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Urban water crises driven by elites' unsustainable consumption

In the format provided by the
authors and unedited

Supplementary material

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Supplementary Table 1| Global water crises: summary of media sources accessed to document urban water crises across the World.

City	Media outlets
Multiple cities	https://www.bbc.com/news/world-42982959
	https://www.circleofblue.org/2019/wef/the-next-urban-water-crisis-inadequate-data-clouds-the-forecast/
Barcelona, Spain	https://www.theguardian.com/world/2008/may/14/spain.water
Rome, Italy	https://www.bbc.com/news/world-europe-41081066
Istanbul, Turkey	https://www.theguardian.com/world/2021/jan/13/turkey-drought-istanbul-run-out-water-45-days
Maputo, Mozambique	https://www.theguardian.com/environment/2018/apr/22/mozambique-prays-for-rain-water-shortages-hit-poor-maputo-southern-africa-drought
Harare, Zimbabwe	https://www.voanews.com/a/africa_zimbabwe-struggles-provide-clean-water-during-pandemic/6194962.html
	https://www.theguardian.com/global-development/2020/oct/28/we-are-drinking-sewage-water-zimbabwe-shortages-threaten-thousands
Sao Paulo, Brazil	https://www.nytimes.com/2015/02/17/world/americas/drought-pushes-sao-paulo-brazil-toward-water-crisis.html
	https://www.circleofblue.org/2014/world/sao-paulo-faces-severe-water-shortage/
Mexico City, Mexico	https://www.theguardian.com/cities/2015/nov/12/mexico-city-water-crisis-source-sewer
	https://www.bbc.com/future/article/20180510-how-a-city-that-floods-is-running-out-of-water
Jakarta, Indonesia	https://www.urbanet.info/jakartas-pandemic-water-stress-hitting-the-economy-and-the-urban-poor/
Beijing, China	https://www.circleofblue.org/2018/water-management/infrastructure/water-stressed-beijing-exhausts-its-options/
Bangalore, India	https://www.thebetterindia.com/235506/bengaluru-running-out-of-groundwater-2020-scarcity-niti-aayog-rooftop-harvesting-cauvery-river-reservoirs-ser106/
	https://bangaloremirror.indiatimes.com/bangalore/others/scientists-warn-of-acute-water-shortage-in-bengaluru/articleshow/85504971.cms
Chennai, India	https://www.theguardian.com/world/2019/jun/28/our-whole-life-is-disrupted-hope-dries-up-as-chennai-battles-historic-drought
Sydney, Australia	https://www.ecowatch.com/sydney-water-shortage-2641353372.html
	https://www.smh.com.au/politics/nsw/sydney-s-water-supply-unable-to-cope-with-population-growth-drought-20200623-p555ao.html

https://www.reuters.com/article/us-australia-drought-idUSKCN1V60FP

Supplementary Table 2| Socio-economic features and characterization of the city's main social groups[1–4].

	HOUSEHOLD MONTLHY INCOME	PERSONS PER HOUSEHOLD	PUBLIC WATER DEMAND	WATER DEPENDENT AMENITIES	PRIVATE WATER SOURCES
ELITE (1,4%)	More than 102.400 Rands (6.350 Euro)	1-8	- Multiple taps and toilets - Frequent showers - Frequent laundry	- Garden - Swimming pool - Multiple cars	YES
UPPER-MIDDLE INCOME (12,3%)	Less than 102.400 Rands (6.350 Euro)	1-8	- Multiple taps and toilets - Frequent showers - Frequent laundry	- Garden - Swimming pool - Multiple cars	YES
LOWER-MIDDLE INCOME (24,8%)	Less than 25.600 Rands (1.580 Euro)	1-8	- Few taps and toilets - Frequent showers - Frequent laundry	- Communal garden - One or no car	MOSTLY NO
LOWER INCOME (40,5%)	Less than 6.400 Rands (395 Euro)	1-16	- One tap and toilet - 1 shower per week - 1 laundry per week	NO	NO
INFORMAL DWELLERS (21 %)	Less than 1.600 Rands (99 Euro)	1-4	- No taps, No toilet - 1 shower per week - 1 laundry per week	NO	NO

Supplementary Table 3| Summary of the state variables and fluxes, where E, UM, LM, LI, ID indicate Elite, Upper Middle income, Lower Middle income, Lower income, and Informal dwellers, respectively. Variables without references result from authors' assumptions.

