URBAN GROUNDWATER…

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The silent emergence of a conundrum…

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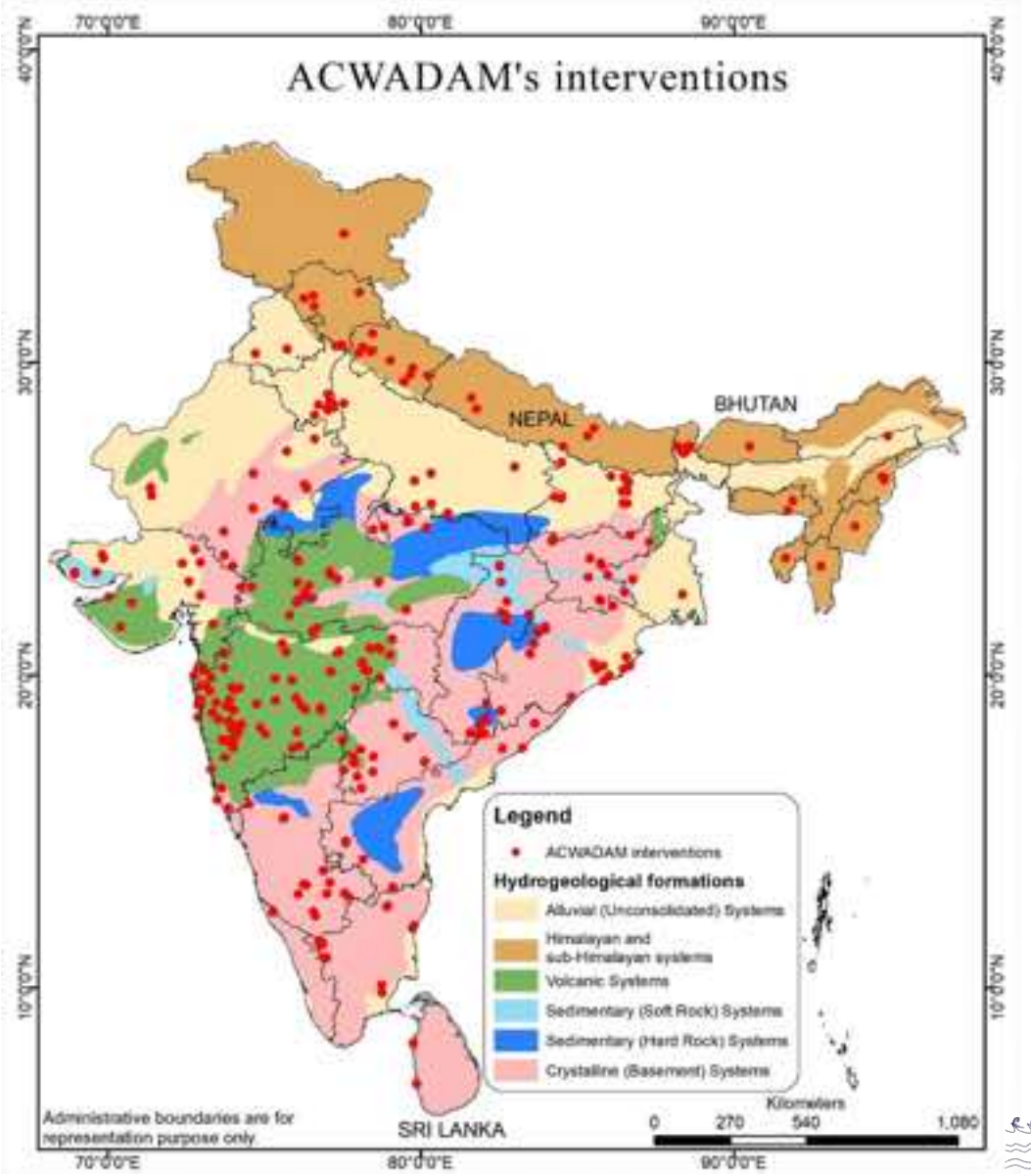
ACWADAM's work: ..in the most hydrogeologically diverse setting in the world – based on partnership and collaboration

We are a think-tank and action-research based organisation working on the science of groundwater and its applications to societal development. We work on the practice and policy of aquifer-based, participatory groundwater management…

- Aquifer-based groundwater management
- Training
- Action research and decision support
- Policy and programmes

Bringing aquifers closer to communities…



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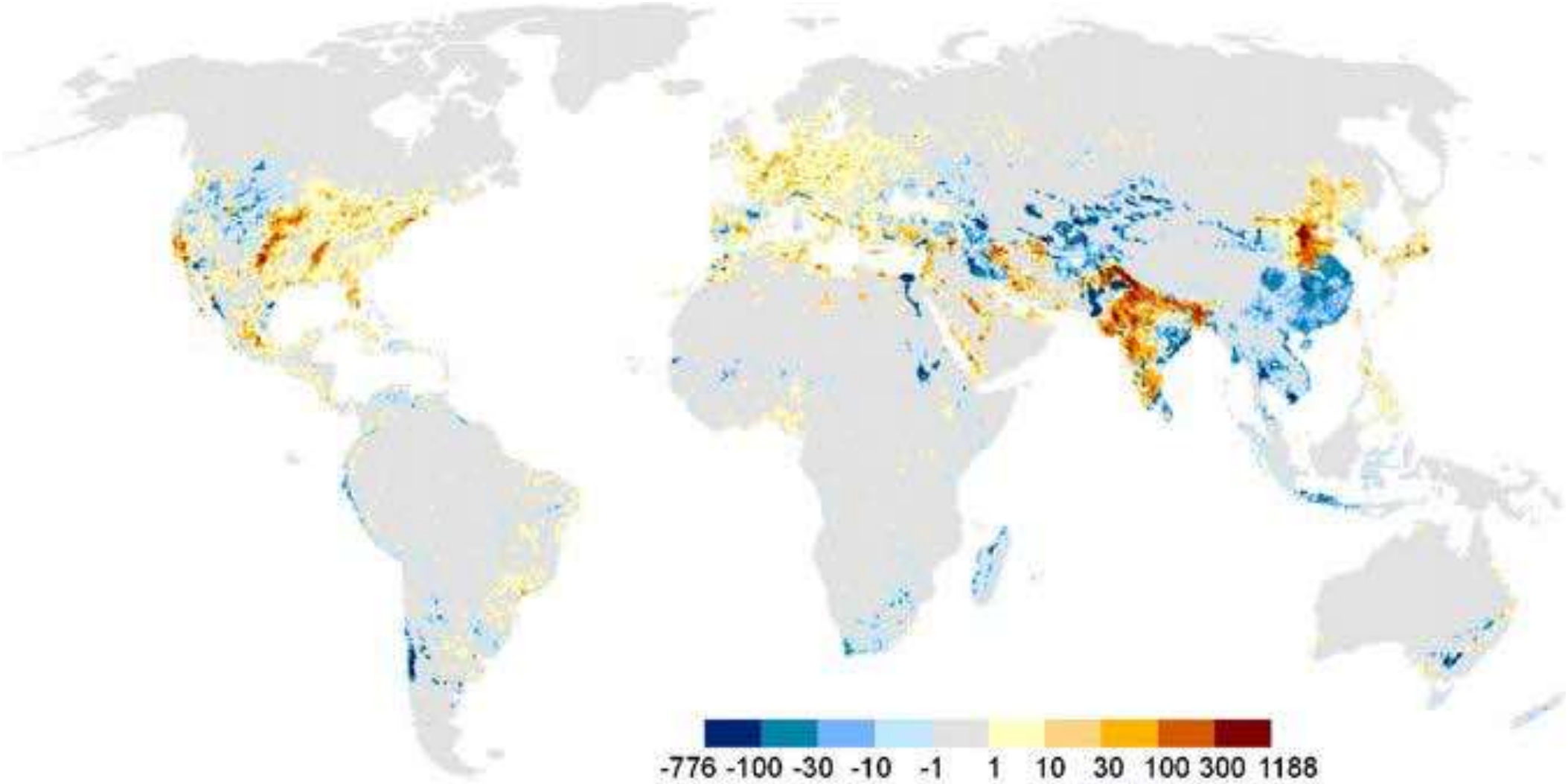
Net Groundwater Abstraction



Doll et al., 2012

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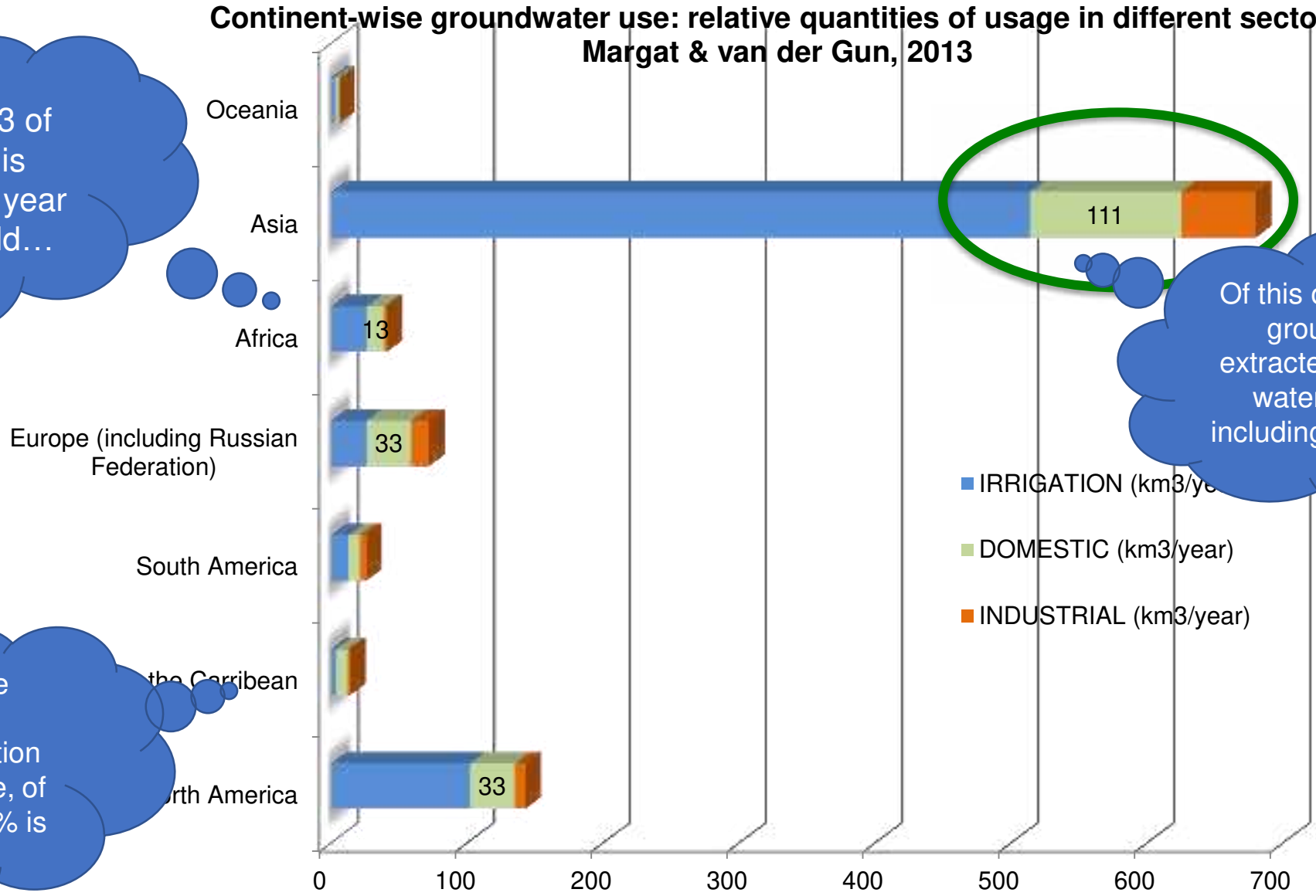
Sector-wise groundwater usage: continents - recent

Nearly 1000 m3 of groundwater is extracted every year across the world…



Of this over 200 m3 of groundwater is extracted for domestic water provisions, including drinking water

Nearly 70% of the annual global groundwater extraction is used in agriculture, of which more than 50% is in Asia alone…

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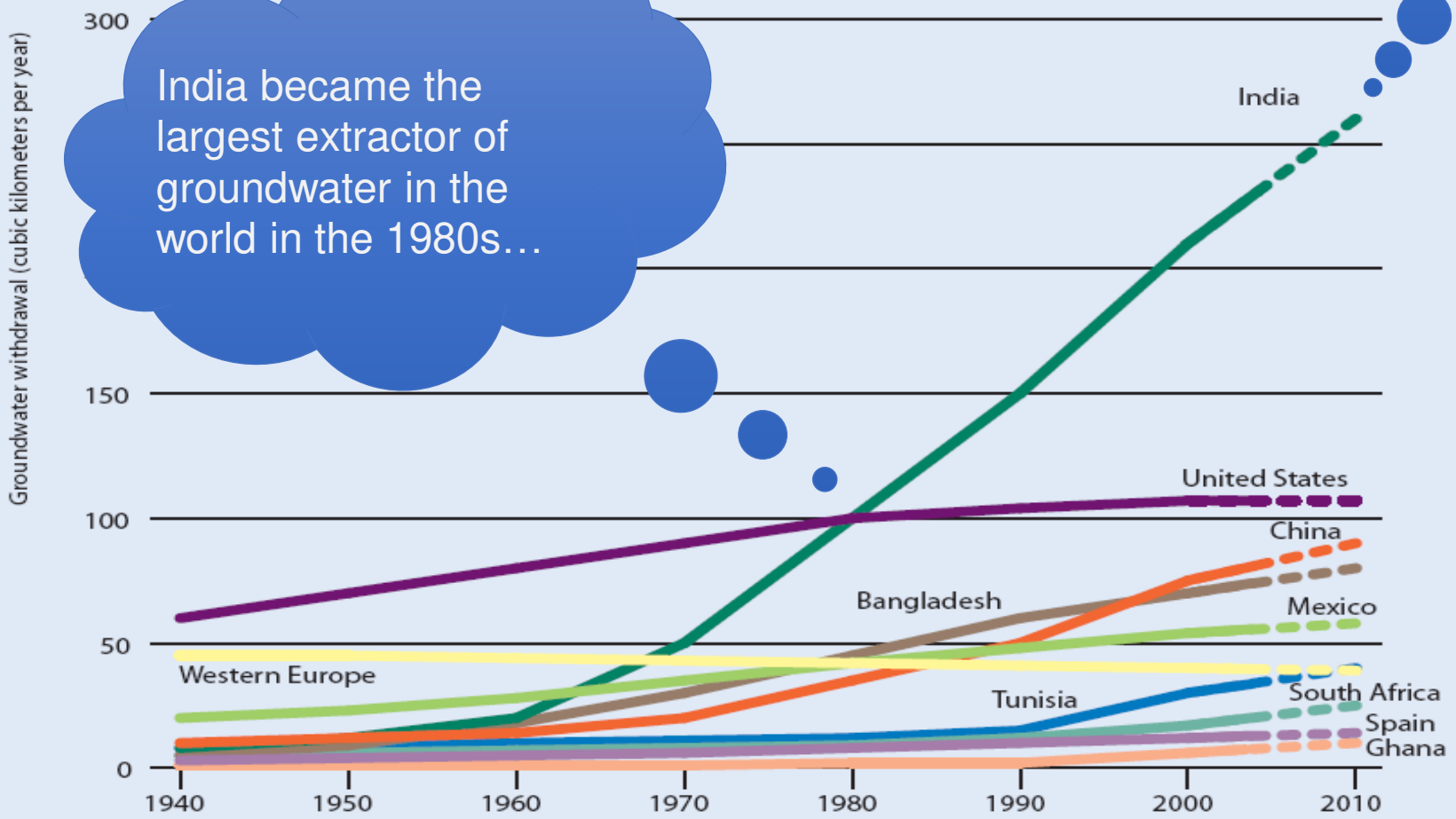
Groundwater use in agriculture: global trends

India's groundwater abstraction has now reached 25% of the global annual total

India became the largest extractor of groundwater in the world in the 1980s…



Source: Shah 2005.

Credit: Comprehensive Assessment of Water Management in Agriculture
Publisher: Earthscan www.earthscan.co.uk

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India's oft-unfathomed groundwater dependencies

- Rural drinking water: almost entirely groundwater – 98%
- Agriculture: 60-70% of total use
- Urban: 48% of water supply share is groundwater
- Industry: *no official figures…*

But 55 percent of the surveyed industries used groundwater in conjunction with or without some other source of water

Well for tigers in Nagzira

Shah (2009), Agriculture Statistics, various years; DDWS (2009); CSE (2012); MoDWS-CAG, 2017; FICCI+Columbia Water Center

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What does the future hold: urbanisation

Various sources

- Global urban population to nearly double to 6.4 billion by 2050
- 90% of the growth in low-income countries
- Urban slum dwellers will number 2 billion in 30 years time
- Urban Indians 800 million by 2050

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[Water Scarce Cities (WSC) Initiative]

ely on groundwater, globally.

pecially in "developing cities" is quite

- Modification of groundwater observed.
- Many problems around grou dicted.

- Two major consequences:
  - Paradox of urban recharge – tra faces and leaking mains and sewers
  - Contaminant loading of sub-sur and haphazard waste-disposal

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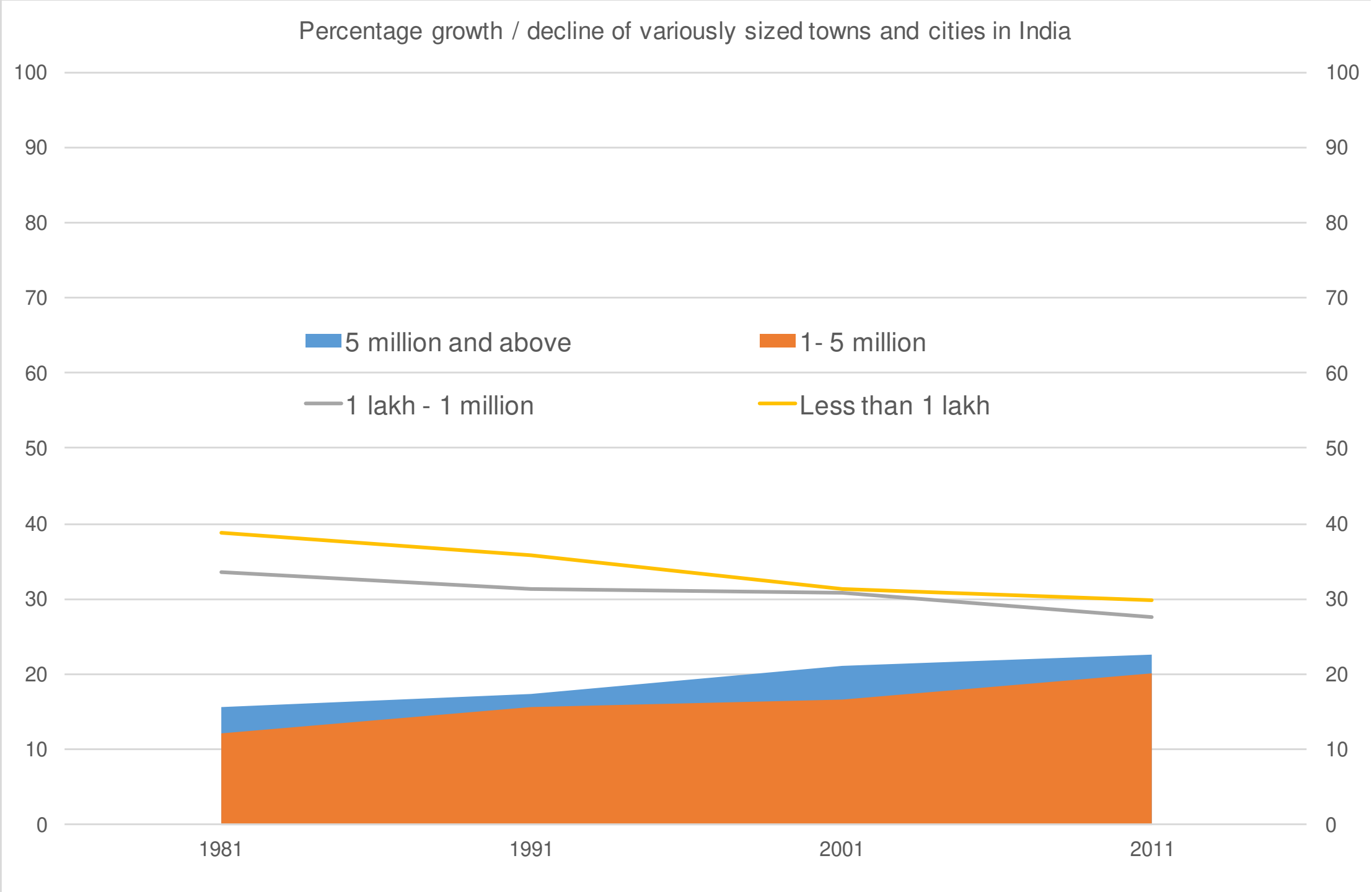

Based on Census of India, 2011

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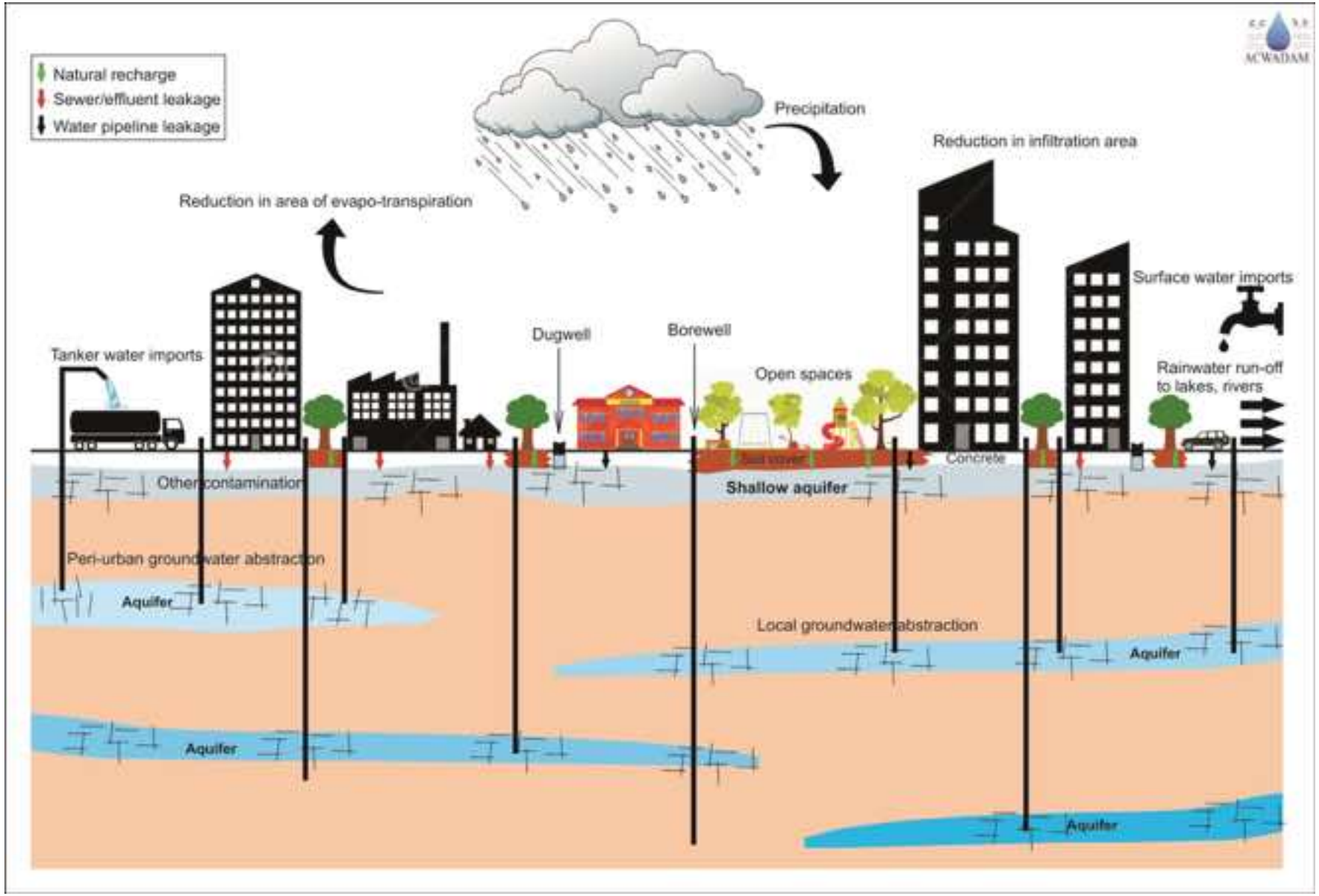
Urban groundwater- snapshot



Schematic diagram based on Foster et al, 2010

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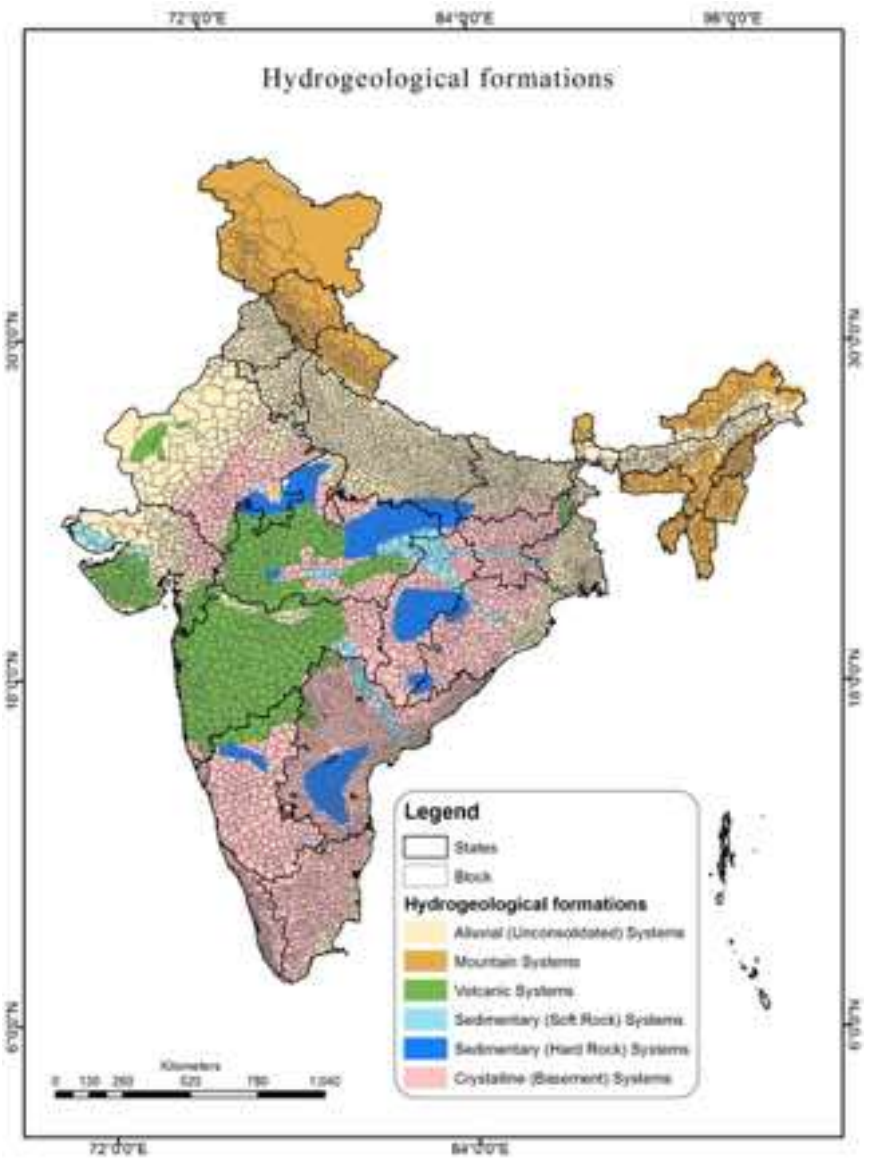
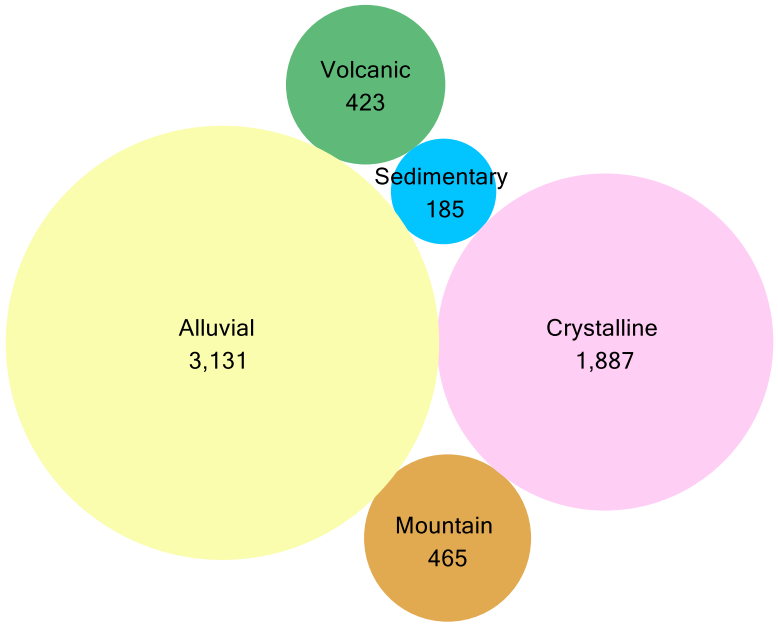
India’s hydrogeological diversity

