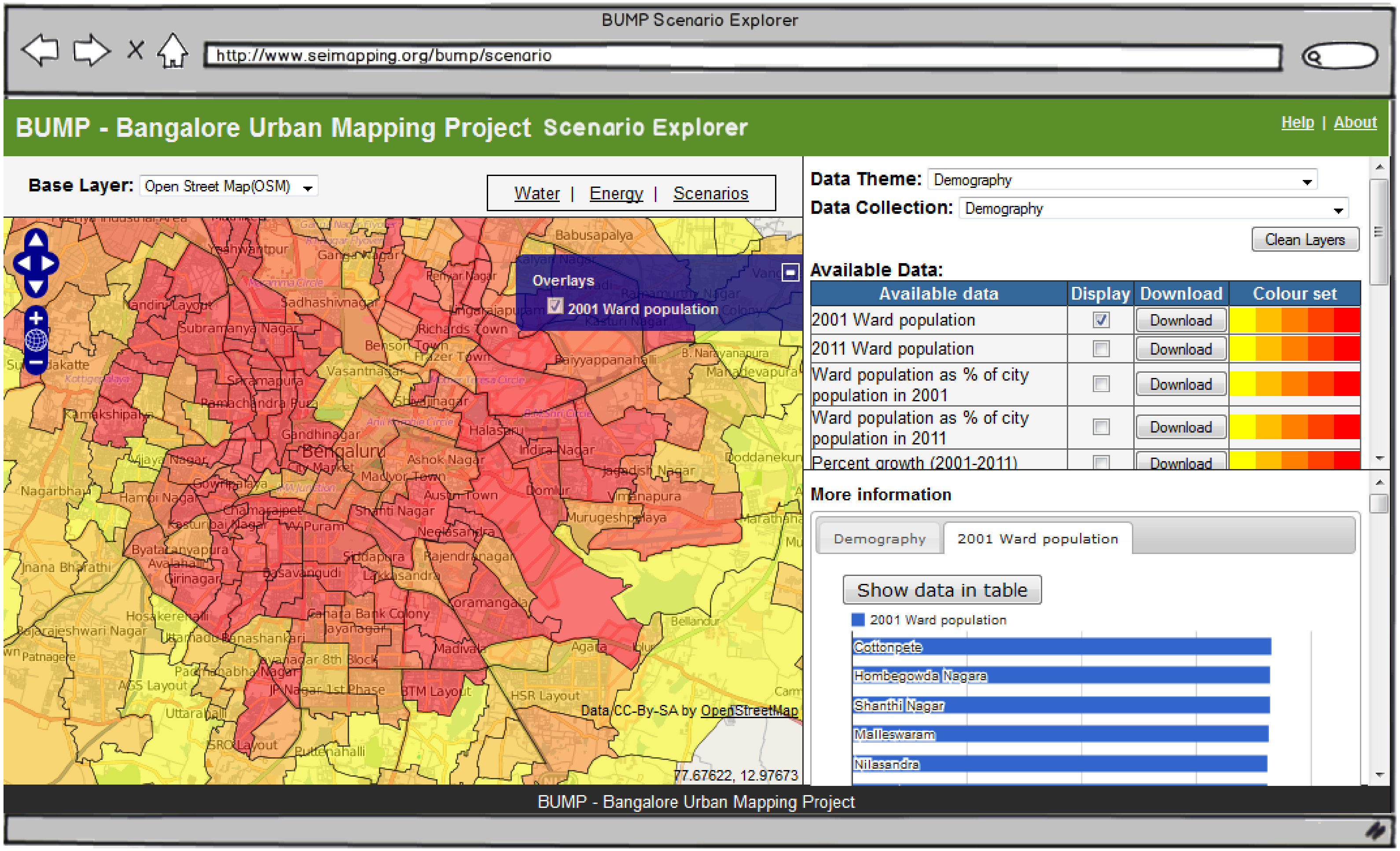
The User’s Mental Model Becomes Part of the Model



