

Since 1959



Science, technology and innovation for sustainable clean water

T. Pradeep

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<https://pradeepresearch.org>

Co-founder

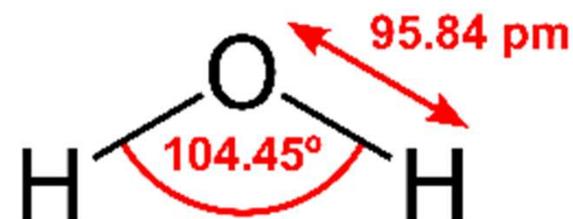
InnoNano Research Pvt. Ltd. 001
InnoDI Water Technologies Pvt. Ltd.
VayuJAL Technologies Pvt. Ltd.
Aqueasy Innovations Pvt. Ltd.
Hydromaterials Pvt. Ltd.
EyeNetAqua Solutions Pvt. Ltd.
DeepSpectrum Innovations Pvt. Ltd.

Professor-in-charge



International Centre for Clean Water

Prof. Umesh Waghmare, President
Mr. N. Maheshchandra, Executive Secretary



National Science Day Lecture, Indian Academy of Sciences, Bengaluru, February 28, 2022



Earthrise, taken on December 24, 1968, by Apollo 8 astronaut William Andres.

Nature photographer Galen Rowell declared it "the most influential environmental photograph ever taken".



① 7

WORLDS IN THE MAKING

THE EVOLUTION OF THE UNIVERSE

BY
SVANTE ARRHENIUS
DIRECTOR OF THE PHYSICO-CHEMICAL NOBEL
INSTITUTE, STOCKHOLM

TRANSLATED BY
DR. H. BORN

ILLUSTRATED



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NEW YORK AND LONDON
HARPER & BROTHERS PUBLISHERS
MCMVIII

Water is the most important inheritance of our planet

“Pale blue dot” Voyager 1 Feb. 14, 1990

The truth

Water is the simplest and simultaneously the most complex problem of humanity.

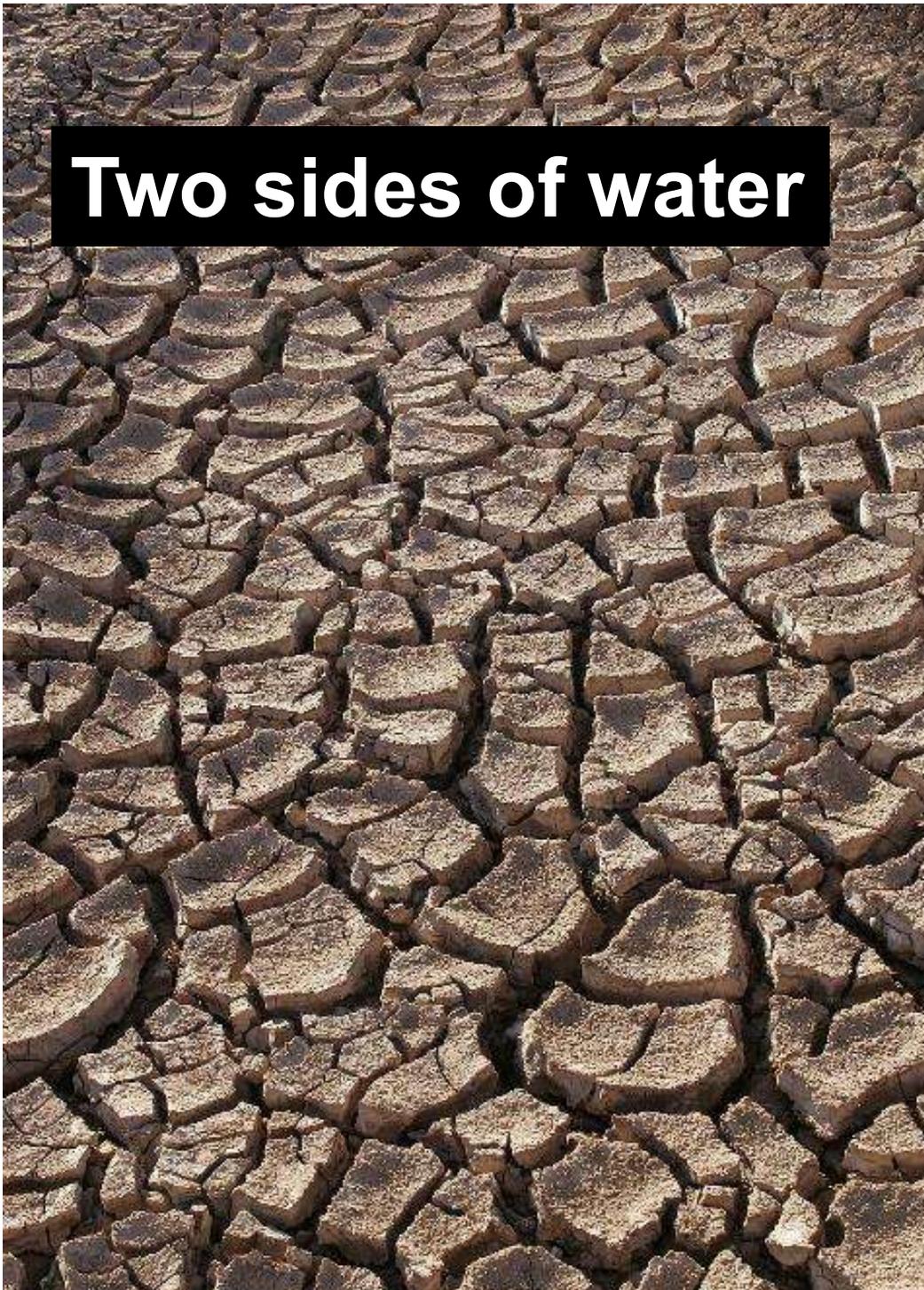
Our economic, social and cultural outcomes can be traced to water.

Everything simplifies to water.

There is water in everything we do.



Two sides of water



© Tomas Castelazo, www.tomascastelazo.com / [Wikimedia Commons](https://commons.wikimedia.org/wiki/File:Desert_cracks.jpg)
Dry ground in the Sonoran Desert, Sonora, Mexico.

Kerala Floods, August 16, 2018, Wiki

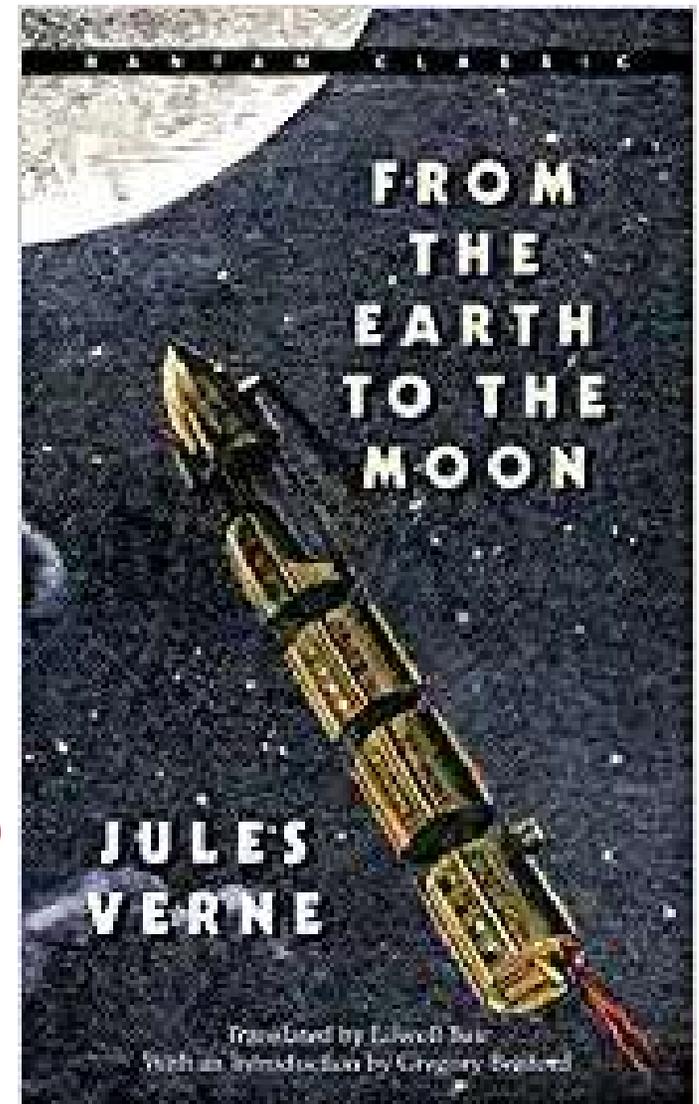
Our dreams become reality with materials

1 kW PV panels @ Rs. 35-45,000

150 Ah rechargeable solar battery @ Rs.18,500

Seawater desalination for 1 CM water @ 2.4 kW, or Rs. 40-50

Green hydrogen-driven seawater desalination - 1 paisa per litre by 2030?