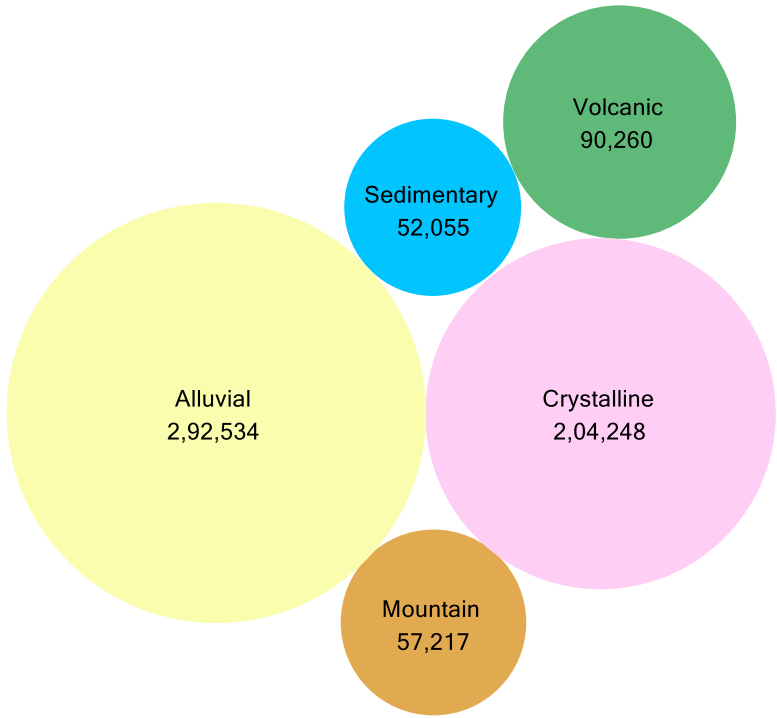


Typology based distribution of urban habitations



Hydrogeological setting
- Null
- Alluvial
- Crystalline
- Mountain
- Sedimentary
- Volcanic

Typology based distribution of rural habitations



After: COMMAN 2005; GSI (various years), ACWADAM (various publ.), CGWB (2012)

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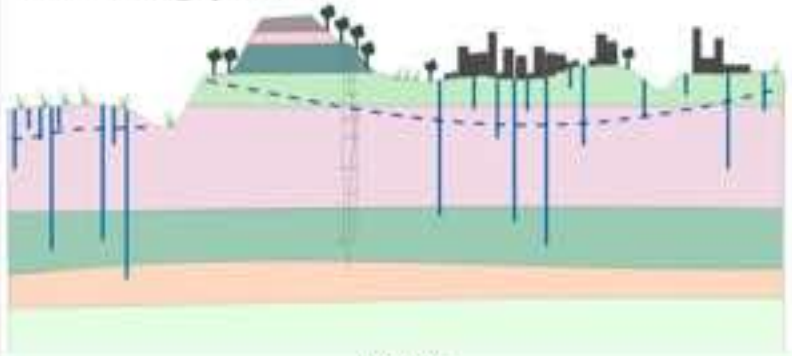
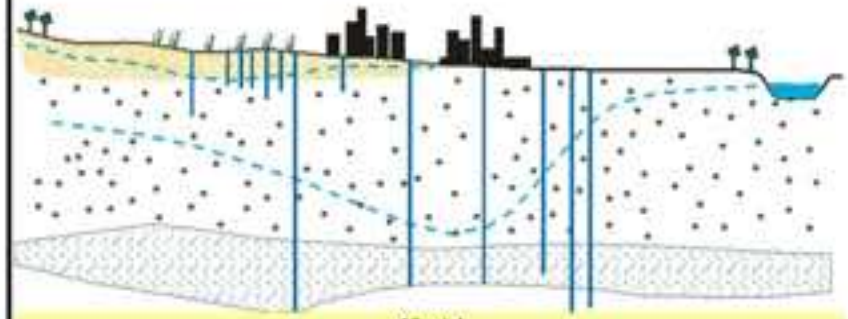
Volcanic – largely basalt



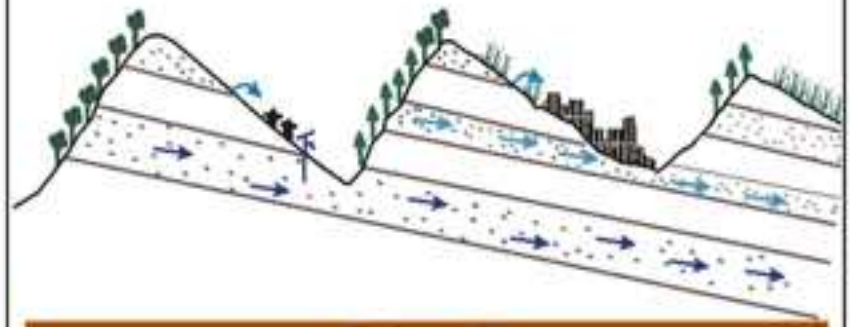
Volcanics		
A	Urban Agglomerations	2
B	Million plus cities	6
C	Lakh plus cities	24
	Total cities(A+B+C)	32
	Total cities %	10.5%
	Smaller towns corresponding to taluka headquarters	391
	Talukas %	7%

Extensive alluvium



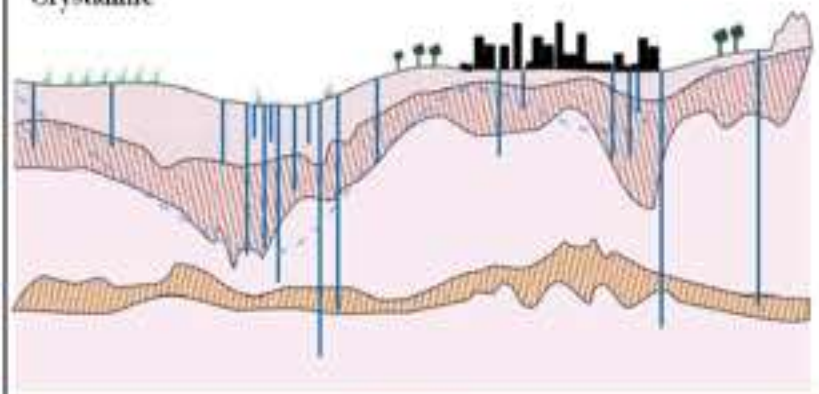
Alluvial		
A	Urban Agglomerations	5
B	Million plus cities	19
C	Lakh plus cities	118
	Total cities(A+B+C)	142
	Total cities %	46%
	Smaller towns corresponding to taluka headquarters	1647
	Talukas %	32%

Himalayan mountain region



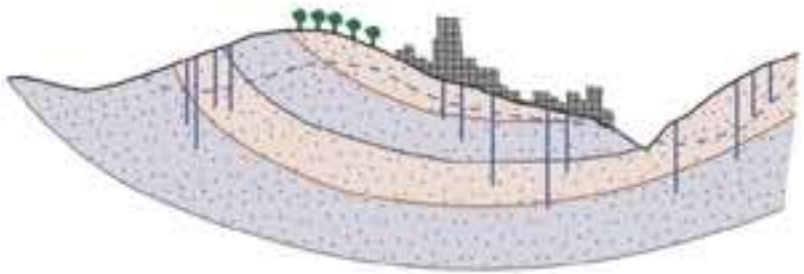
Himalayan region		
A	Urban Agglomerations	0
B	Million plus cities	0
C	Lakh plus cities	8
	Total cities(A+B+C)	8
	Total cities %	2.5%
	Smaller towns corresponding to taluka headquarters	457
	Talukas %	8%

Crystalline



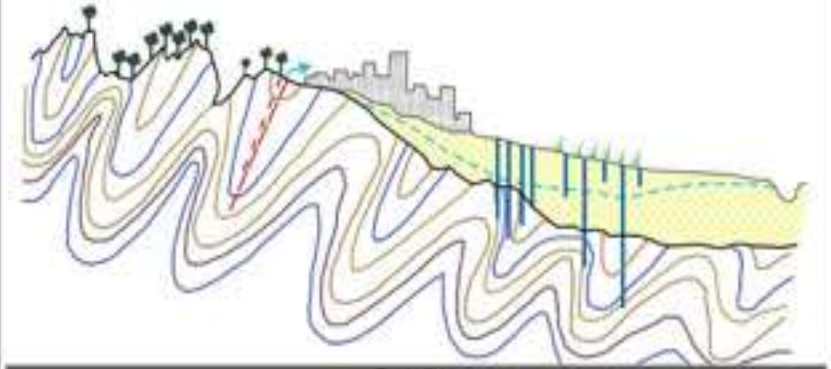
Crystallines		
A	Urban Agglomerations	4
B	Million plus cities	21
C	Lakh plus cities	89
	Total cities(A+B+C)	114
	Total cities %	35.5%
	Smaller towns corresponding to taluka headquarters	1773
	Talukas %	31%

Consolidated sedimentary



Sedimentary Systems		
A	Urban Agglomerations	0
B	Million plus cities	1
C	Lakh plus cities	12
	Total cities(A+B+C)	13
	Total cities %	4.0%
	Smaller towns corresponding to taluka headquarters	172
	Talukas %	3.0%

Transition



Transition		
A	Urban Agglomerations	
B	Million plus cities	
C	Lakh plus cities	
	Total cities(A+B+C)	0
	Total cities %	
	Smaller towns corresponding to taluka headquarters	1142
	Talukas %	20%

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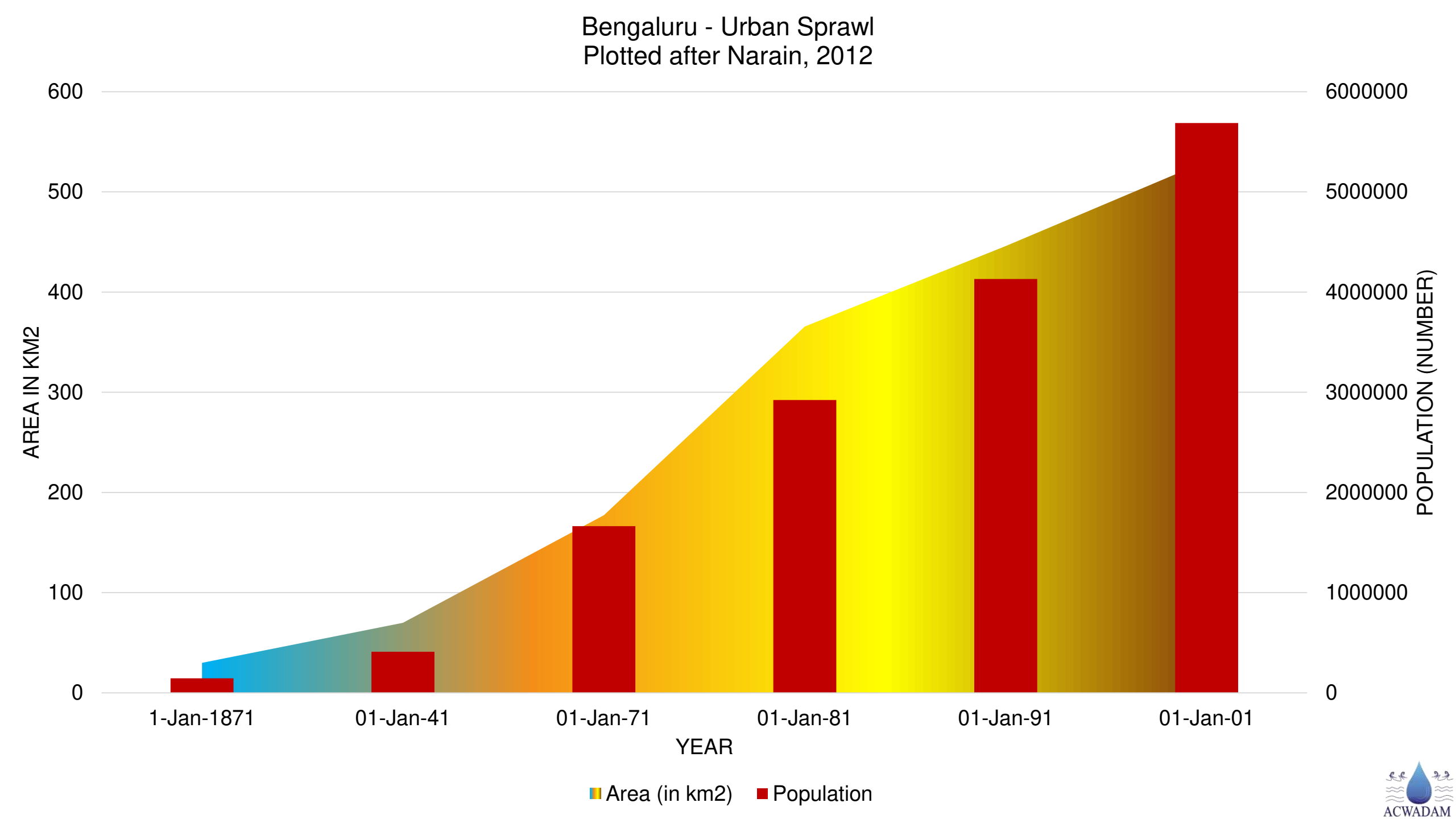
Bengaluru - Urban Sprawl
Plotted after Narain, 2012
600
500
400
300
200
100
0
AREA IN KM2
6000000
5000000
4000000
3000000
2000000
1000000
0
POPULATION (NUMBER)
1-Jan-1871
01-Jan-41
01-Jan-71
01-Jan-81
01-Jan-91
01-Jan-01
YEAR
Area (in km2)
Population
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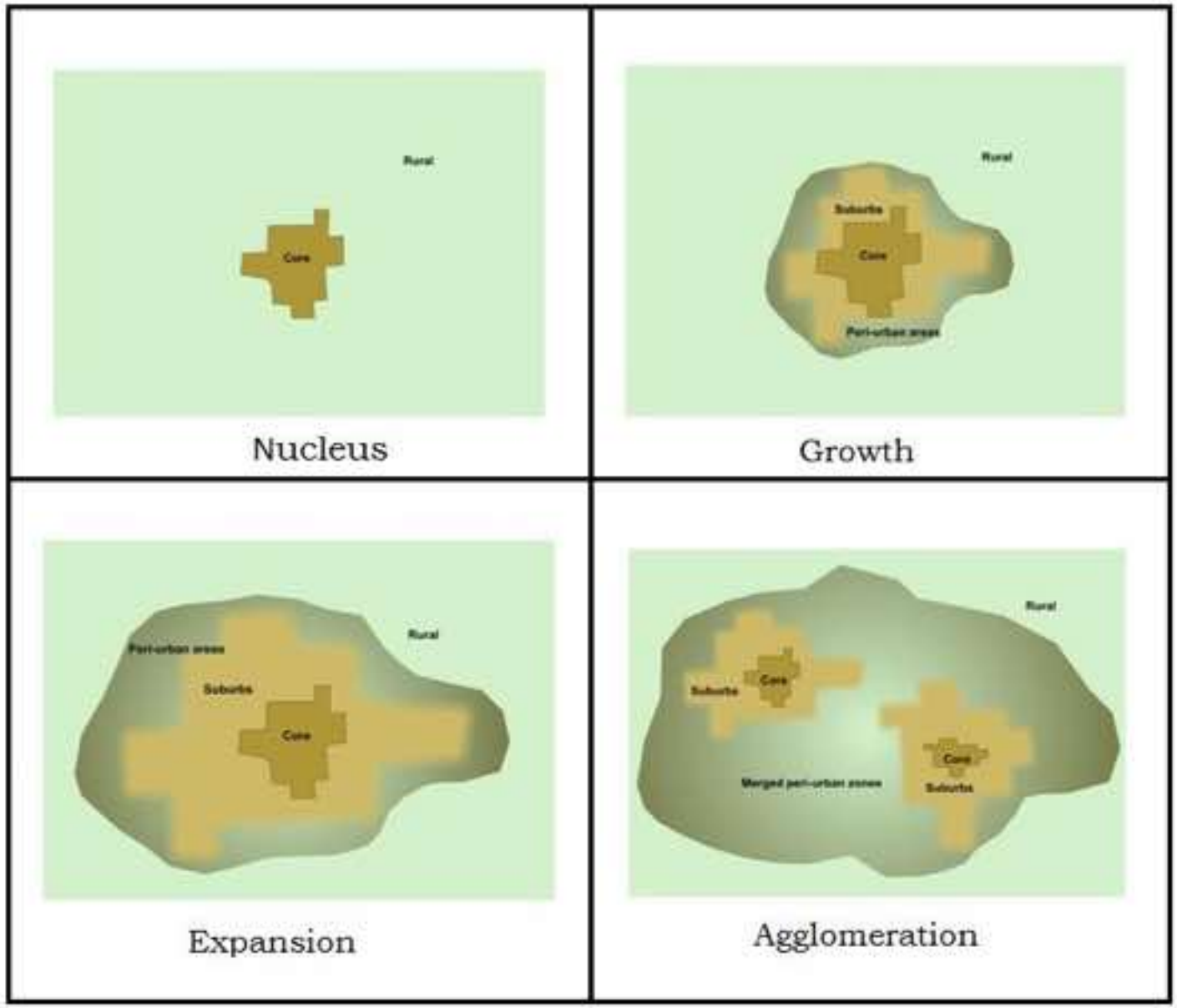
The Urban Continuum: A Schema in Four Stages (after:Shah and Kulkarni, 2015)



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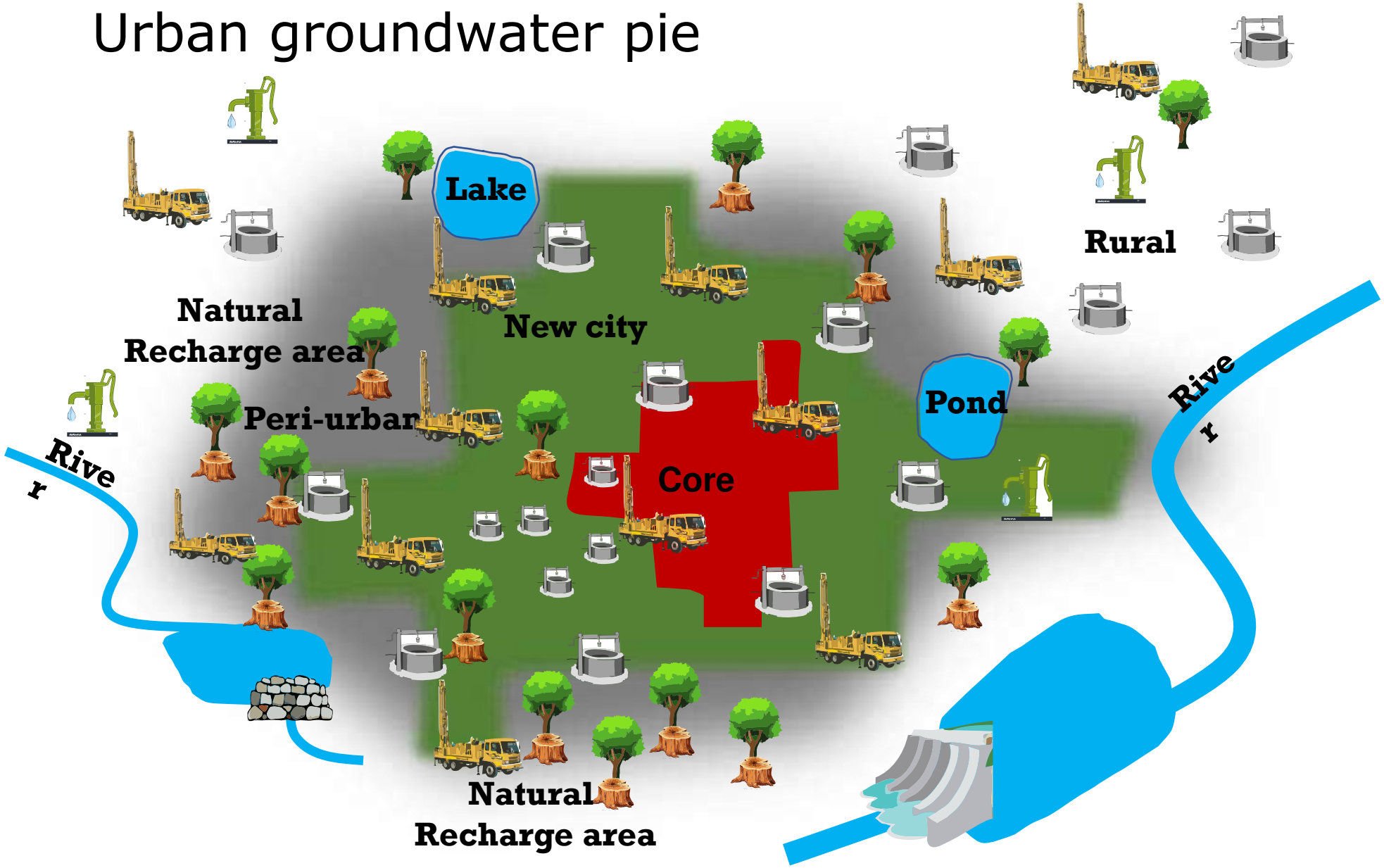
Urban groundwater pie



Adapted from Kulkarni, H; Shah, M (2014)

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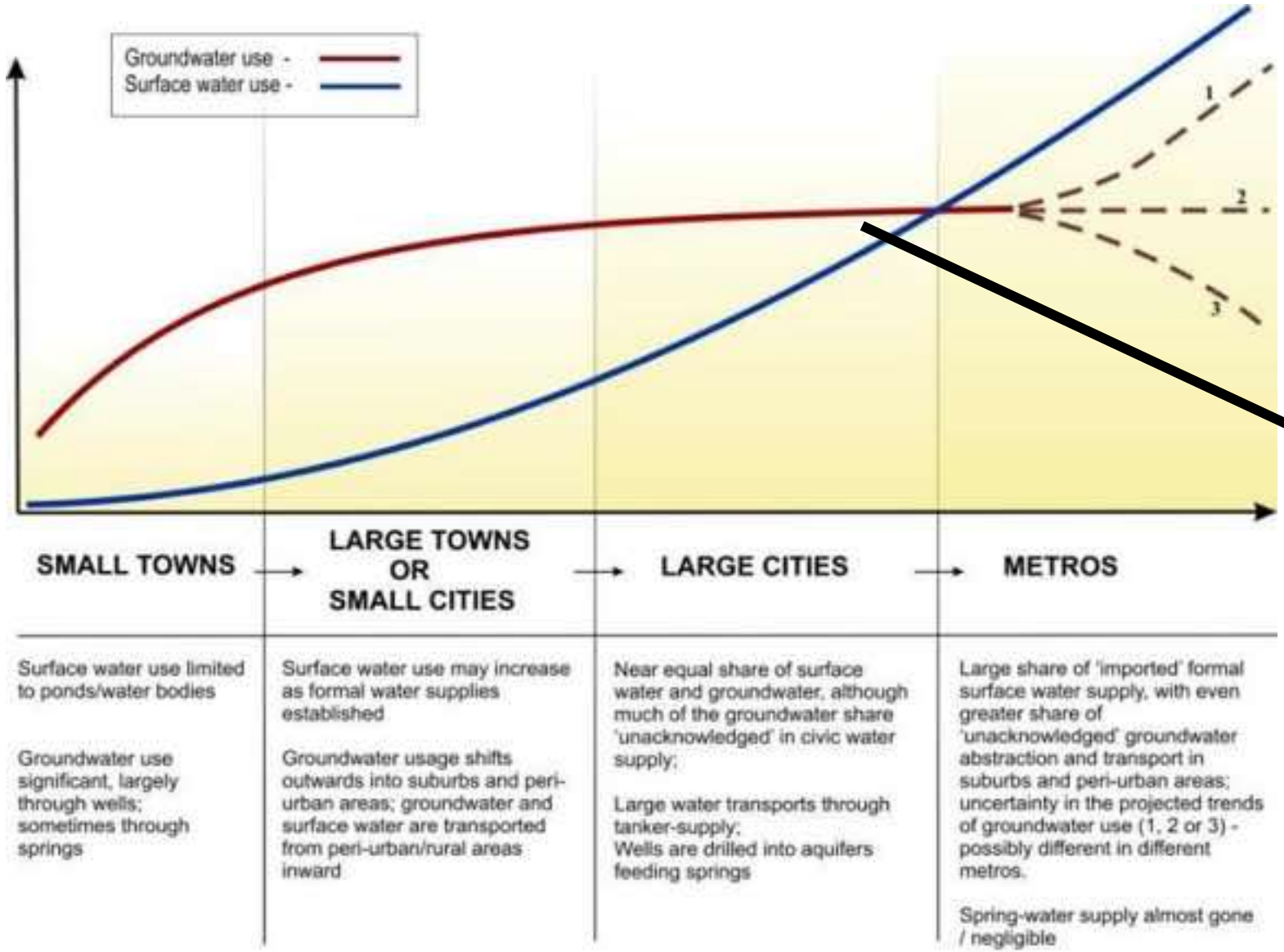
Trends in Surface and Groundwater use across variously sized Urban Settlements in India

Source: Kulkarni, H; Shah, M (2014)



