URBAN GROUNDWATER…

The case of Pune city

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Major sections of the presentation represent results from ACWADAM's ongoing initiative on Pune's aquifers, supported by WIPRO Foundation

The silent emergence of a conundrum…

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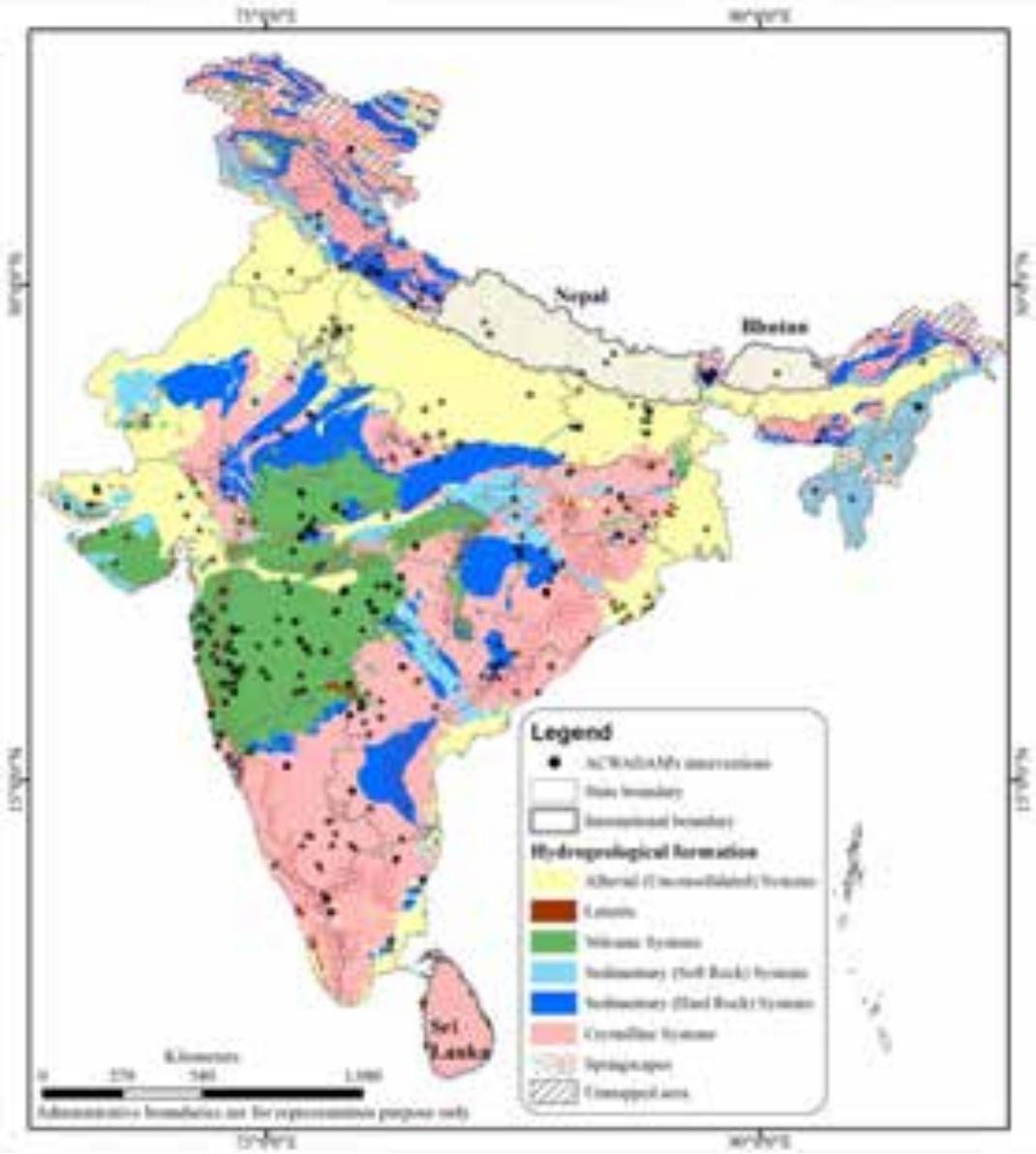
ACWADAM's work: ..in the most hydrogeologically diverse setting in the world – based on partnership and collaboration

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 communities closer to their aquifers…



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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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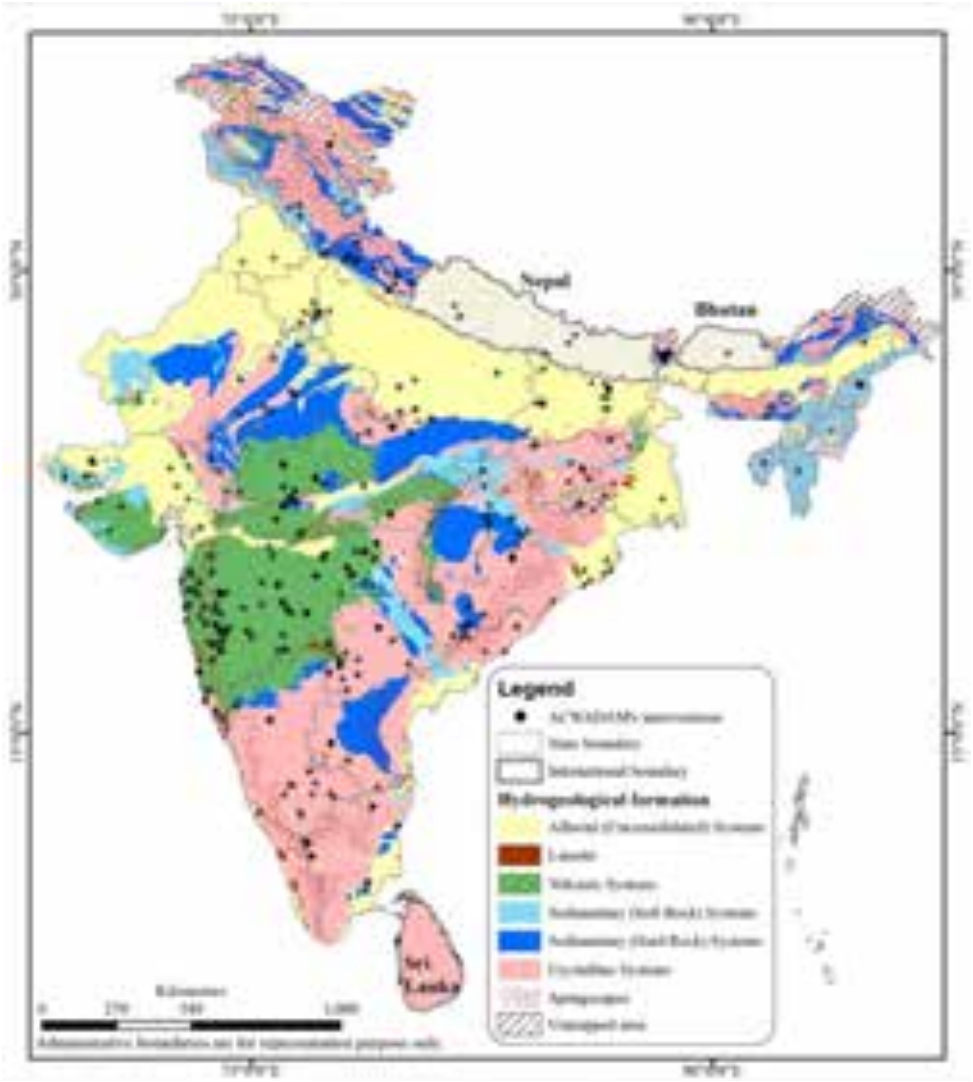
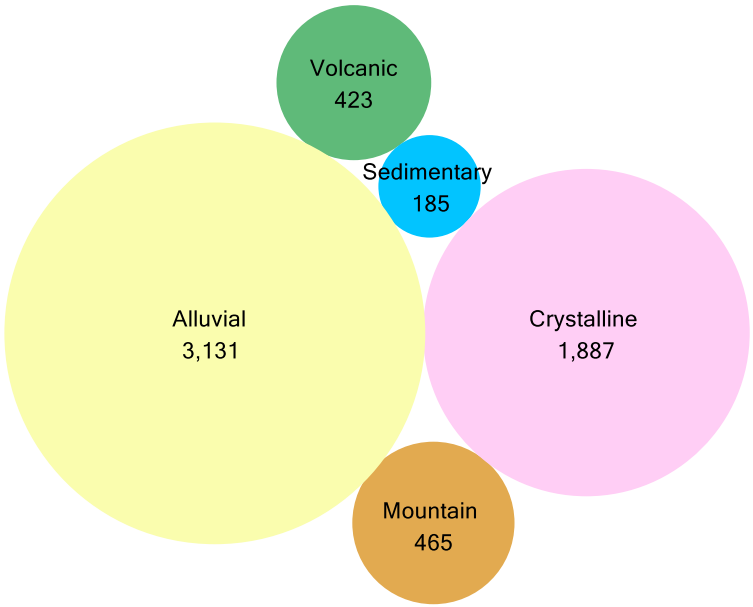
India’s hydrogeological diversity

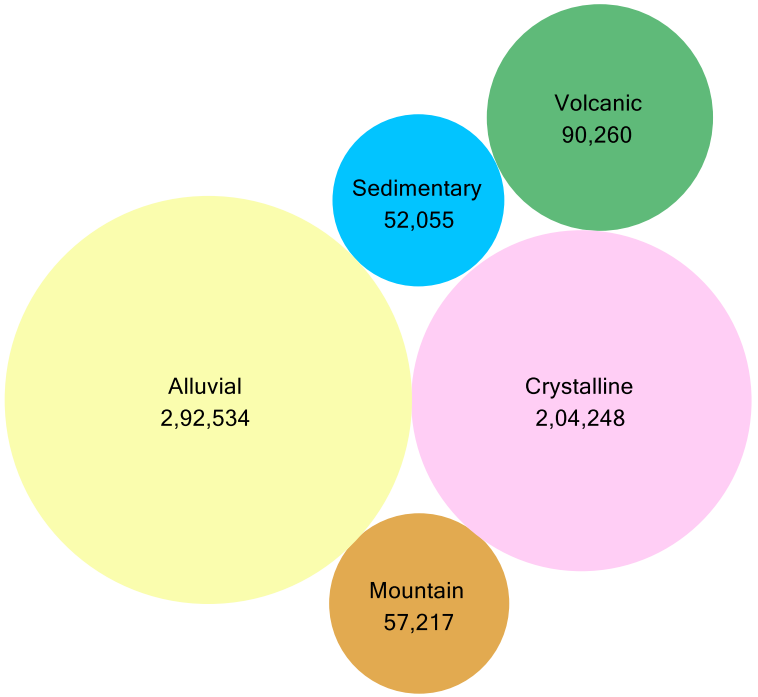


Typology based distribution of urban habitations



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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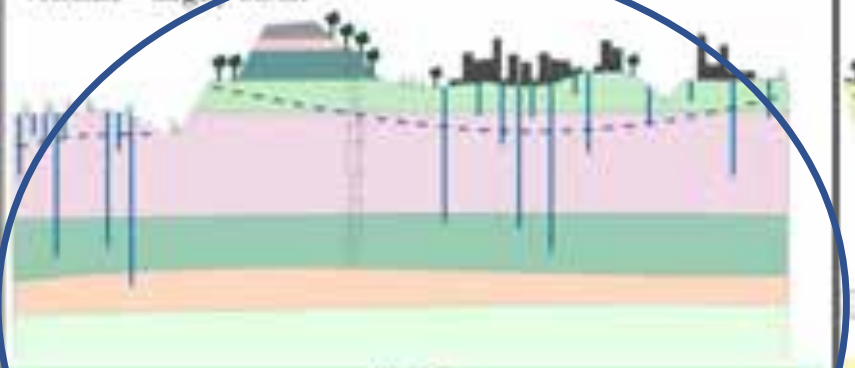
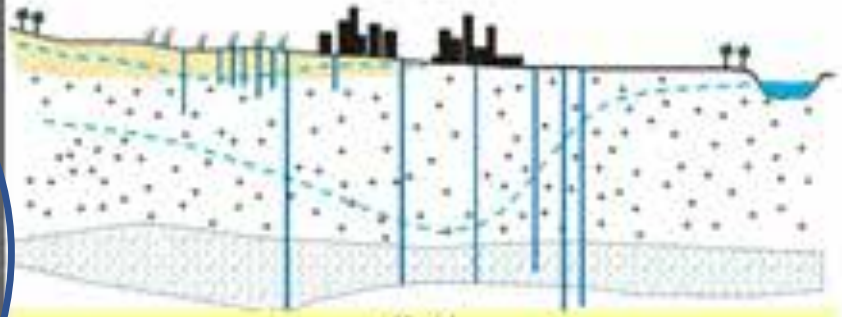
Volcanic – largely basalt