Name	Description	Initial value	Units
V	Reservoir storage[6]	$7.2 \cdot 10^8$	m^3
Q^I	Observed monthly reservoir inflow[7]	$1.3 \cdot 10^6$	m^3/s
Q^E	Environmental flow[7]	$8.2 \cdot 10^4$	m^3/s
ET	Losses to evapotranspiration[7]	$6.4 \cdot 10^6$	m^3/s
W	Water withdrawals	0	m^3/s
Q^S	Reservoir spillway release	0	m^3/s
V_{MAX}	Maximum reservoir storage[6]	$8.9 \cdot 10^8$	m^3
Pu	Public water demand	$1.4 \cdot 10^7$	
T	Average monthly temperature	21	C
B	Water for basic needs (E, UM, LM, LI, ID)[8]	39.1–27–12–9–1.2	m^3/HH/mo
A	Drought awareness	0	-
R	Restriction level	0	-
C	Water costs (E, UM, LM, LI, ID) [9]	$1.8 \cdot 10^3$–752.5–166.2–78.8–0	South African rand/mo
M	Water amenities (E, UM, LM, LI, ID)[3,4]	37.6–13.5–1.3–0–0	m^3/HH/mo
TW	Total water use[3,4] (E, UM, LM, L, I)	76.7–40.5–13.3–9–1.2	m^3/HH/mo

Supplementary Table 4| Summary of the model parameters where E, UM, LM, LI, ID indicate Elite, Upper Middle income, Lower Middle income, Lower income, and Informal dwellers, respectively. Parameters without references result from authors' assumptions.

	Description	E	UM	LM	LI	ID	Units
K_P	Hedging release slope[10]			3			-
α_D	Decay rate of changes in basin needs consumptions[11]			0.15			1/mo
B_{min}	Minimum per-capita basic water needs	10.5	4.5	1.2	1.2	1.2	m^3/HH/mo
B_{max}	Maximum per-capita basic water needs	39.1	27	12	9	1.2	m^3/HH/mo
M_{min}	Minimum per-capita amenities water needs	30.1	10.8	1.0	0	0	m^3/HH/mo
μ_D	Decay of drought awareness over time[10]			0.1			1/mo
I	Mean income of the social group[4]	$1.2 \cdot 10^5$	$6.4 \cdot 10^4$	$1.4 \cdot 10^4$	1600	0.5	South African rand/mo
ε_W	Average water demand for swimming pool[12]			2.5			m^3/mo
δ^S	Percentage of households with swimming pool[13]	1	0.5	0.05	0	0	-
ε_G	Percentage of water use for gardening[14]	0.5	0.3	0.05	0	0	
ε_C	Average water demand for car cleaning	0.4	0.2	0.15	0	0	m^3
χ	Average number of cars in the household	5	2	1	0	0	-
η	Number of times per month for car cleaning	4	1	1	0	0	-
α_M	Decay rate of changes in amenities[15]			0.01			1/mo
d	Normalized average distance to the private water sources	0.01	0.2	0.5	0.8	1	-
c	Convenience of using private water use	1	0.8	0.5	0.2	0	-
HH	Total number of households[1]	0.15	1.31	2.7	4.3	2.3	10^5

Supplementary Table 5| Restriction level based on the different values of reservoir storage[5]