Pune's annual groundwater footprint as much as 4-5 TMC…

Surface water
13 TMC estimated for Pune city

PUNE CITY

Groundwater
3-4 TMC from bore holes

1-2 TMC from dug wells – needs further validation

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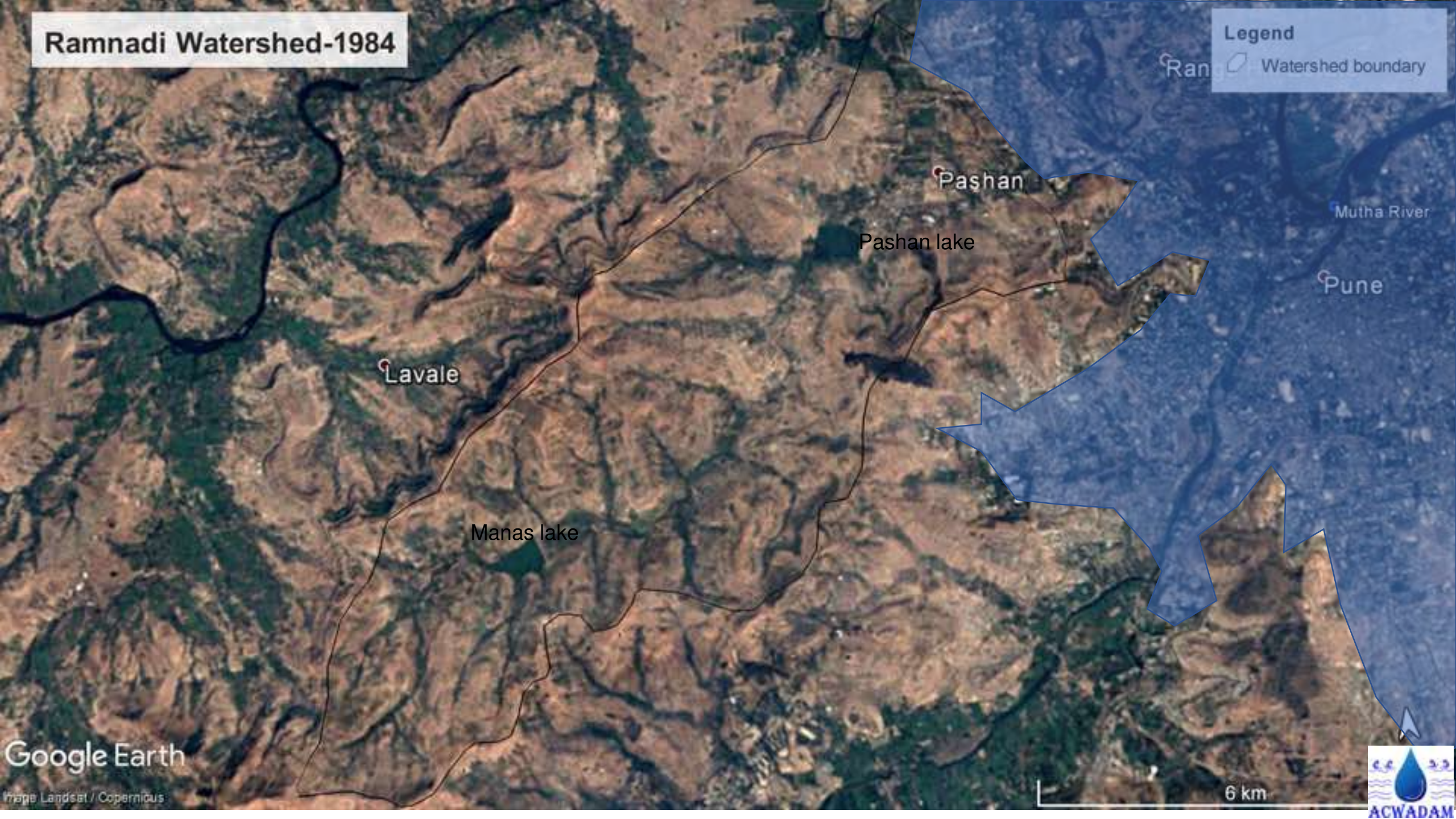
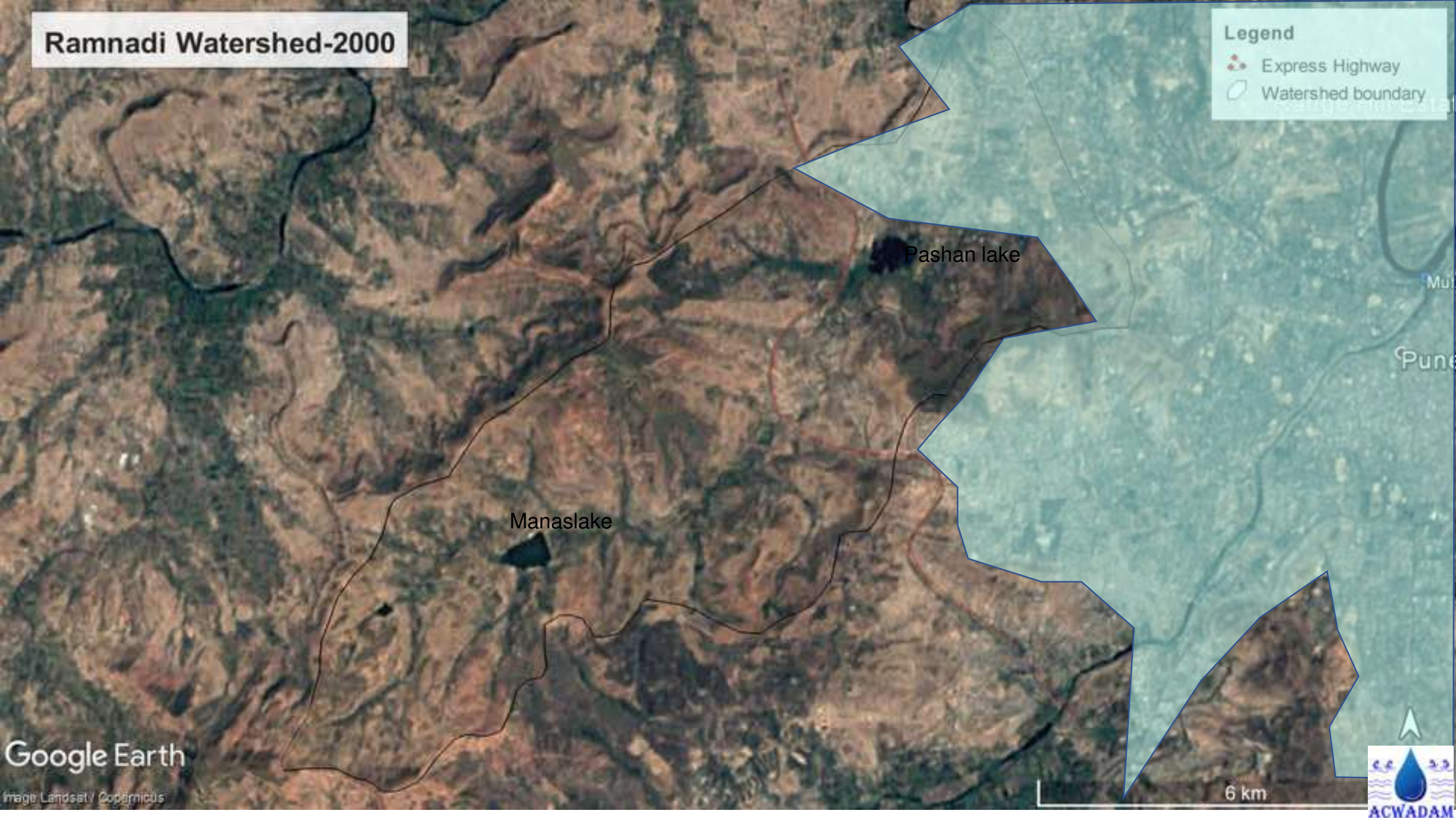
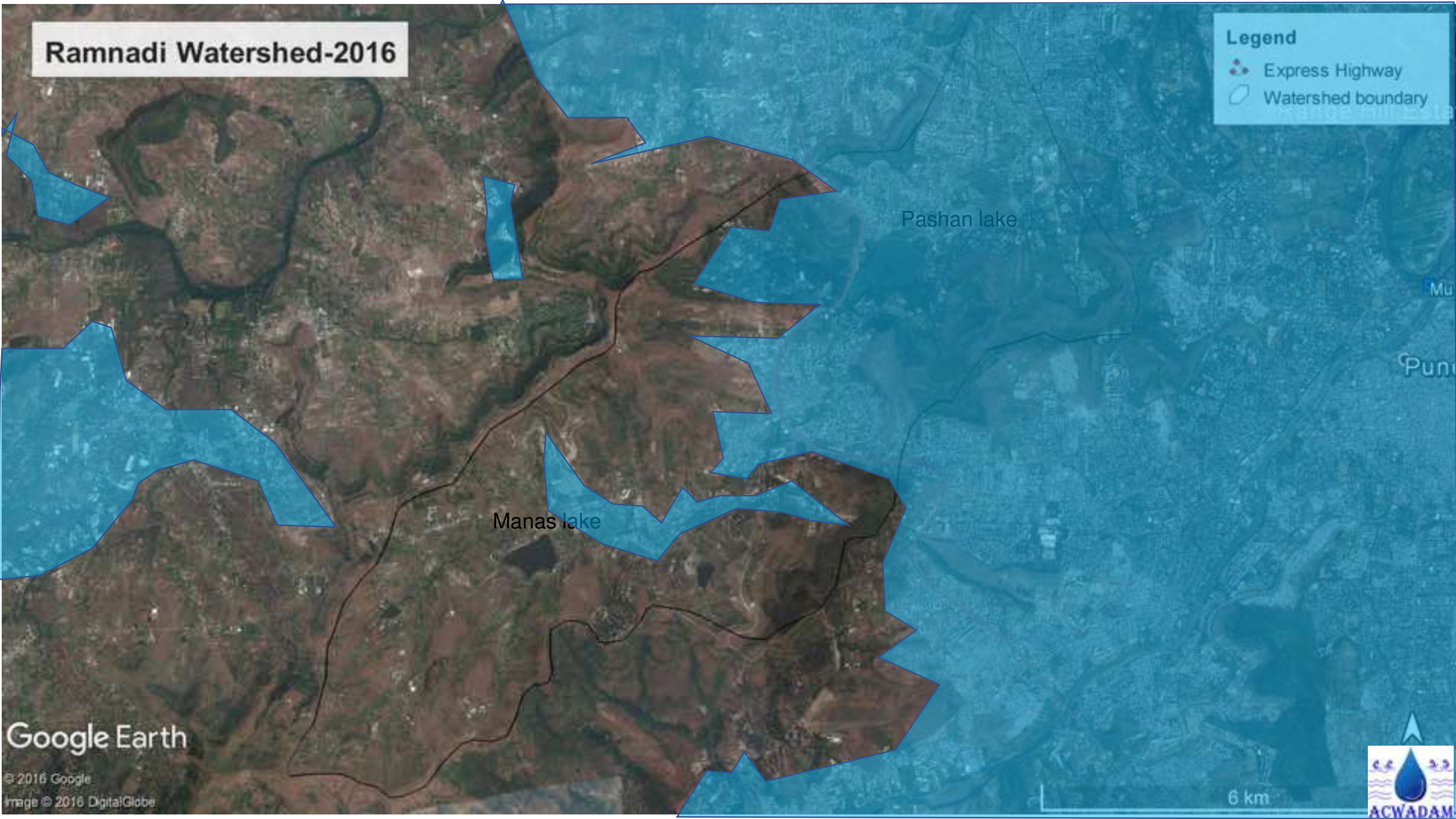

Ramnadi Watershed-1984
Legend
Watershed boundary
Ran
Pashan
Mutha River
Pashan lake
Pune
Lavale
Manas lake
Google Earth
Image Landsat / Copernicus
6 km
ACWADAM


Ramnadi Watershed-2000
Legend
Express Highway
Watershed boundary
Pashan lake
Manaslake
Google Earth
Image Landsat / Copernicus
6 km
ACWADAM


Ramnadi Watershed-2016
Legend
Express Highway
Watershed boundary
Pashan lake
Manas lake
Google Earth
© 2016 Google
Image © 2016 DigitalGlobe
6 km
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URBAN DEMAND EQUALS PRECIPITATION IN MANY CITIES…

	Sr. No.	Name	Typology	Water demand (mm)	Actual annual rainfall (mm)
Metropolitan Region of India	1	Greater Mumbai city	Volcanic	1770	2257
	2	Delhi city	Alluvial	1108	747
	3	Kolkata city	Alluvial	1987	1709
	4	Chennai city	Crystalline	1032	1324
	5	Bengaluru city	Crystalline	574	870
	6	Hyderabad city	Crystalline	512	851
	7	**Pune PMRDA**	**Volcanic**	**1084**	**1015**

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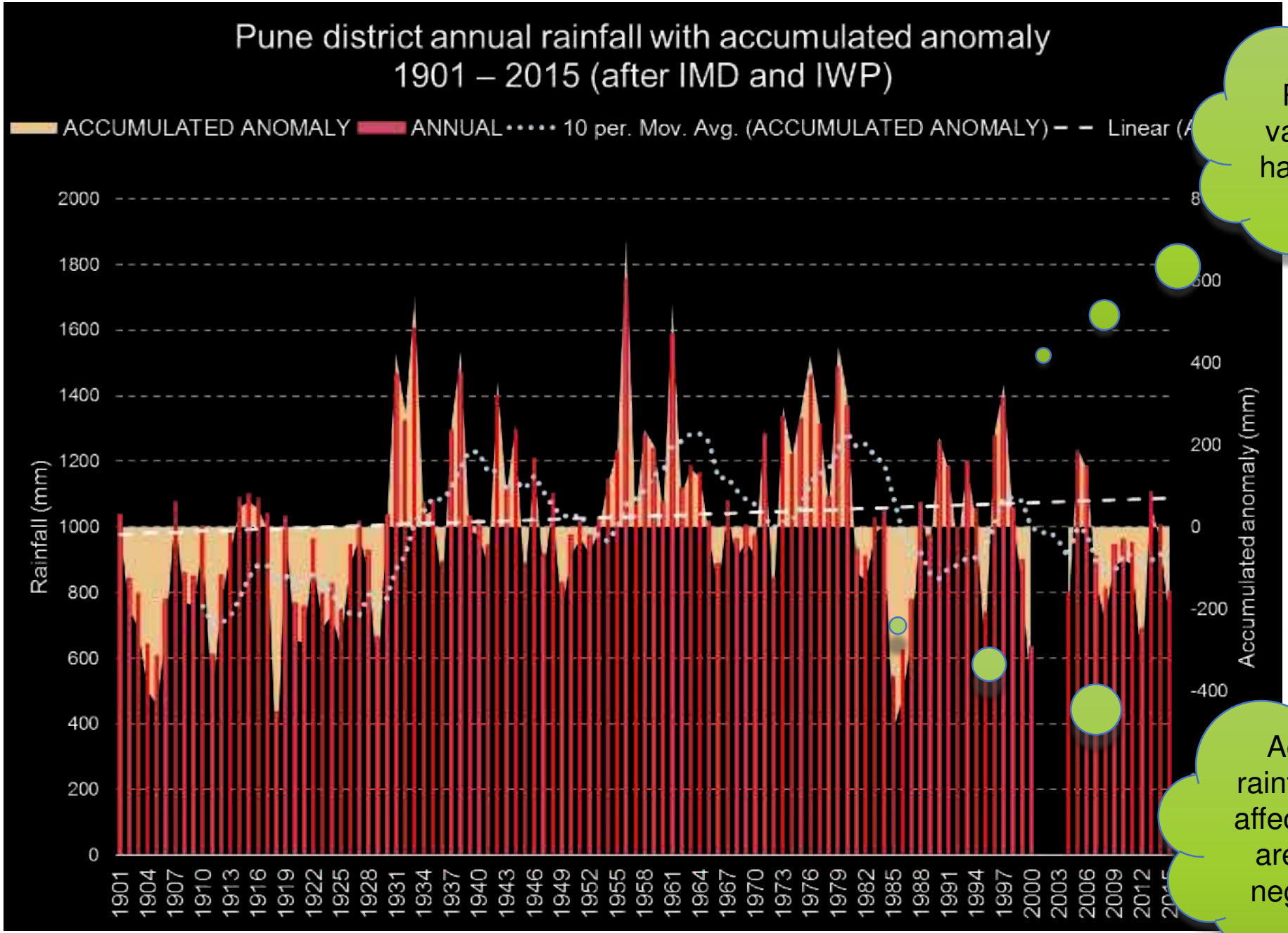

Rainfall and variability both have increased

Accumulated rainfall anomalies affecting recharge are dominantly negative now…

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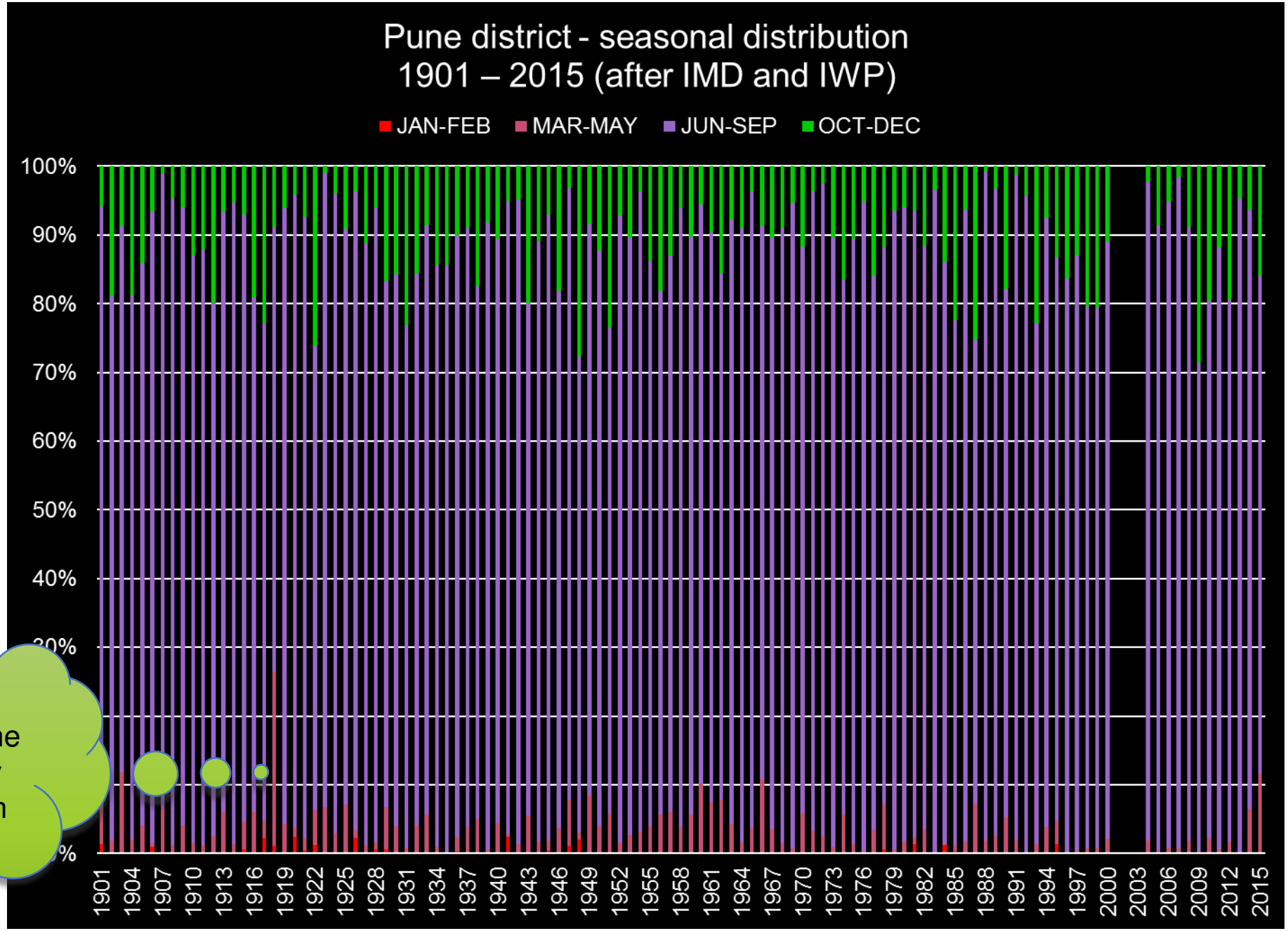

Decrease in the January-May precicipitation

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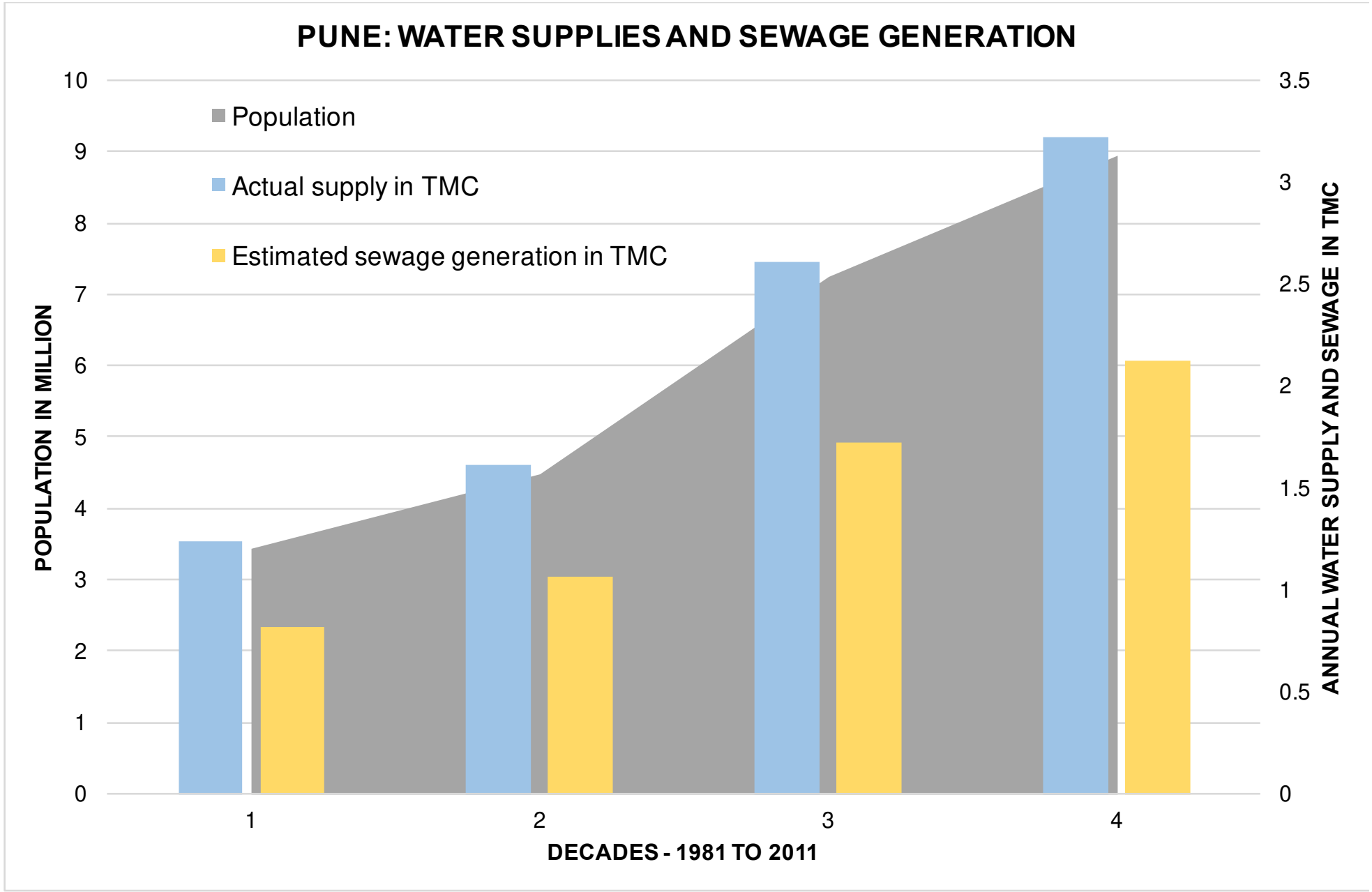
PUNE: WATER SUPPLIES AND SEWAGE GENERATION
Population
Actual supply in TMC
Estimated sewage generation in TMC
POPULATION IN MILLION
ANNUAL WATER SUPPLY AND SEWAGE IN TMC
DECADES - 1981 TO 2011
0
1
2
3
4
5
6
7
8
9
10
0
0.5
1
1.5
2
2.5
3
3.5
1
2
3
4

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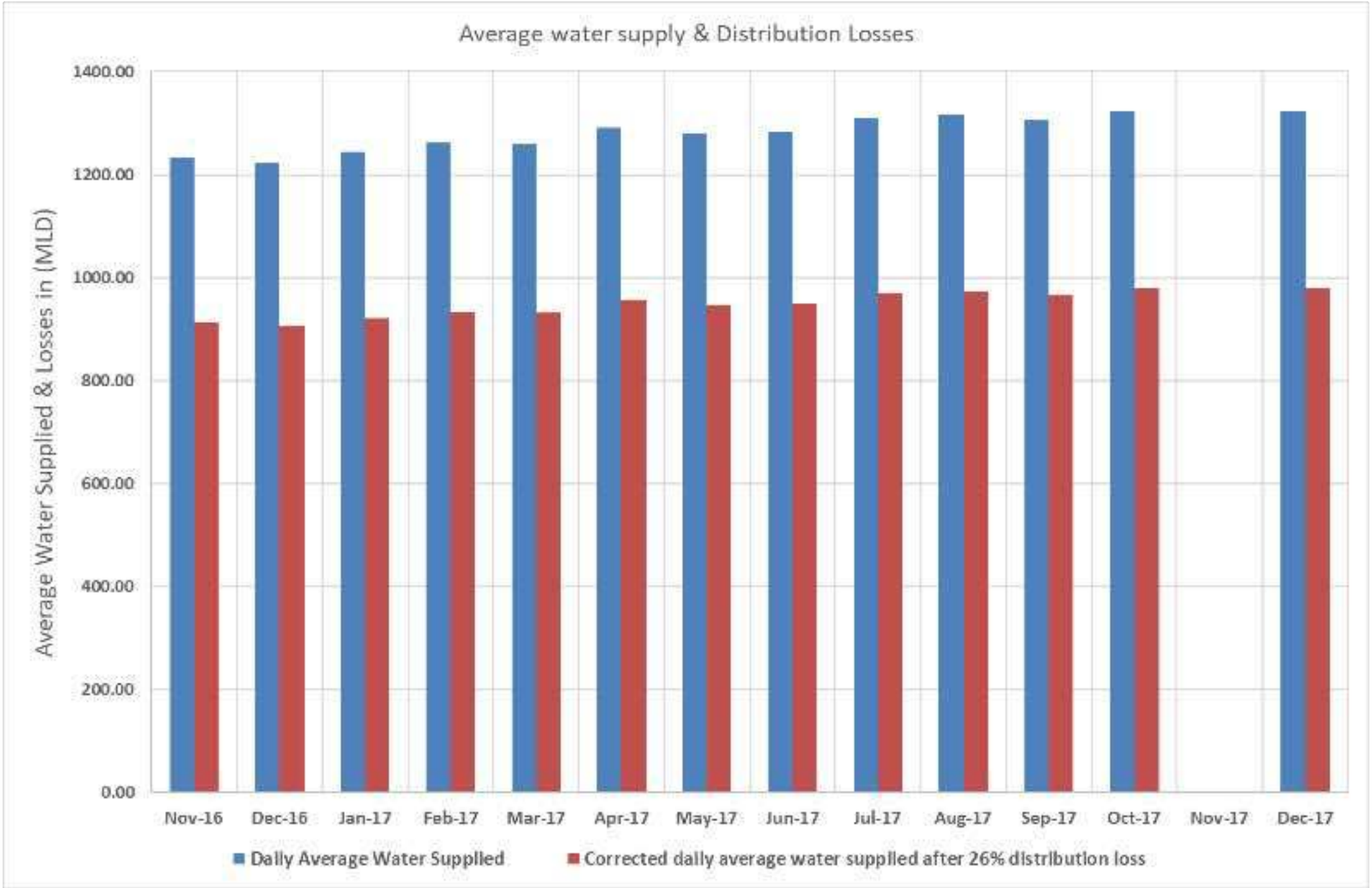
Average water supply & Distribution Losses
Average Water Supplied & Losses in (MLD)
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
Nov-16
Dec-16
Jan-17
Feb-17
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Sep-17
Oct-17
Nov-17
Dec-17
Daily Average Water Supplied
Corrected daily average water supplied after 26% distribution loss

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WATER SUPPLY METRICS

Year	Population	Population (Million)	Growth	Growth Rate (%)	Per capita supply as per norms 150 LPCD	As per PMC data Actual supply 228 LPCD	Supply as per norm in TMC/Year @ 150 LPCD	Actual Supply in TMC/Year @ 228 LPCD	Excess water supply in TMC	Estimated Sewage generation as per PMC data TMC/Year
1981	1.203.351	1.20	0	0%	180502650	274364028	2.33	3.54	1.21	2.33
1991	1.566.651	1.57	363.300	30.19%	234997650	357196428	3.03	4.60	1.58	3.04
2001	2.538.473	2.54	971.822	62.03%	380770950	578771844	4.91	7.46	2.55	4.92
2011	3.132.143	3.13	593.670	23.39%	469821450	714128604	6.06	9.21	3.15	6.08

1. Supply @ 228 lpcd corrected to 26% losses	6.8 TMC
2. Sewage generated at 66% of actual supply (above)	4.5 TMC
3. Estimated/actual sewage generation	6.08 TMC
4. Estimated additional sewage generation due to groundwater usage	1.58 TMC or 44740616 m^3 or **166 mm**
5. Estimated extraction of groundwater from the additional estimate of sewage due to groundwater usage (applying the index of 66% as in point 2)	**3.78 TMC OR 107037676** m^3 or **400 mm**

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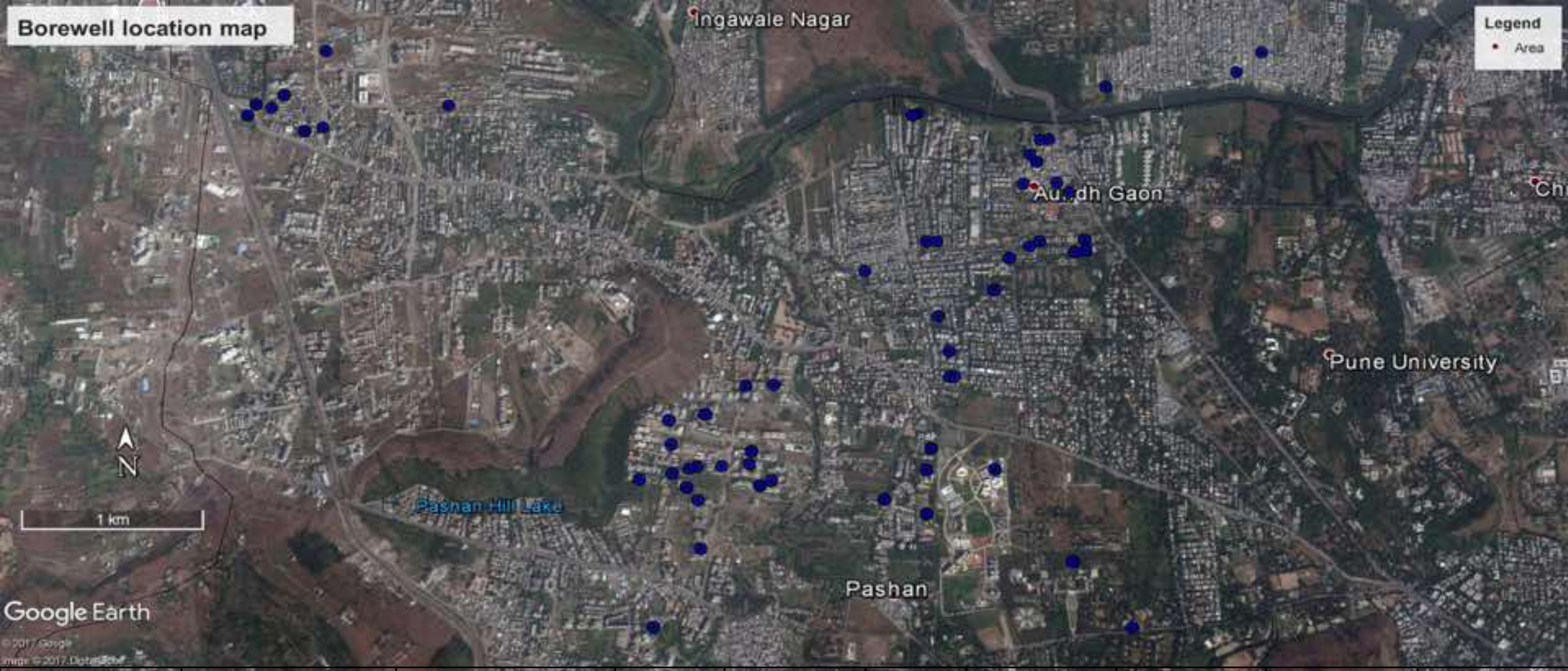

Pump capacity (Hp)	Pump output (LPM) (min postulated)	Pump output (M3/hr)	Daily pumping hours (Avg)	Groundwater abstraction (M3/day)	Pumping days	Total Groundwater abstraction/ borewell (M3)	No of BWs in and around Pune city	Total Groundwater abstraction (M3)	Total Groundwater abstraction (TMC)
2	80	4.8	2.74	13.2	90	1184	125000	147960000	5.23
2	80	4.8	2.74	13.2	90	1184	80000	94694400	3.34