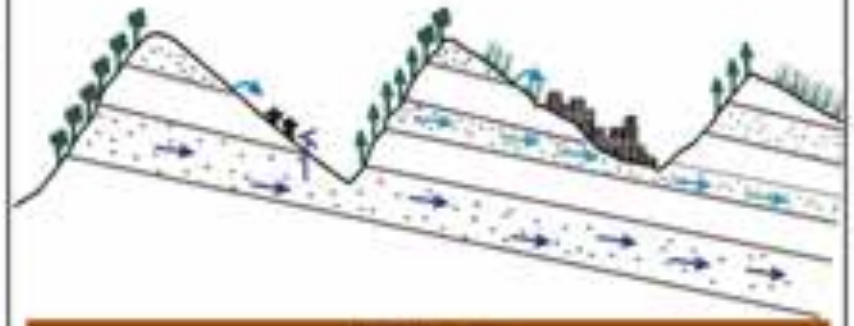
	Volcanics	
A	Urban Agglomerations	2
B	Million plus cities	5
C	Lakh plus cities	24
	Total cities(A+B+C)	32
	Total cities %	10.8%
	Smaller towns corresponding to taluka headquarters	261
	Talukas %	7%

Extensive alluvium



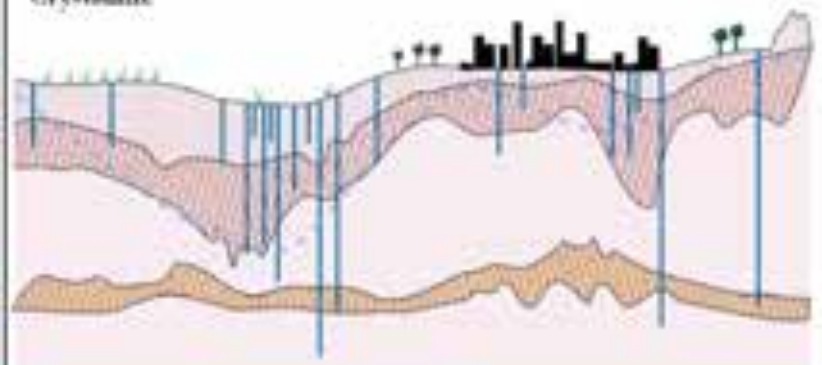
	Alluvial	
A	Urban Agglomerations	5
B	Million plus cities	19
C	Lakh plus cities	118
	Total cities(A+B+C)	142
	Total cities %	48%
	Smaller towns corresponding to taluka headquarters	1847
	Talukas %	32%

Himalayan mountain region



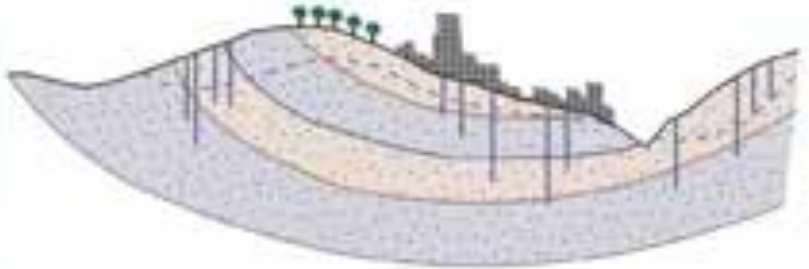
	Himalayan region	
A	Urban Agglomerations	0
B	Million plus cities	0
C	Lakh plus cities	8
	Total cities(A+B+C)	8
	Total cities %	2.5%
	Smaller towns corresponding to taluka headquarters	457
	Talukas %	8%

Crystalline



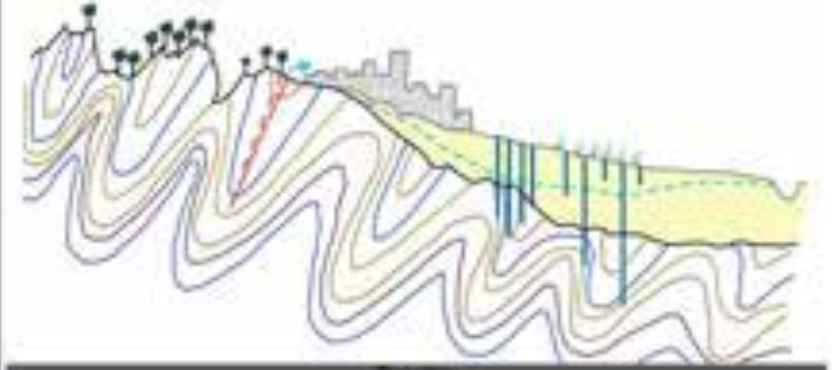
	Crystallines	
A	Urban Agglomerations	4
B	Million plus cities	21
C	Lakh plus cities	89
	Total cities(A+B+C)	114
	Total cities %	35.8%
	Smaller towns corresponding to taluka headquarters	1773
	Talukas %	31%

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%

After: Kulkarni and Mahamuni (2014); Shah and Kulkarni (2015)

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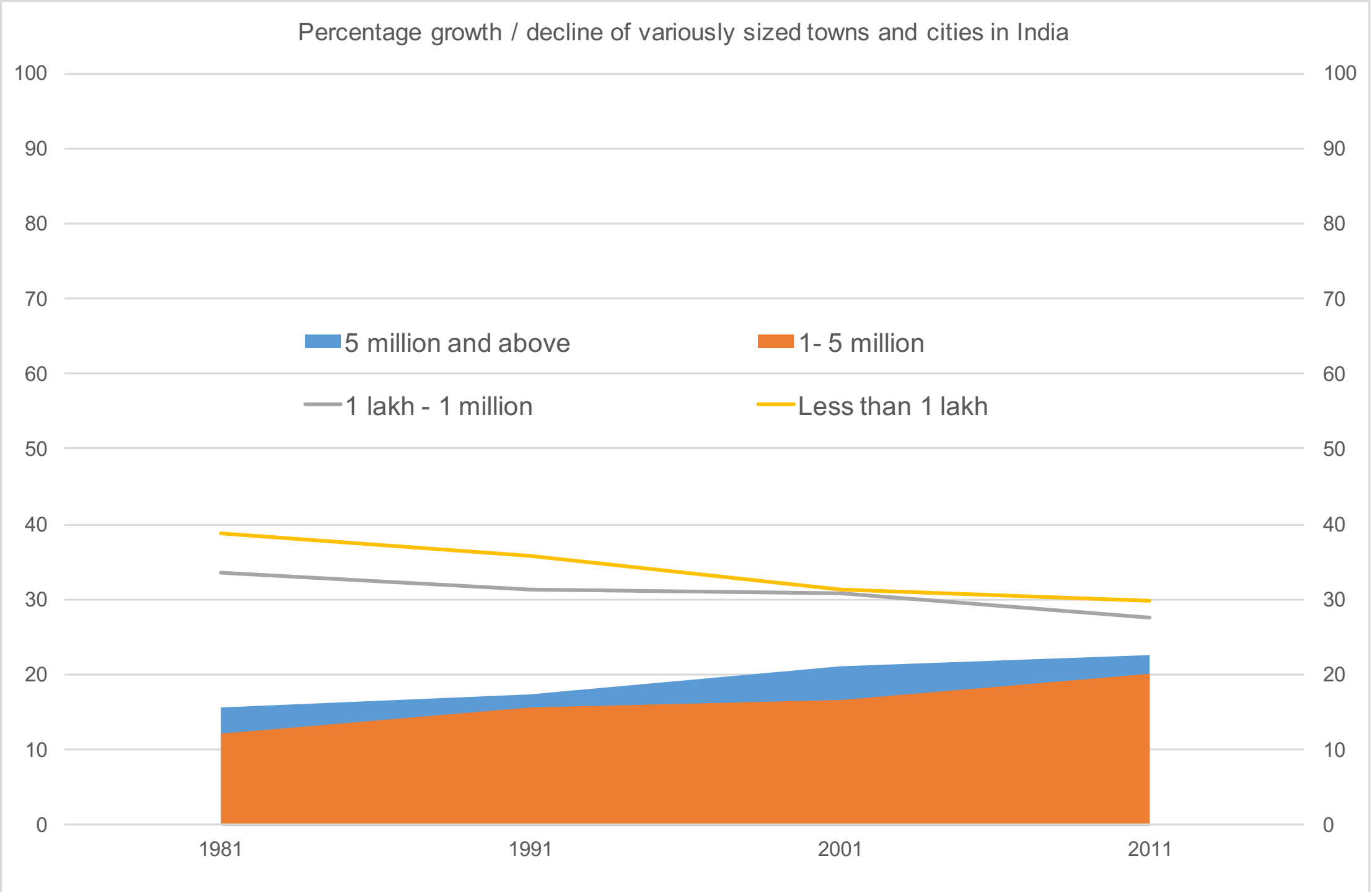

Based on Census of India, 2011

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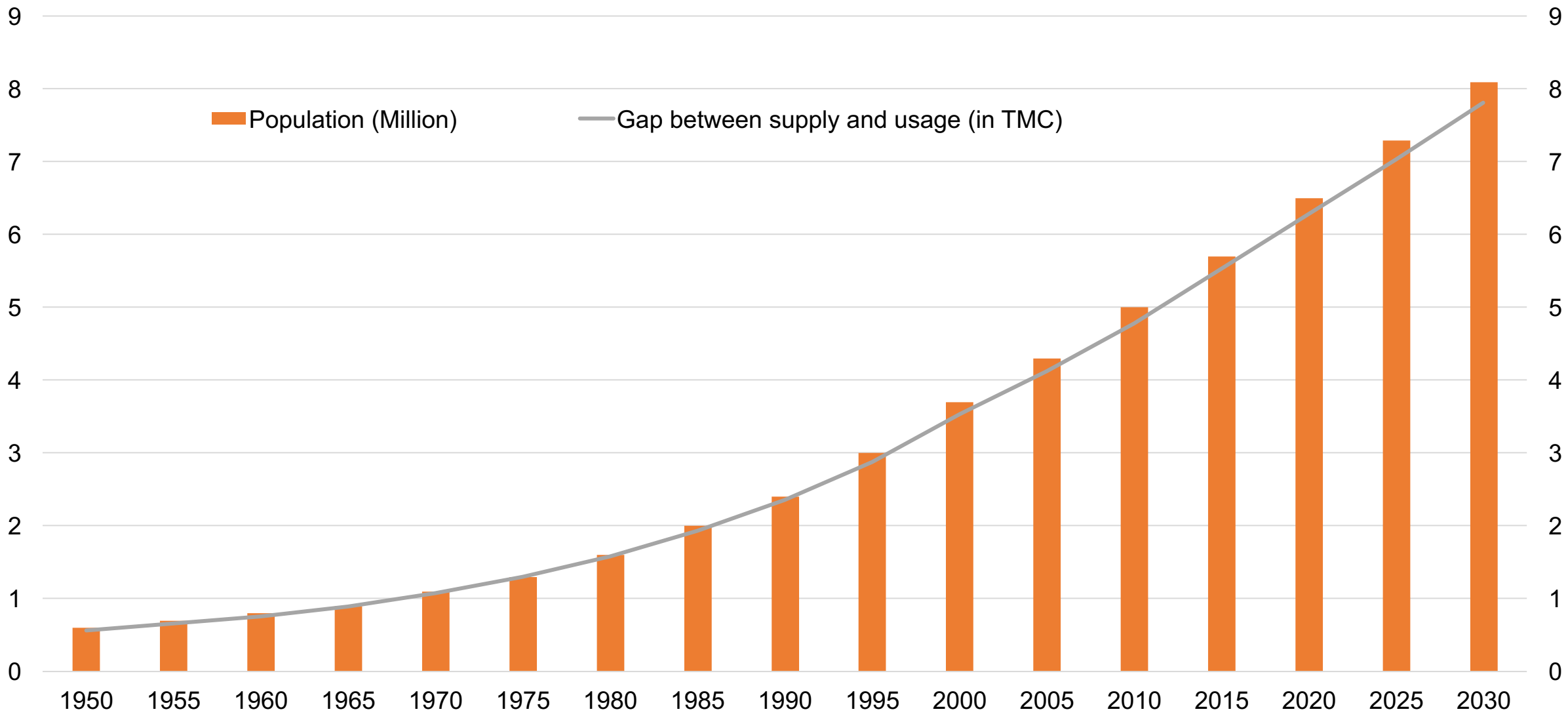
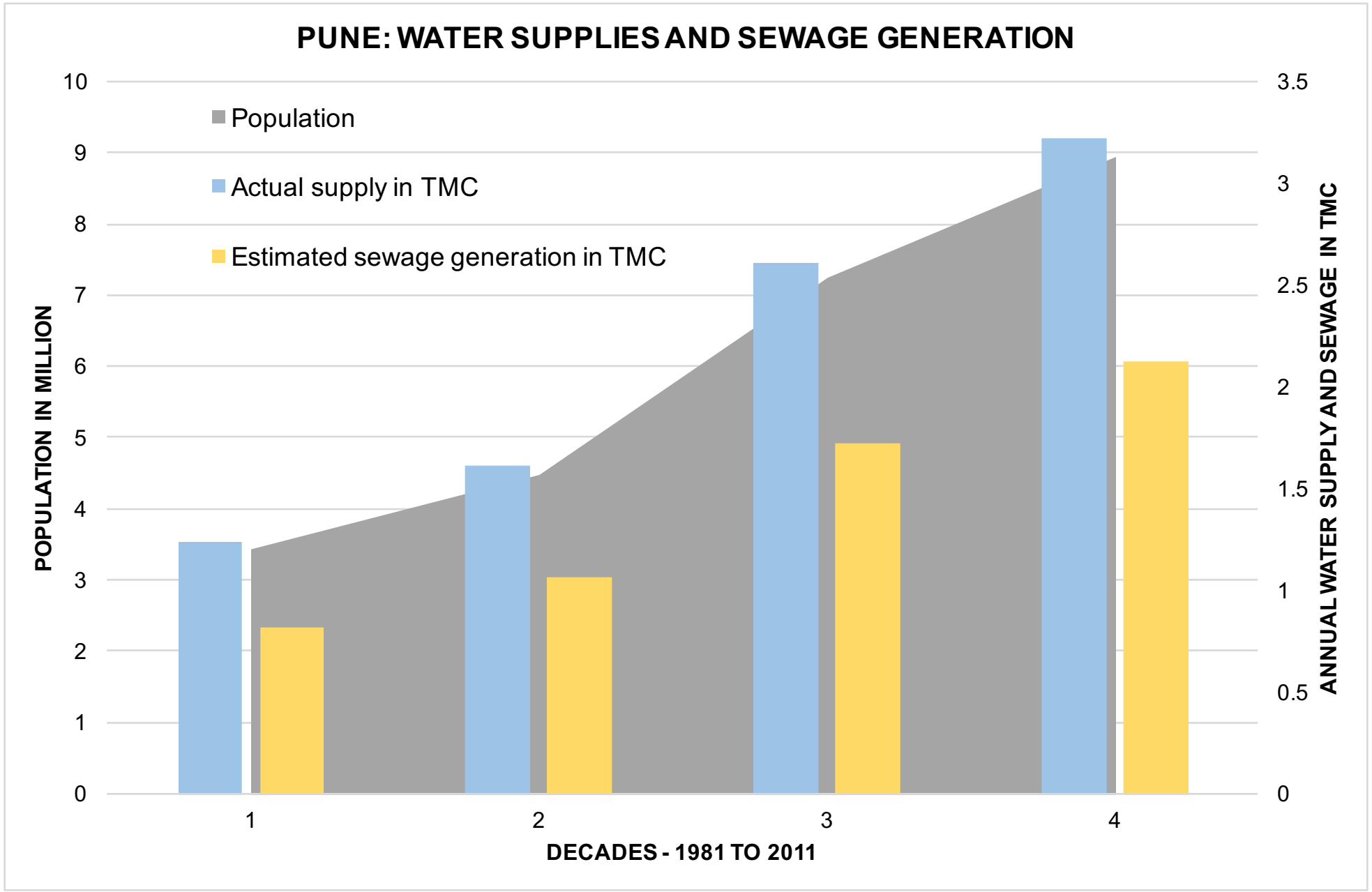
Pune city: population growth and the supply-usage gap