Some calculation

Hydrogen + Oxygen → Water + 286,000 joules of energy per mole

1 kg of solar hydrogen is now at Rs. 600 and could be Rs. 150 soon.

It can make 143,000,000 J of energy.

Desalination needs 2.4 kWh or 8,640,000 joules for 1 cubic meter of drinking water.

1 kg of hydrogen can therefore make 16.56 cubic meter water.

Or Rs. 9.06 per cubic meter, 0.9 paise per litre!

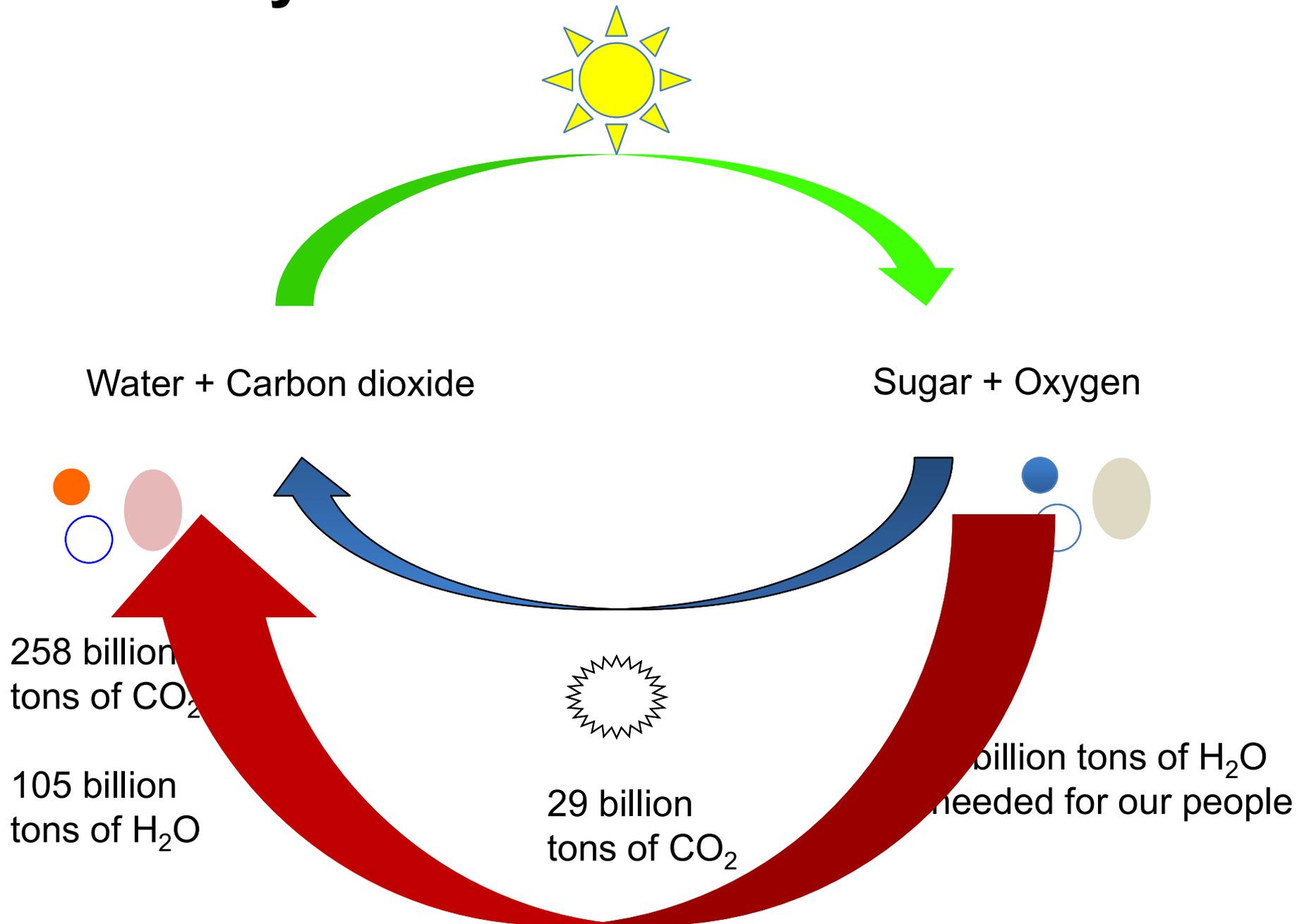
Well, add efficiency, other costs of plant, transportation, etc.



The truth

Water cycle is
NetZero – we have
opened the cycle

Circularity and threats



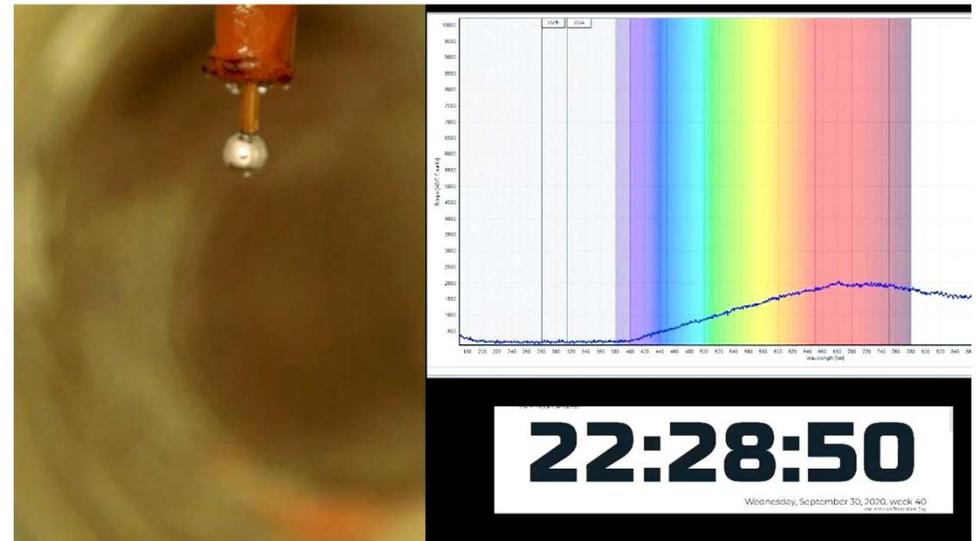
Water continues to fascinate science

Elastic ice



Xu, P. *et al.*, *Science*, **2021**, 373, 187–192

Metallic water



Mason, P. E. *et al.*, *Nature*, **2021**, 595, 673–676

Water is big and India is safe

1.386 billion km³ ($\sim 1.4 \times 10^{18}$ tons)
2.5% is freshwater and 0.3% surface water