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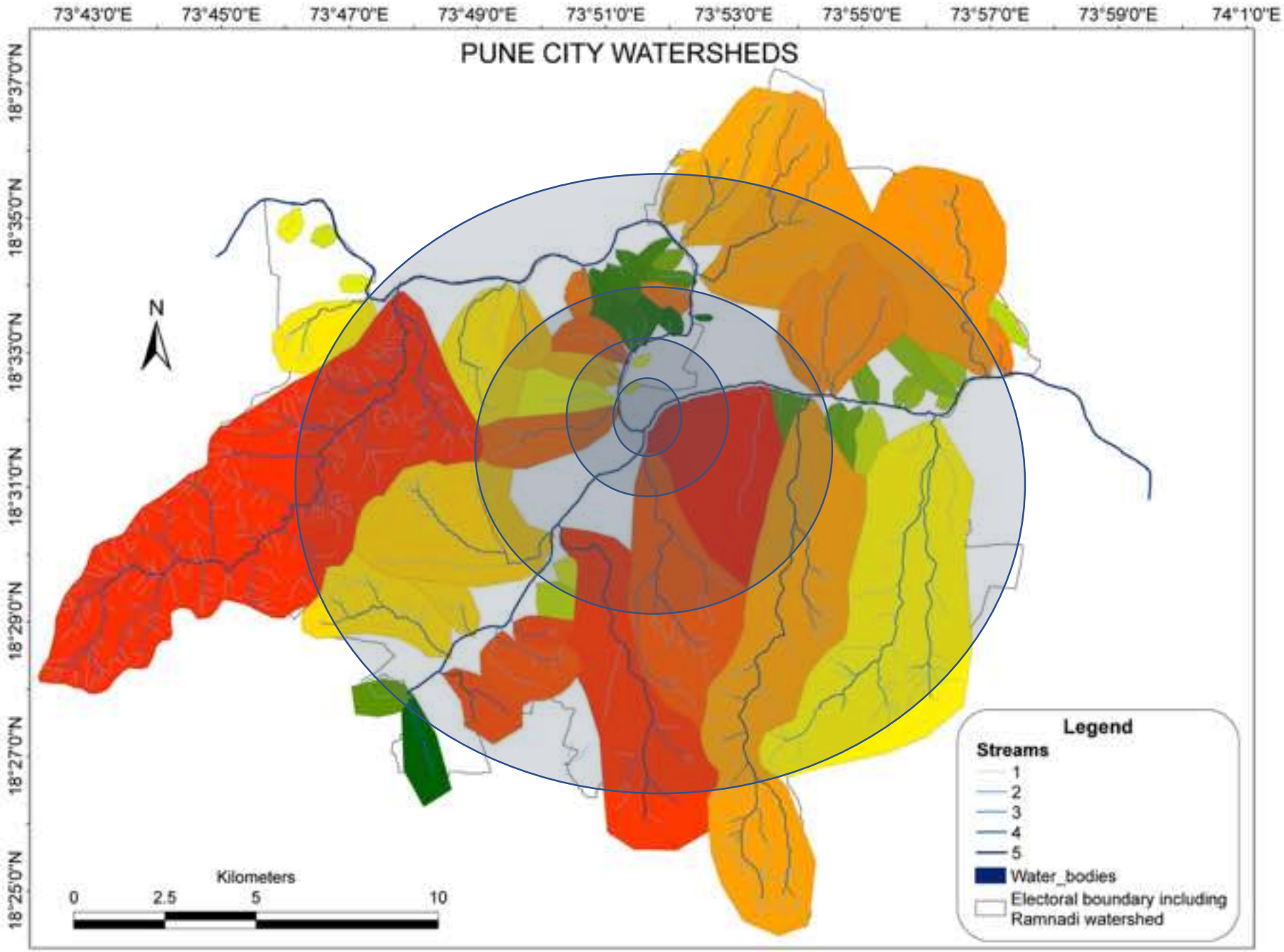
										Season wise Pumping hours			Season wise Groundwater abstraction (m3)			
Number of residents	Water requirement per capita per day (in liters)	Total water requirement per day (liters)	Supply from MIDC per day (liters)	water deficit per day (liters)	water deficit per day (m3)	water deficit per year (m3)	Pump capacity (HP)	Pump output (LPM) (minimum postulated on the basis of sample measurements)	Pump output (m^3/hour.)	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Total Groundwater abstraction/ year (m3)
37000	228	8436000	400000	8036000	8036	2933140	5	200	12	581	612	657	6966	7348	7883	22197



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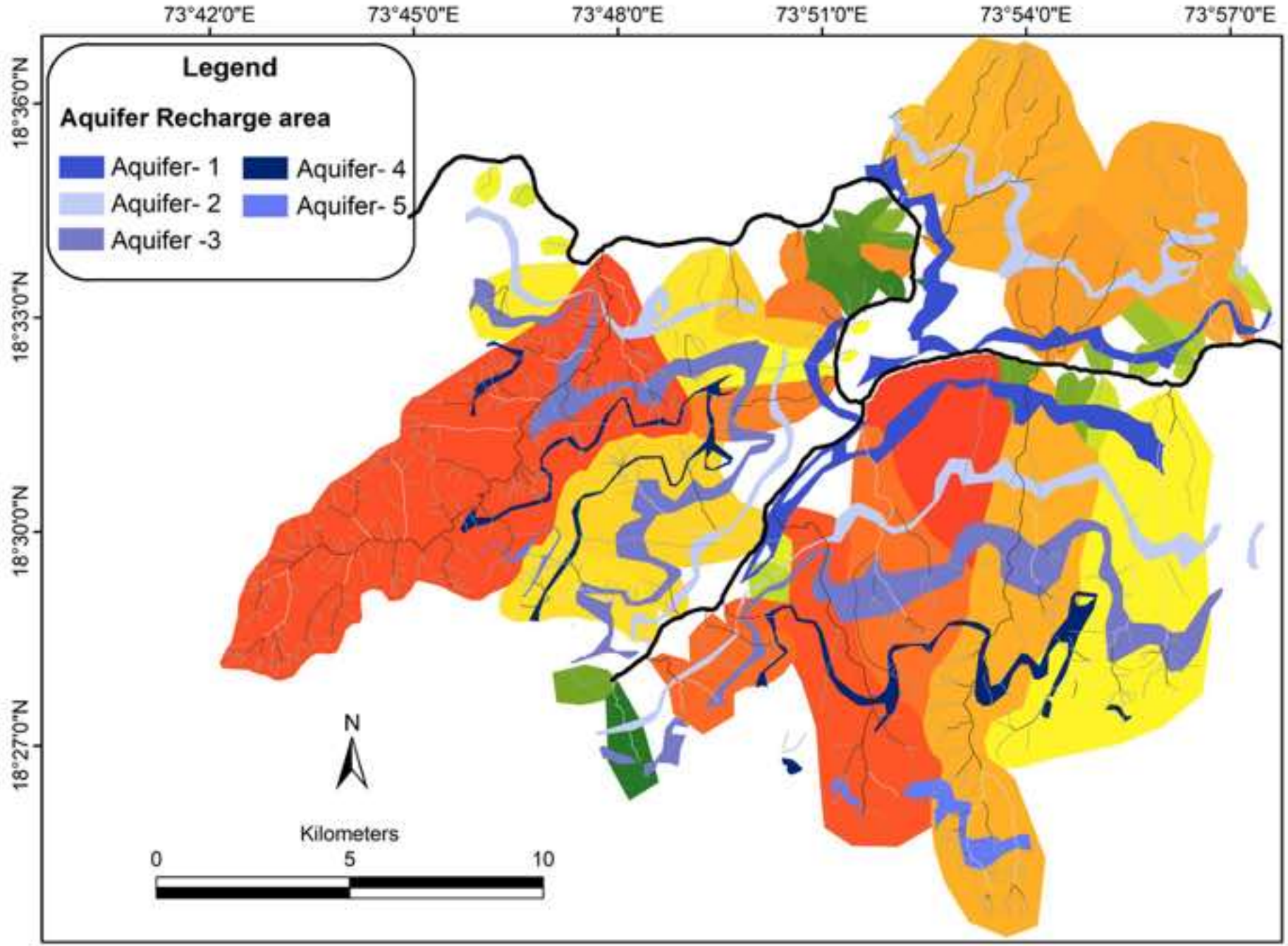
73°42'0"E
73°45'0"E
73°48'0"E
73°51'0"E
73°54'0"E
73°57'0"E
18°36'0"N
18°33'0"N
18°30'0"N
18°27'0"N
Legend
Aquifer Recharge area
Aquifer- 1
Aquifer- 2
Aquifer -3
Aquifer- 4
Aquifer- 5
N
Kilometers
0
5
10

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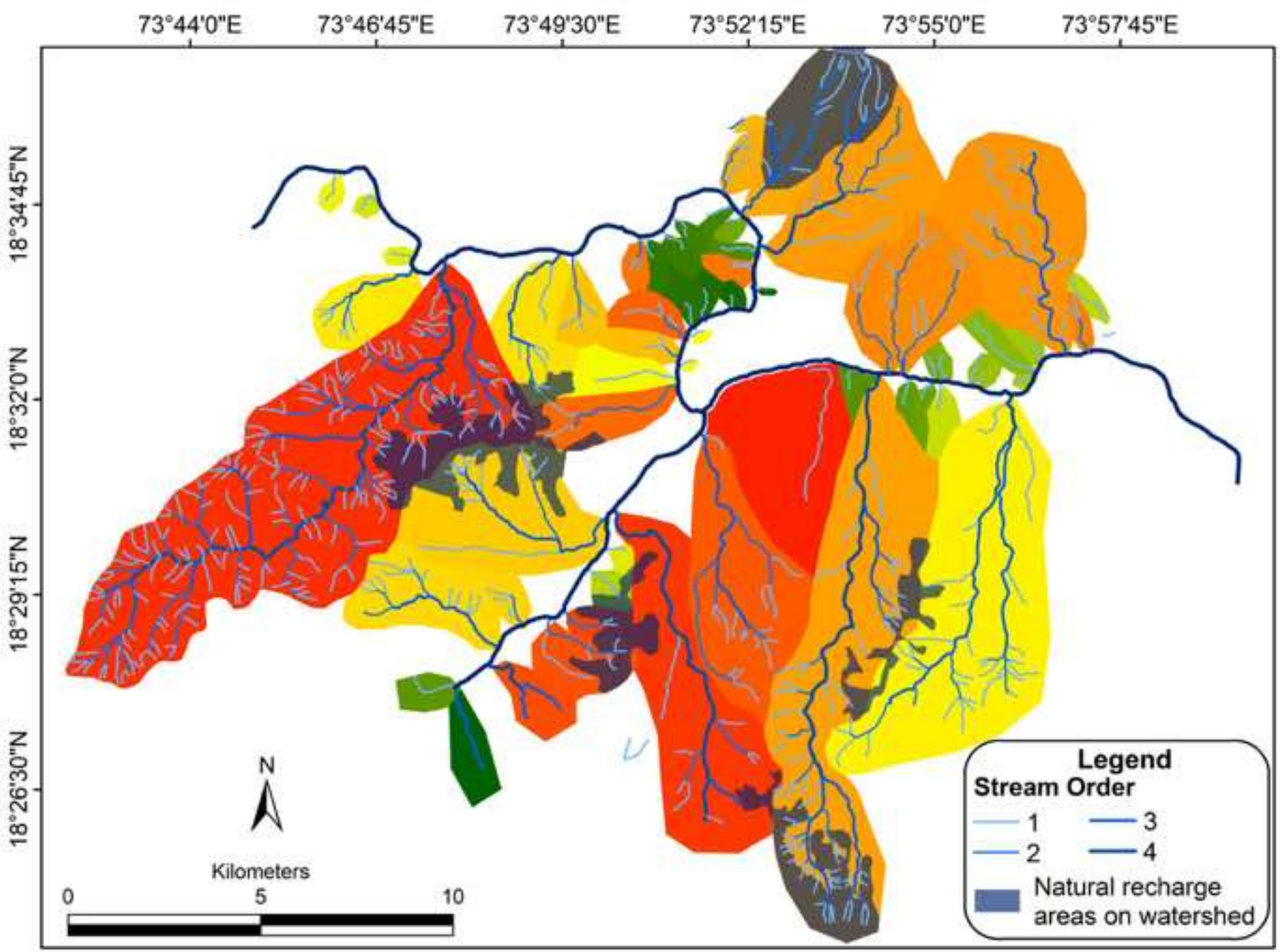
73°44'0"E
73°46'45"E
73°49'30"E
73°52'15"E
73°55'0"E
73°57'45"E
18°34'45"N
18°32'0"N
18°29'15"N
18°26'30"N
N
Kilometers
0
5
10
Legend
Stream Order
1
2
3
4
Natural recharge areas on watershed

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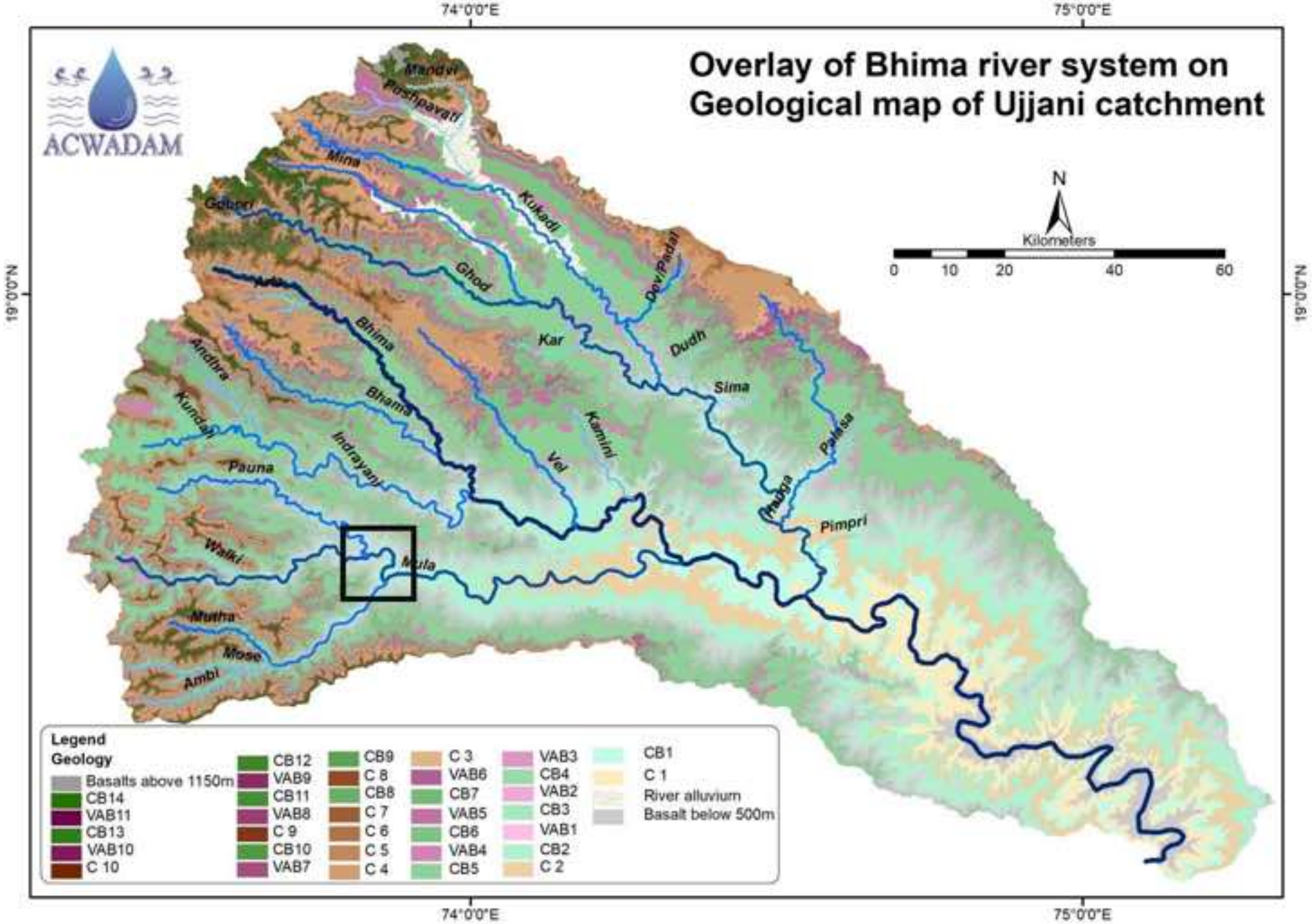
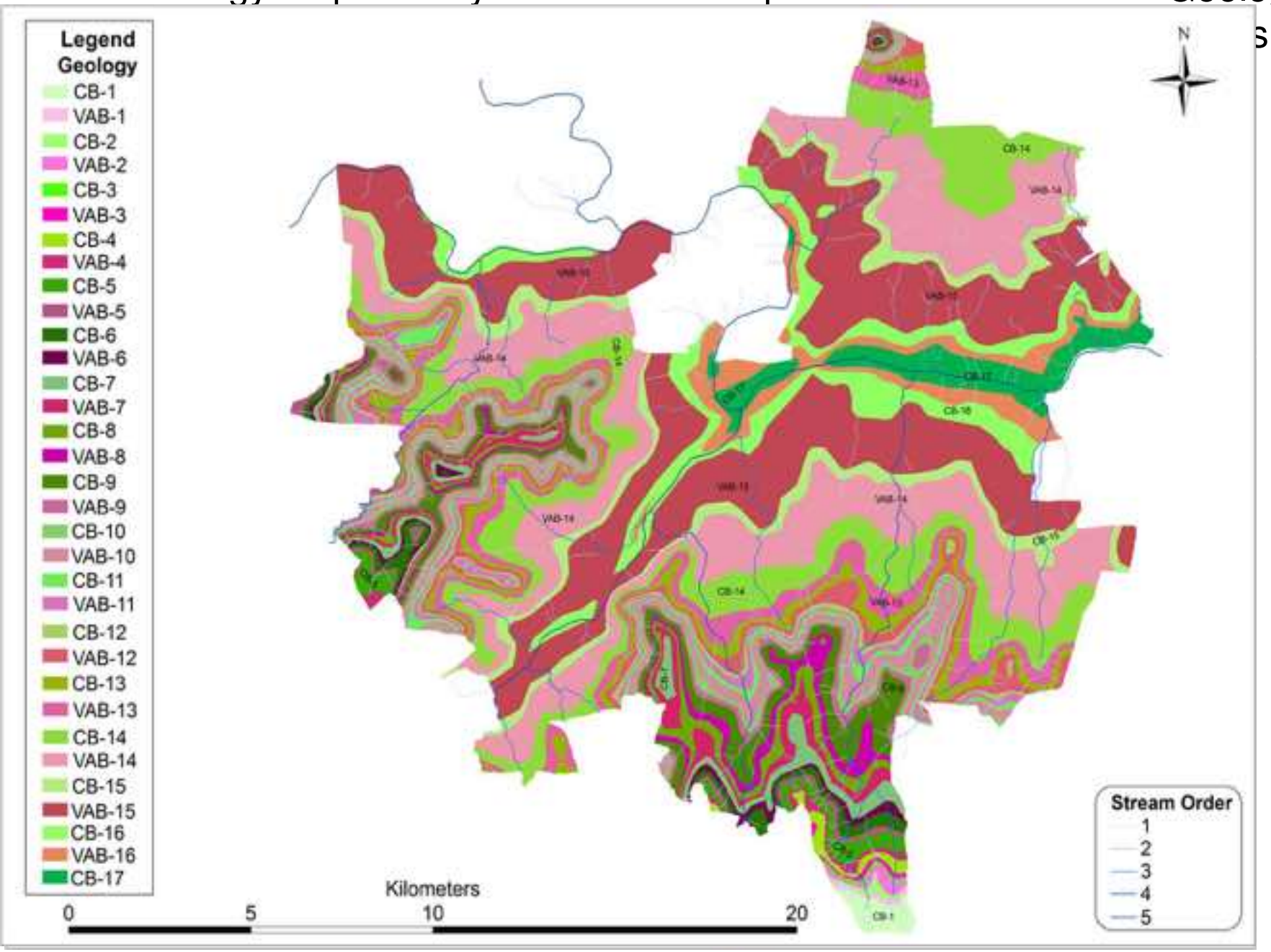

Overlay of Bhima river system on
Geological map of Ujjani catchment
ACWADAM
N
Kilometers
0 10 20 40 60
74°0'0"E
75°0'0"E
19°0'0"N
Maadvi
Pershpavati
Mina
Kukadi
Ghod
Kar
Dudh
Sima
Kamini
Vel
Bhima
Bhama
Andhra
Kundali
Indrayani
Pauna
Walki
Mula
Mutha
Mose
Ambi
Devi Pasdari
Palasa
Pimpri
Legend
Geology
Basalts above 1150m
CB14
VAB11
CB13
VAB10
C 10
CB12
VAB9
CB11
VAB8
C 9
CB10
VAB7
CB9
C 8
CB8
C 7
C 6
C 5
C 4
C 3
VAB6
CB7
VAB5
CB6
VAB4
CB5
VAB3
CB4
VAB2
CB3
VAB1
CB2
C 2
CB1
C 1
River alluvium
Basalt below 500m

Geology map overlay on Pune municipal

Geology on municipal

s



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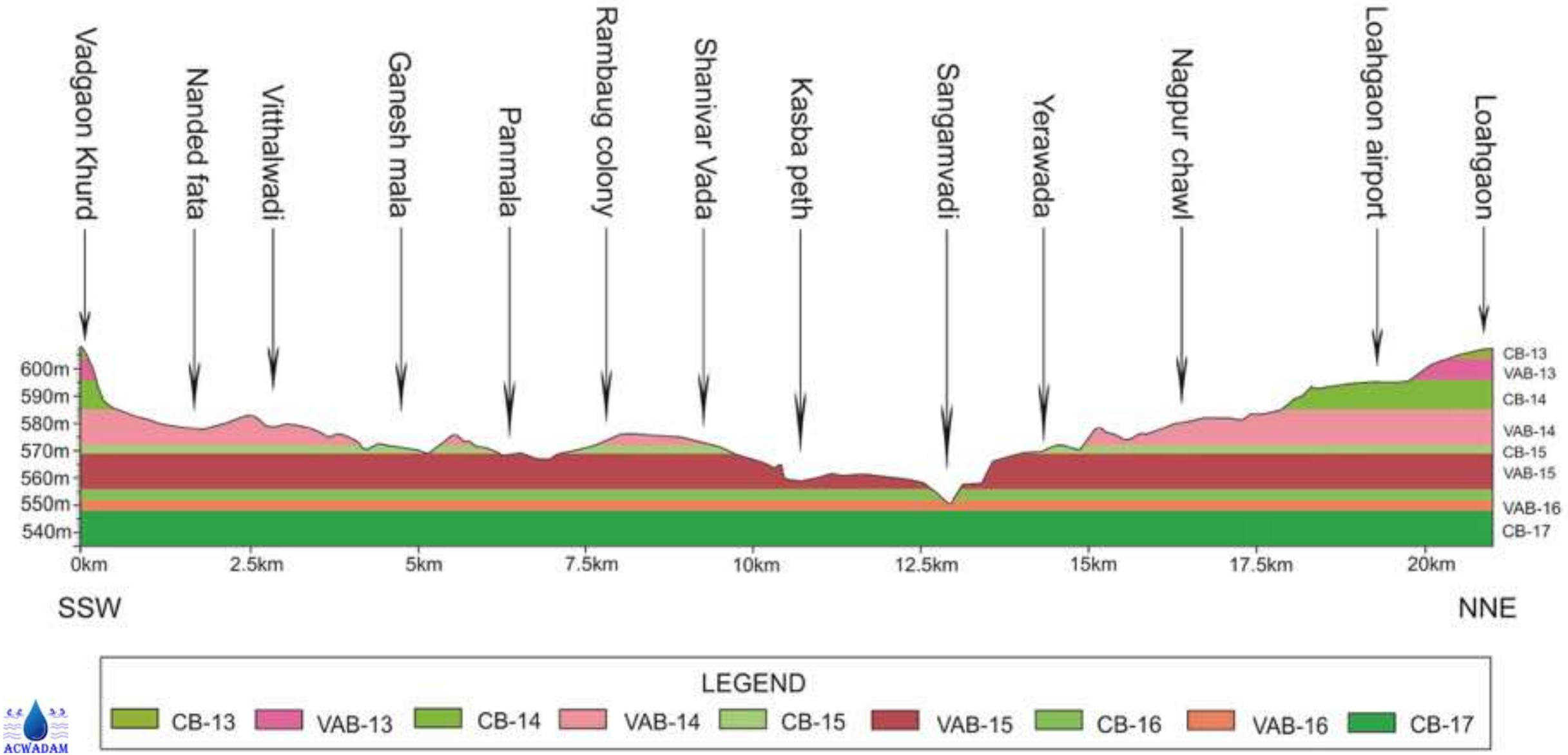

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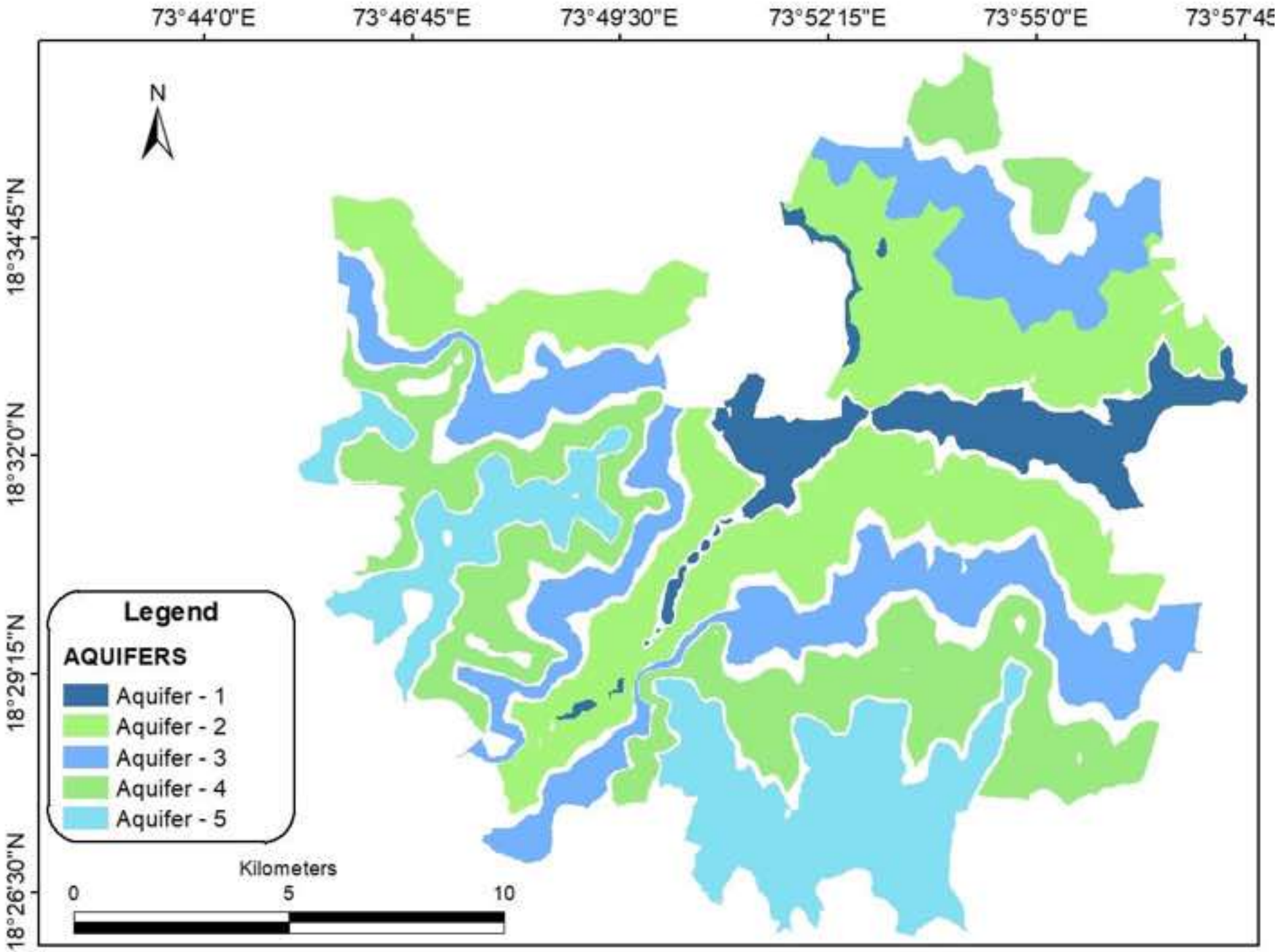
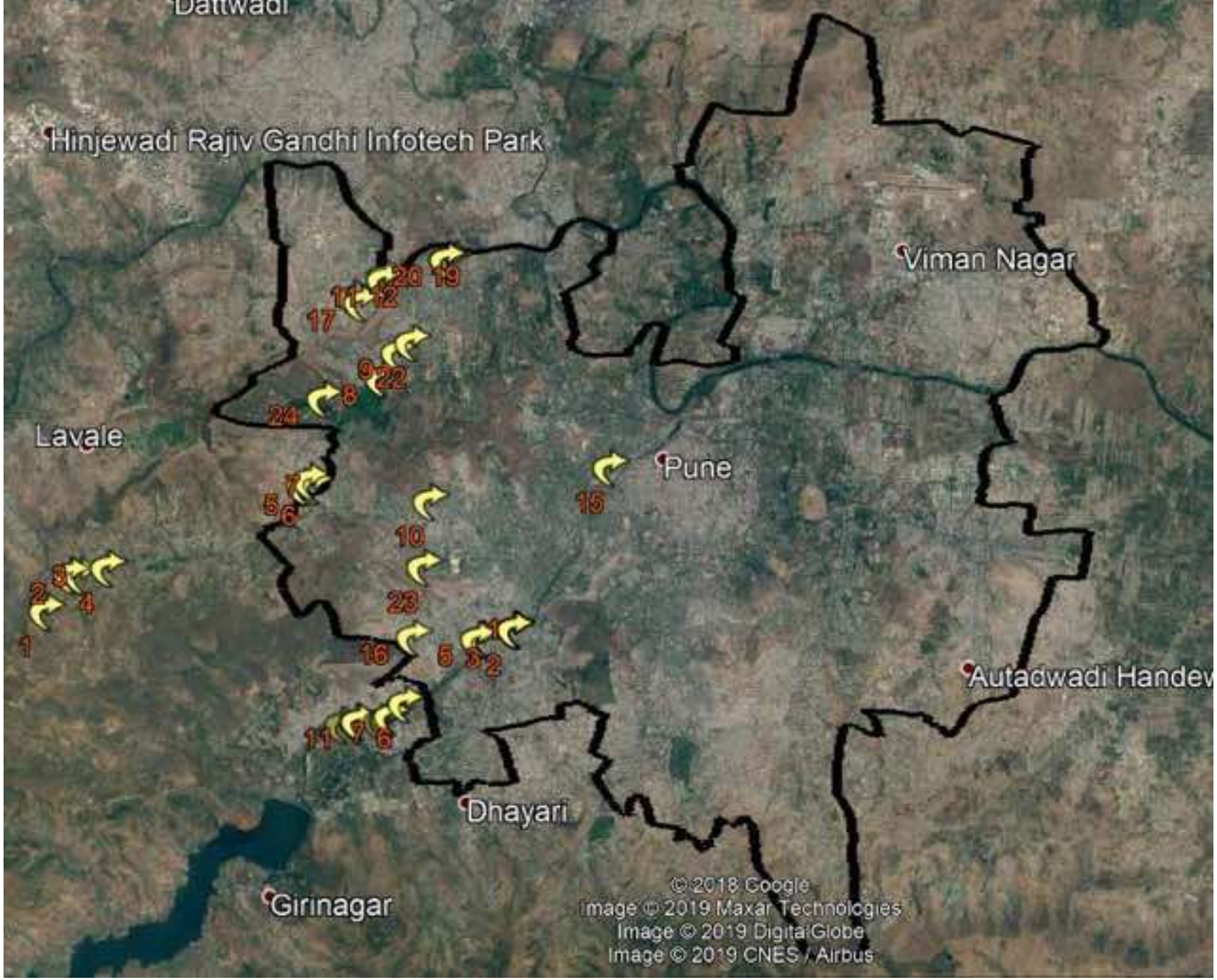
PUNE'S AQUIFER SYSTEM