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

SO, HOW MUCH GROUNDWATER DOES PUNE CITY EXTRACT?

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
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

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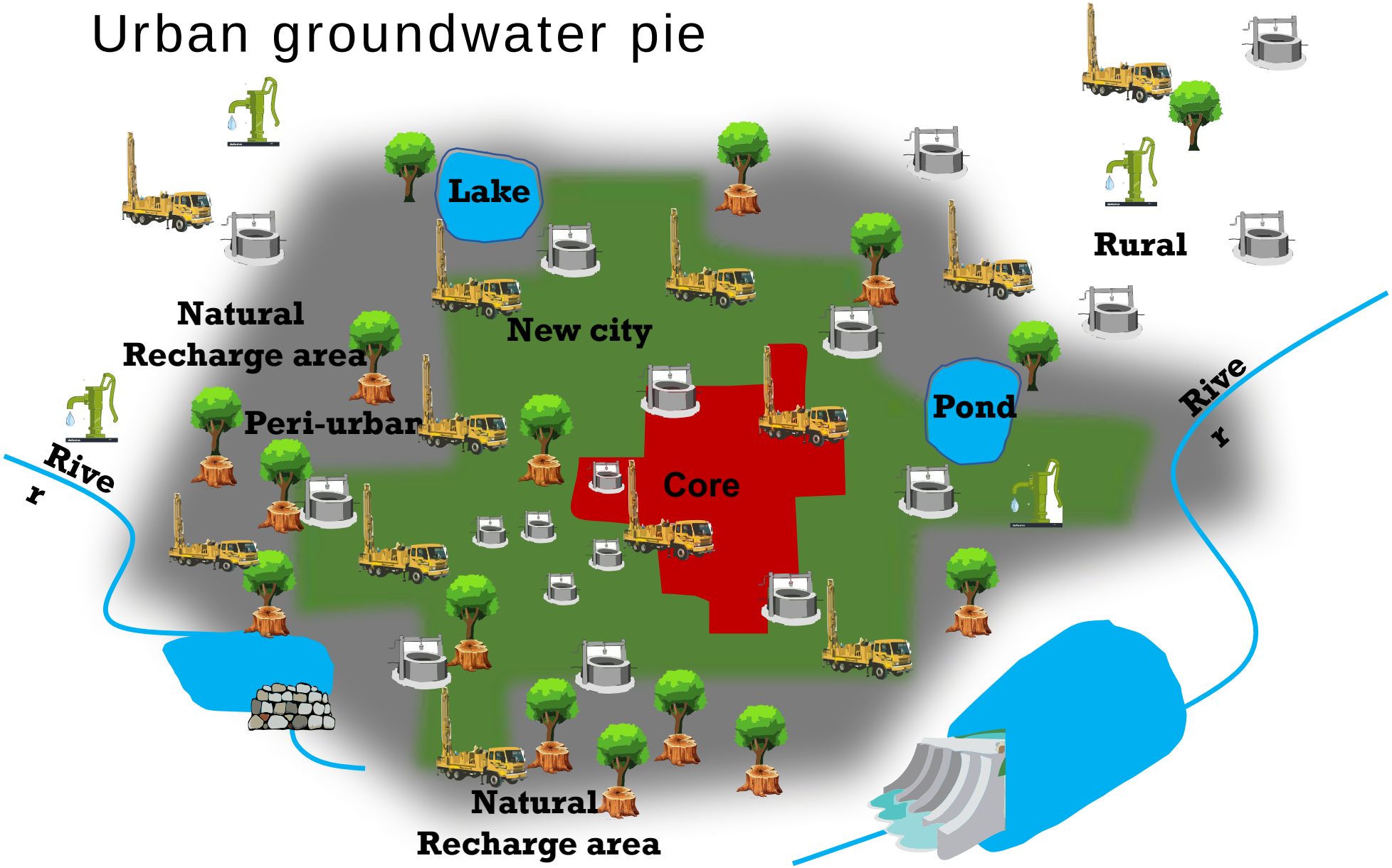
Urban groundwater pie



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

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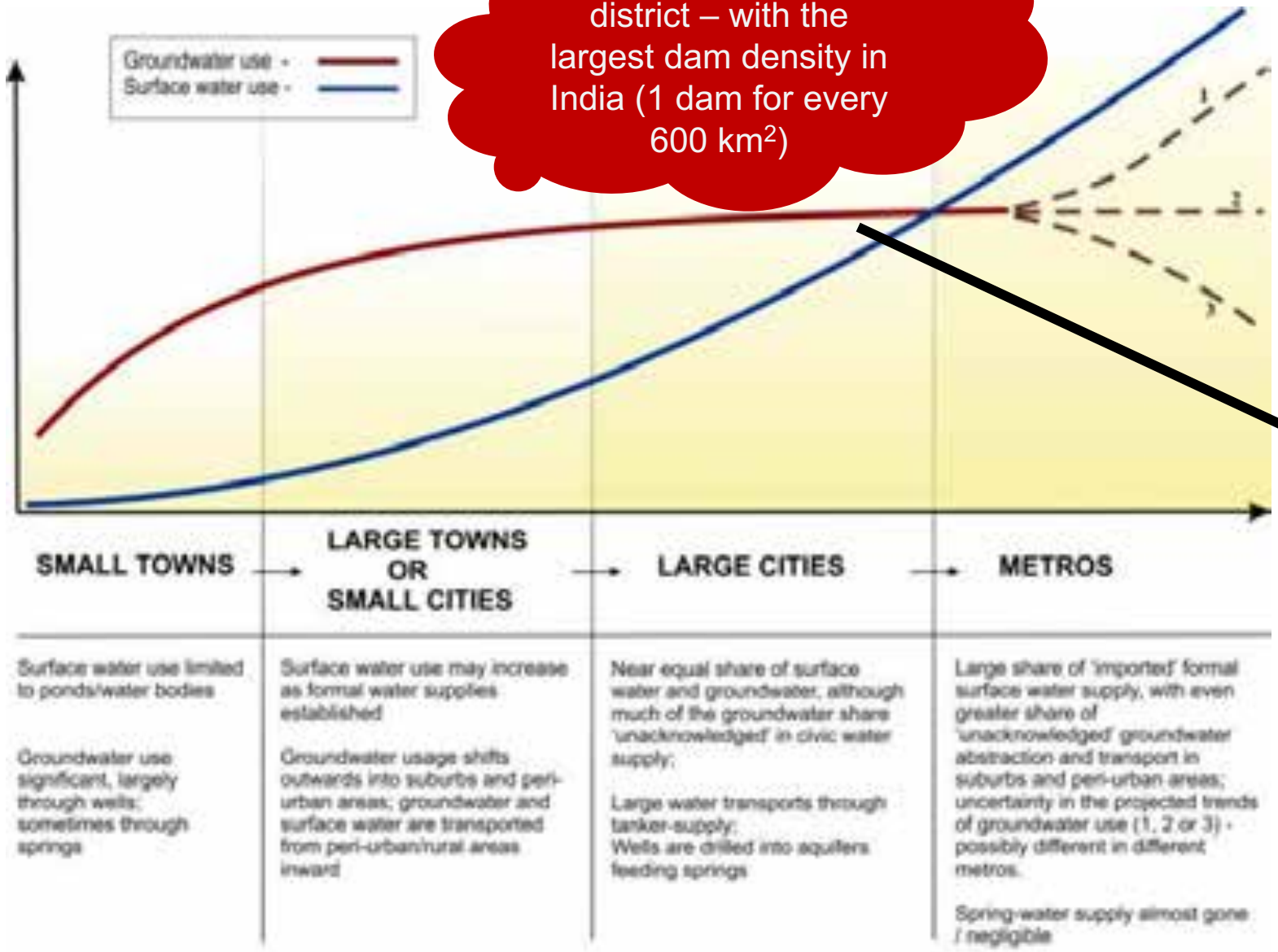
Trends in Surface and Groundwater use across variously sized Urban Settlements in India

Source: Shah & Kulkarni (2014)

Pune city: Part of Pune district – with the largest dam density in India (1 dam for every 600 km^2)