Control Panel Mockup for Scenario Explorer



Output Example



Tools for Integrated Water Resources Management

Will retail customers practice conservation?
Demand side models

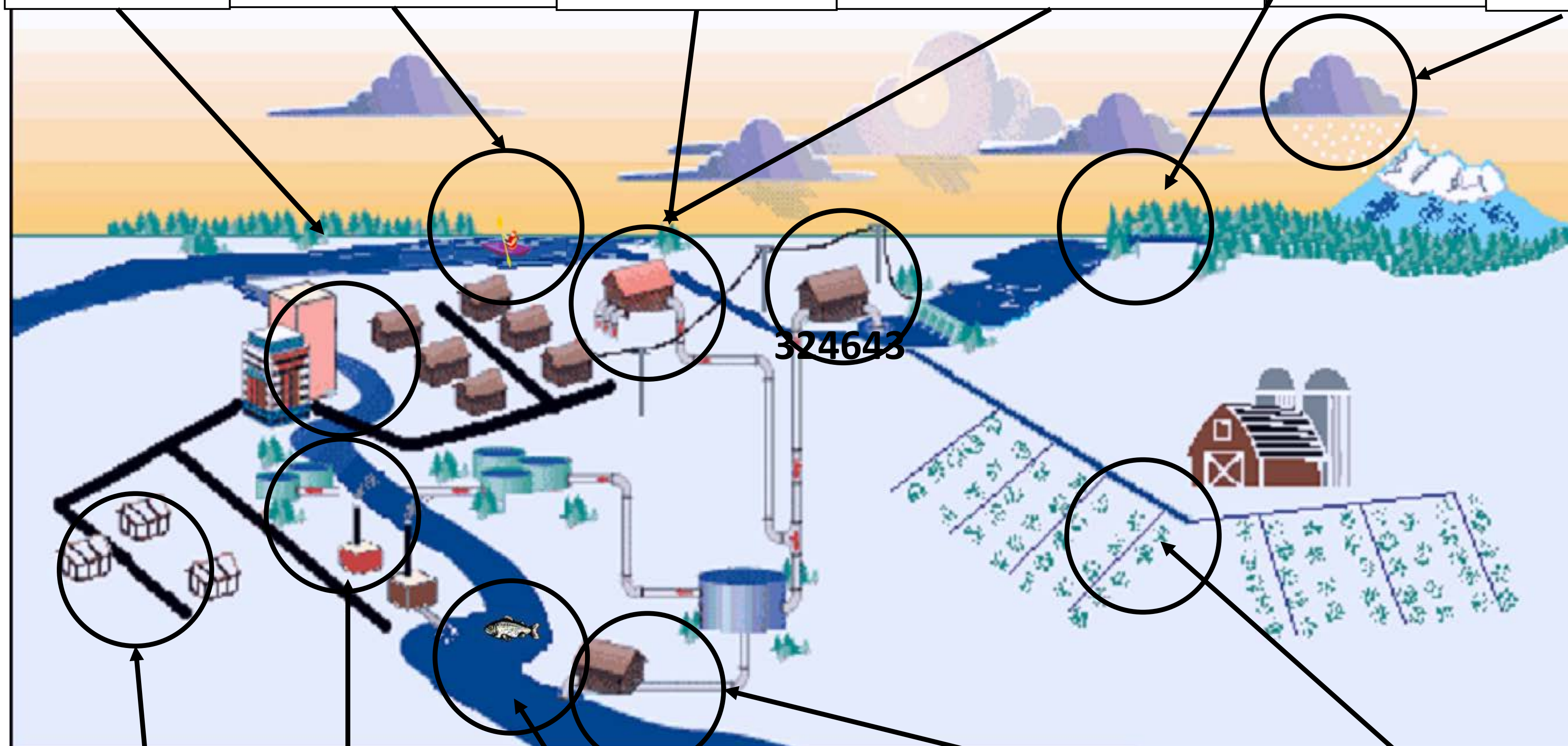
Will recreation remain compatible with future operations?
Recreational use surveys with future projections

Will groundwater remain viable?
Groundwater flow and transport models

Will hydropower management change in response to shifts in the market?
Energy policy analysis with energy sector forecast models

Will the hydrology change?
Hydrology models with land use projections

How will climate change?
Climate models



How much will new residential construction increase demand?
Regional economic models