ACWADAM


Dattwadi
Hinjewadi Rajiv Gandhi Infotech Park
Viman Nagar
Lavale
Pune
Autadwadi Handev
Dhayari
Girinagar
© 2018 Google
Image © 2019 Maxar Technologies
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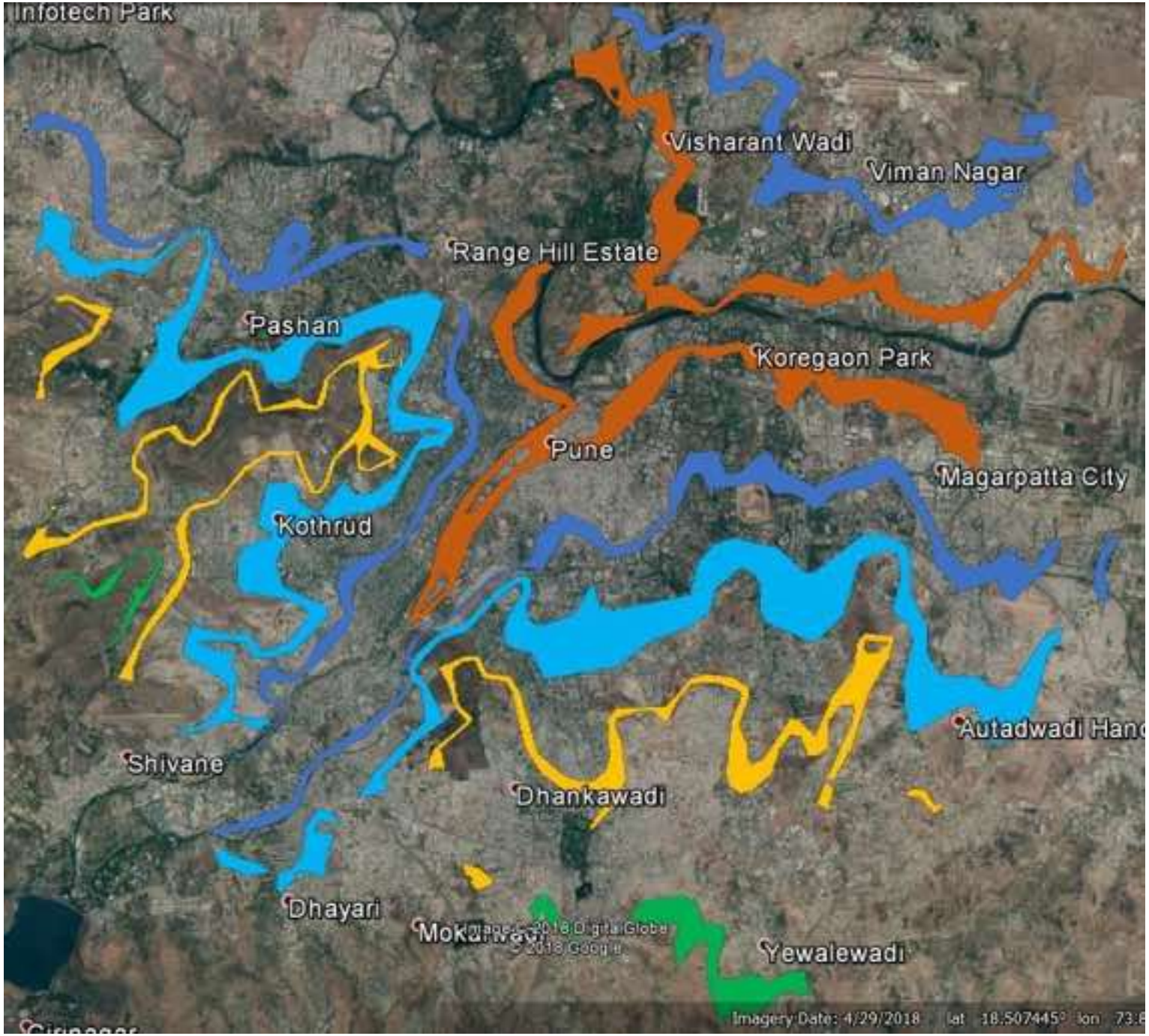
Broad recharge-conducive areas of Pune



- Aquifer - 1
- Aquifer - 2
- Aquifer - 3
- Aquifer - 4
- Aquifer - 5

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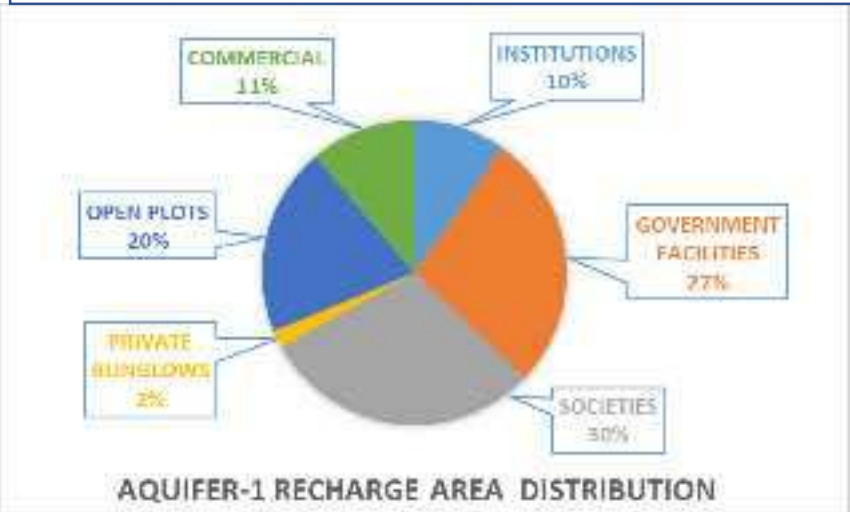
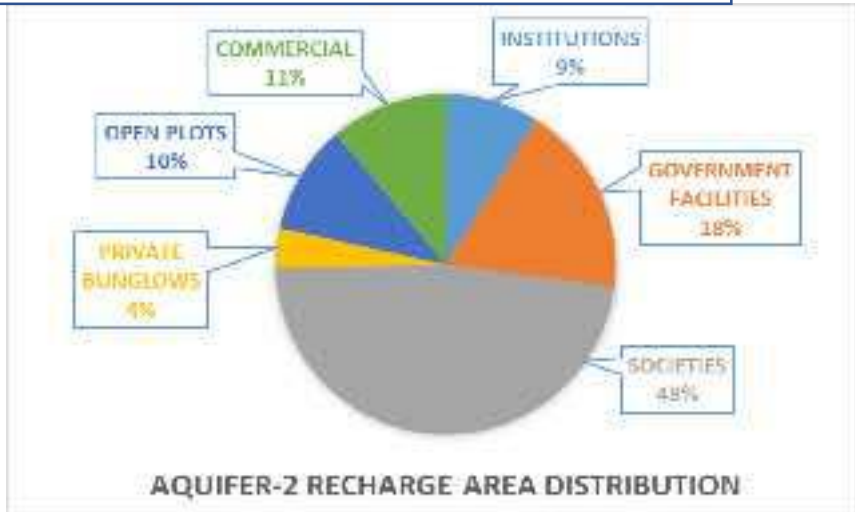
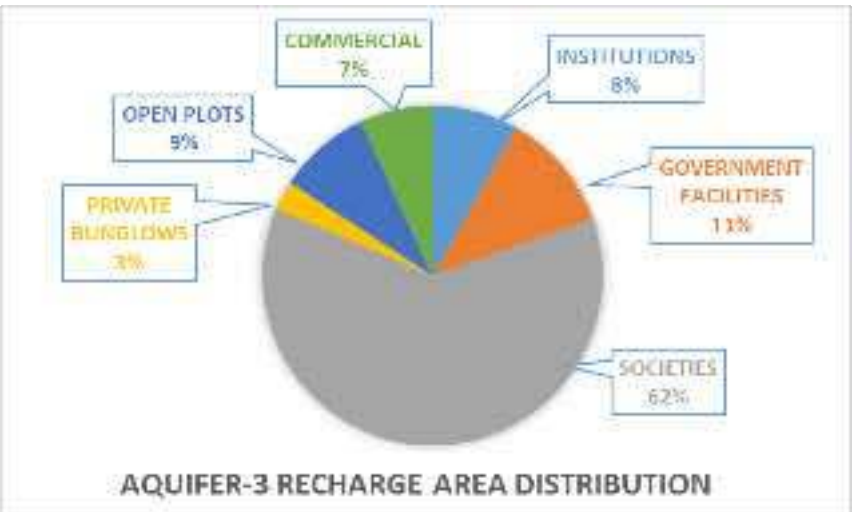
Aquifer-wise distribution of broad land-cover types



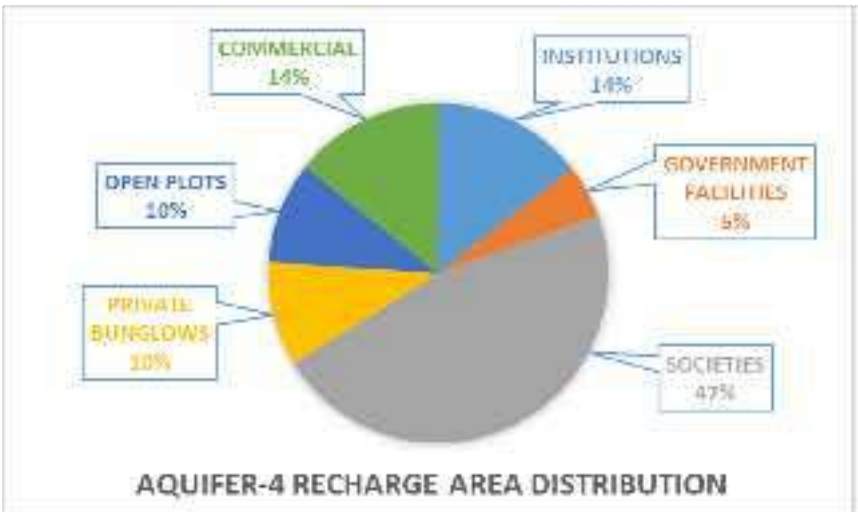
AQUIFER-1 RECHARGE AREA DISTRIBUTION



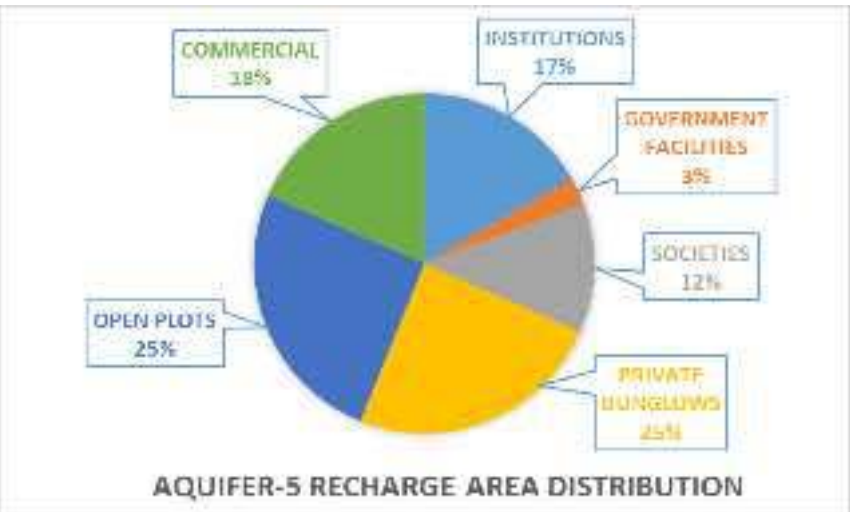
AQUIFER-2 RECHARGE AREA DISTRIBUTION



AQUIFER-3 RECHARGE AREA DISTRIBUTION



AQUIFER-4 RECHARGE AREA DISTRIBUTION



AQUIFER-5 RECHARGE AREA DISTRIBUTION

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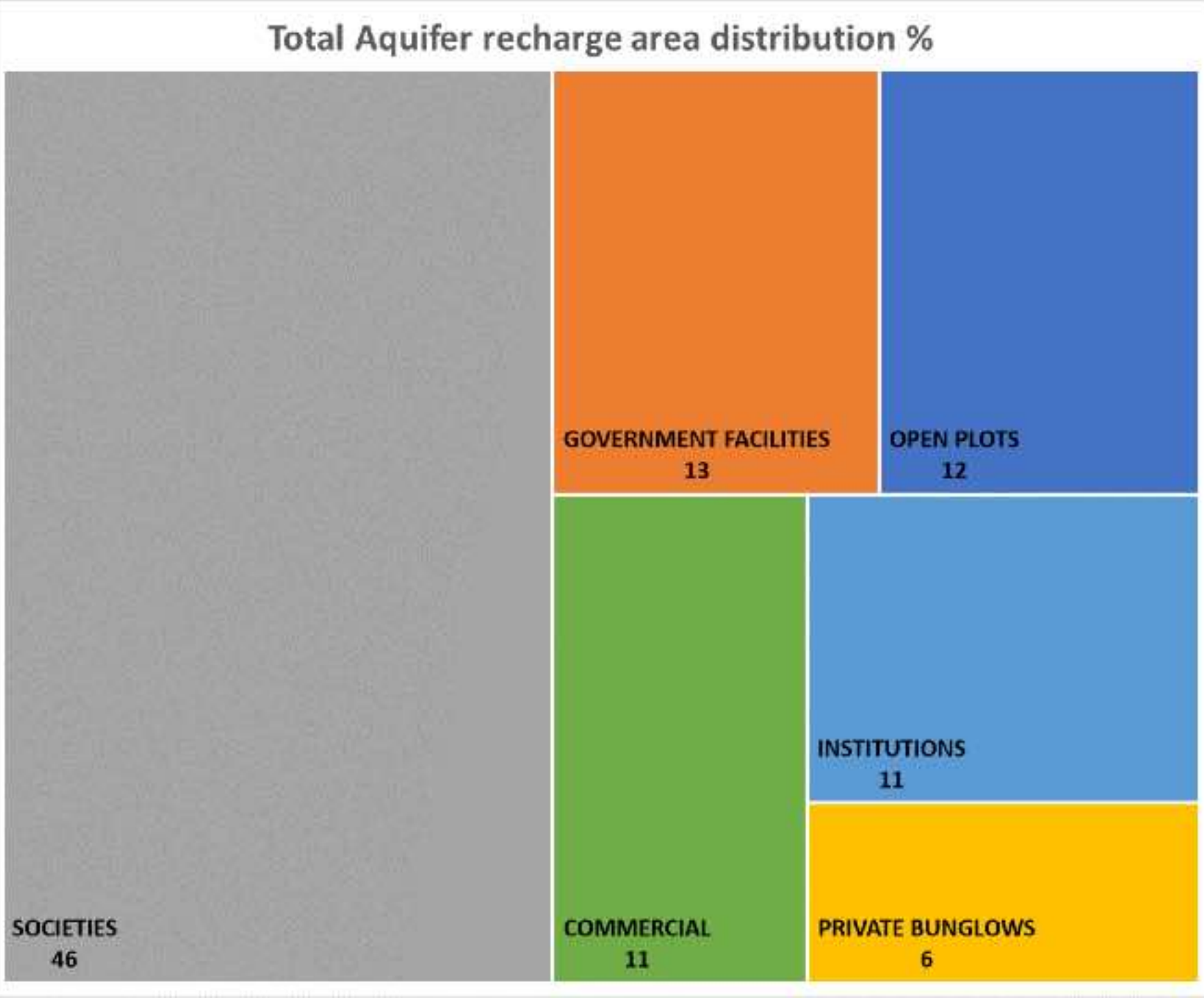

Recharge area matrix

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Wh

require co-
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action..
ESHIPS!!

EMS

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Urban Groundwater Management – COMPONENTS

Local resources

Community participation

Governance – public trust doctrine

- Phase 1: MAPPING
  - Mapping and Registration of Key Groundwater Sou
  - Participatory Aquifer Mapping, including a recharge p
  - Stakeholder database
- Phase 2: MANAGEMENT
  - Strategic recharge activities – concept of public recharge
  - Participatory Groundwater Management - efficiency, equity and sustainability
- Phase 3: GOVERNANCE
  - Regulatory framework
    - Securing Groundwater from impacts of Sanitation and Waste Disposal
    - Protection of Recharge Zones
  - Institutions that are organised around Urban Governance structures – mohallas, wards etc.

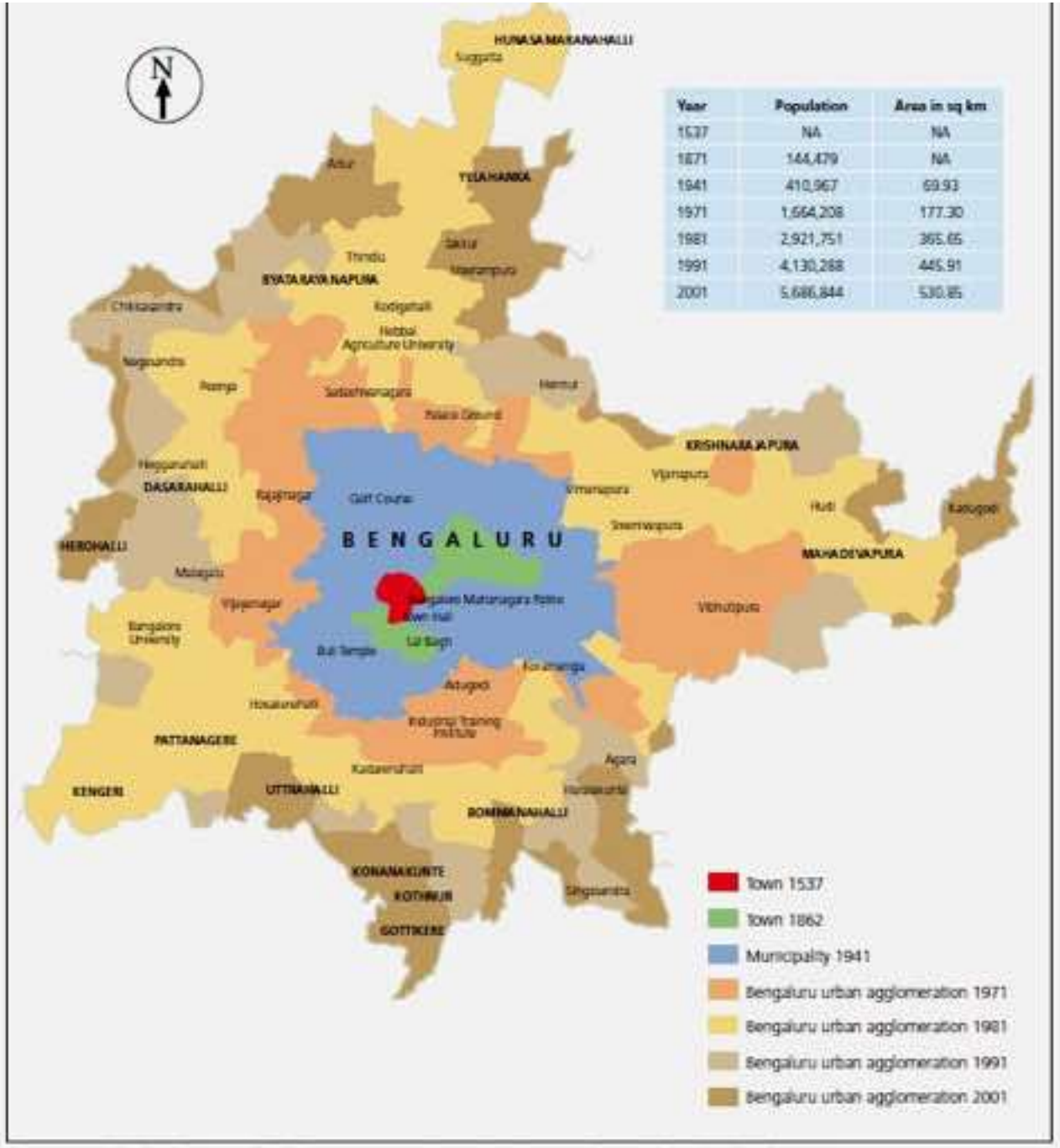
ACWADAM

Advanced Center for Water Resources Development and Management (ACWADAM)

acwadam@gmail.com
www.acwadam.org

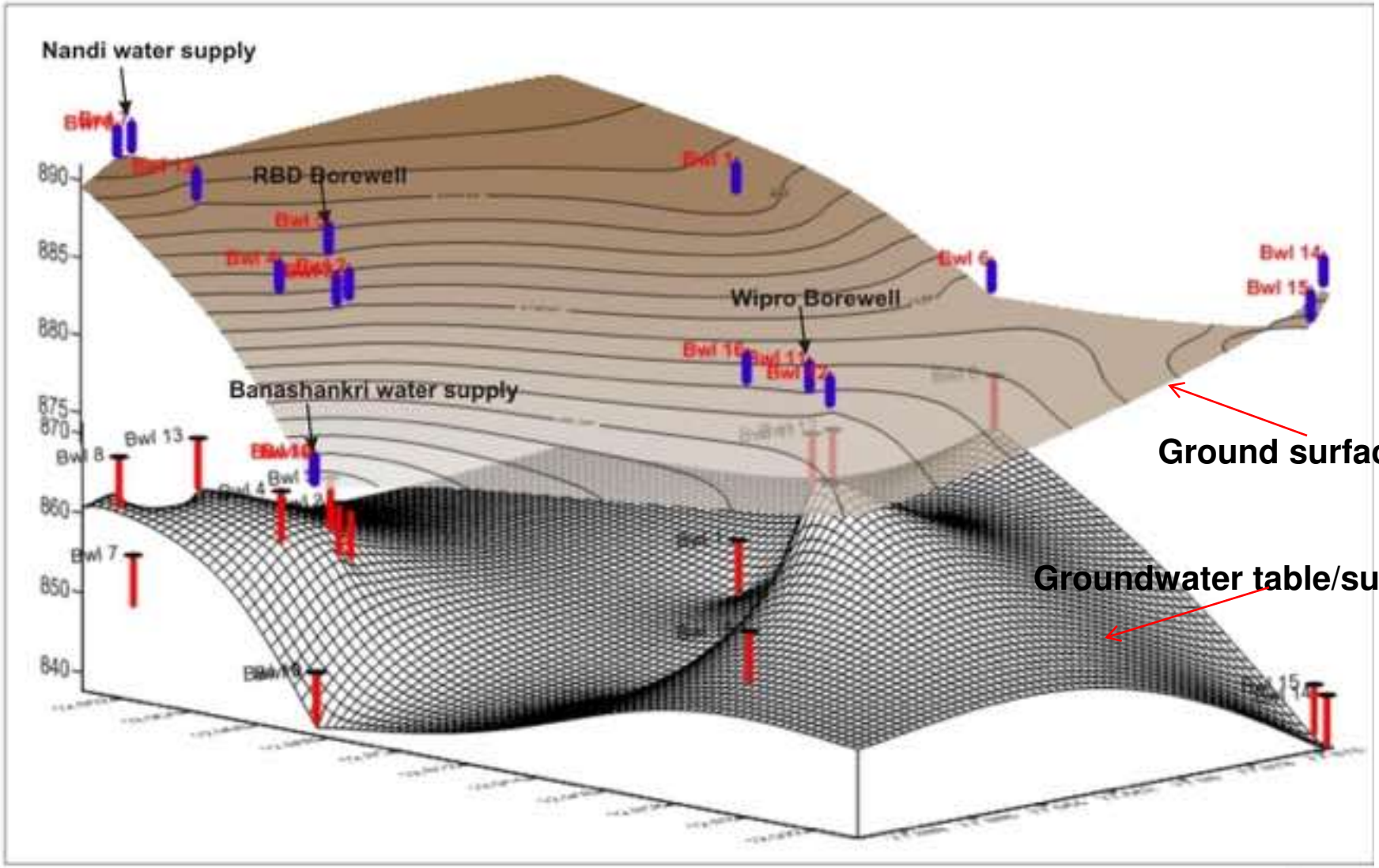
Growth of Bengaluru (NOT TO SCALE)

NARAIN, 2012

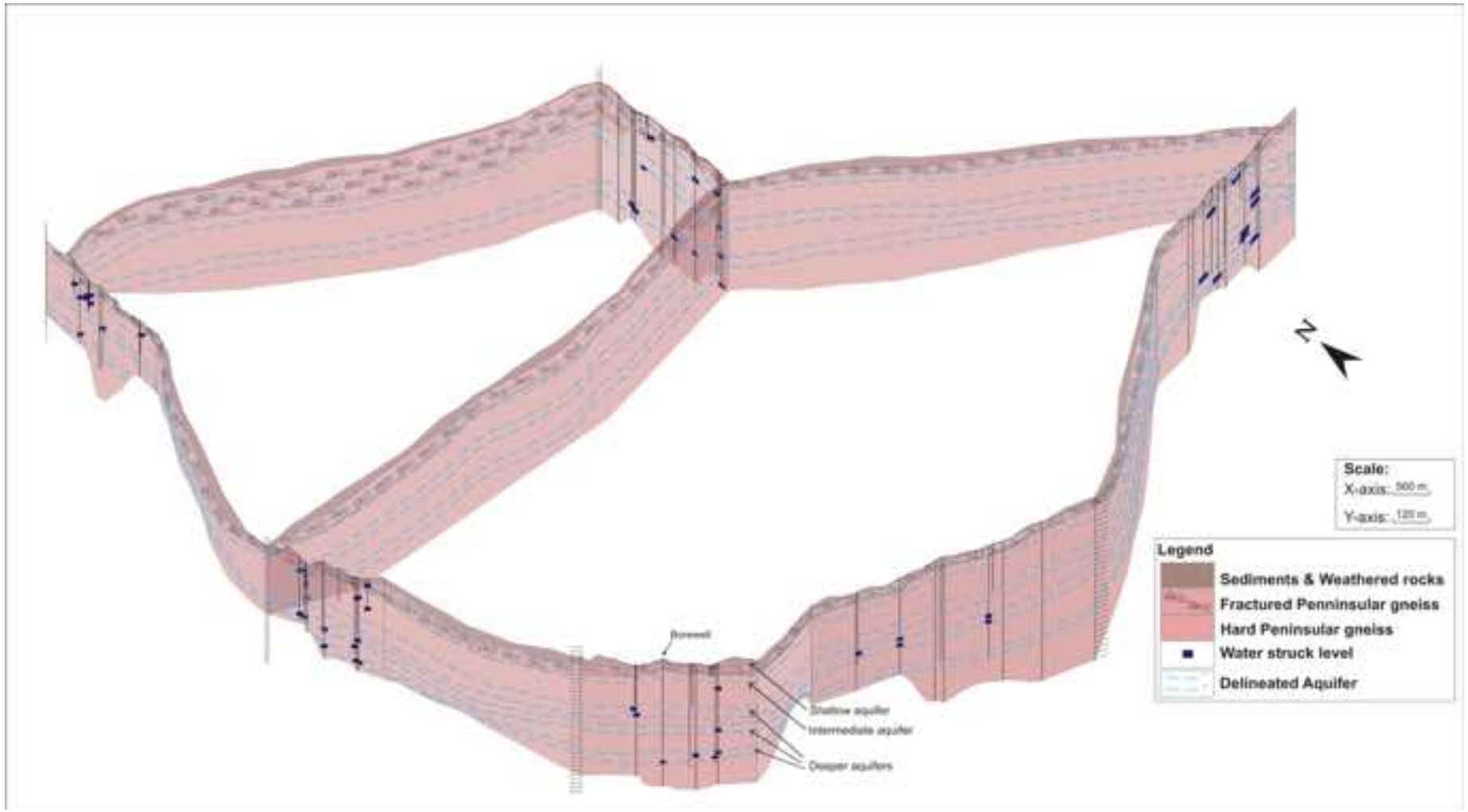


Source: Anon 2006, *City Development Plan for Bangalore*, Jawaharlal Nehru National Urban Renewal Mission (JNNURM), Bengaluru