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

Surface water
13 - 15 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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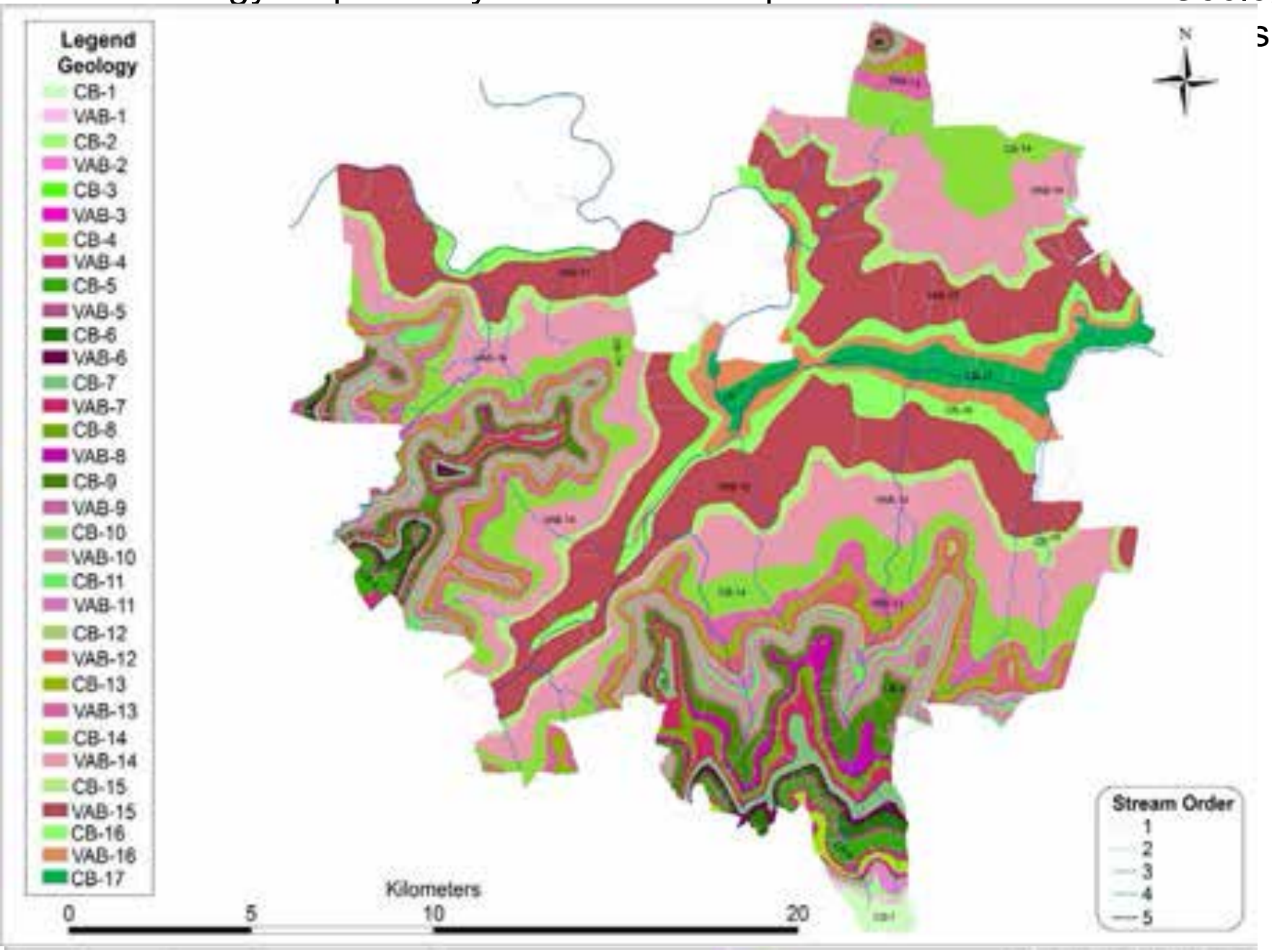
Geology map overlay on Pune municipal

Geology on municipal

s



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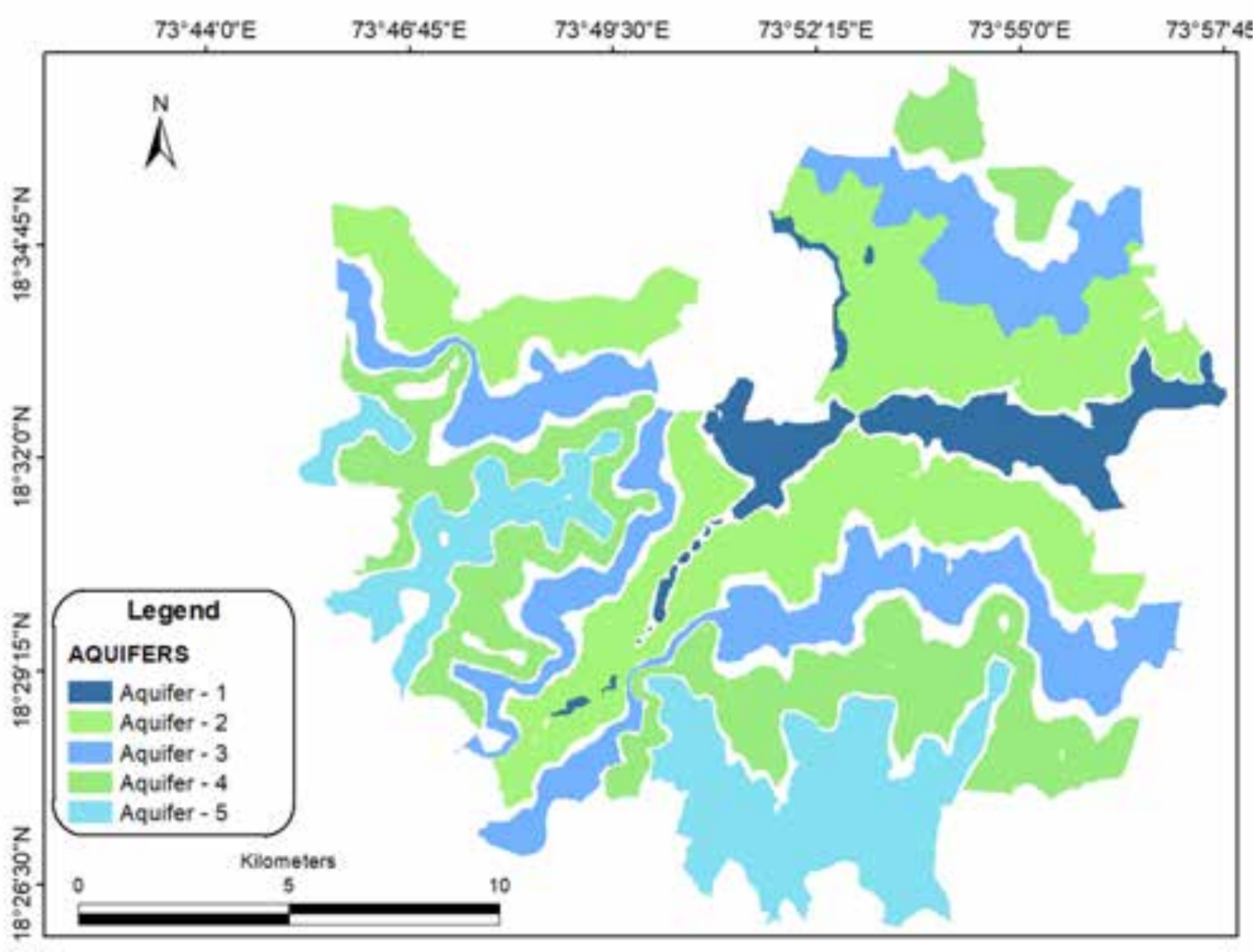
PUNE'S AQUIFER SYSTEM



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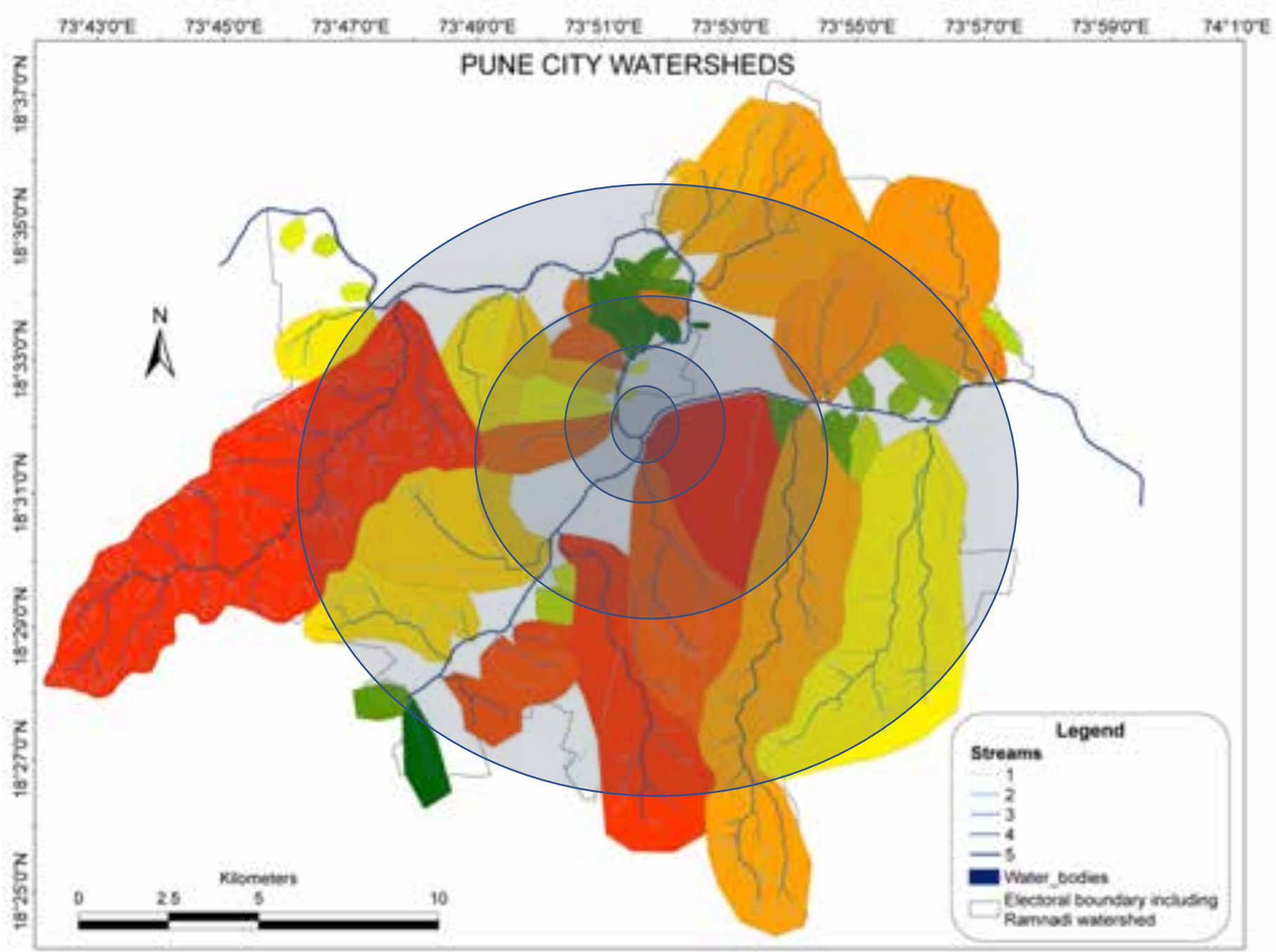
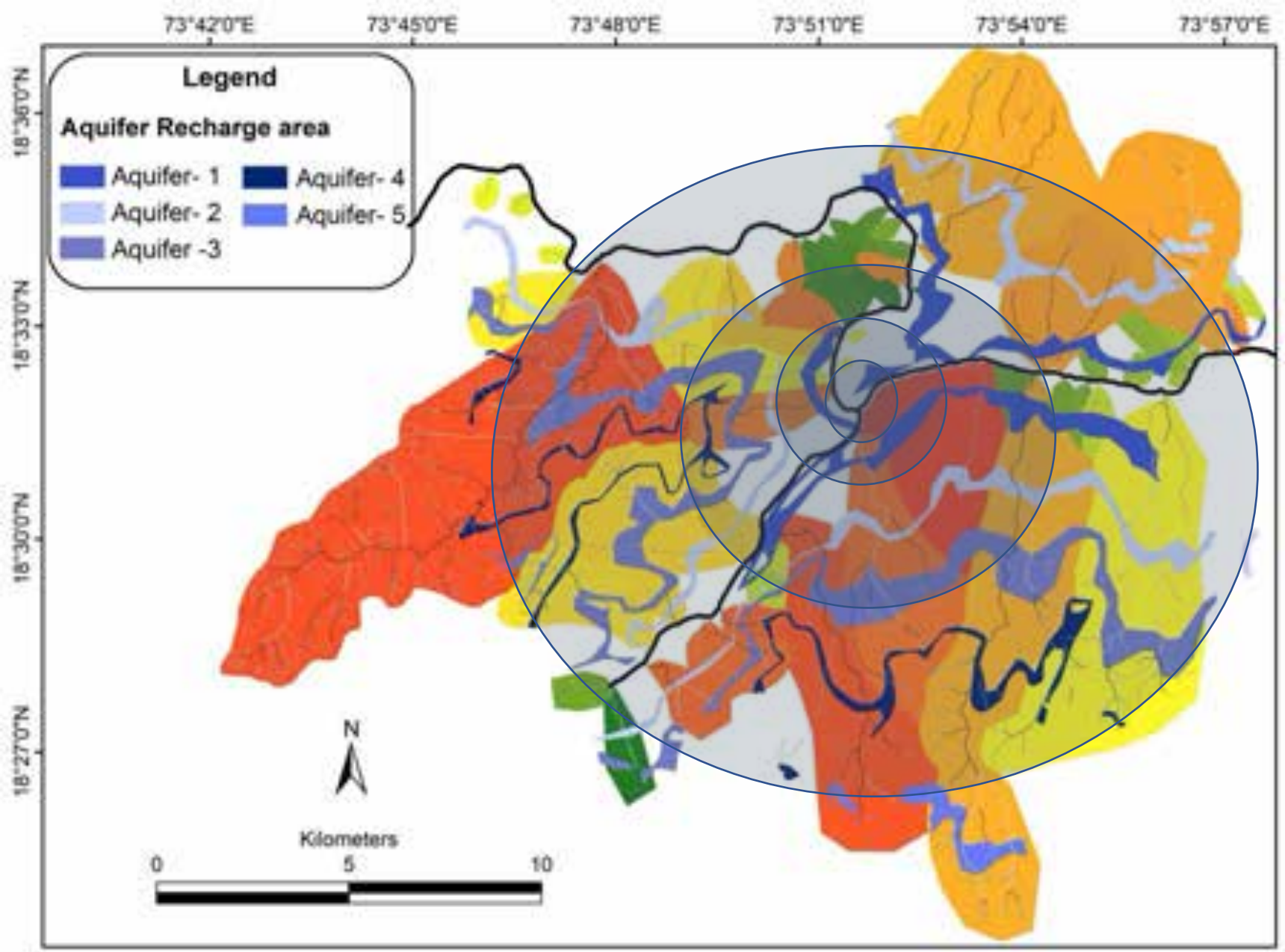