Total precipitation – 505,000 BCM

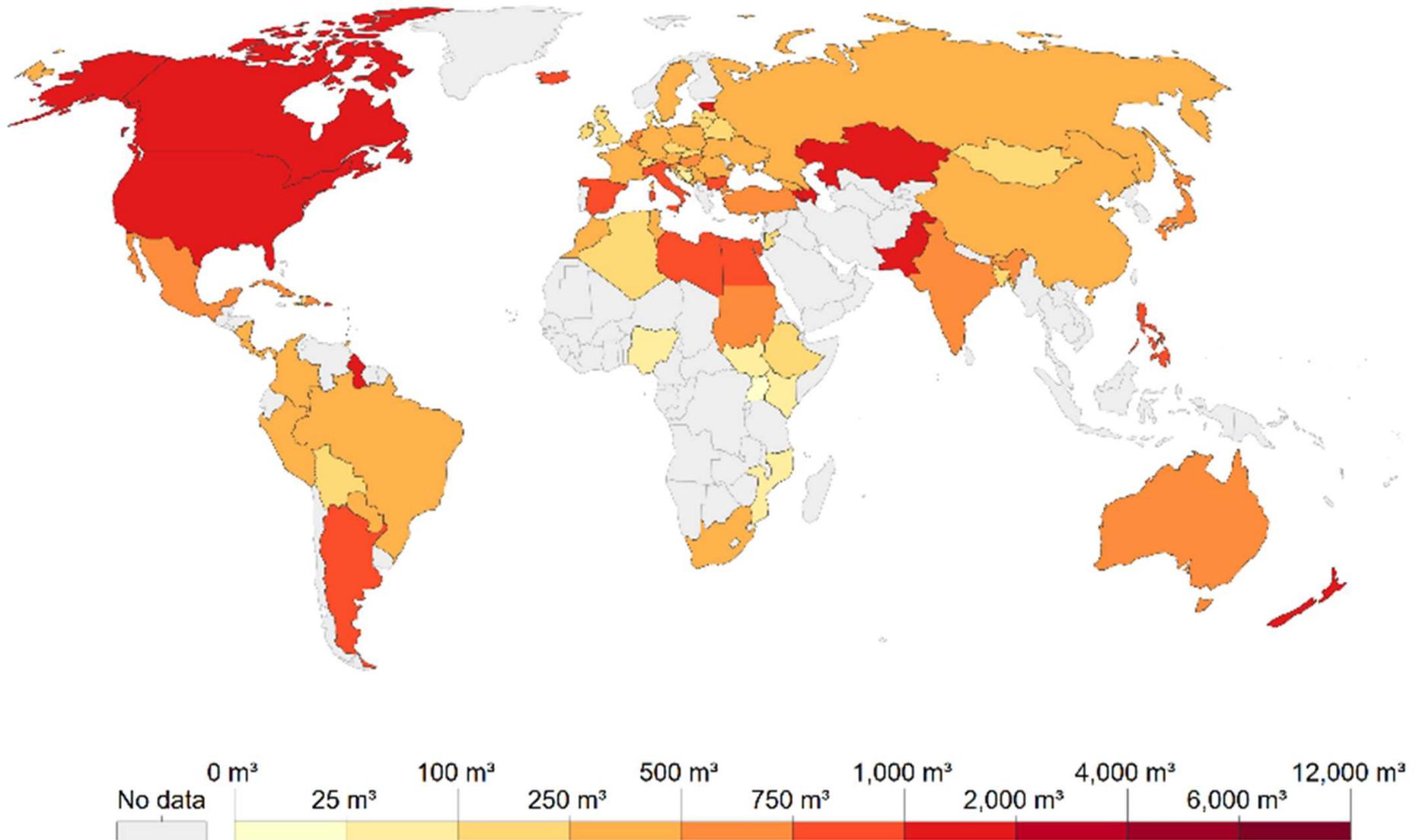
India – 4000 BCM, geographical area 328.7 million hectare

Per capita water availability – 1500 CM

Average rainfall 1085 mm, 85th in a list of 186 countries with Egypt at 51 mm at the bottom and Columbia at 3240 mm at the top (2014)

Water is big in every scale – Gaps, opportunities, wealth, satisfaction

Water withdrawals per capita, 2015



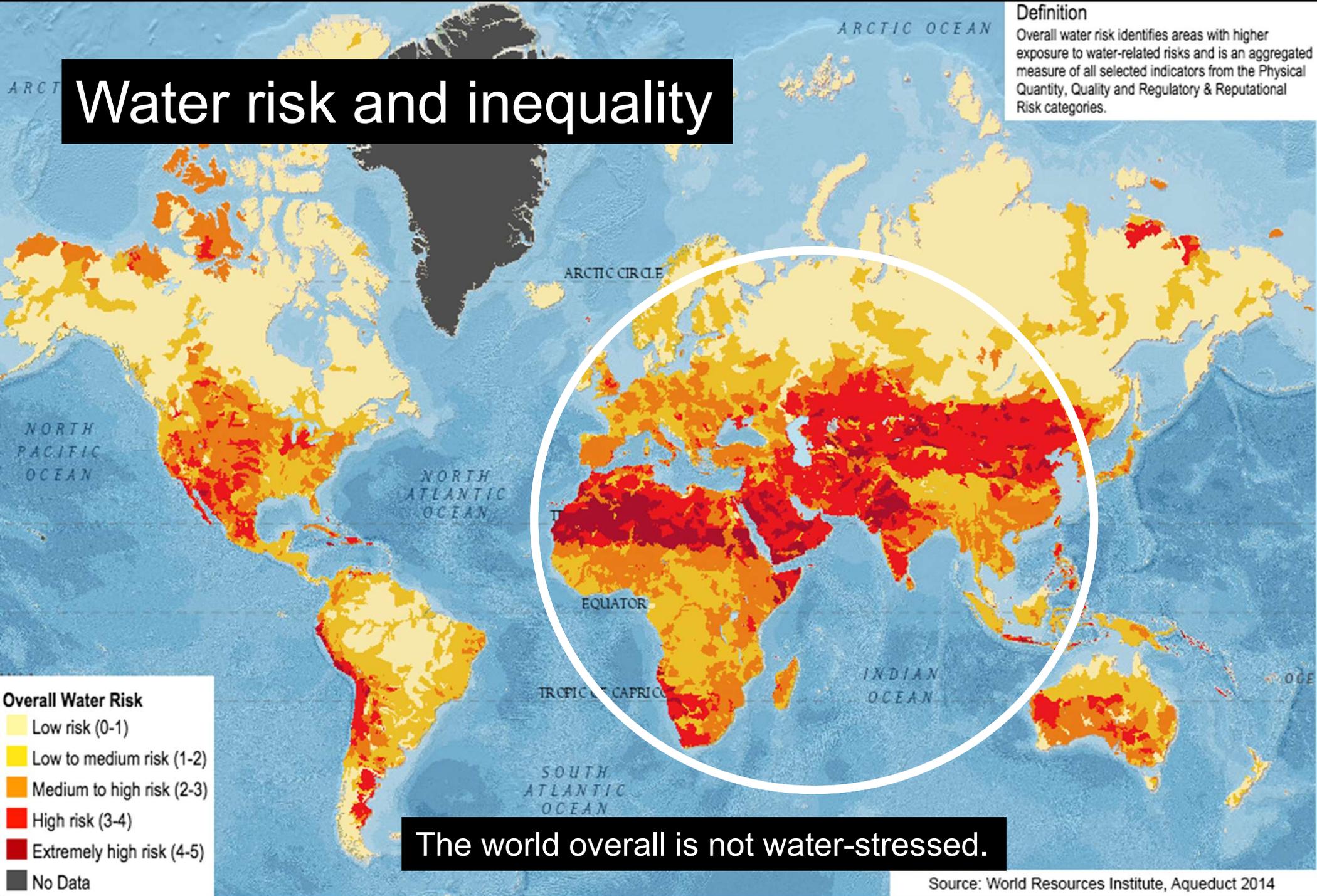
Source: UN Food and Agricultural Organization (FAO) AQUASTAT