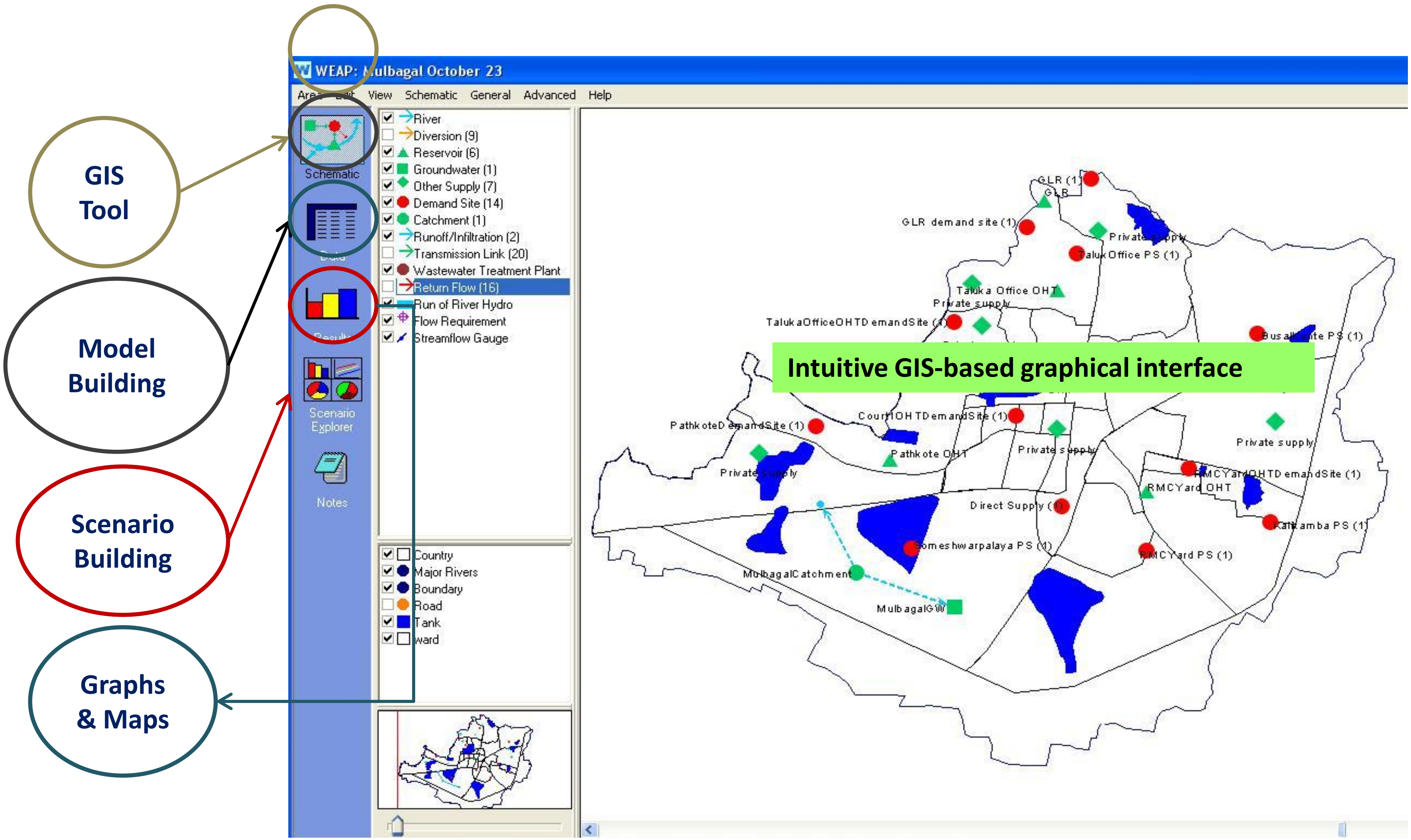
Will industrial discharges change?
Regulatory and emerging technology analysis with industry

Will this fish be listed for protection?
Habitat and species lifecycle models with Ecosystem databases

Can we tap into a new supply?
River hydraulic and contaminant transport models with water

Will agriculturecompete for shared water supplies or become a potential source?
Agricultural production models with water rights database

WEAP Network Schematic



Putting it All Together