Reservoir storage	Restriction level, R
0.75 $V_{MAX} \leq V < 0.5\ V_{MAX}$	1
0.5 $V_{MAX} \leq V < 0.45\ V_{MAX}$	2
0.45 $V_{MAX} \leq V < 0.4\ V_{MAX}$	3
0.4 $V_{MAX} \leq V < 0.35\ V_{MAX}$	4
0.35 $V_{MAX} \leq V < 0.3\ V_{MAX}$	5
0.3 $V_{MAX} \leq V < 0.25\ V_{MAX}$	6
0.25 $V_{MAX} \leq V < 0.2\ V_{MAX}$	7
0.2 $V_{MAX} \leq V$	8

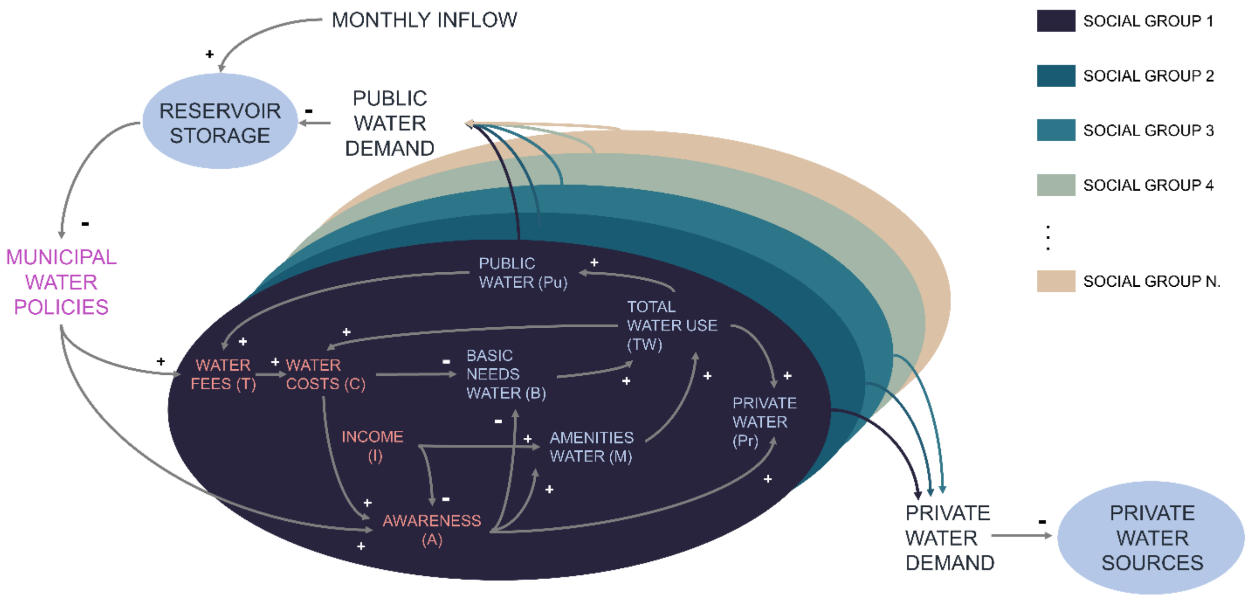
Supplementary Table 6| Monthly water tariff values depending on public water use Pu and restriction levels. Tariffs are expressed in South African Rand6 per m3, excluding VAT (14%)

Restr. Level, R	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
$\mathbf{0 \leq Pu < 6}$	0	0	0	0	0	4	4	4	26.25
$\mathbf{6 \leq Pu < 10.5}$	8.75	10.22	14.51	14.51	14.51	15.57	15.57	15.57	46
$\mathbf{10.5 \leq Pu < 20}$	12.54	16	20.65	20.65	20.65	22.78	22.78	22.78	100
$\mathbf{20 \leq Pu < 35}$	18.58	26.09	35.93	35.93	35.93	38.32	38.32	38.32	300
$\mathbf{35 \leq Pu < 50}$	22.94	39.82	38.32	38.32	38.32	99.99	99.99	99.99	800
$\mathbf{50 \leq Pu}$	30.27	74.64	300	300	300	265.12	265.12	265.12	800