PUNE CITY WATERSHEDS
73°43'0"E
73°45'0"E
73°47'0"E
73°49'0"E
73°51'0"E
73°53'0"E
73°55'0"E
73°57'0"E
73°59'0"E
74°1'0"E
18°37'0"N
18°35'0"N
18°33'0"N
18°31'0"N
18°29'0"N
18°27'0"N
18°25'0"N
N
Kilometers
0
2.5
5
10
Legend
Streams
1
2
3
4
5
Water_bodies
Electoral boundary including Ramnadi watershed


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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Broad recharge-conducive areas of Pune

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

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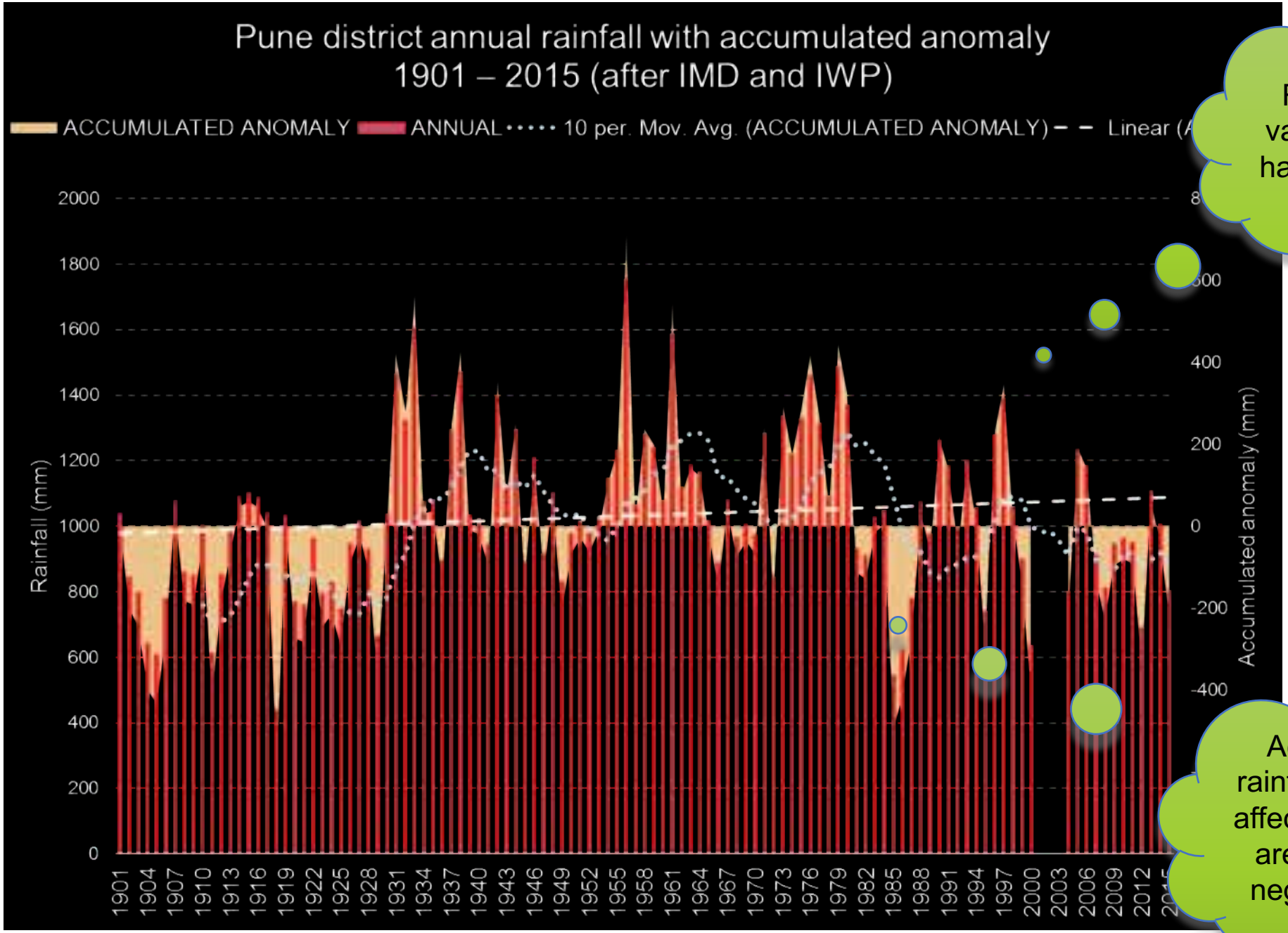

Rainfall and variability both have increased

Accumulated rainfall anomalies affecting recharge are dominantly negative now…

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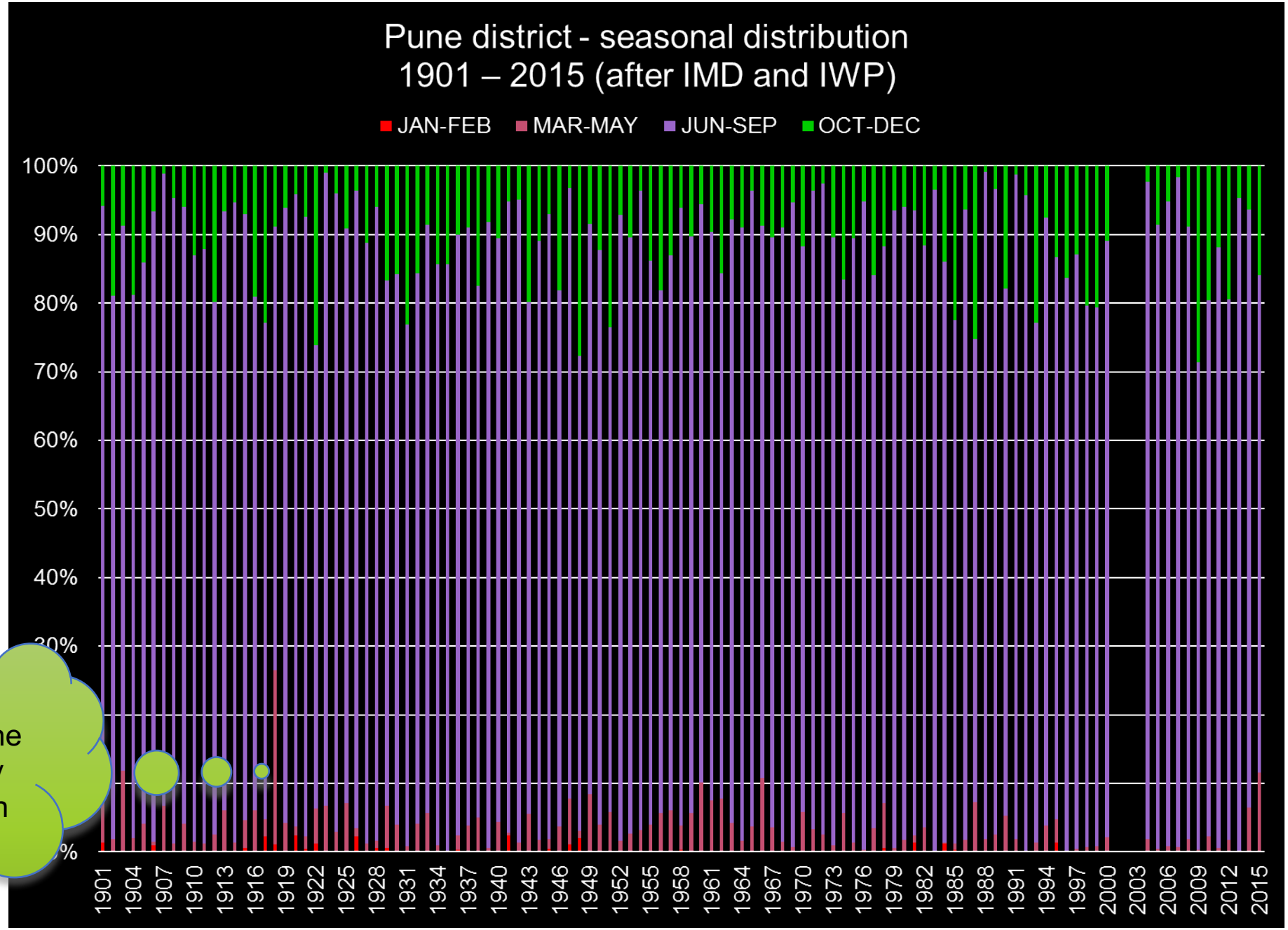

Decrease in the January-May precicipitation

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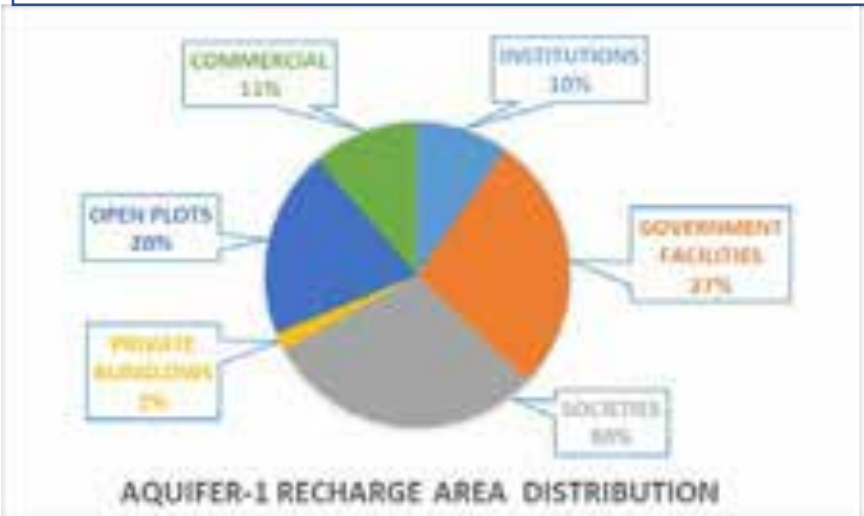
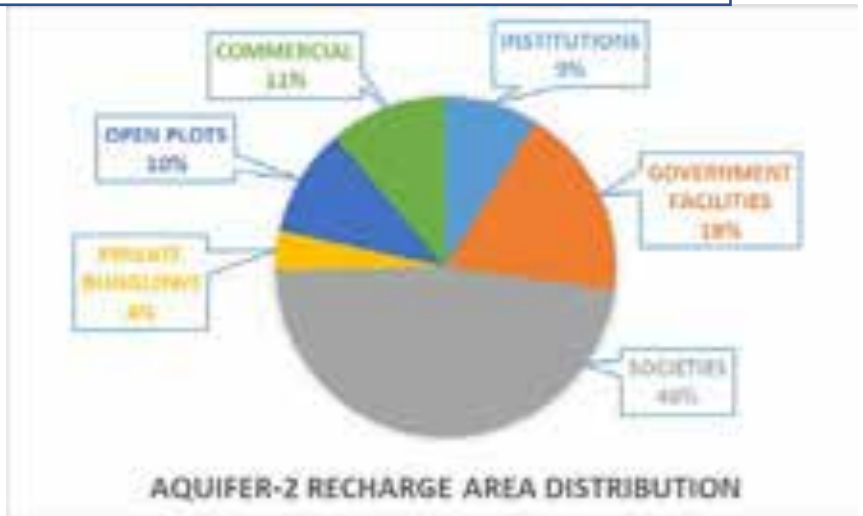
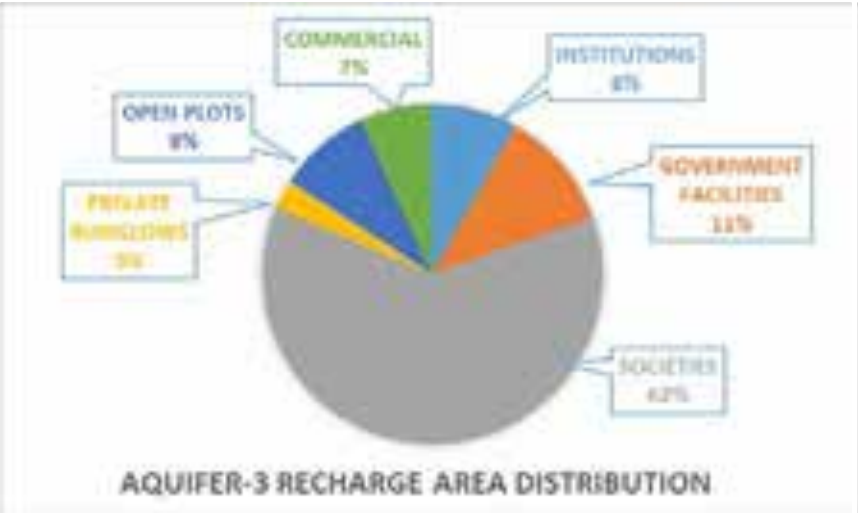
Aquifer-wise distribution of broad land-cover types