OurWorldInData.org/water-access-resources-sanitation/ • CC BY

Water risk and inequality

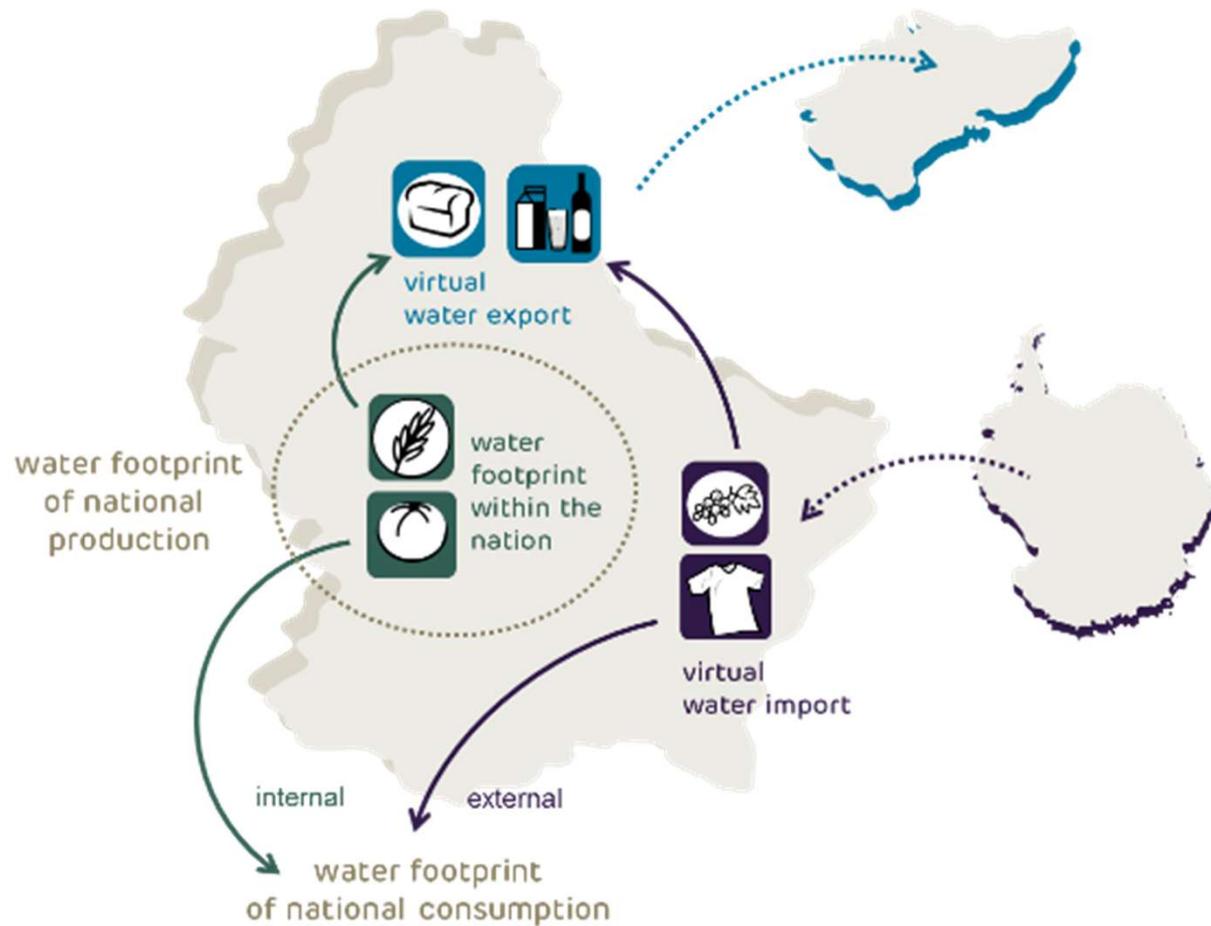
Definition

Overall water risk identifies areas with higher exposure to water-related risks and is an aggregated measure of all selected indicators from the Physical Quantity, Quality and Regulatory & Reputational Risk categories.



The world overall is not water-stressed.

Water footprint: Production and consumption



Water cost in products and services

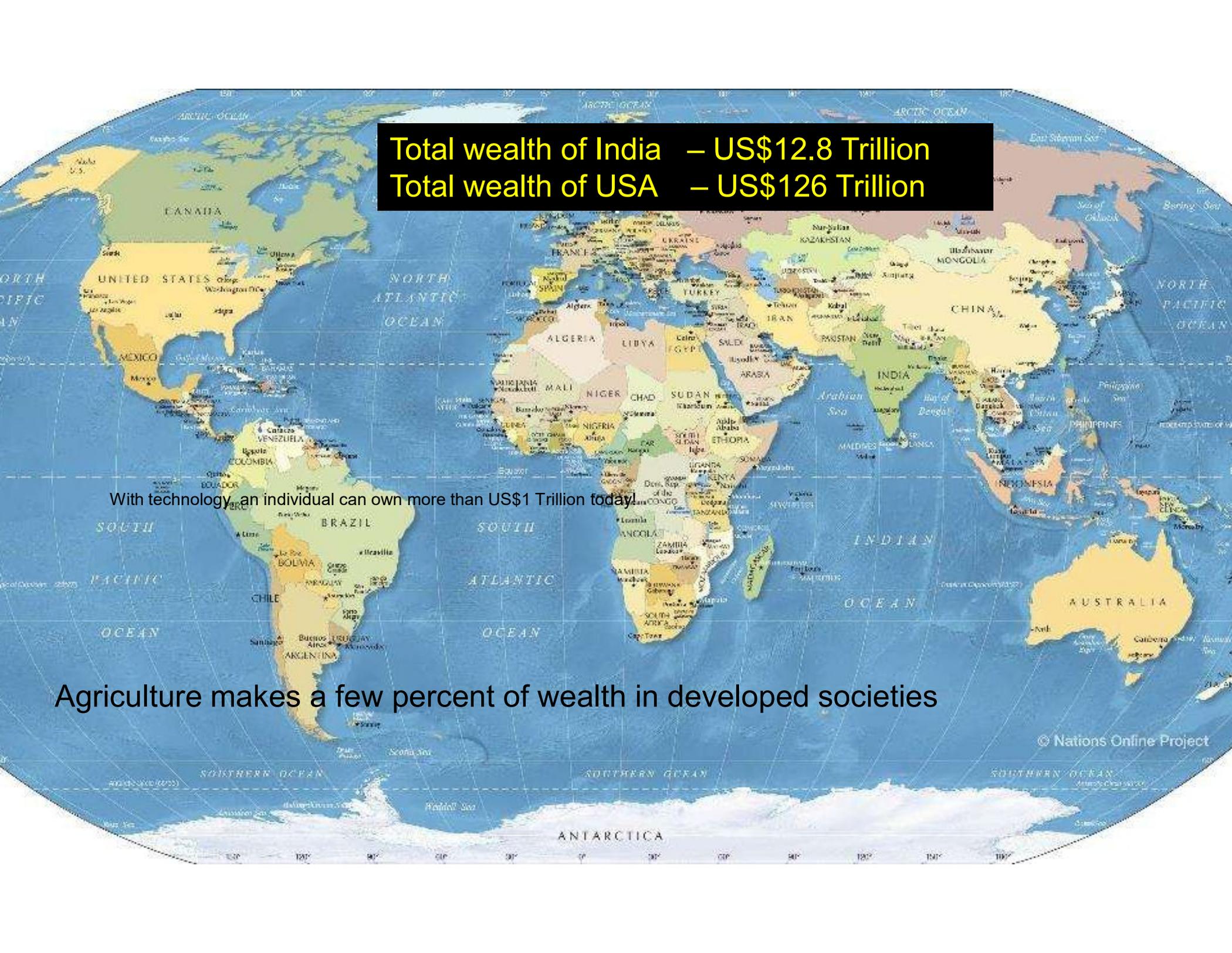
<https://waterfootprint.org/en/water-footprint/national-water-footprint/>

Water, sanitation and inequality

Assuming that investments for water supply and wastewater management are similar in magnitude, the total water infrastructure value for a connected global population of 9 billion people would amount to about US\$60 trillion (M. Maurer, D. Rothenberger, T. A. Larsen, Water Sci. Technol. 5, 145–154 (2006))

A modeling study based on past investment patterns estimated that even on the most optimistic assumptions, only 36% of the African population and 44% of the Asian population will be connected to a sewer network by 2050.