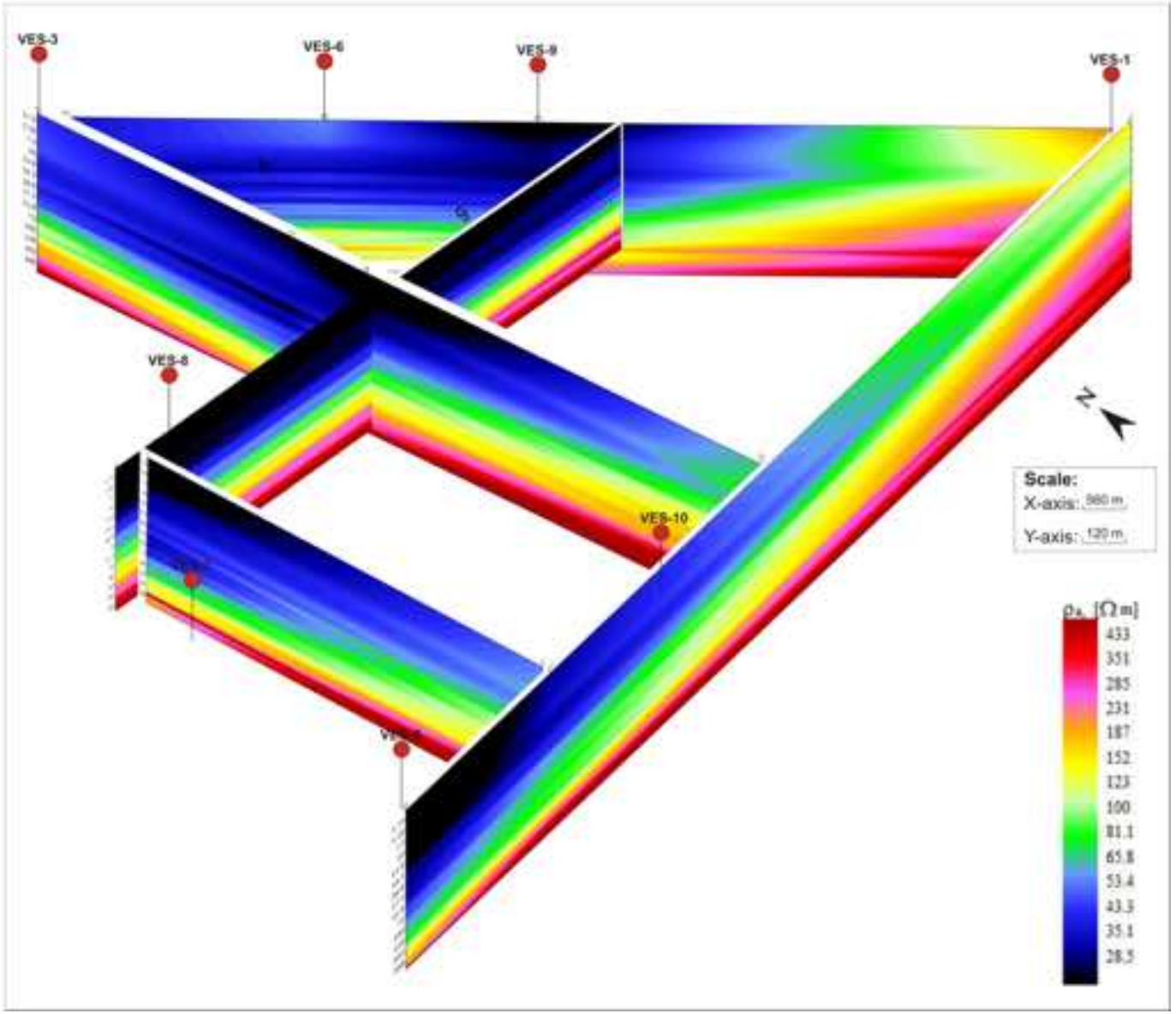
Wipro Bengaluru campus

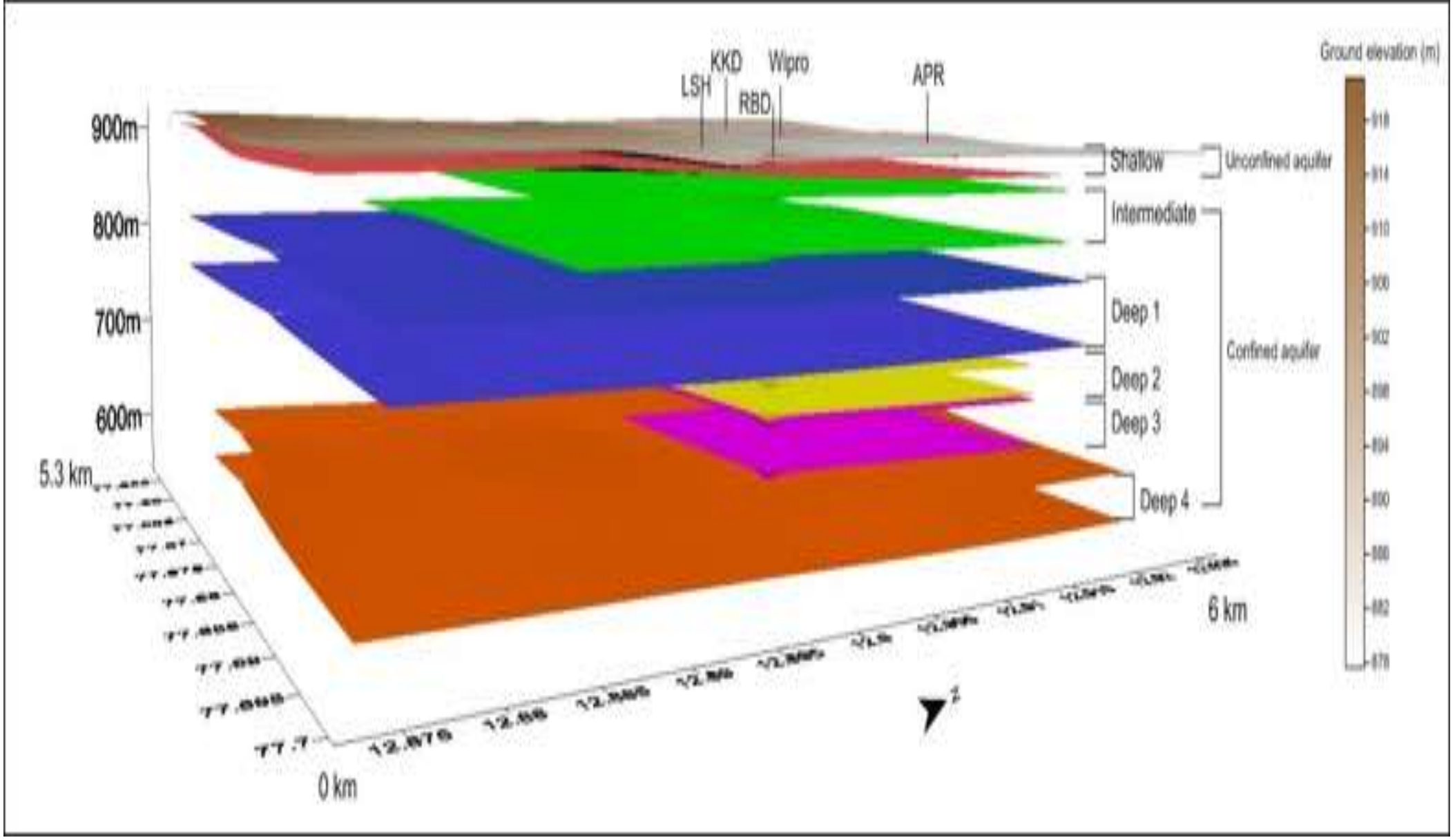


Fence diagram of watershed drawn from borehole logs based on narrative information by various stakeholders…



Fence diagram of watershed drawn from VES data based sections – ratification of social narratives





SARJAPURA AQUIFER LAYOUT-3D

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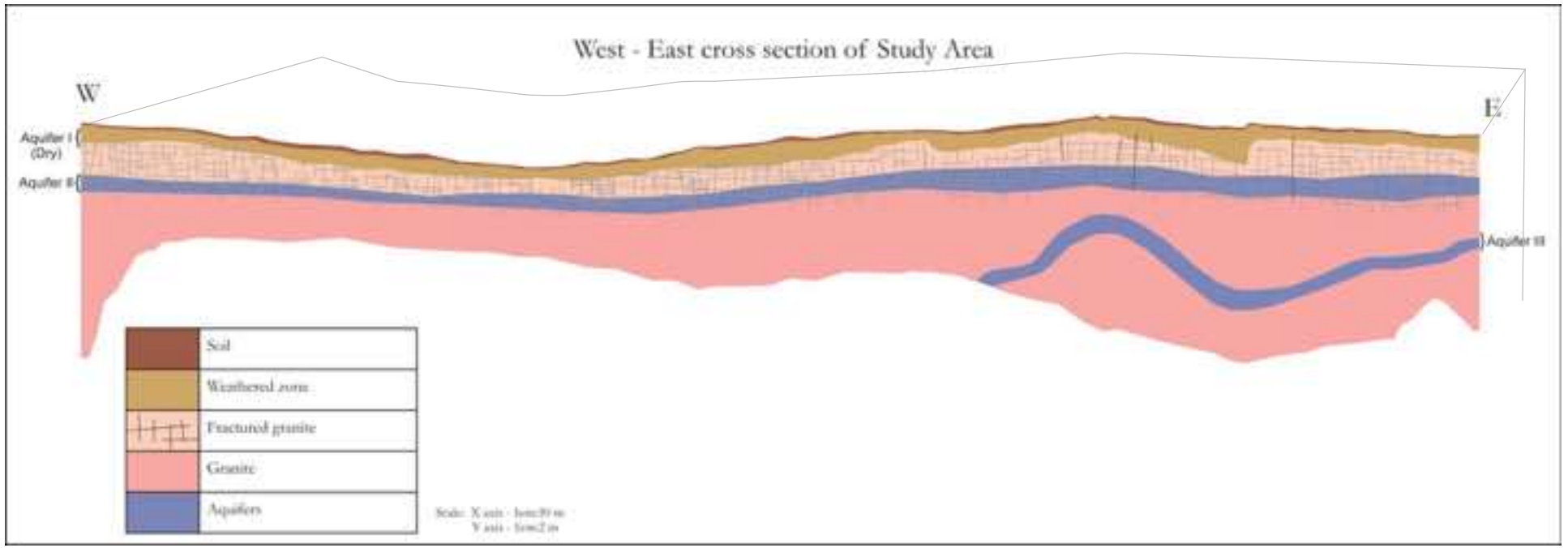
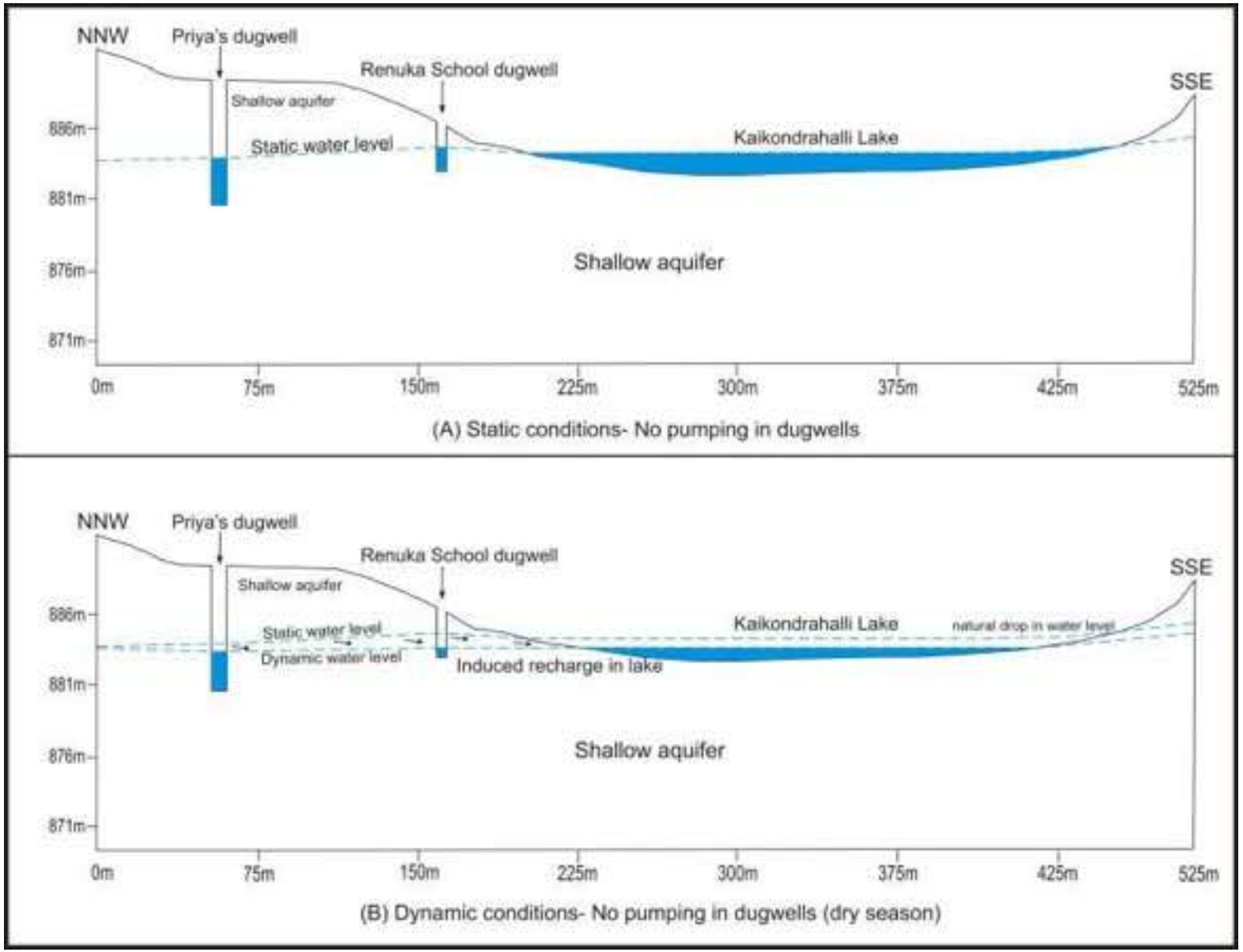
Aquifer mapping: Output

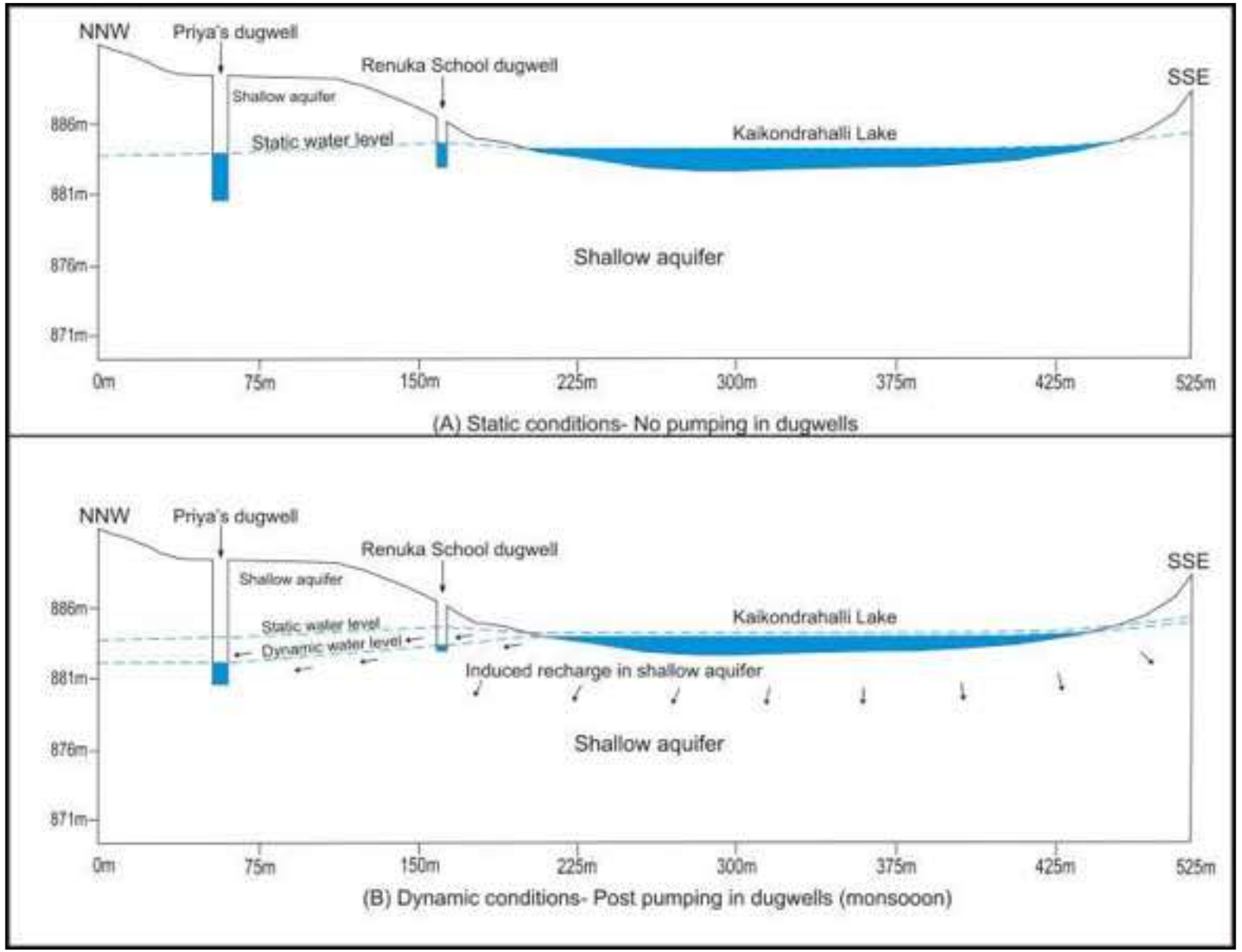


Output from Excel polished in corel

Lake-groundwater interaction: Pre-monsoon

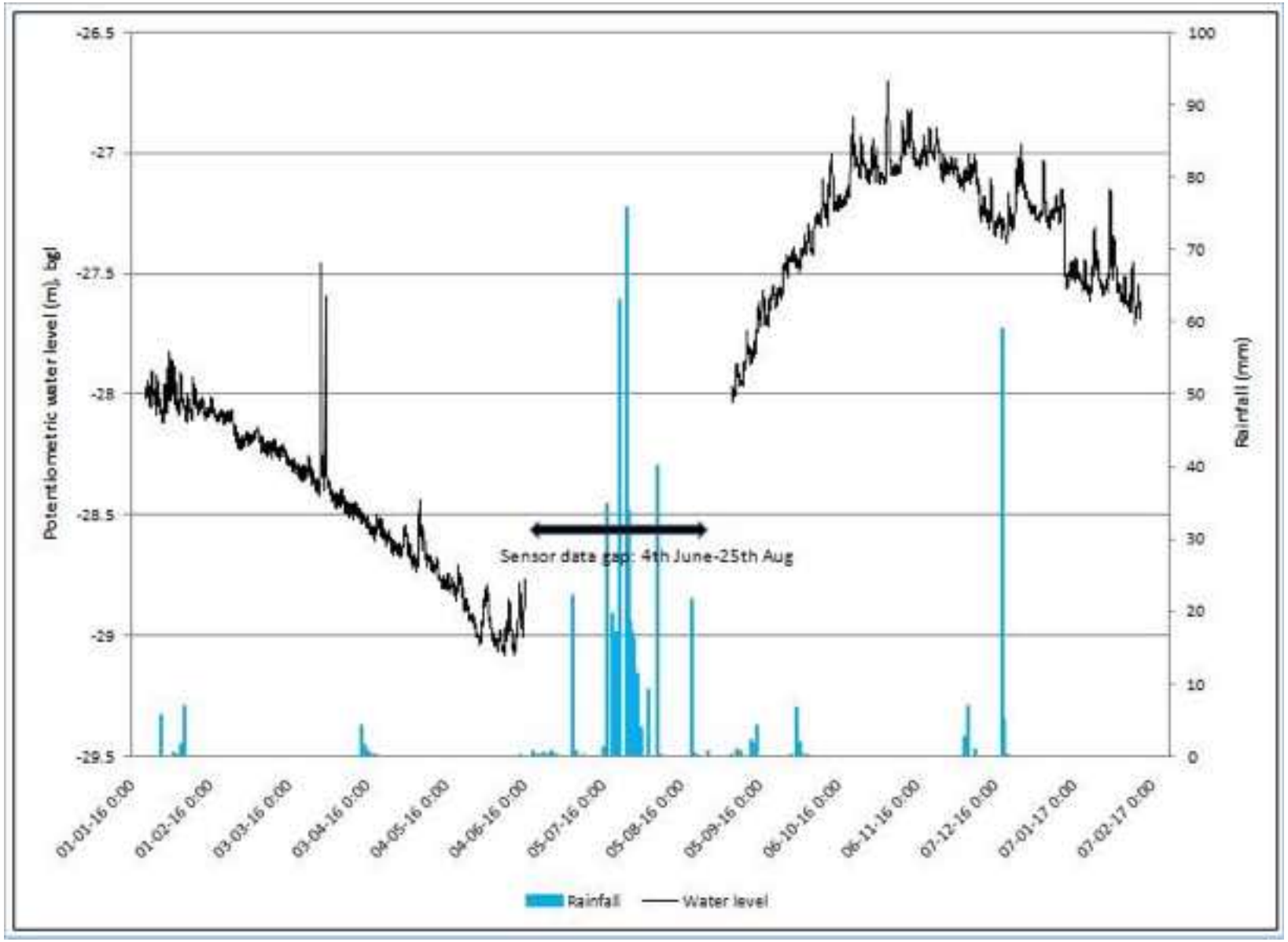


Lake-groundwater interaction: Post-monsoon



RECHARGE WELLS IN RBD

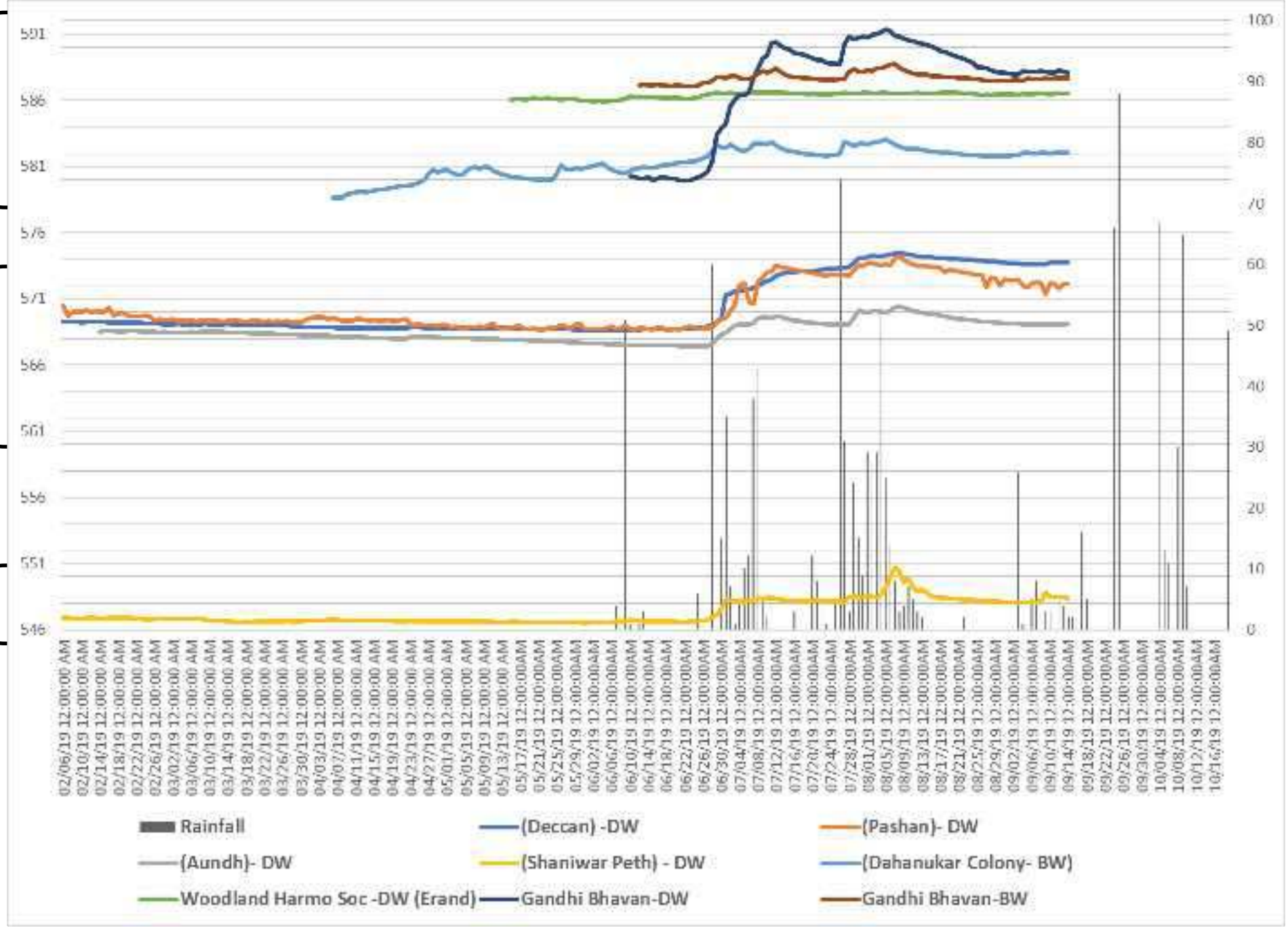
1 year water level data from a borewell tapping Deep aquifer