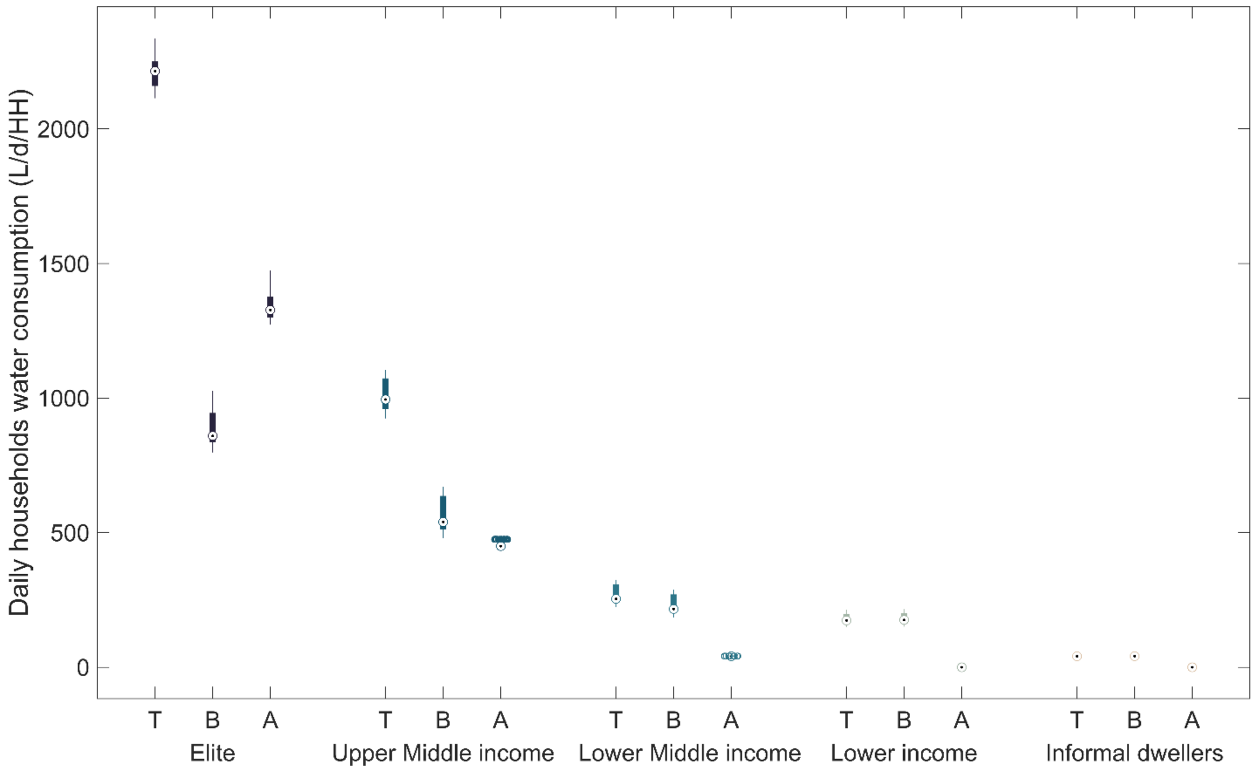
Supplementary Table 7 Changes in the variables of inflow, temperature, number of households, income and water needs for each scenario. where E, UM, LM, LI, ID indicate Elite, Upper Middle income, Lower Middle income, Lower income, and Informal dwellers, respectively

	Baseline	**Population growth**	**Climate change**	**Increased consumption by privileged groups**	**Equal and sustainable consumption**
Inflow Q^I [m^3/mo]	-	-	Linear decrease annual 10% Source: Cook et al.[46]	-	-
Temperature *T* [C]	-	-	+2°C Source: UNFCCC[45]	-	-
Households *HH* [-]	-	Linear increase annual 2% Source: Stassa[44]	-	-	-
Initial basic needs *B* [m^3/mo/HH]	-	-	-	E +80% UM: +40% LM: +20% LI: +0% ID: +0%	All classes consume the same basic needs water than LM
Initial amenities *M* [m^3/mo/HH]				E +80% UM: +40% LM: +20% LI: +0% ID: +0%	No amenities
Mean Income *I* [Rand/mo]	-	-	-	E +60% UM: +30% LM: +0% LI: -10% ID: -30%	All classes have same main income than LM