G. Van Drecht, A. F. Bouwman, J. Harrison, J. M. Knoop, Global Biogeochem. Cycles 23, GB0A03 (2009). doi:10.1029/2009GB003458

A world map showing the continents and oceans. A black rectangular box is overlaid on the map, containing yellow text. The text compares the total wealth of India and the USA. The map also has other text overlays: 'With technology, an individual can own more than US\$1 Trillion today!' in the lower-left and 'Agriculture makes a few percent of wealth in developed societies' in the lower-center. The map includes labels for major oceans, seas, and countries.

Total wealth of India – US\$12.8 Trillion
Total wealth of USA – US\$126 Trillion

With technology, an individual can own more than US\$1 Trillion today!

Agriculture makes a few percent of wealth in developed societies



SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD

1 NO POVERTY

2 ZERO HUNGER

3 GOOD HEALTH AND WELL-BEING

4 QUALITY EDUCATION

5 GENDER EQUALITY

6 CLEAN WATER AND SANITATION

7 AFFORDABLE AND CLEAN ENERGY

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

10 REDUCED INEQUALITIES

11 SUSTAINABLE CITIES AND COMMUNITIES

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

14 LIFE BELOW WATER

15 LIFE ON LAND

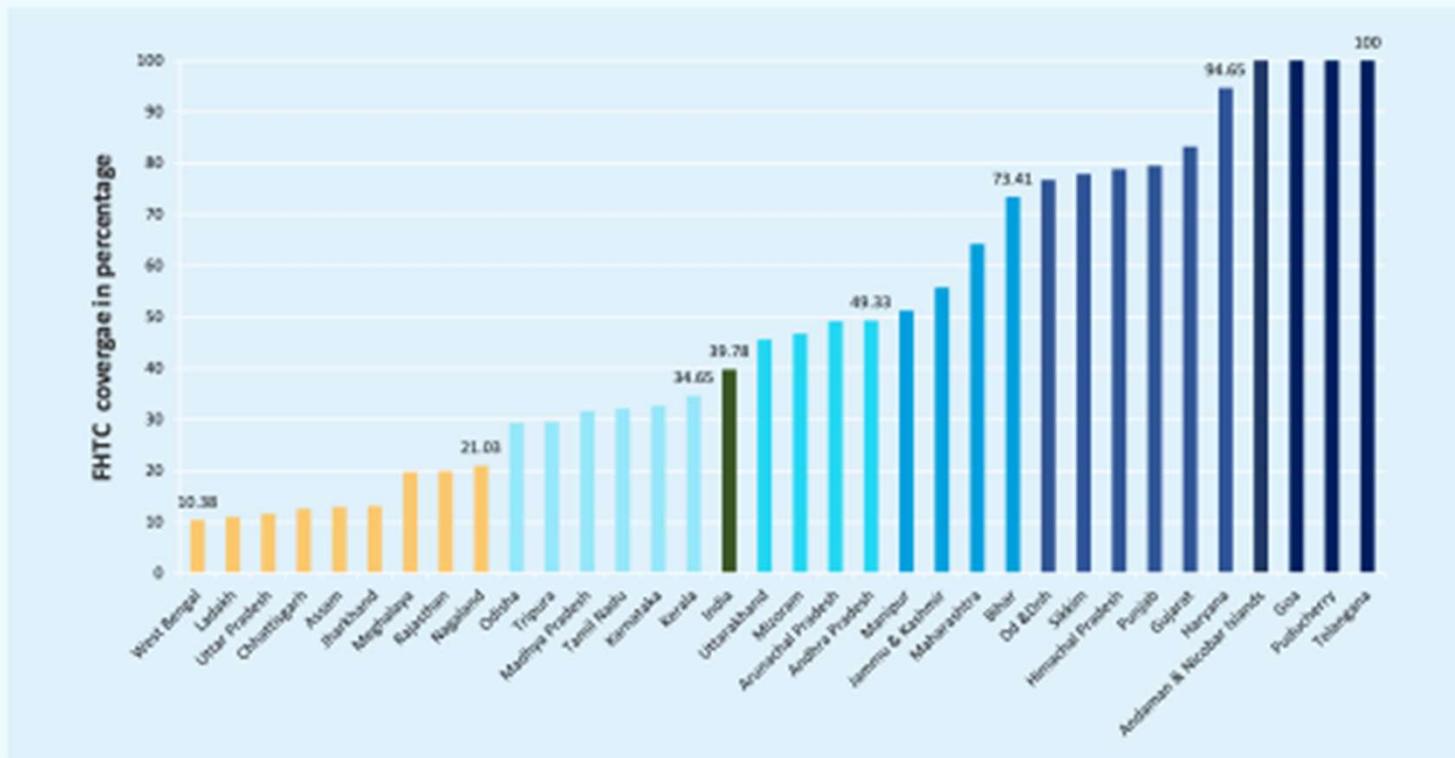
16 PEACE, JUSTICE AND STRONG INSTITUTIONS

17 PARTNERSHIPS FOR THE GOALS

17 SUSTAINABLE DEVELOPMENT GOALS

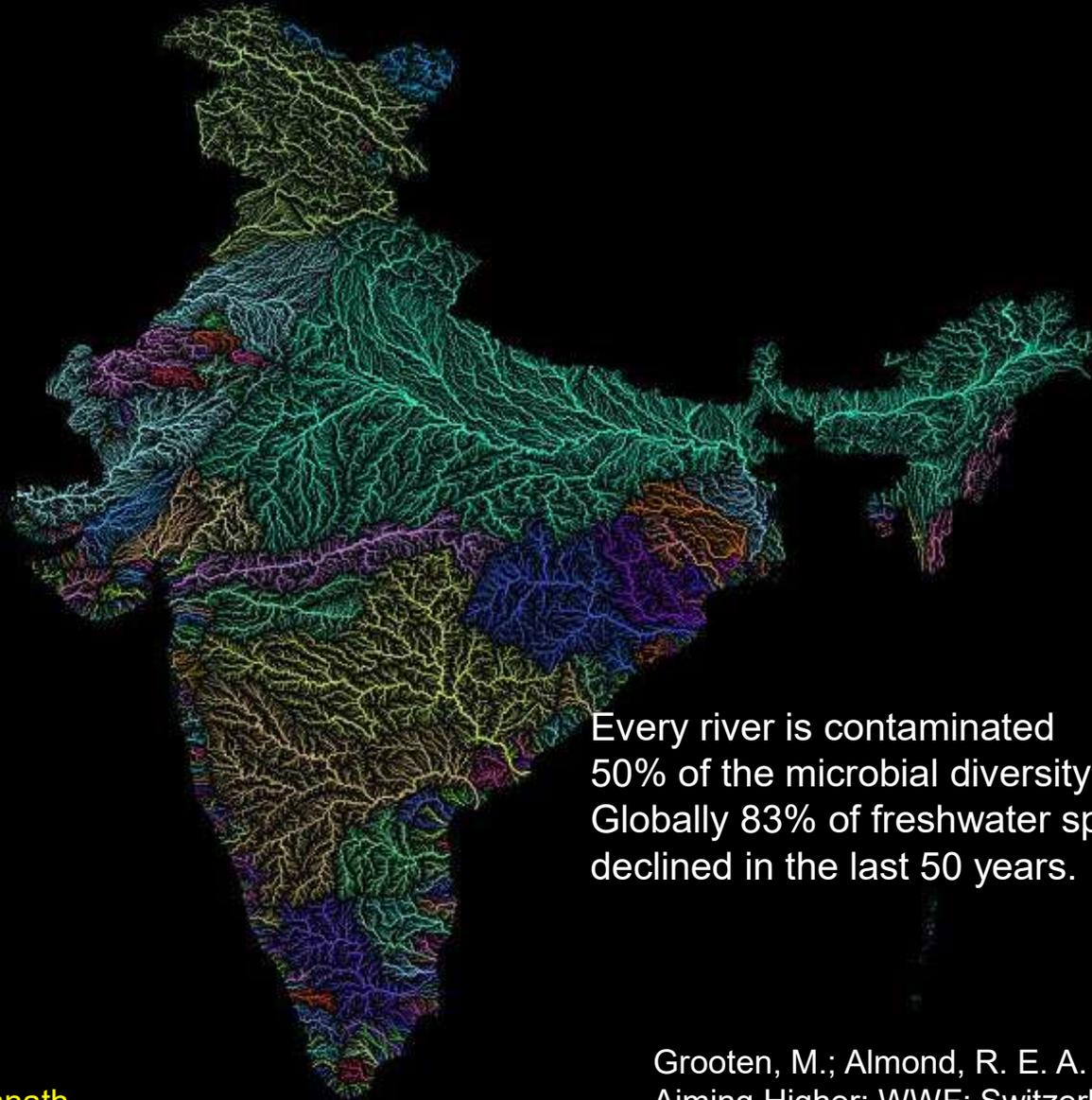
Despite odds, we are making progress

Comparative FHTC coverage status of States/ UTs (as on 30.06.2021)