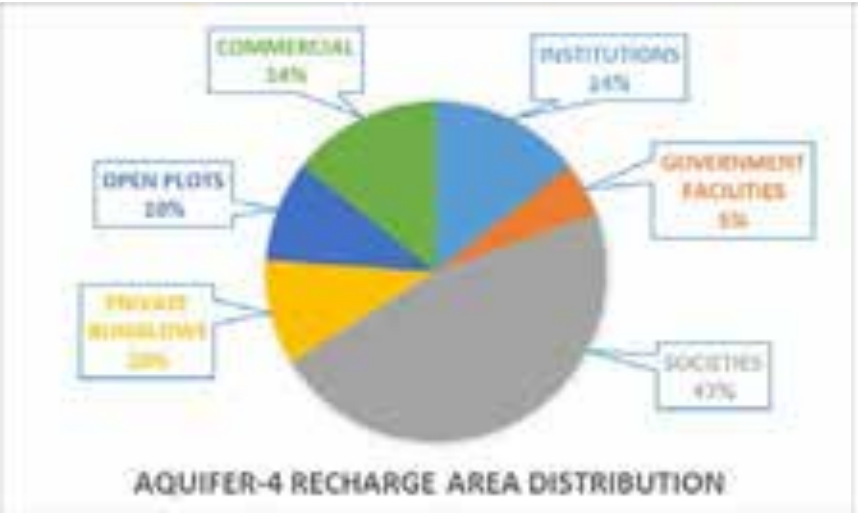
AQUIFER-1 RECHARGE AREA DISTRIBUTION



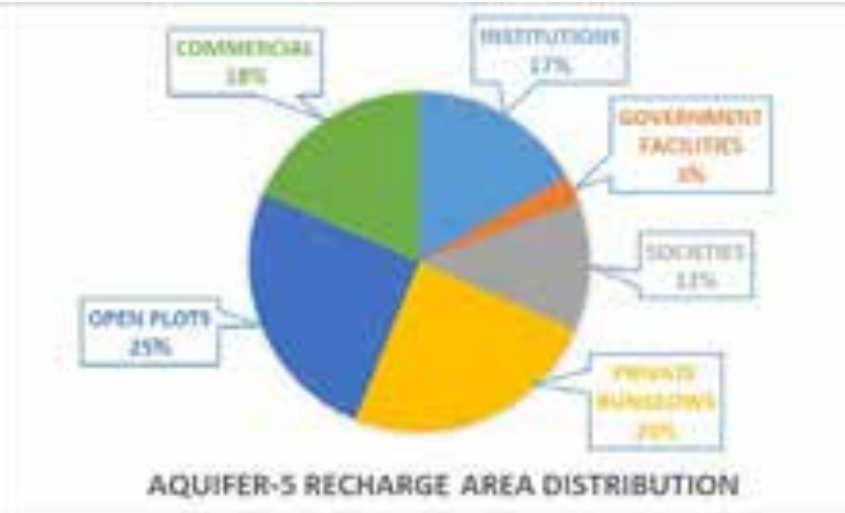
AQUIFER-2 RECHARGE AREA DISTRIBUTION



AQUIFER-3 RECHARGE AREA DISTRIBUTION



AQUIFER-4 RECHARGE AREA DISTRIBUTION



AQUIFER-5 RECHARGE AREA DISTRIBUTION

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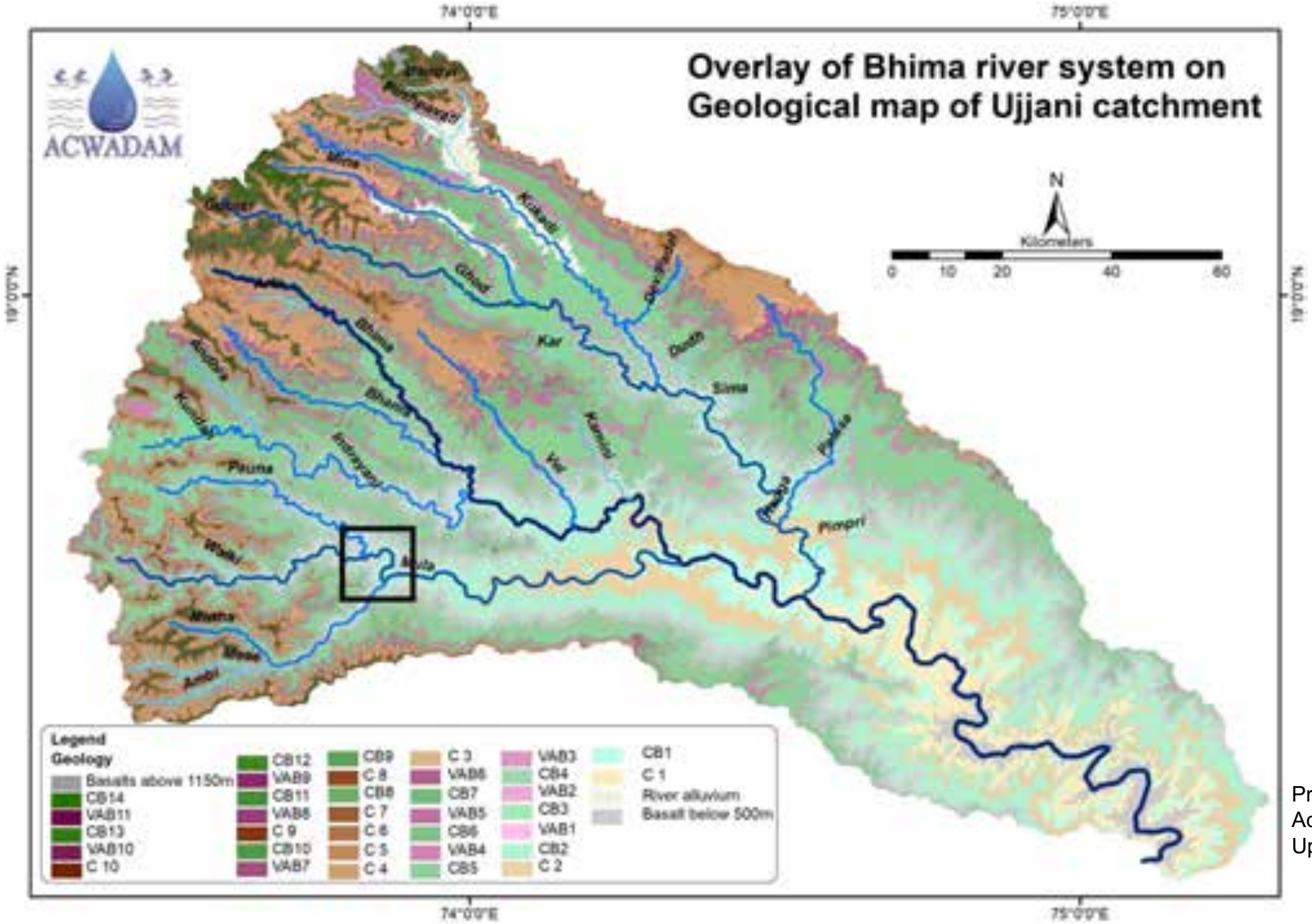

Prepared for:
Adarsh Foundation's
Upper Bhima Mapping Project

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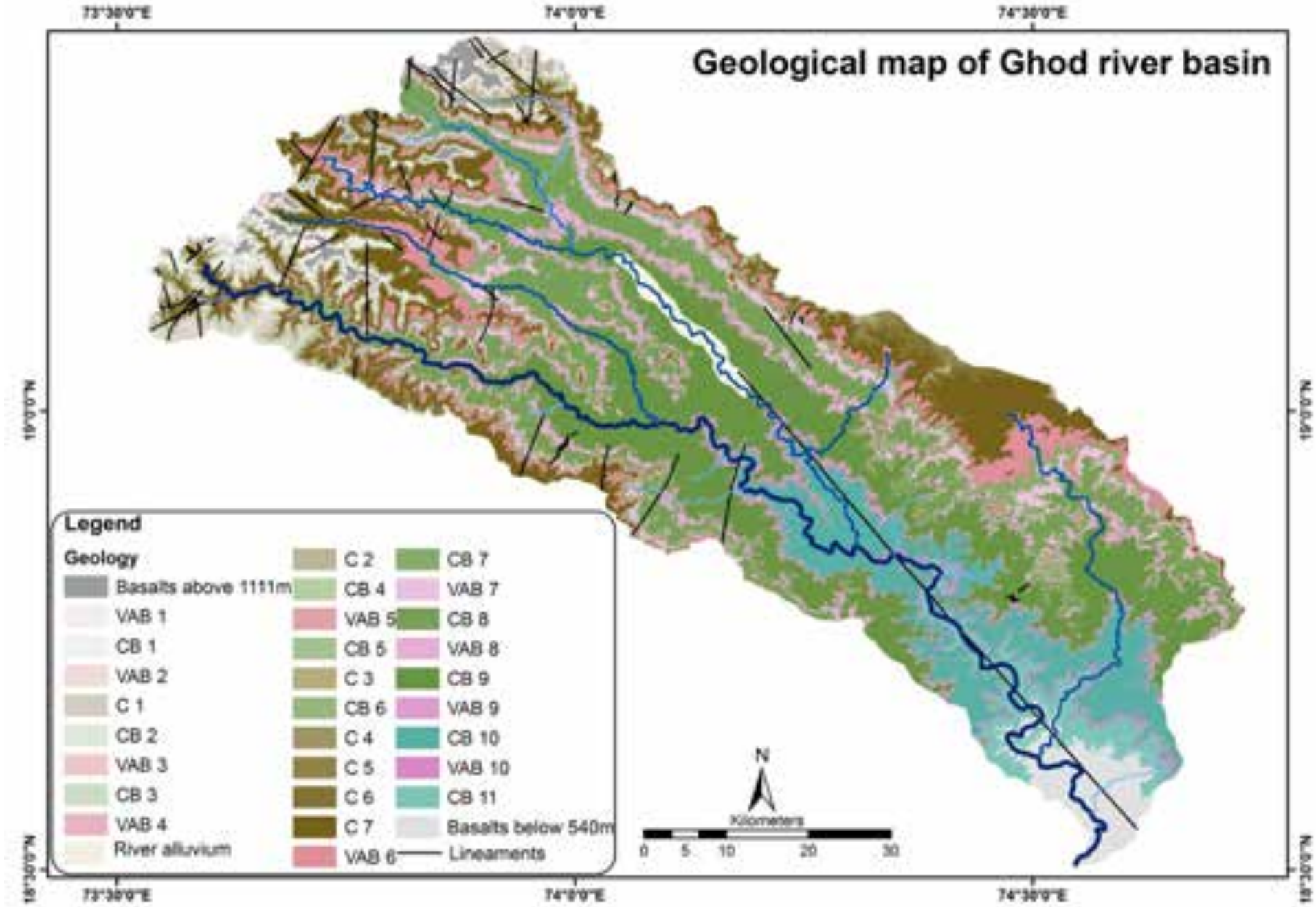
Pune urban: Demand supply matrix