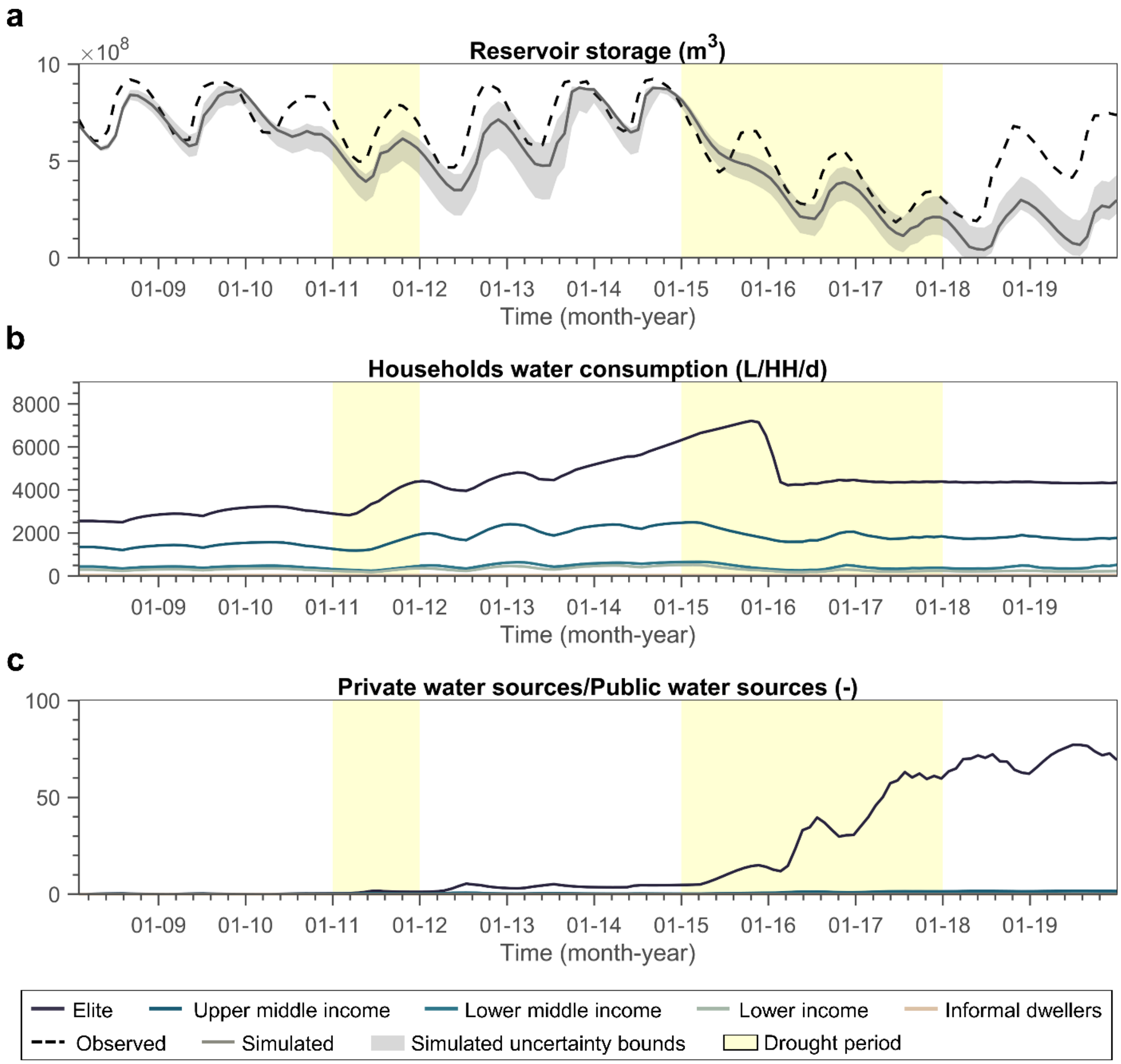
Figures



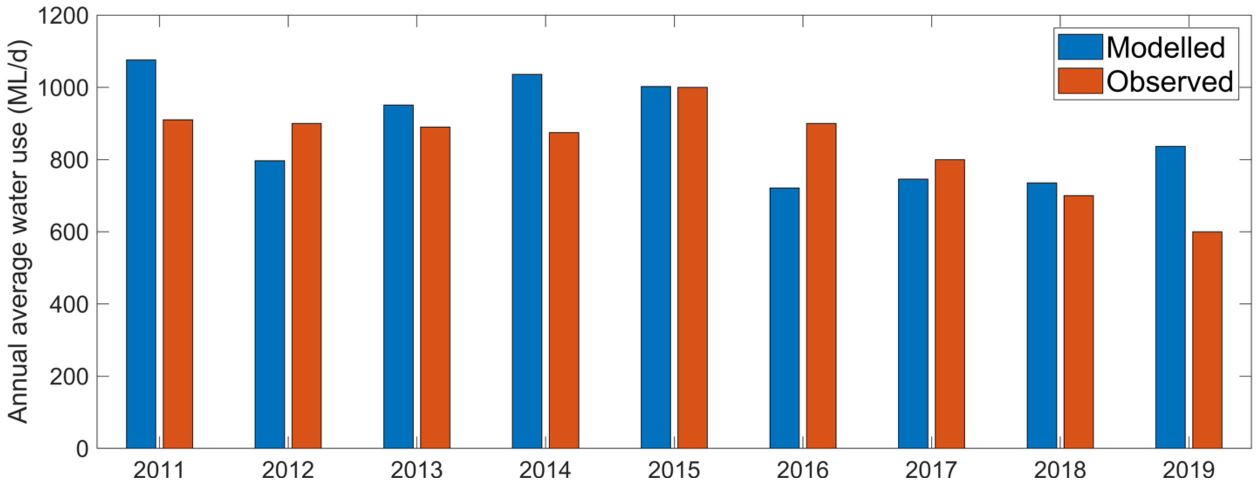
Supplementary Fig.1| Causal loop representing the uneven urban water interplay within a city. Each social group is represented by an elliptic of different colour. Each elliptic includes a number of variables and causal relationships that represent the socioeconomic characteristics and determine water consumption behaviour of a household. The variables of each elliptic or social group maintain specific parameters and coefficients to mark socioeconomic characteristics and behaviours. Moreover, the figure shows the relationships between each elliptic or social group and the urban water systems, represented by reservoirs storage (public water sources) and private water sources.



Supplementary Fig. 2| Results of the sensitivity analysis expressed in terms of daily household's consumption in terms of total (T), basin (B), and amenities (A). The analysis is performed by randomly perturbing the decay rate of drought awareness by 80% of the initial value of each social group. A total of 10000 simulations is carried out. Each single boxplot shows the median (white circle), and the 25th and 75th percentiles (bottom and top edges of the box) of the ensemble data.



Supplementary Fig. 3| Results of the structural validity test in which the model parameters K_P, α_D, B_{min}, B_{max}, M_{min}, μ_D, α_M are assumed to be three times their original value. This test is performed to assess model capability to represent model conditions. The uncertainty bounds and simulated value are representative of the 5th, 95th, and median, respectively, of the 10^5 simulated reservoir storage obtained by perturbing the model parameters by 30% of their assigned value..



Supplementary Fig. 4| Results of the behaviour validity test. Comparison of observed values of annual average water consumption [ML/d] with the model simulation between 2011-2019.

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