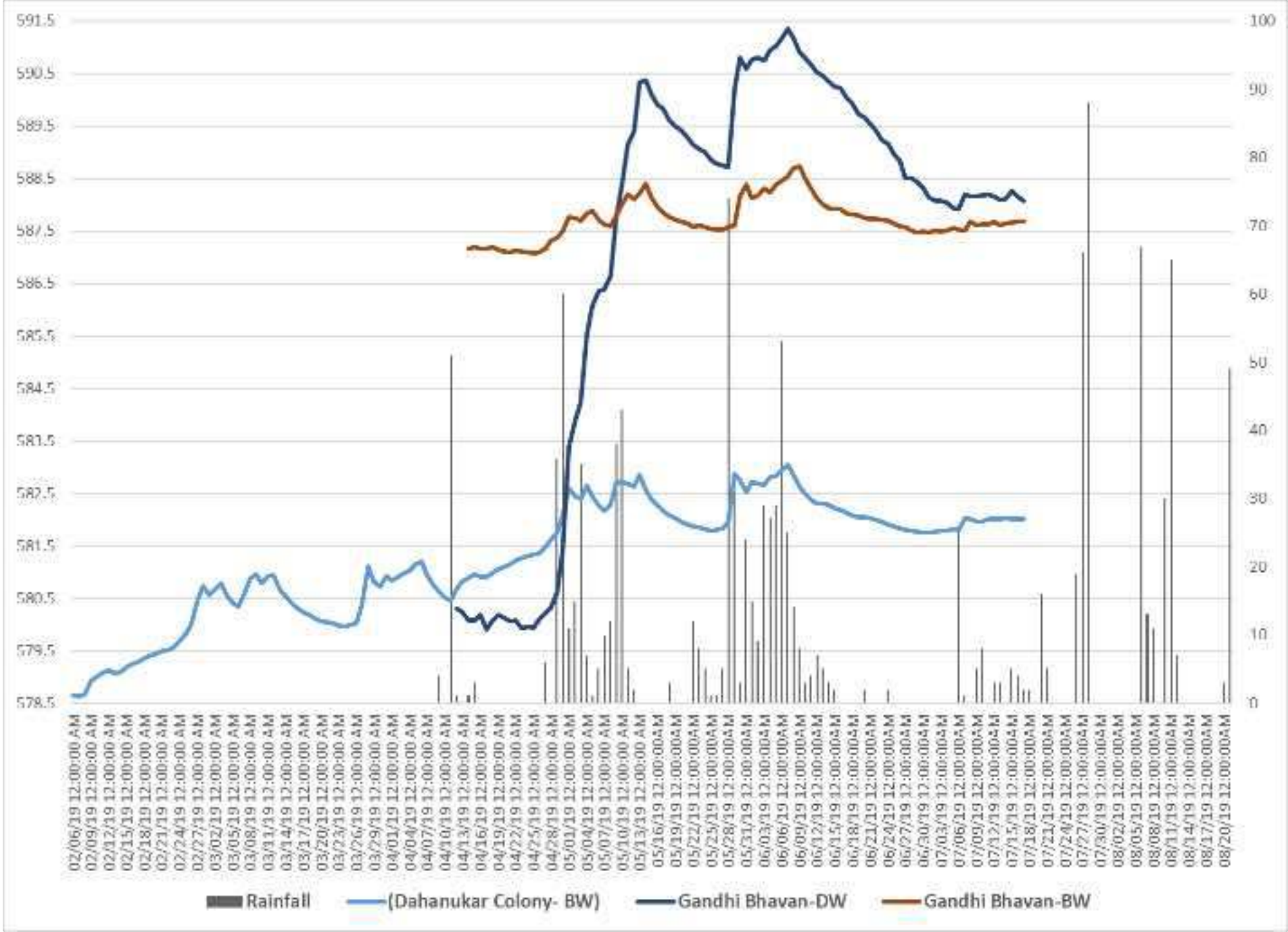
AQUIFER - 3

AQUIFER - 2

AQUIFER - 1



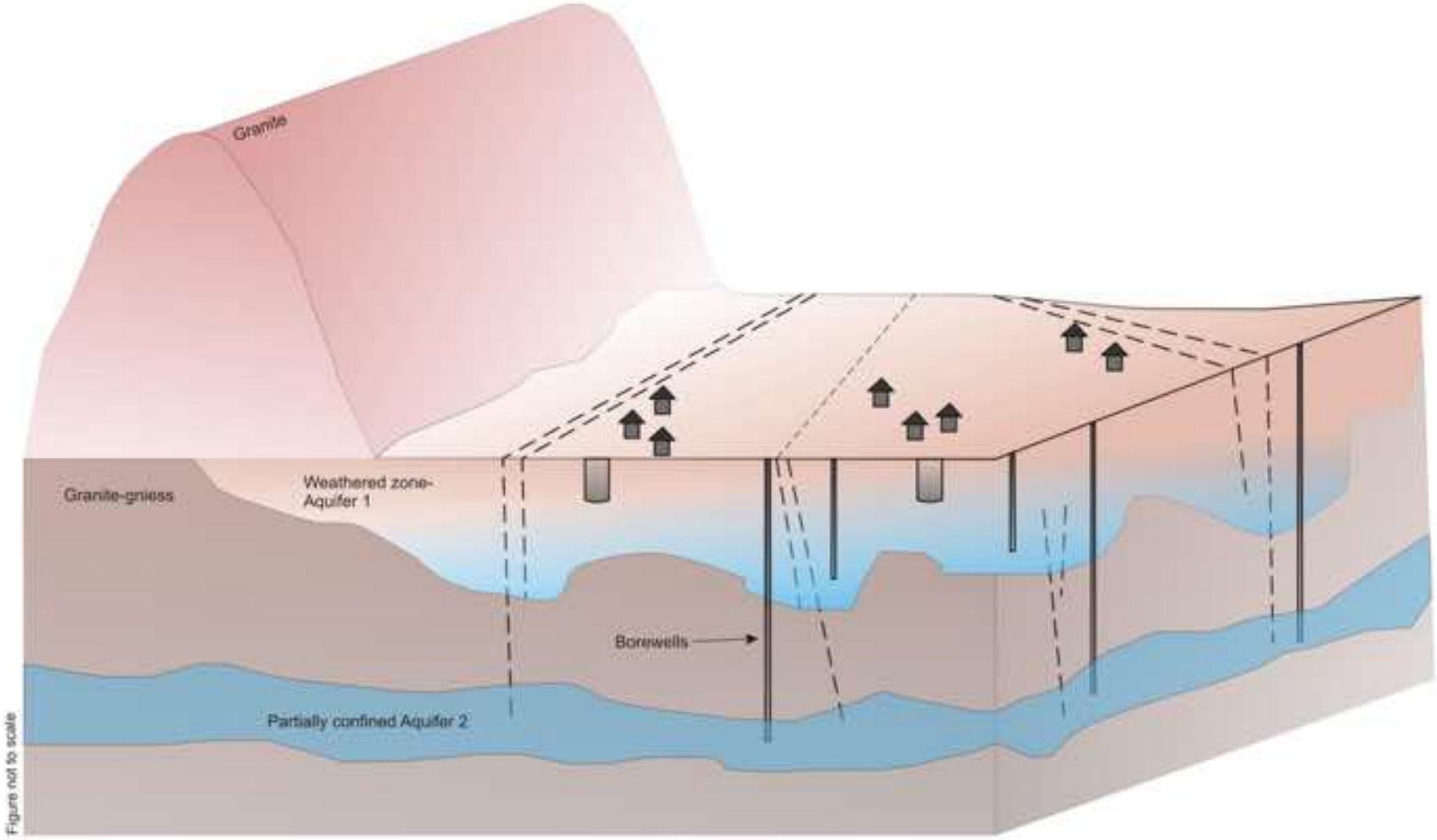
WATER LEVEL FLUCTUATION AND CONFINED, UNCONFINED DYNAMICS IN AQUIFER - 3



DUG WELL VERSUS BOREWELL WATER LEVEL FLUCTUATION IN AQUIFER - 3

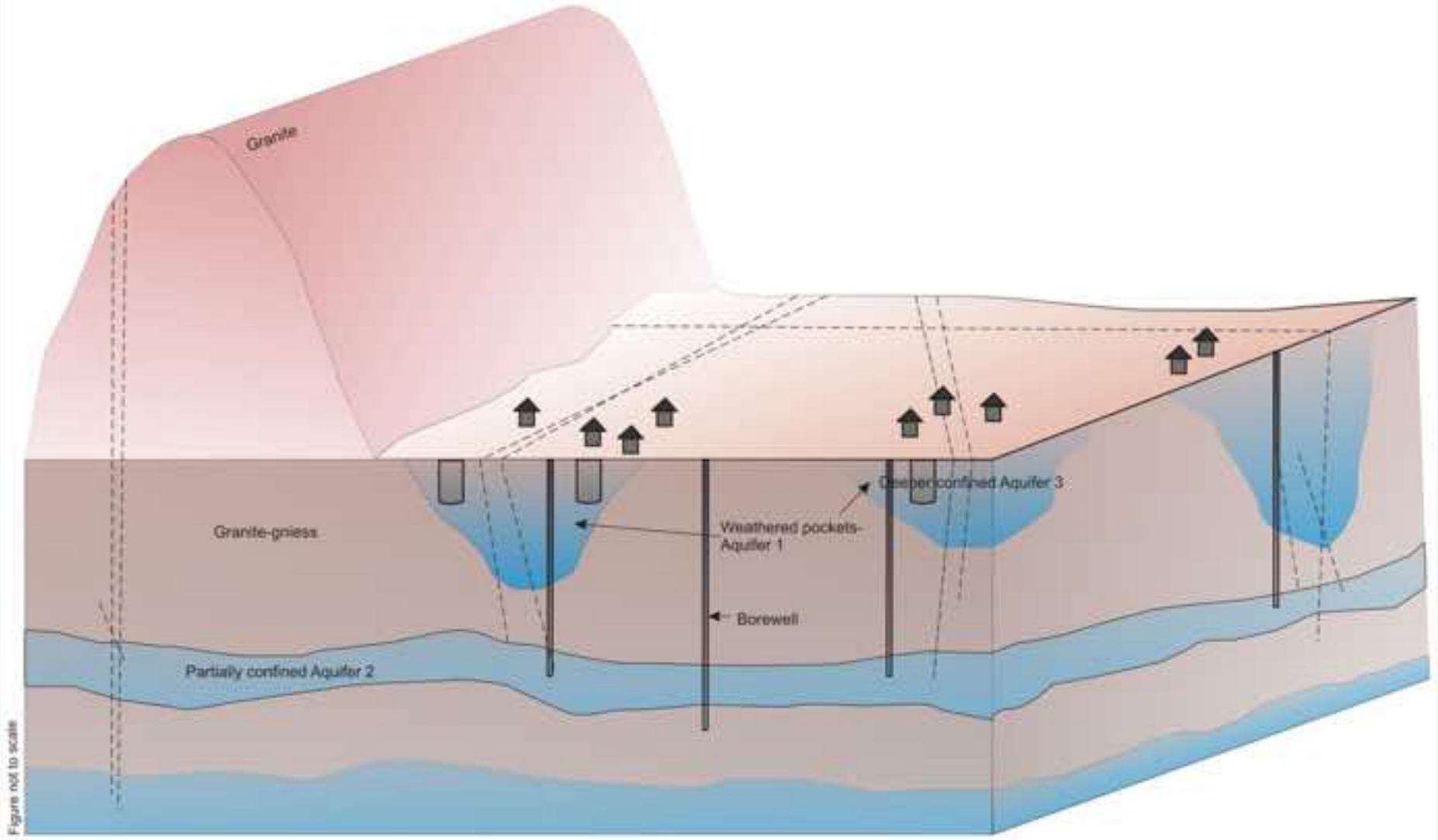
Aquifer patterns: Case 1

South India



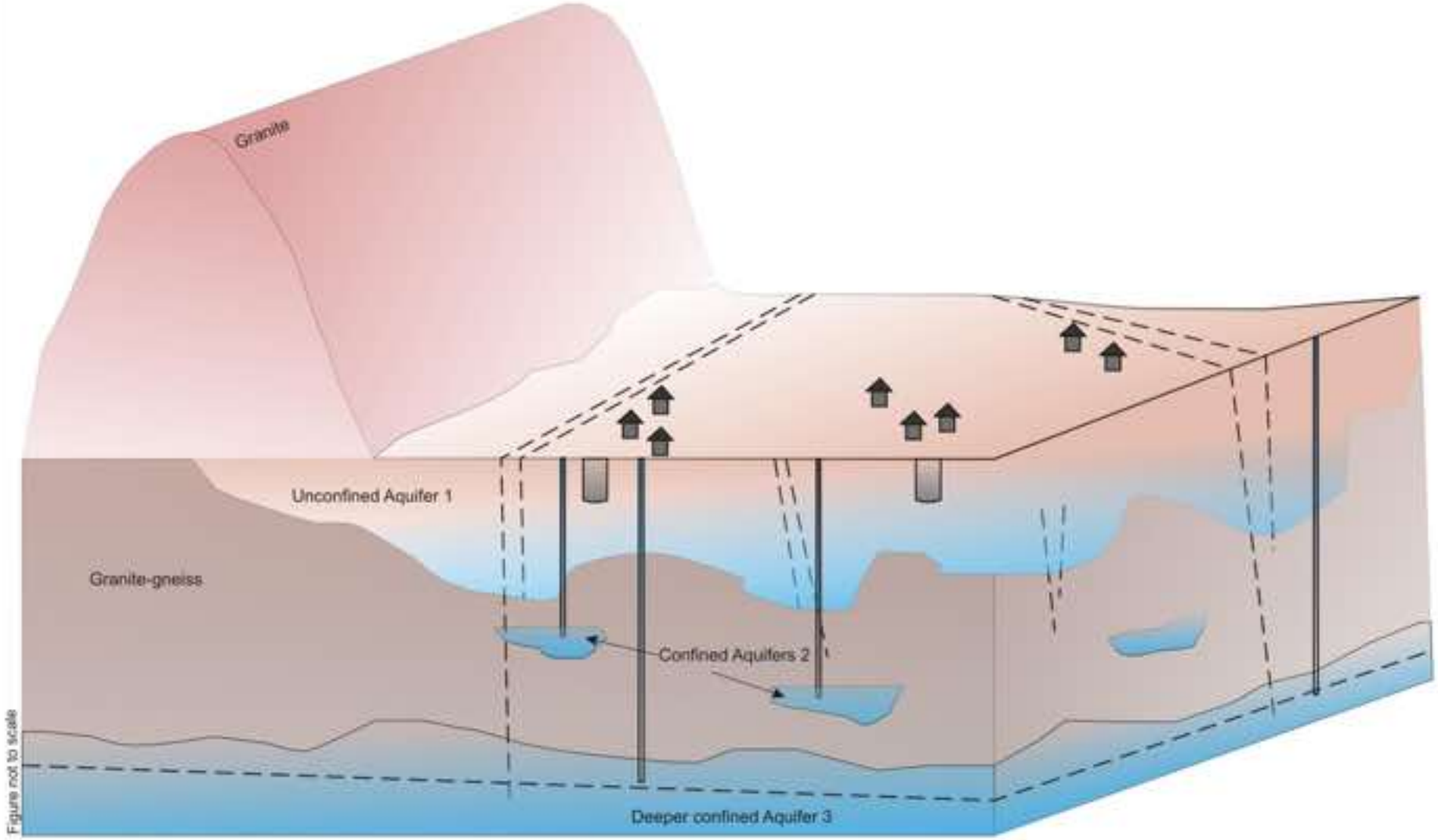
Aquifer patterns: Case 2

South India

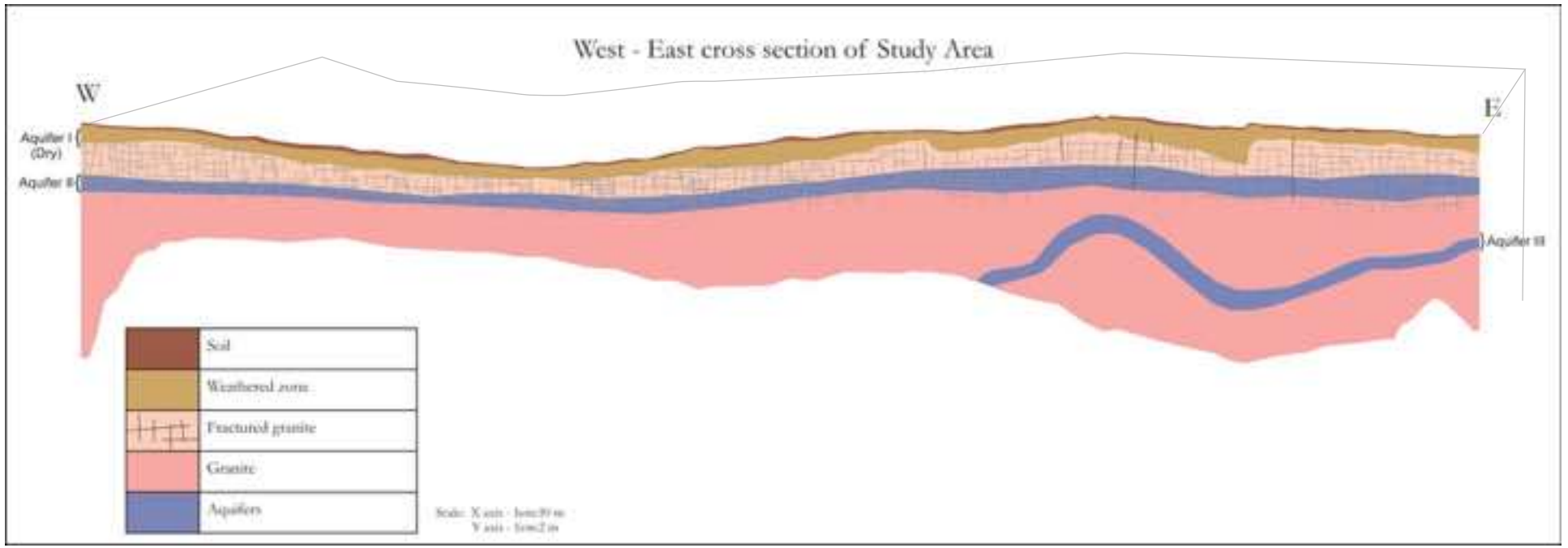


Aquifer patterns: Case 3

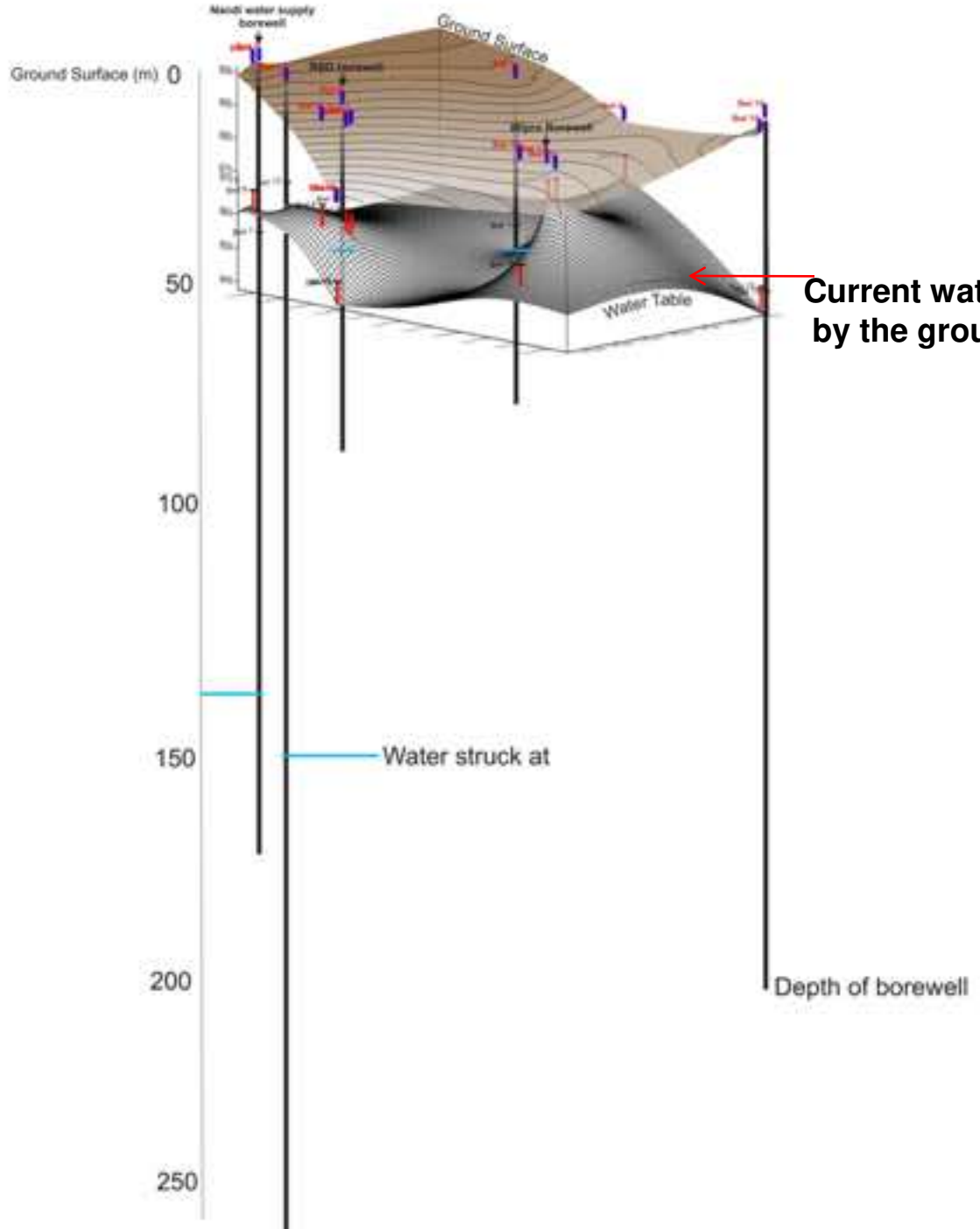
South India



Aquifer mapping: Output

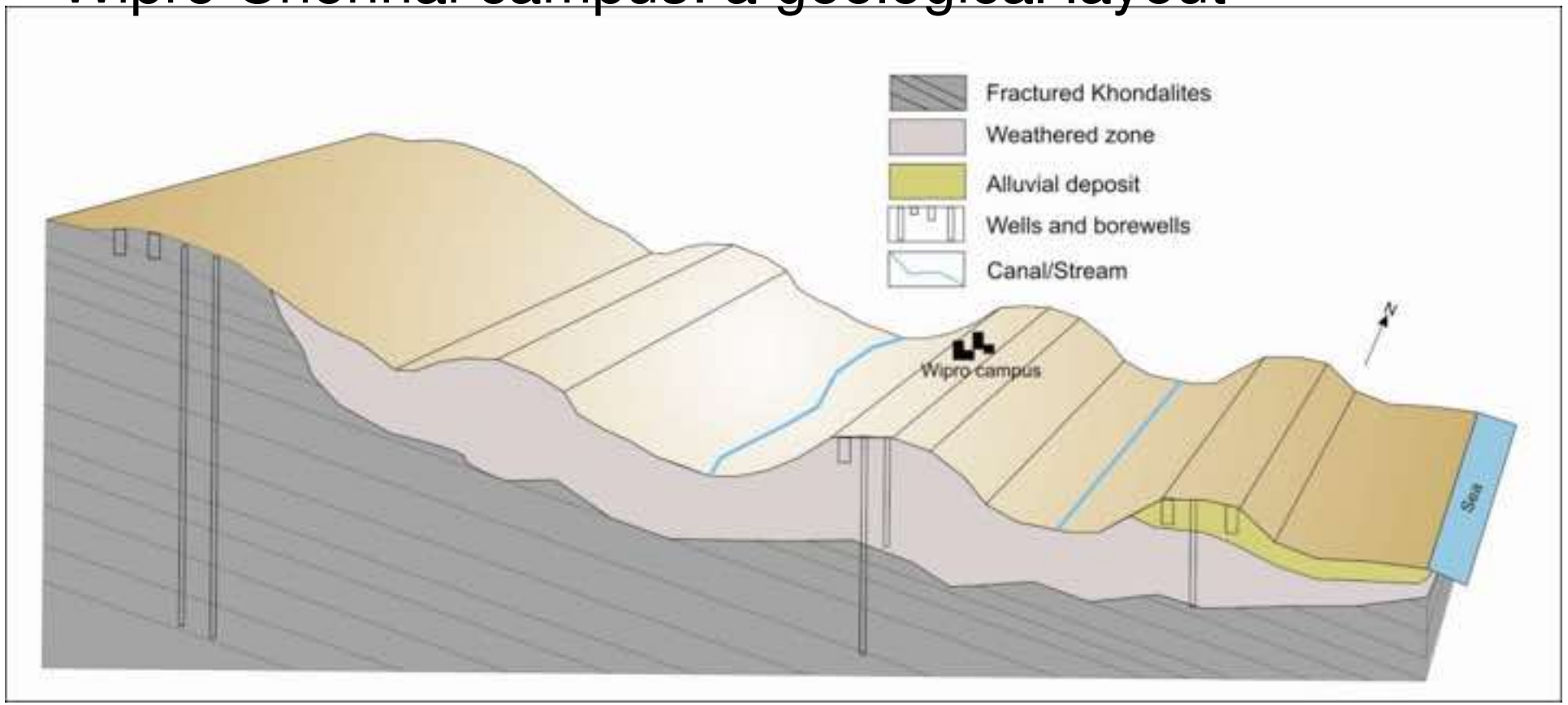


Output from Excel polished in corel

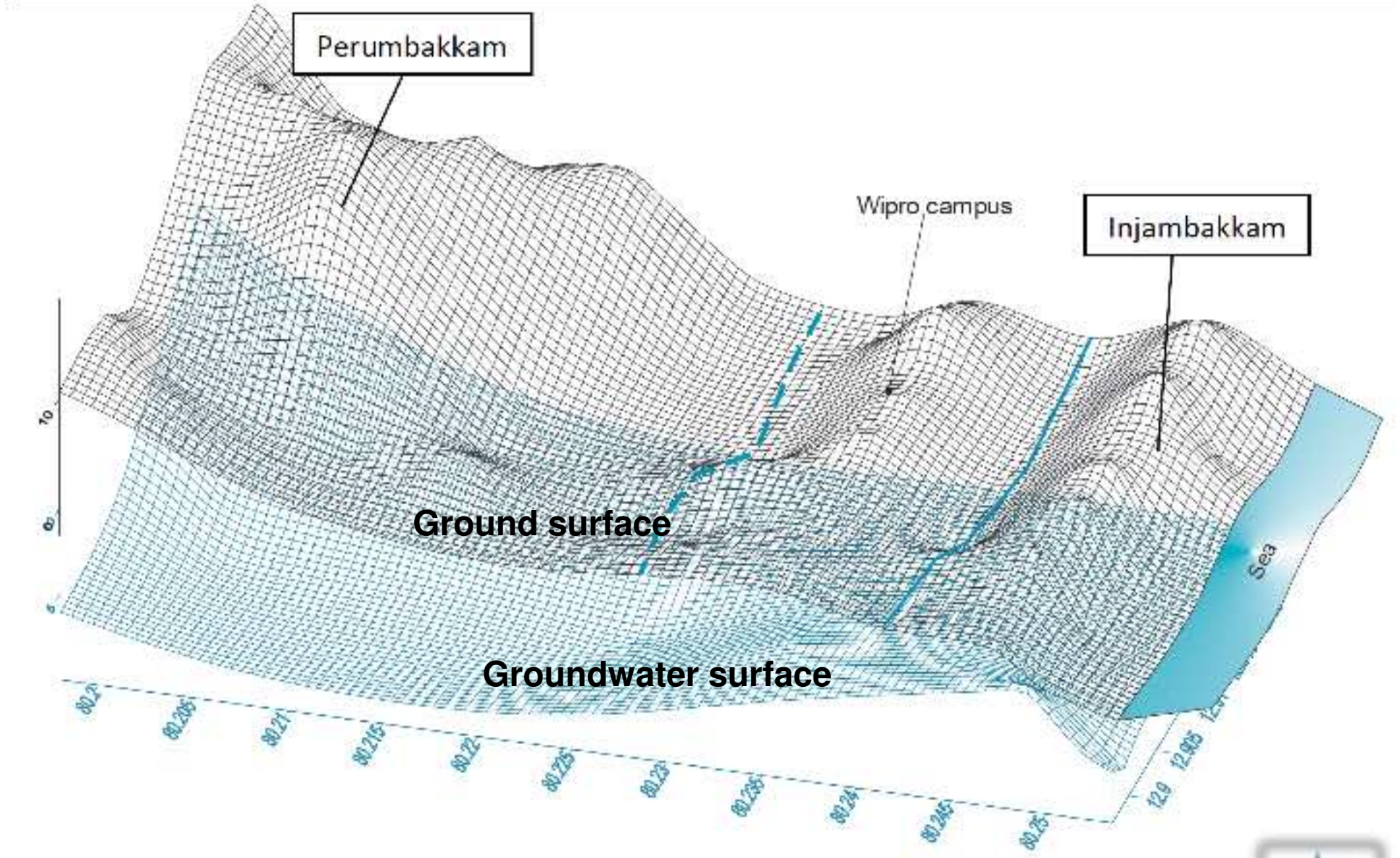


Current water level represented by the groundwater surface

Wipro Chennai campus: a geological layout

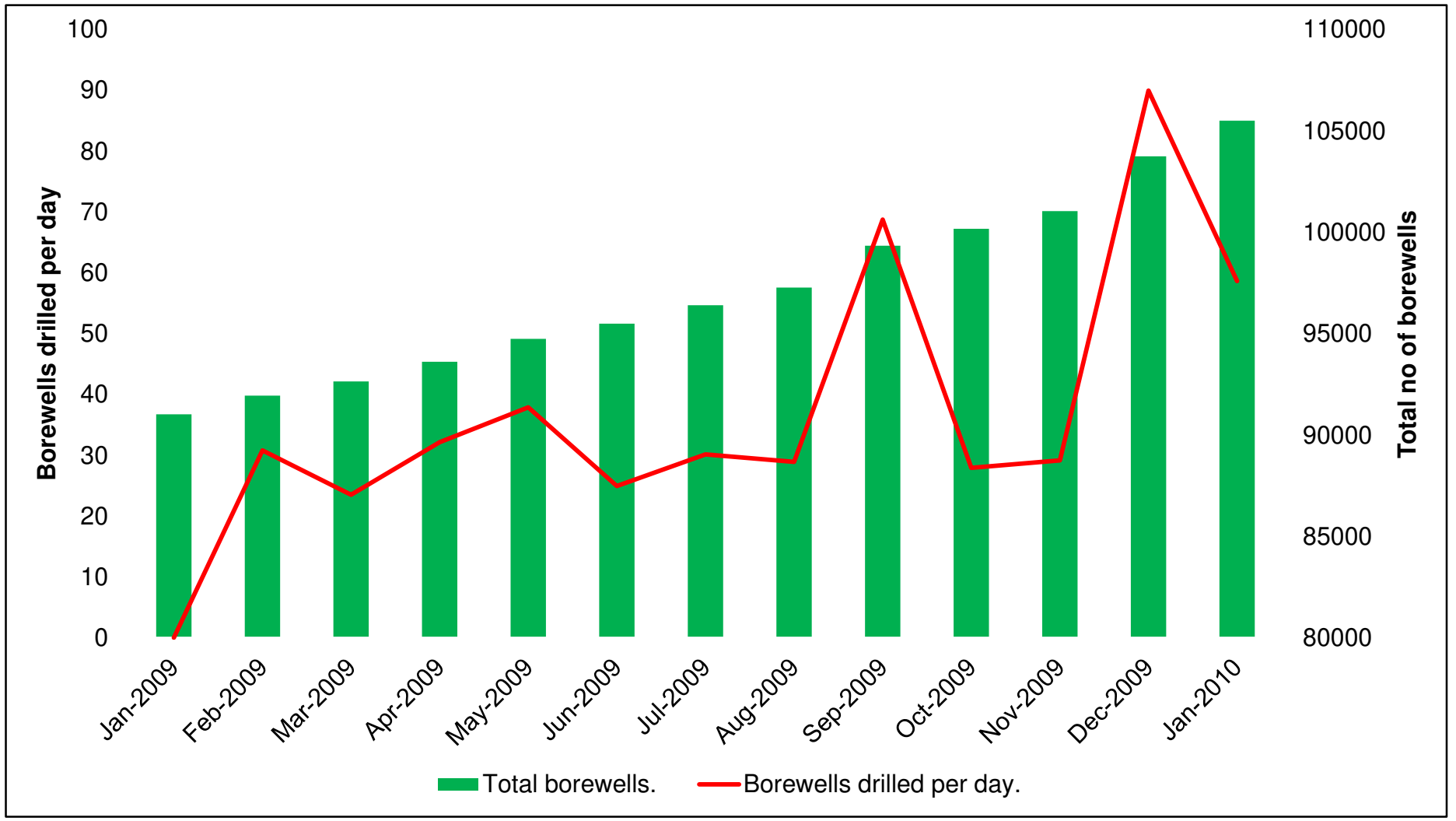


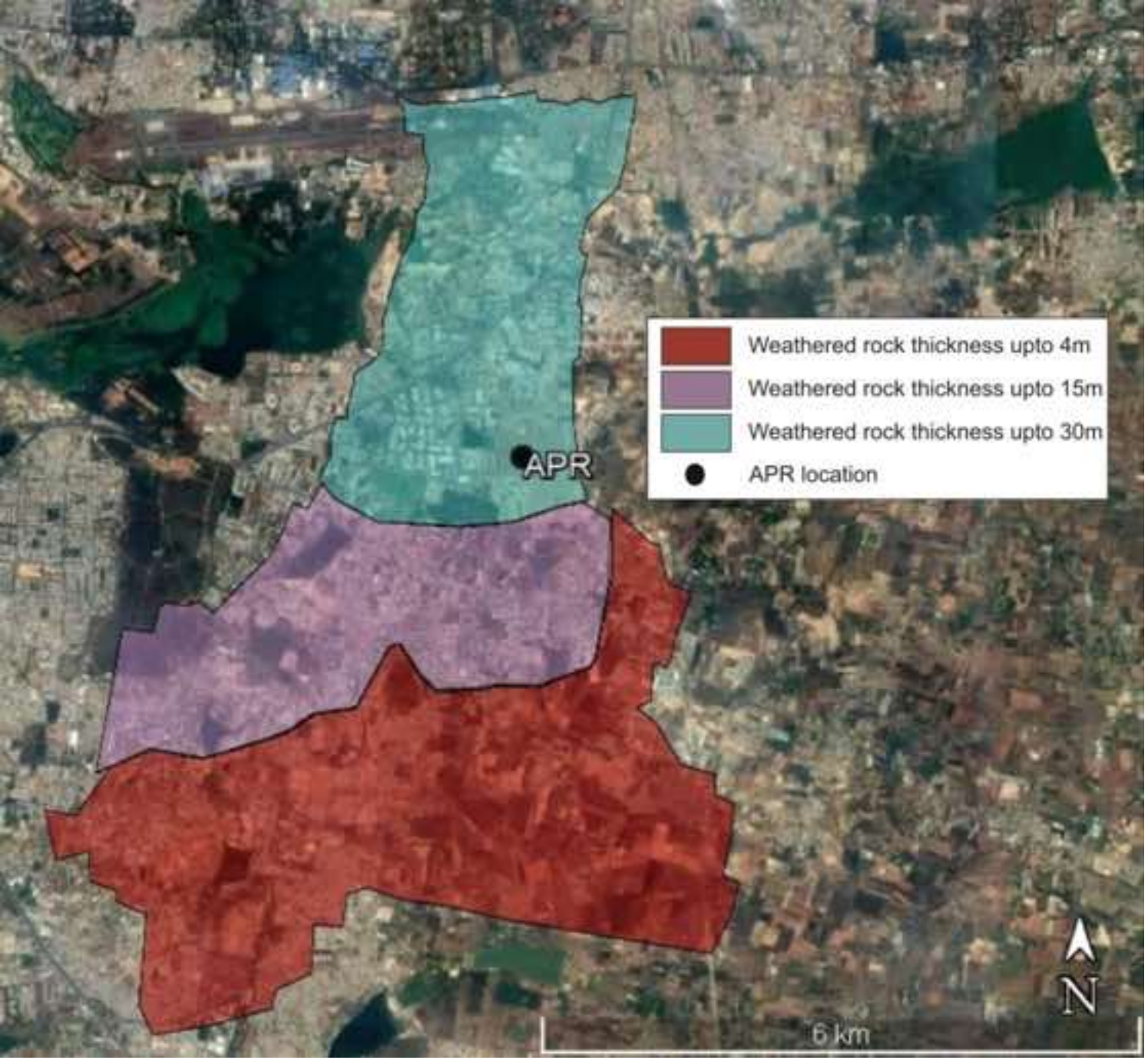
Wipro Chennai campus



Borewell statistics

- 1 out of 5 houses has borewell + municipal connection
- Approx. 320 BW per km^2, avg 40 new BW drilled/day (S. Vishwanath-Biome)
- 1.75 lakh borewells as of 2013 (BWSSB-*unofficially*)



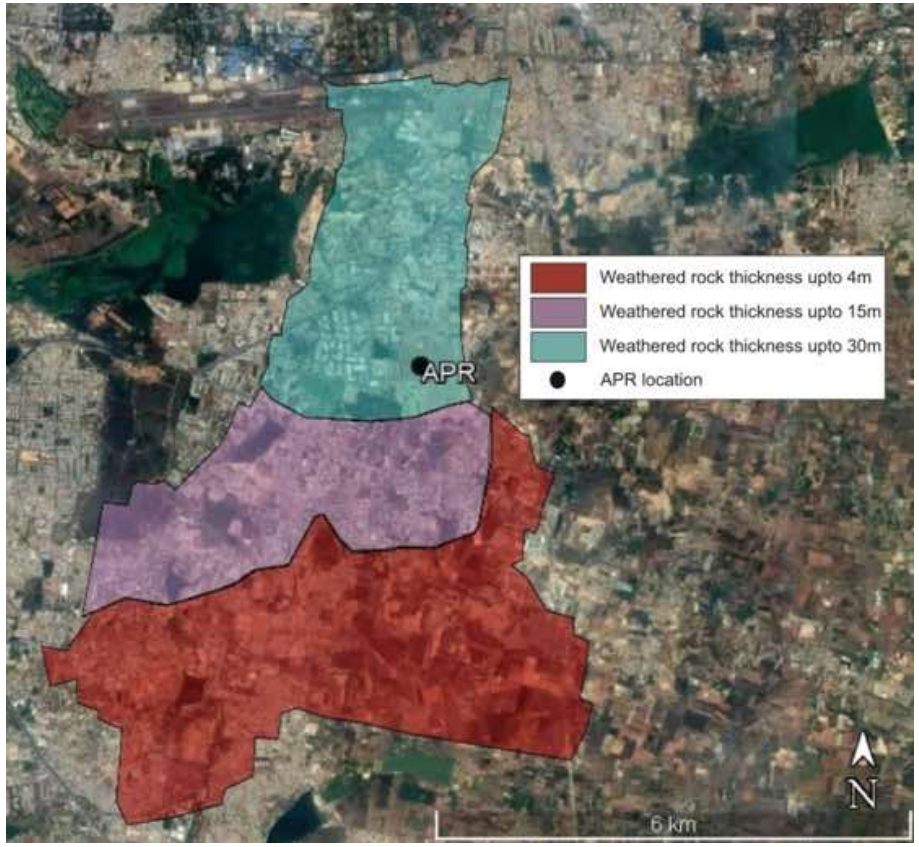

Weathered rock thickness upto 4m
Weathered rock thickness upto 15m
Weathered rock thickness upto 30m
APR location
APR
N
6 km

Adarsh Palm Retreat (APR) cluster

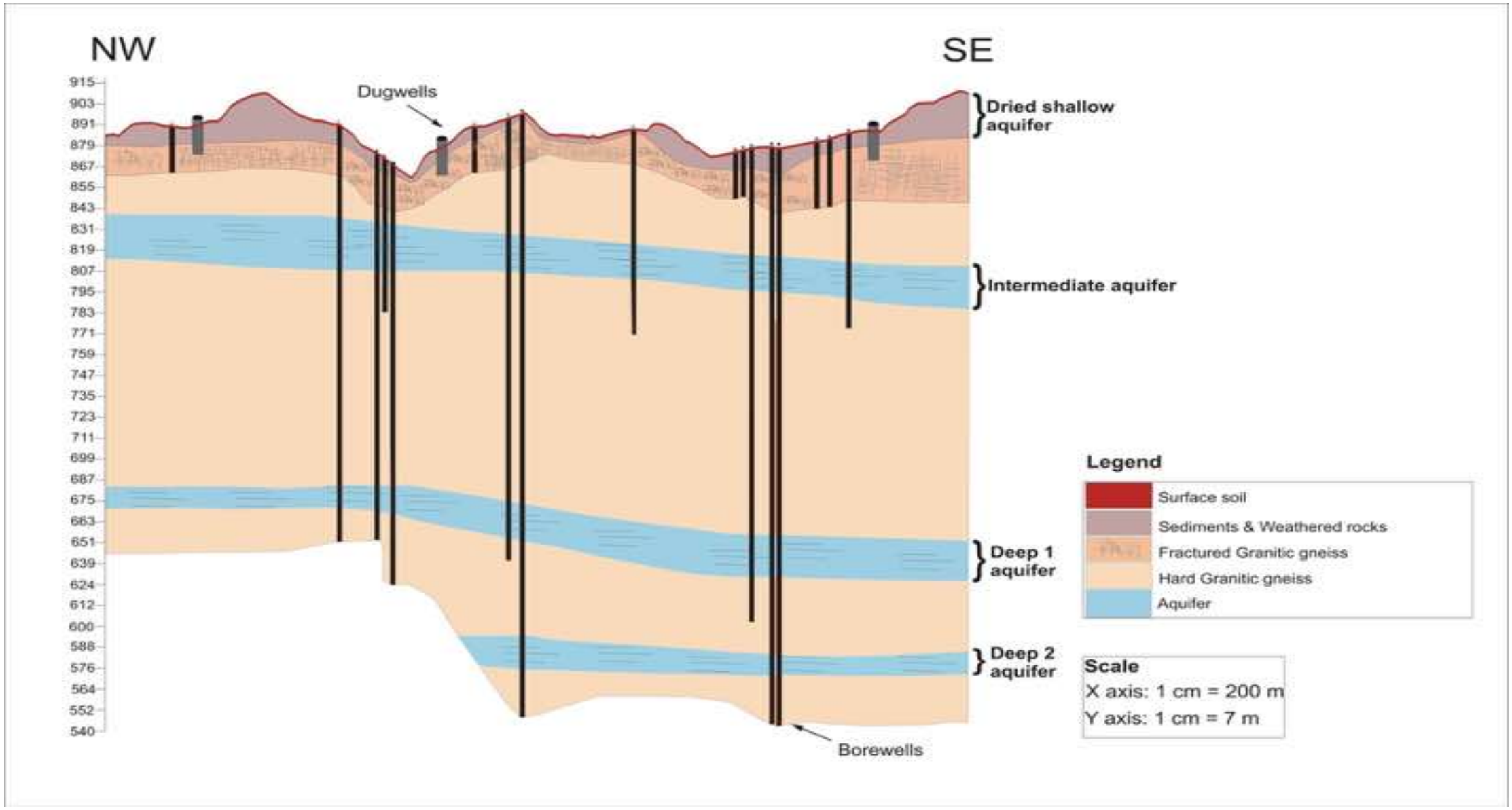
Area: 127 acres, Population: 6000

<u>Shallow Aquifer (Solution within the challenge)</u>