Year	Population	Population (Million)	Growth	Growth Rate (%)	Lit/day @150 LPCD (Standard)	Lit/day @228 LPCD (PMC actual supply)	m3/month	TMC/month	TMC/Year Standard supply @ 150 LPCD	TMC/Year actual supply @ 228 LPCD	Excess water supply in TMC
1950	581,000	0.6	0	0.0%	87150000	132468000	3974040	0.14	1.12	1.68	0.56
1955	680,000	0.7	99,000	17.0%	102000000	155040000	4651200	0.16	1.31	1.97	0.66
1960	777,000	0.8	97,000	14.3%	116550000	177156000	5314680	0.19	1.50	2.25	0.75
1965	924,000	0.9	147,000	18.9%	138600000	210672000	6320160	0.22	1.79	2.68	0.89
1970	1,105,000	1.1	181,000	19.6%	165750000	251940000	7558200	0.27	2.14	3.20	1.07
1975	1,345,000	1.3	240,000	21.7%	201750000	306660000	9199800	0.32	2.60	3.90	1.30
1980	1,642,000	1.6	297,000	22.1%	246300000	374376000	11231280	0.40	3.17	4.76	1.58
1985	1,998,000	2.0	356,000	21.7%	299700000	455544000	13666320	0.48	3.86	5.79	1.93
1990	2,430,000	2.4	432,000	21.6%	364500000	554040000	16621200	0.59	4.70	7.04	2.35
1995	2,978,000	3.0	548,000	22.6%	446700000	678984000	20369520	0.72	5.76	8.63	2.87
2000	3,655,000	3.7	677,000	22.7%	548250000	833340000	25000200	0.88	7.07	10.59	3.53
2005	4,270,000	4.3	615,000	16.8%	640500000	973560000	29206800	1.03	8.26	12.38	4.12
2010	4,951,000	5.0	681,000	15.9%	742650000	1128828000	33864840	1.20	9.57	14.35	4.78
2015	5,728,000	5.7	777,000	15.7%	859200000	1305984000	39179520	1.38	11.07	16.60	5.53
2017	6,037,000	6.0	309,000	5.4%	905550000	1376436000	41293080	1.46	11.67	17.50	5.83
2020	6,502,000	6.50	465000	8%	975300000	1482456000	44473680	1.57	12.57	18.85	6.28
2025	7,285,000	7.29	783000	12%	1092750000	1660980000	49829400	1.76	14.09	21.12	7.03
2030	8,091,000	8.09	806000	11%	1213650000	1844748000	55342440	1.95	15.64	23.45	7.81


Geological map of Ghod river basin
73°30'0"E
74°0'0"E
74°30'0"E
19°0'0"N
18°30'0"N
Legend
Geology
Basalts above 1111m
VAB 1
CB 1
VAB 2
C 1
CB 2
VAB 3
CB 3
VAB 4
River alluvium
C 2
CB 4
VAB 5
CB 5
C 3
CB 6
C 4
C 5
C 6
C 7
VAB 6
CB 7
VAB 7
CB 8
VAB 8
CB 9
VAB 9
CB 10
VAB 10
CB 11
Basalts below 540m
Lineaments
N
Kilometers
0 5 10 20 30

Ghod River basin: Unit-wise potential groundwater storage

Geology	Area (km^2)	Effective phreatic aquifer thickness (m)	Storativity	Potential aquifer storage (MCM)	Potential aquifer storage (mm)
Basalts above 1111m	56.22	10	0.001	0.56	10.00
VAB 1	9.02	11	0.005	0.50	55.00
CB 1	55.25	5	0.001	0.28	5.00
VAB 2	22.21	15	0.005	1.67	75.00
C 1	16.21	10	0.003	0.49	30.00
CB 2	18.48	5	0.001	0.09	5.00
VAB 3	17.44	8	0.007	0.98	56.00
CB 3	60.49	5	0.001	0.30	5.00
VAB 4	20.37	10	0.01	2.04	100.00
C 2	47.88	10	0.005	2.39	50.00
CB 4	22.64	5	0.001	0.11	5.00
VAB 5	5.87	3	0.02	0.35	60.00
CB 5	11.84	5	0.001	0.06	5.00
C 3	10.80	5	0.005	0.27	25.00
CB 6	21.82	5	0.001	0.11	5.00
C 4	40.85	10	0.005	2.04	50.00
C 5	61.65	10	0.005	3.08	50.00
C 6	106.07	10	0.005	5.30	50.00
C 7	455.25	10	0.005	22.76	50.00
VAB 6	324.60	15	0.01	48.69	150.00
CB 7	217.39	5	0.007	7.61	35.00
VAB 7	253.42	16	0.012	48.66	192.00
CB 8	651.97	5	0.012	39.12	60.00
VAB 8	199.74	10	0.015	29.96	150.00
CB 9	881.25	5	0.017	74.91	85.00
VAB 9	102.57	5	0.02	10.26	100.00
CB 10	410.41	5	0.011	22.57	55.00
VAB 10	41.98	4	0.02	3.36	80.00
CB 11	160.69	5	0.005	4.02	25.00
Basalts Below 540m	155.15	10	0.005	7.76	50.00
Alluvium	118.09	12	0.12	170.05	1440.00
Total	**4577.62**			**510.34**	**111.49**

Ghod River basin: Sustainable ground water potential from phreatic aquifers

Elevation	Geology	Area (km^2)	Thickness (m)	Effective phreatic aquifer thickness (m)	Inferred Water table fluctuation (m)	Storativity	Potential aquifer storage (MCM)	Potential aquifer storage (mm)	Recharge (MCM)	Recharge (mm)
1111										
1100	VAB 1	8.88	11	11	9	0.02	1.95	220	1.60	180.00
1050	CB 1	54.91	50	5	5	0.001	0.27	5	0.27	5.00
1035	VAB 2	22.10	15	15	11	0.02	6.63	300	4.86	220.00
1025	C 1	16.15	10	10	9	0.005	0.81	50	0.73	45.00
1015	CB 2	18.42	10	5	5	0.001	0.09	5	0.09	5.00
1007	VAB 3	17.39	8	8	8	0.02	2.78	160	2.78	160.00
980	CB 3	60.30	27	5	5	0.001	0.30	5	0.30	5.00
970	VAB 4	20.29	10	10	8	0.02	4.06	200	3.25	160.00
945	C 2	47.69	25	10	8	0.005	2.38	50	1.91	40.00
933	CB 4	22.53	12	5	5	0.001	0.11	5	0.11	5.00
930	VAB 5	5.84	3	3	3	0.02	0.35	60	0.35	60.00
924	CB 5	11.78	6	5	5	0.001	0.06	5	0.06	5.00
919	C 3	10.74	5	5	5	0.005	0.27	25	0.27	25.00
909	CB 6	21.70	10	5	5	0.001	0.11	5	0.11	5.00
892	C 4	40.59	17	10	6.71	0.005	2.03	50	1.36	33.55
871	C 5	61.34	21	10	6.71	0.005	3.07	50	2.06	33.55
840	C 6	105.47	31	10	9.75	0.005	5.27	50	5.14	48.75
750	C 7	453.18	90	10	9.75	0.005	22.66	50	22.09	48.75
715	VAB 6	321.79	35	15	8.65	0.01	48.27	150	27.84	86.50
700	CB 7	213.40	15	5	5	0.007	7.47	35	7.47	35.00
684	VAB 7	253.39	16	16	9.16	0.012	48.65	192	27.85	109.92
652	CB 8	685.66	32	5	5	0.012	41.14	60	41.14	60.00
642	VAB 8	228.81	10	10	7.4	0.015	34.32	150	25.40	111.00
600	Alluvial	45.00	15	15	12	0.12	81.00	1800	64.80	1440.00
598	CB 9	900.36	44	5	5	0.017	76.53	85	76.53	85.00
593	VAB 9	102.86	5	5	5	0.02	10.29	100	10.29	100.00
565	CB 10	410.41	28	5	5	0.011	22.57	55	22.57	55.00
561	VAB 10	41.98	4	4	4	0.02	3.36	80	3.36	80.00
540	CB 11	160.69	21	5	5	0.005	4.02	25	4.02	25.00
		4363.67					**430.83**	**99**	**358.60**	**82.18**

Ghod River basin: Dynamics in groundwater storages

Geology	Groundwater stock (1st June 2016) (MCM)	Groundwater stock (1st June 2016) (mm)	Groundwater stock (1stOct 2016) (MCM)	Groundwater stock (1stOct 2016) (mm)	Groundwater stock (1stJune 2017) (MCM)	Groundwater stock (1stJune 2017) (mm)
Basalts above 1111m	0.00	0.00	0.56	10.00	0.00	0.00
VAB 1	0.02	2.50	0.50	55.00	0.02	2.50
CB 1	0.00	0.00	0.21	3.75	0.00	0.00
VAB 2	0.06	2.50	1.67	75.00	0.06	2.50
C 1	0.00	0.00	0.41	25.50	0.00	0.00
CB 2	0.00	0.00	0.07	3.75	0.00	0.00
VAB 3	0.10	5.60	0.98	56.00	0.10	5.60
CB 3	0.00	0.00	0.23	3.75	0.00	0.00
VAB 4	0.16	8.00	2.04	100.00	0.16	8.00
C 2	0.24	5.00	2.04	42.50	0.24	5.00
CB 4	0.00	0.00	0.08	3.75	0.00	0.00
VAB 5	0.12	20.00	0.35	60.00	0.12	20.00
CB 5	0.00	0.00	0.04	3.75	0.00	0.00
C 3	0.05	5.00	0.23	21.25	0.05	5.00
CB 6	0.00	0.00	0.08	3.75	0.00	0.00
C 4	0.00	0.00	1.81	44.35	0.19	4.55
C 5	0.00	0.00	2.97	48.15	0.28	4.55
C 6	0.00	0.00	4.46	42.00	0.65	6.10
C 7	1.87	4.10	21.28	46.75	0.00	0.00
VAB 6	8.00	24.66	39.34	121.20	1.27	3.90
CB 7	1.23	5.67	5.17	23.80	0.32	1.47
VAB 7	4.96	19.56	31.66	124.92	3.41	13.44
CB 8	3.83	5.88	34.66	53.16	3.44	5.28
VAB 8	3.72	18.60	26.72	133.80	4.70	23.55
CB 9	12.58	14.28	69.96	79.39	9.14	10.37
VAB 9	1.25	12.20	8.60	83.80	0.00	0.00
CB 10	2.62	6.38	18.96	46.20	1.67	4.07
VAB 10	0.32	7.60	2.69	64.00	0.50	11.80
CB 11	0.42	2.60	3.44	21.40	0.30	1.85
Basalts Below 540m	0.78	5.00	6.98	45.00	0.78	5.00
Alluvial	0.00	0.00	141.71	1200.00	0.00	0.00
Total	**42.33**	**9.25**	**429.89**	**93.91**	**27.38**	**5.98**