The land of rivers

and the greater impact



Every river is contaminated
50% of the microbial diversity is lost for ever
Globally 83% of freshwater species have
declined in the last 50 years.

From S. Vishwanath

Grooten, M.; Almond, R. E. A. Living Planet Report - 2018:
Aiming Higher; WWF: Switzerland, 2018.

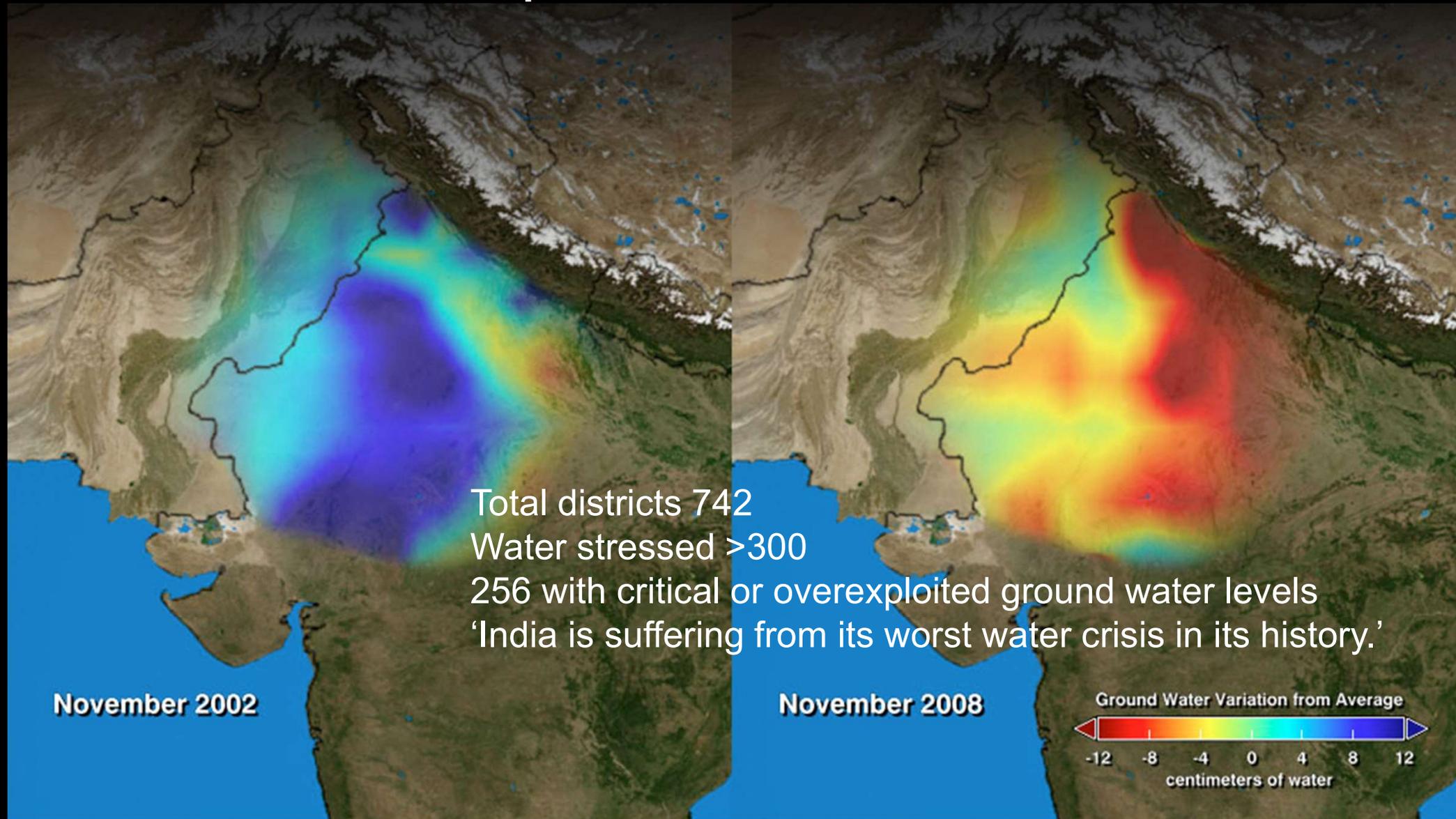
No river is free of pollution



<https://www.livemint.com/news/india/delhi-cpcb-raises-concerns-on-pollution-in-yamuna-river-11607261448670.html>