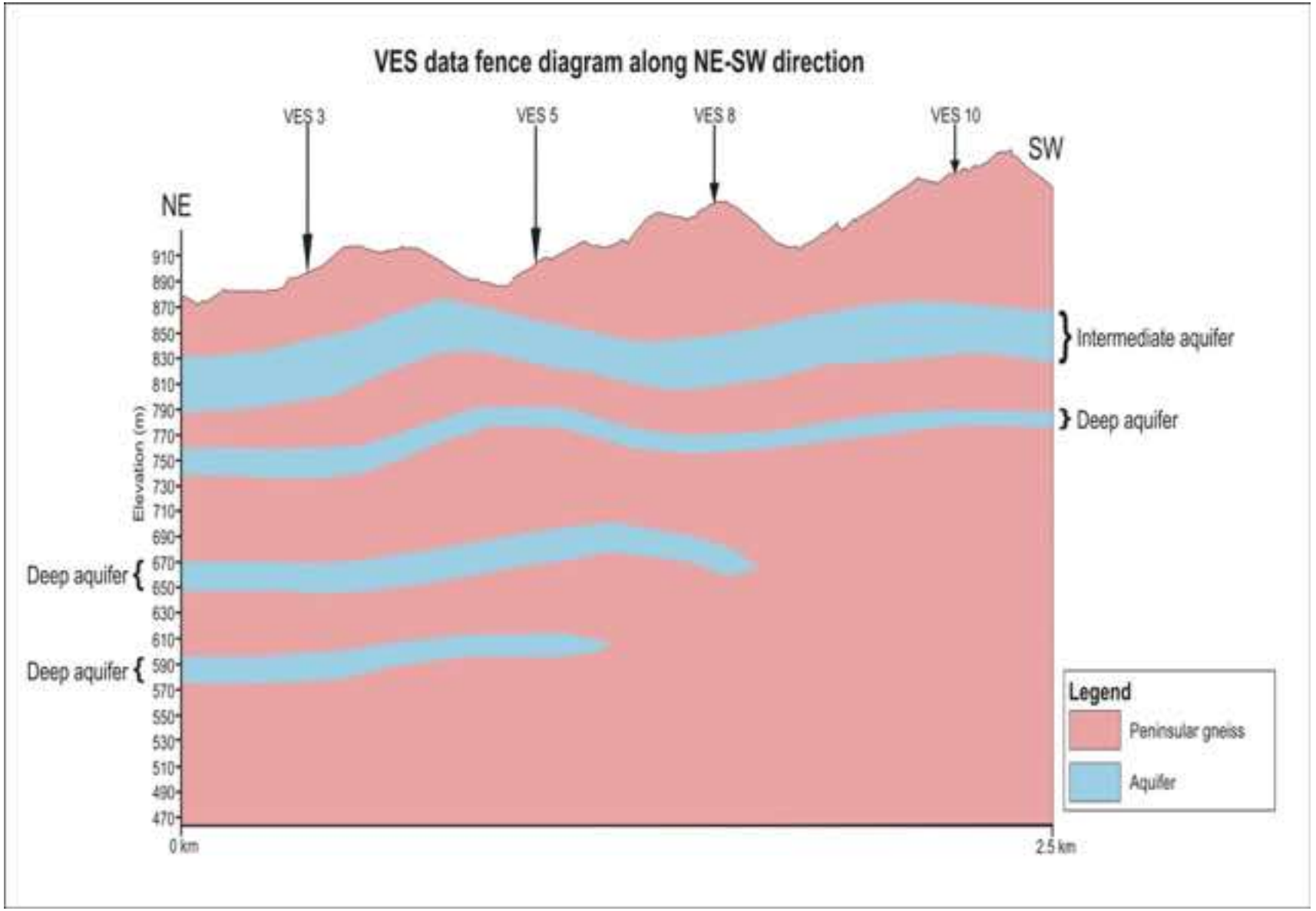
- Prevent water seepage/flooding in the basement
- Minimize external source of water



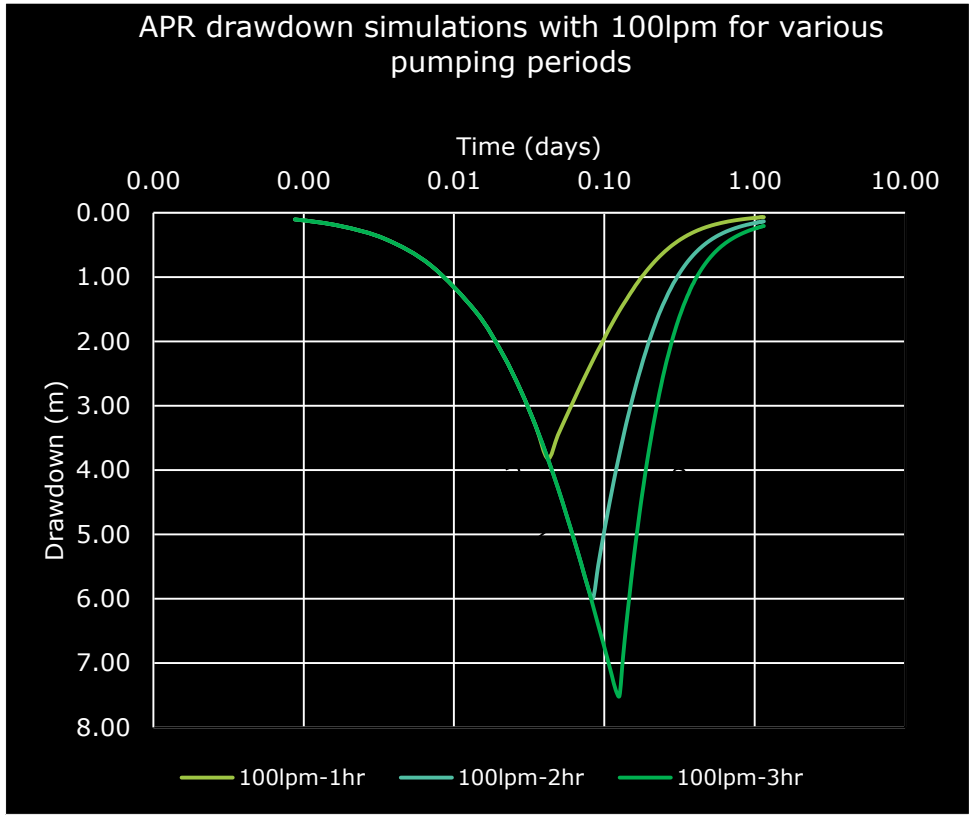
HYDROGEOLOGICAL SECTION OF THE AREA

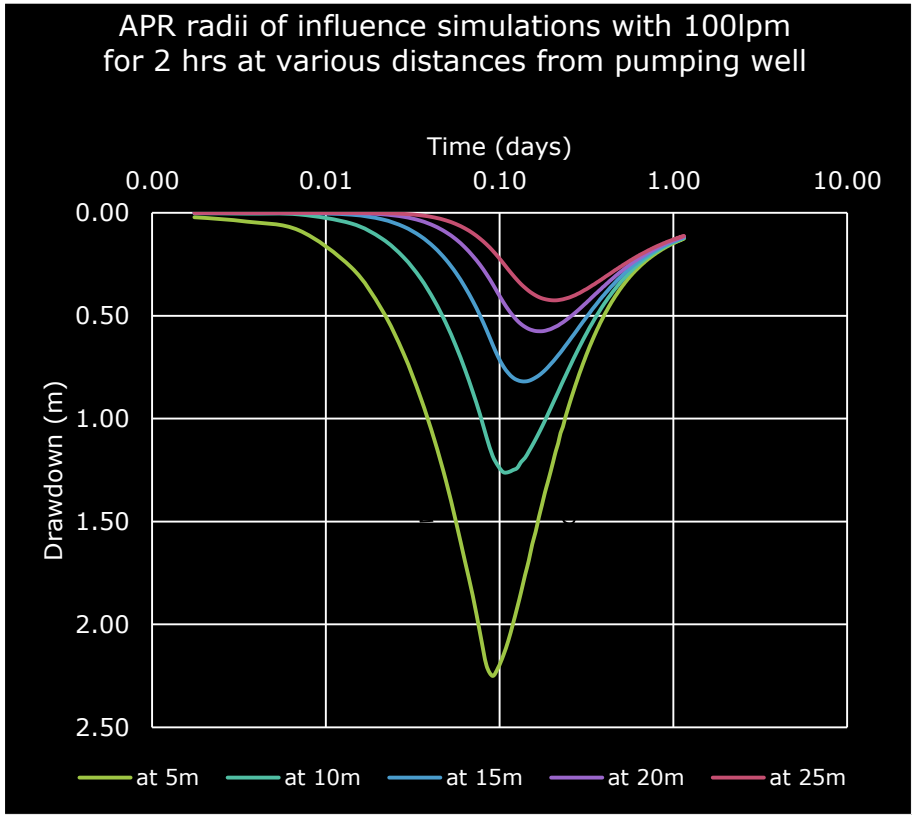


VES resistivity data based section

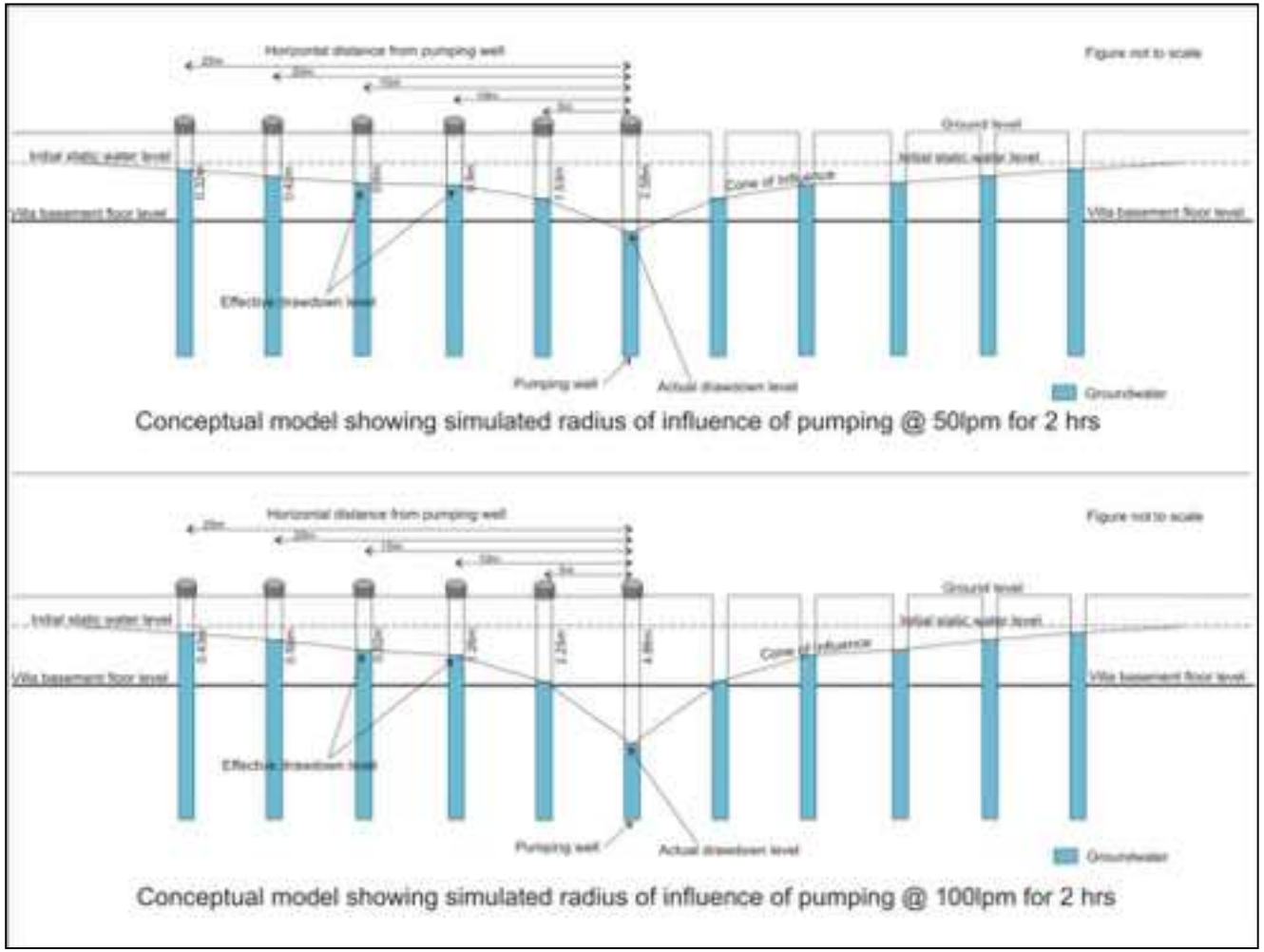


Shallow aquifer pumping model based on T=2 m^2/day & S=0.03





Monsoon: Pumping @ 100 lpm for 2 hrs followed by 2.5 days of recovery.
Dry season: Pumping @ 100 lpm for 1 hr followed by 8 days of recovery.



Conceptual model showing simulated radius of influence of pumping @ 50lpm for 2 hrs

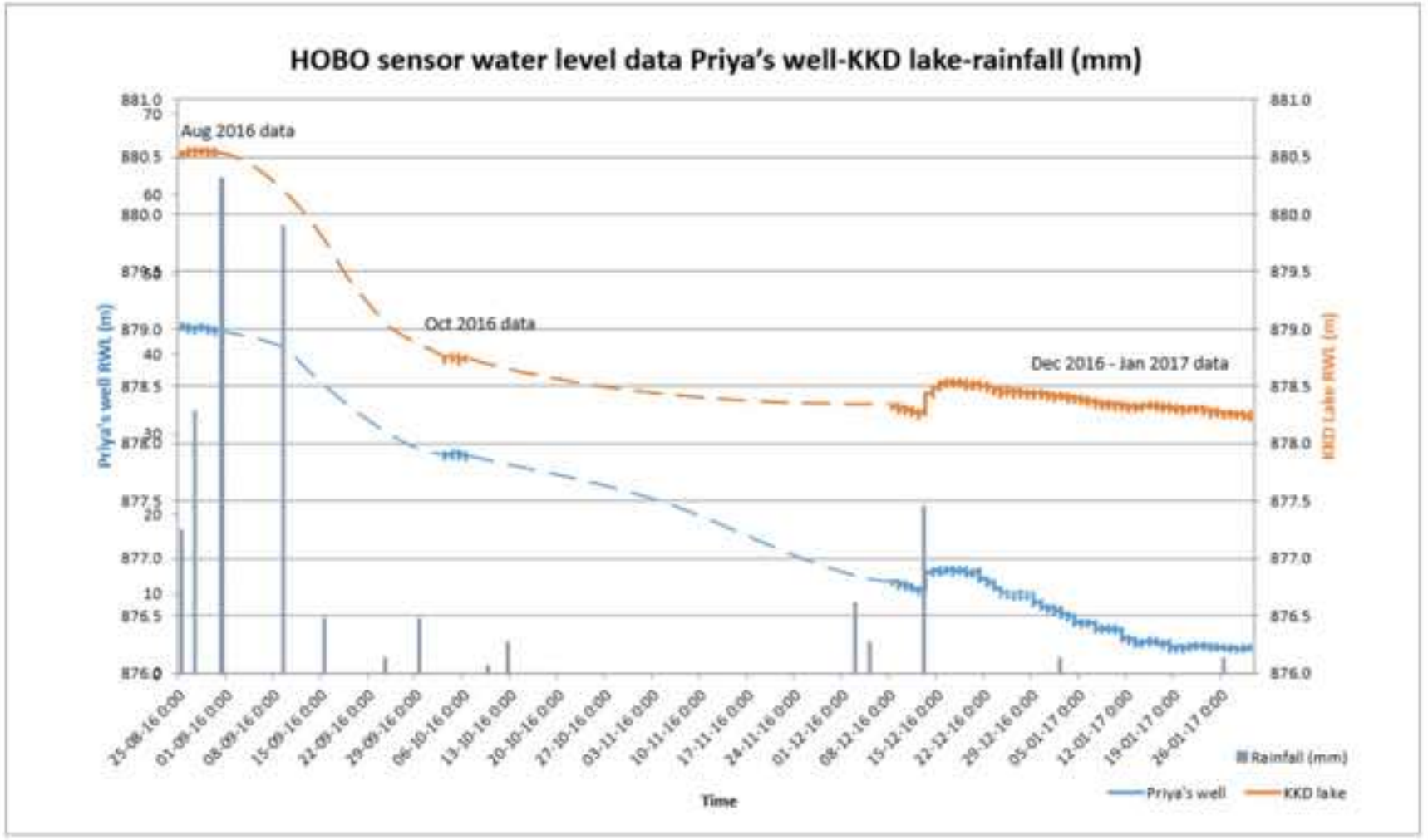
Conceptual model showing simulated radius of influence of pumping @ 100lpm for 2 hrs

Outcome

- "Water seepage and flooding problem is a blessing in disguise".
- Leveraging thicker shallow aquifer and vast area by diligent pumping & concurrent rainwater recharge.

Kaikondrahalli cluster

Kaikondrahalli (KKD) – Inter-relationship between Lake and surrounding wells tapping shallow aquifer & lake conservation.



Rainbow Drive (RBD) cluster

Area: 34 acres, Population: 1200

Challenges:

- No formal municipal water supply, entirely borewell & tanker water dependent

Actions:

- Communitizing borewells
- Optimal waste-water management
- Banning of borewell drilling
- Water metering & LPCD reduction
- Recharge wells

- Identifying & delineating aquifers.
- Demarcating discharge & recharge areas.