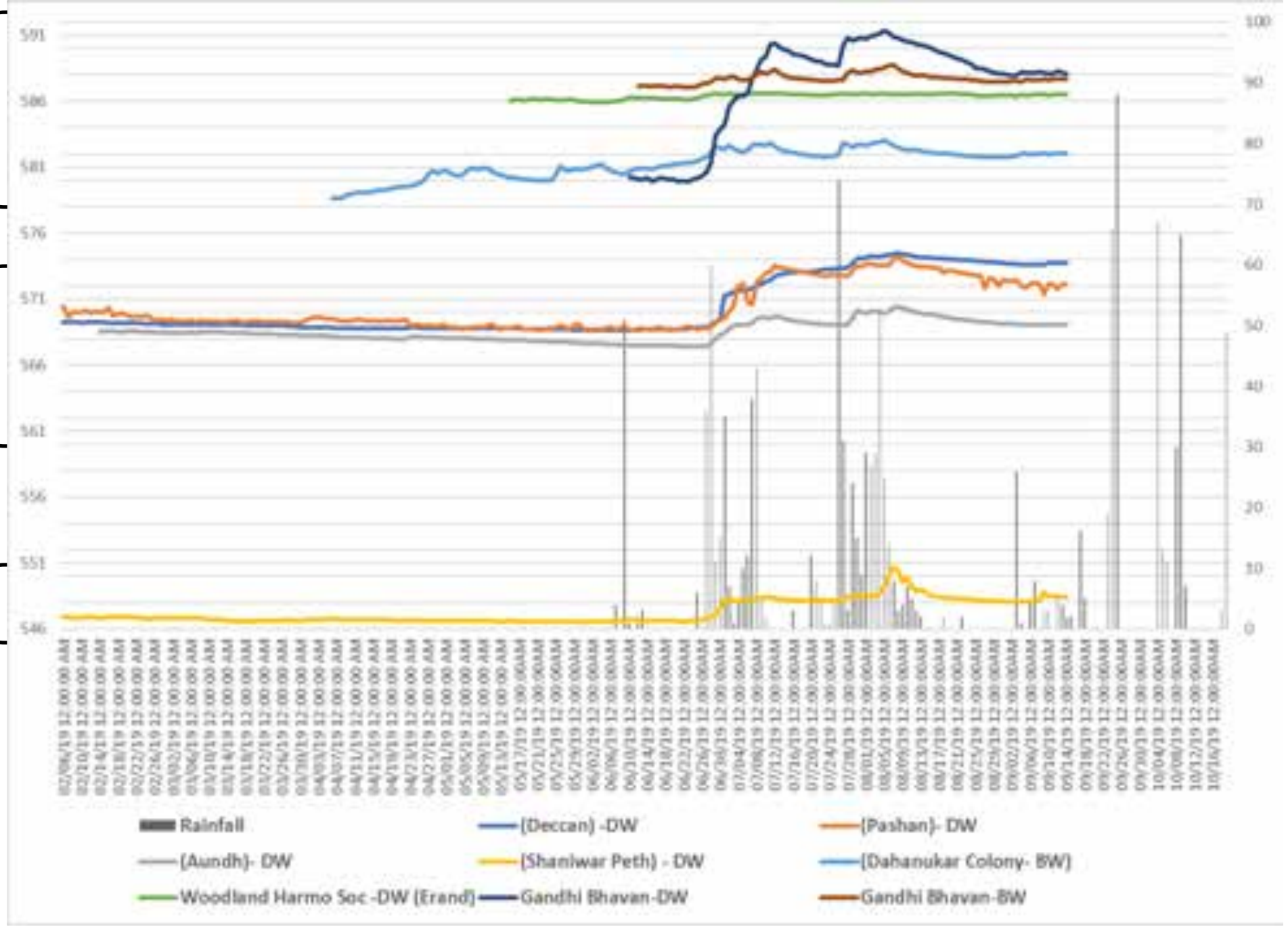
Pune city area: sustainable potential aquifer stocks

Geology	Area (km2)	Thickness	Effective **phreatic** aquifer thickness (m)	Storativity	Potential aquifer storage (m3)	Potential aquifer storage (TMC)	Potential aquifer storage (mm)
CB-1	1.37			0.003	0	0.0000	0
VAB-1	0.26	16	12	0.020	61,273	0.0022	240
CB-2	0.32	14	8	0.005	12,856	0.0005	40
VAB-2	0.49	14	11	0.015	80,114	0.0028	165
CB-3	0.19	4	1.5	0.006	1,687	0.0001	9
VAB-3	0.29	6	4	0.010	11,748	0.0004	40
CB-4	0.90	12	5	0.004	17,946	0.0006	20
VAB-4	0.87	7	4.5	0.010	39,301	0.0014	45
CB-5	2.28	19	9.5	0.005	108,083	0.0038	48
VAB-5	1.13	1	0.6	0.013	8,791	0.0003	8
CB-6	2.37	11	5	0.005	59,240	0.0021	25
VAB-6	1.71	5	3.5	0.010	59,854	0.0021	35
CB-7	3.85	9	4	0.006	92,486	0.0033	24
VAB-7	4.31	5	2.5	0.013	140,144	0.0049	33
CB-8	4.20	5	1	0.005	21,846	0.0008	5
VAB-8	4.59	5	3	0.010	137,842	0.0049	30
CB-9	8.69	10	4.5	0.005	175,908	0.0062	20
VAB-9	4.02	5	3.5	0.020	281,598	0.0099	70
CB-10	3.29	4	2.5	0.005	41,128	0.0015	13
VAB-10	7.20	9	5	0.019	683,775	0.0241	95
CB-11	3.92	4	1.5	0.005	31,775	0.0011	8
VAB-11	4.76	5	1.5	0.015	107,108	0.0038	23
CB-12	3.42	1	0.45	0.006	8,782	0.0003	3
VAB-12	7.07	7	4	0.020	565,469	0.0200	80
CB-13	8.12	6	3	0.006	151,073	0.0053	19
VAB-13	12.18	8	4	0.015	730,927	0.0258	60
CB-14	28.68	11	4.5	0.006	774,321	0.0273	27
VAB-14	46.81	13	9	0.020	8,426,226	0.2976	180
CB-15	13.56	3	1	0.004	54,241	0.0019	4
VAB-15	56.78	13	8	0.020	9,084,738	0.3208	160
CB-16	15.11	4	1.4	0.005	105,773	0.0037	7
VAB-16	8.51	4	2	0.025	425,338	0.0150	50
CB-17	7.71	10	4.5	0.004	138,861	0.0049	18
	268.97				**22,640,253**	**0.80**	**84**

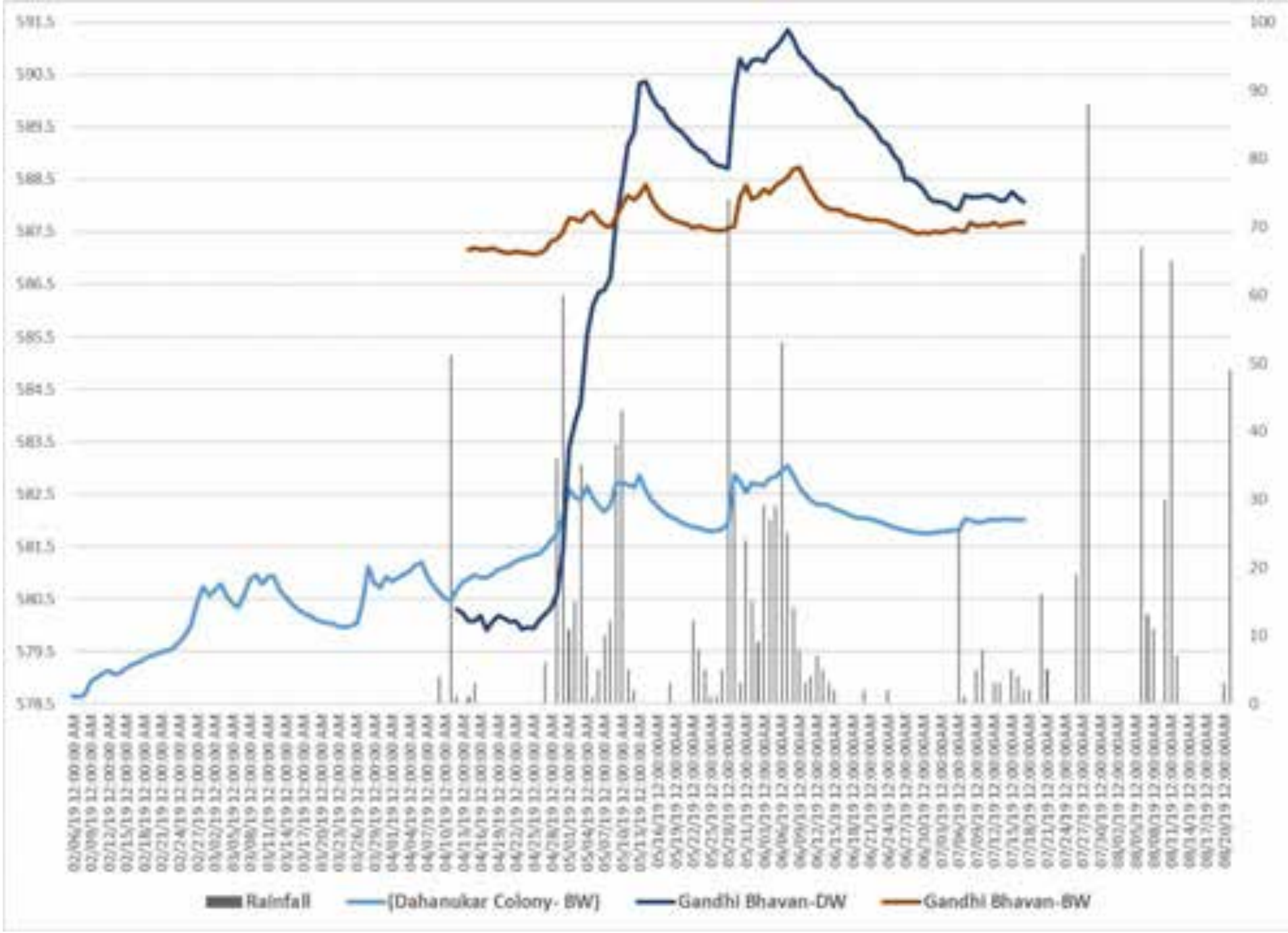
AQUIFER - 3

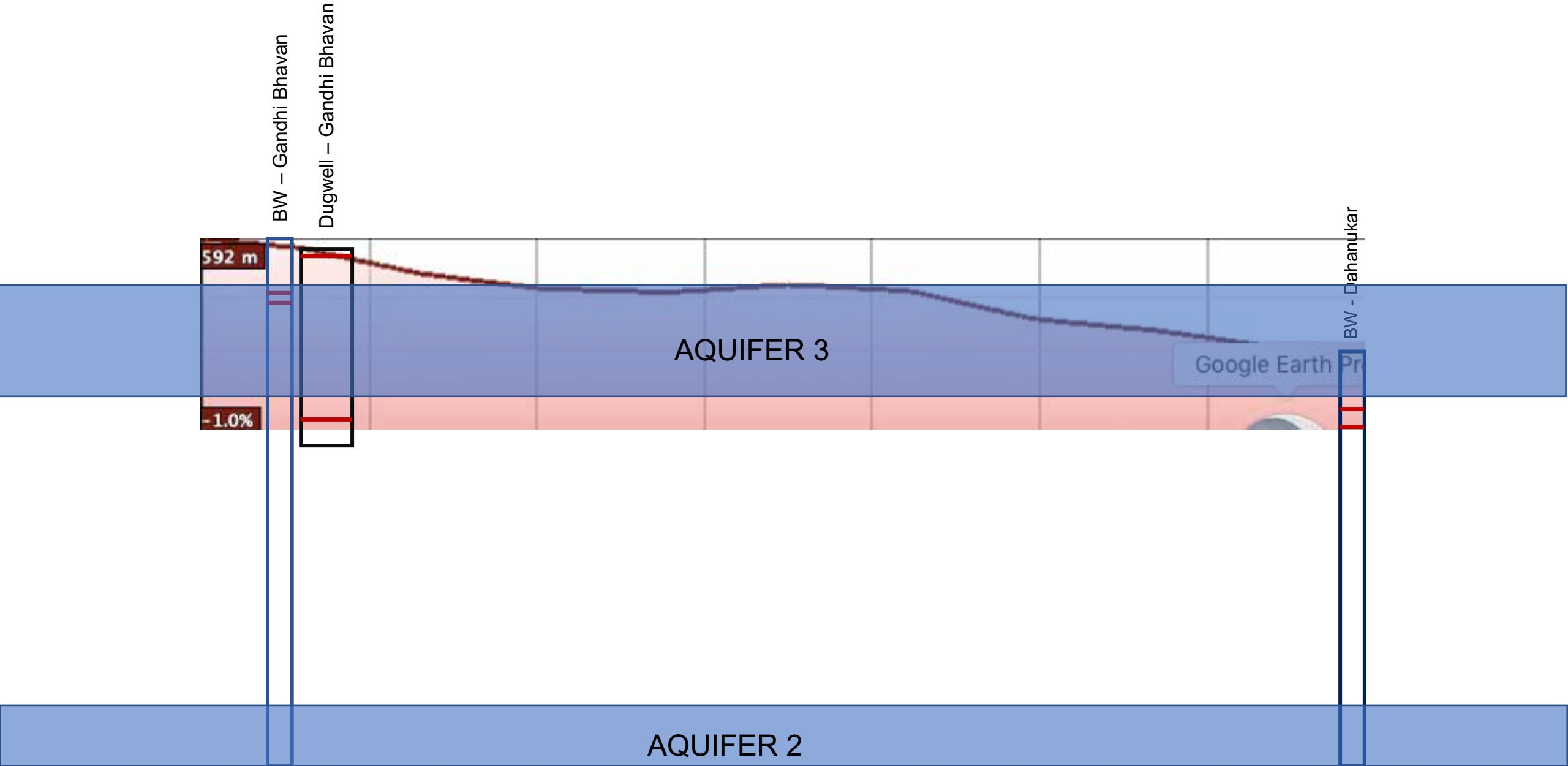
AQUIFER - 2

AQUIFER - 1



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

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Urban Groundwater Management

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 must have precedence over individual (privatised) 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

ACWADAM

Advanced Center for Water Resources Development and Management (ACWADAM)

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