Dec. 6, 2020

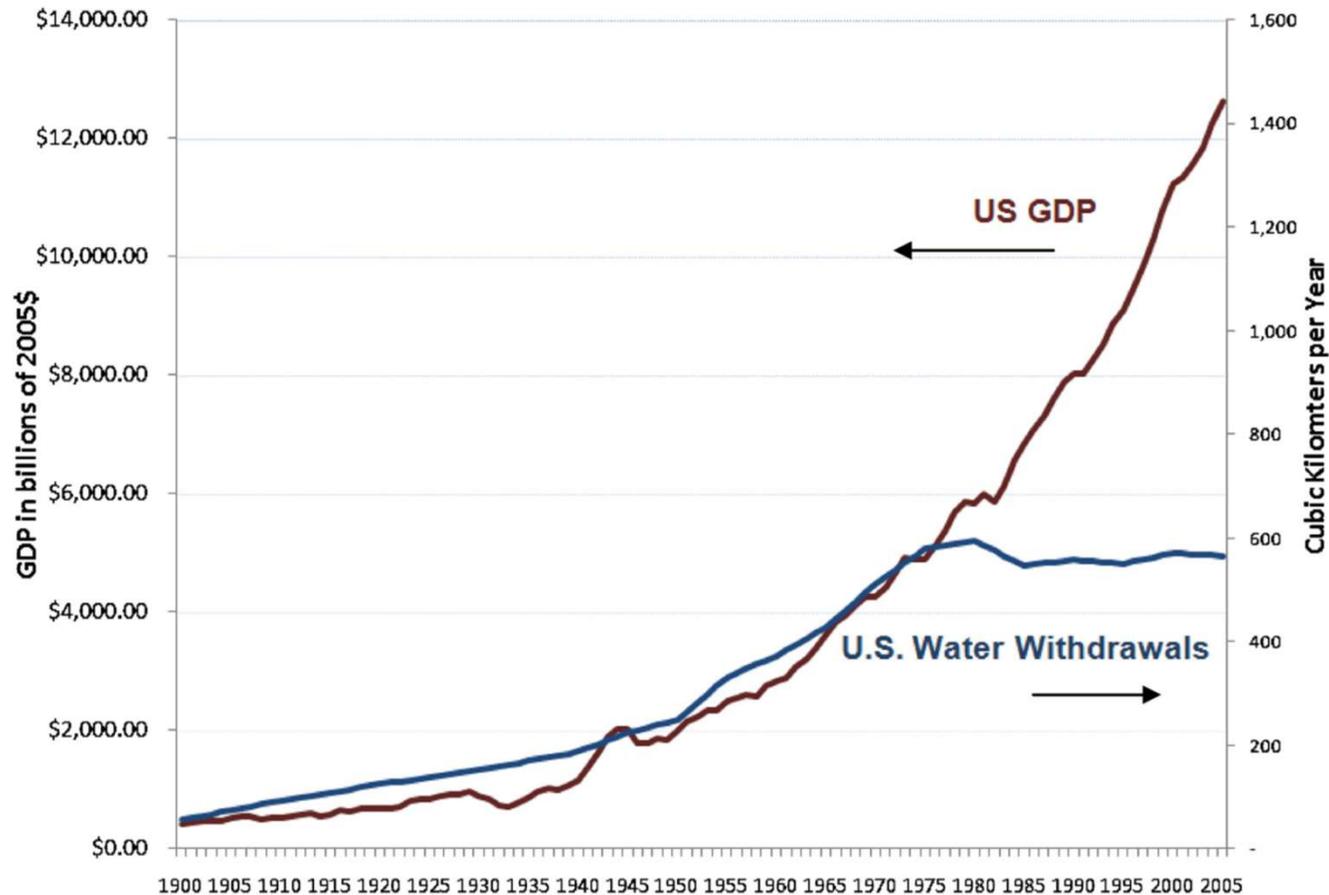
Groundwater depletion



Data from NASA

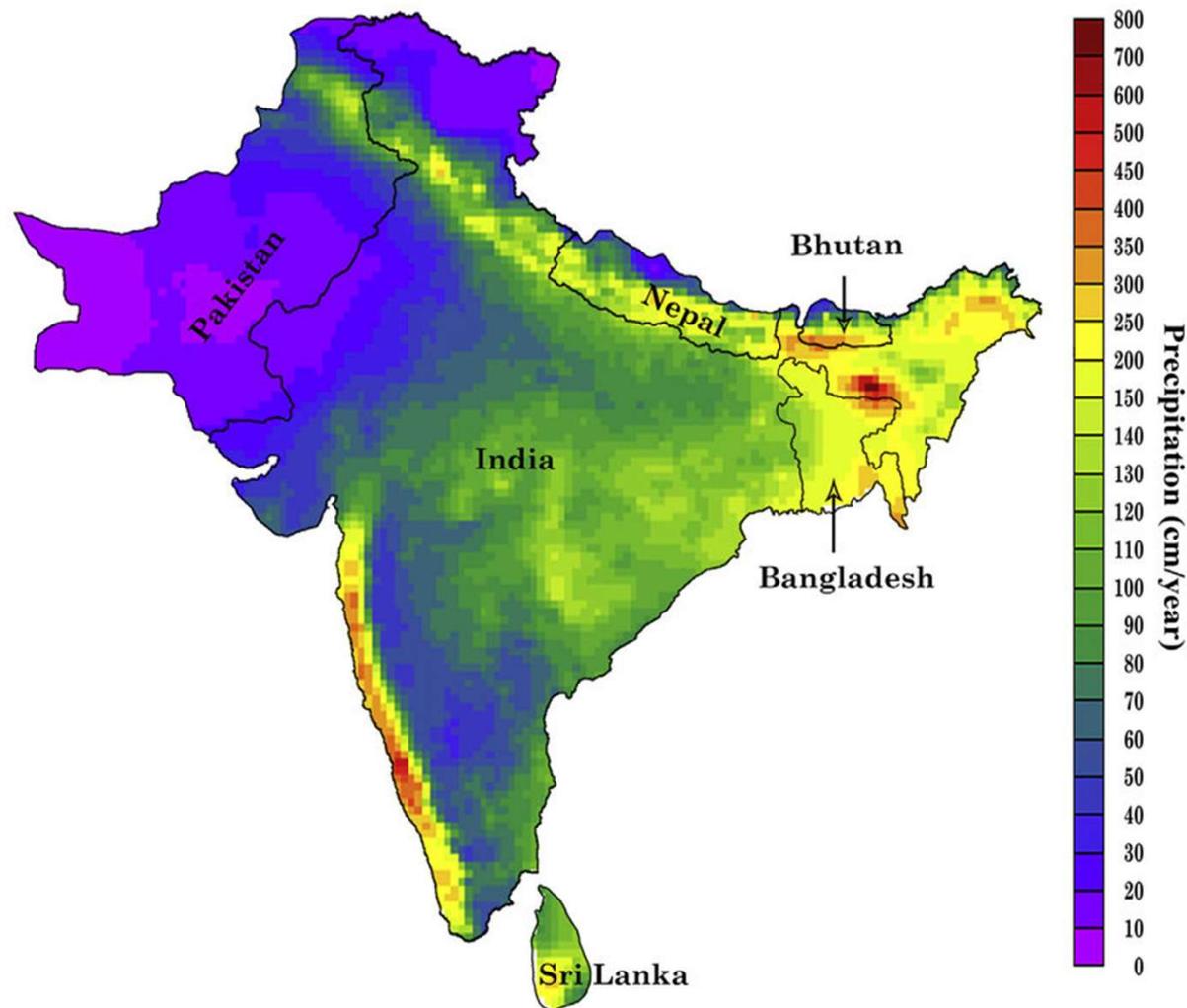
Can we grow without water?

Peak water



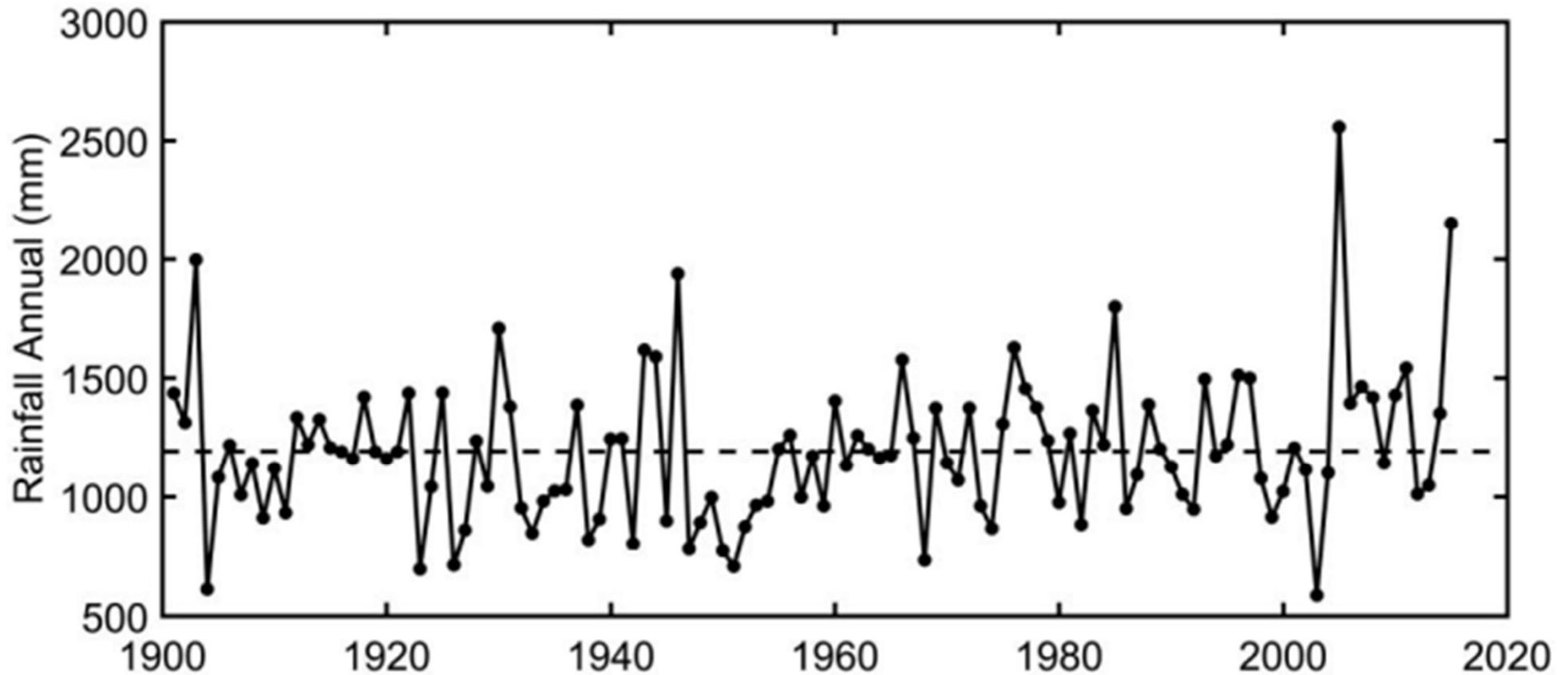
US gross domestic product (GDP) in 2005 dollars from 1900 to 2005 (left axis) plotted with total water withdrawals for all purposes in cubic kilometers per year (right axis). Data on GDP come from the US Bureau of Economic Analysis; data on water use comes from the US Geological Survey.

Precipitation 1961-2007



Groundwater systems of the Indian Sub-Continent, Abhijit Mukherjee, Dipankar Saha, Charles F. Harvey, Richard G. Taylor, Kazi Matin Ahmed, Soumendra N. Bhanja, *Journal of Hydrology: Regional Studies*, 4 (2015) 1–14

Our cities are rich - The story of Chennai



Annual rainfall in Chennai, 1901-2015

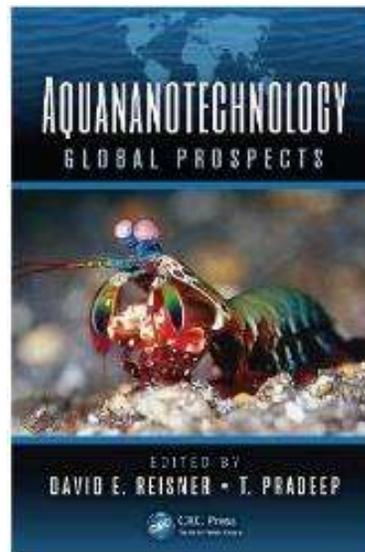
Water purification, history

Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

Year	Milestone
1804	Setup of world's first city-wide municipal water treatment plant (Scotland, sand-filter technology)
1810	Discovery of chlorine as a disinfectant (H. Davy)
1852	Formulation of Metropolis Water Act (England)
1879	Formulation of Germ Theory (L. Pasteur)
1902	Use of chlorine as a disinfectant in drinking water supply (calcium hypochlorite, Belgium)
1906	Use of ozone as a disinfectant (France)
1908	Use of chlorine as a disinfectant in municipal supply, New Jersey
1914	Federal regulation of drinking water quality (USPHS)
1916	Use of UV treatment in municipal supplies
1935	Discovery of synthetic ion exchange resin (B. A. Adams, E. L. Holmes)
1948	Nobel Prize to Paul Hermann Muller (insecticidal properties of DDT)
1959	Discovery of synthetic reverse osmosis membrane (S. Yuster, S. Loeb, S. Sourirajan)
1962	<i>Silent Spring</i> published, first report on harmful effects of DDT (R. Carson)
1965	World's first commercial RO plant launched
1974	Reports on carcinogenic by-products of disinfection with chlorine Formulation of Safe Drinking Water Act (USEPA)
1975	Development of carbon block for drinking water purification
1994	Report on use of zerovalent iron for degradation of halogenated organics (R. W. Gillham, S. F. O'Hannesin)
1997	Report on use of zerovalent iron nanoparticles for degradation of halogenated organics (C-B. Wang, W.-X. Zhang)
1998	Drinking Water Directive applied in EU
2000	Adoption of Millennium Declaration during the UN Millennium Summit (UN Millennium Development Goals)
2003	Report on use of noble metal nanoparticles for the degradation of pesticides (A.S. Nair, R. T. Tom, T. Pradeep)
2004	Stockholm Convention, banning the use of persistent organic pollutants
2007	Launch of noble metal nanoparticle-based domestic water purifier (T. Pradeep, A. S. Nair, Eureka Forbes Limited)

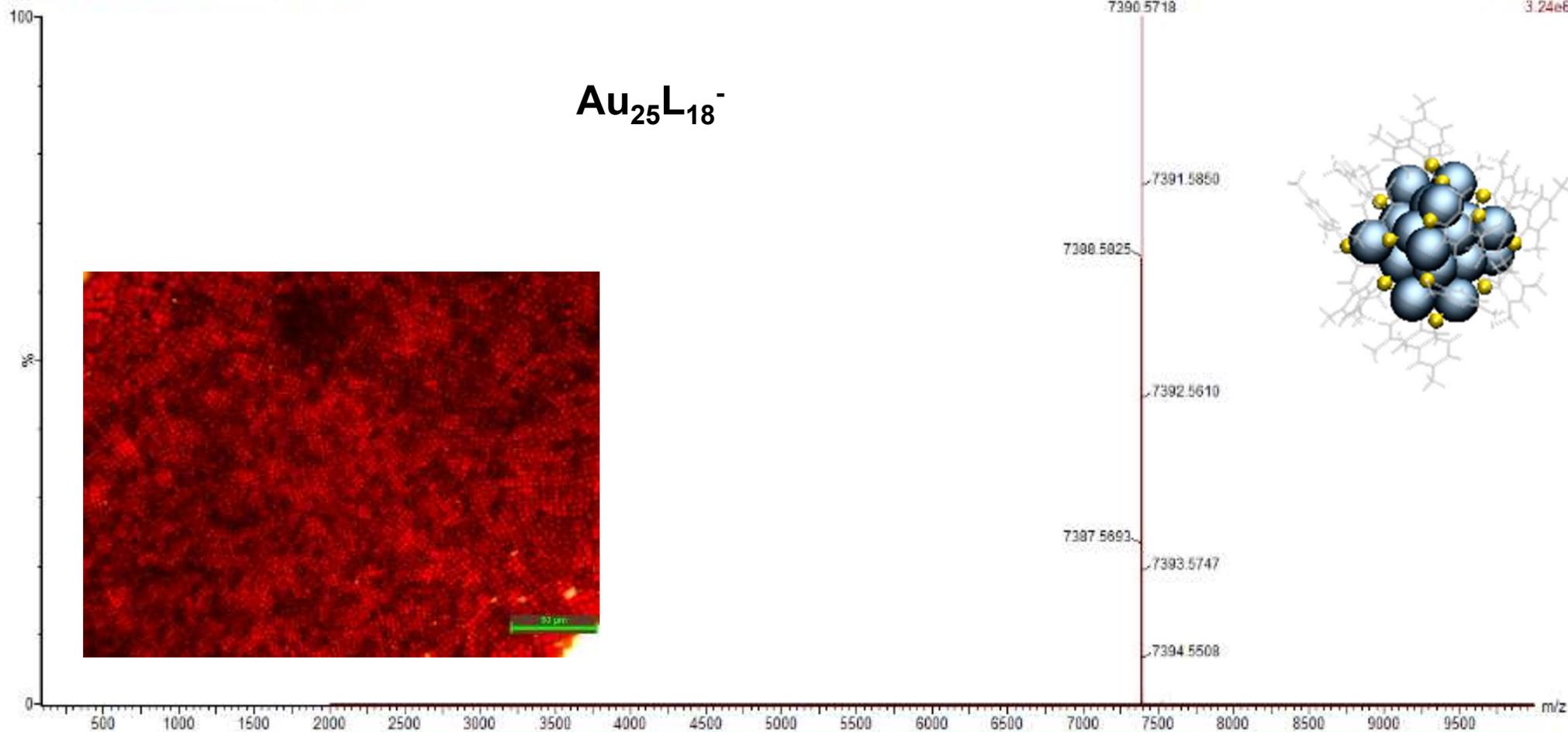
Affordable clean water is a problem of advanced materials

- New adsorbents
- New sensors
- New catalysts
- Novel phenomena
- New devices



Nanomaterials are now atomically precise

AU25PET16_RES_NEG_MS_3 32 (0.658) Cm (5:00)

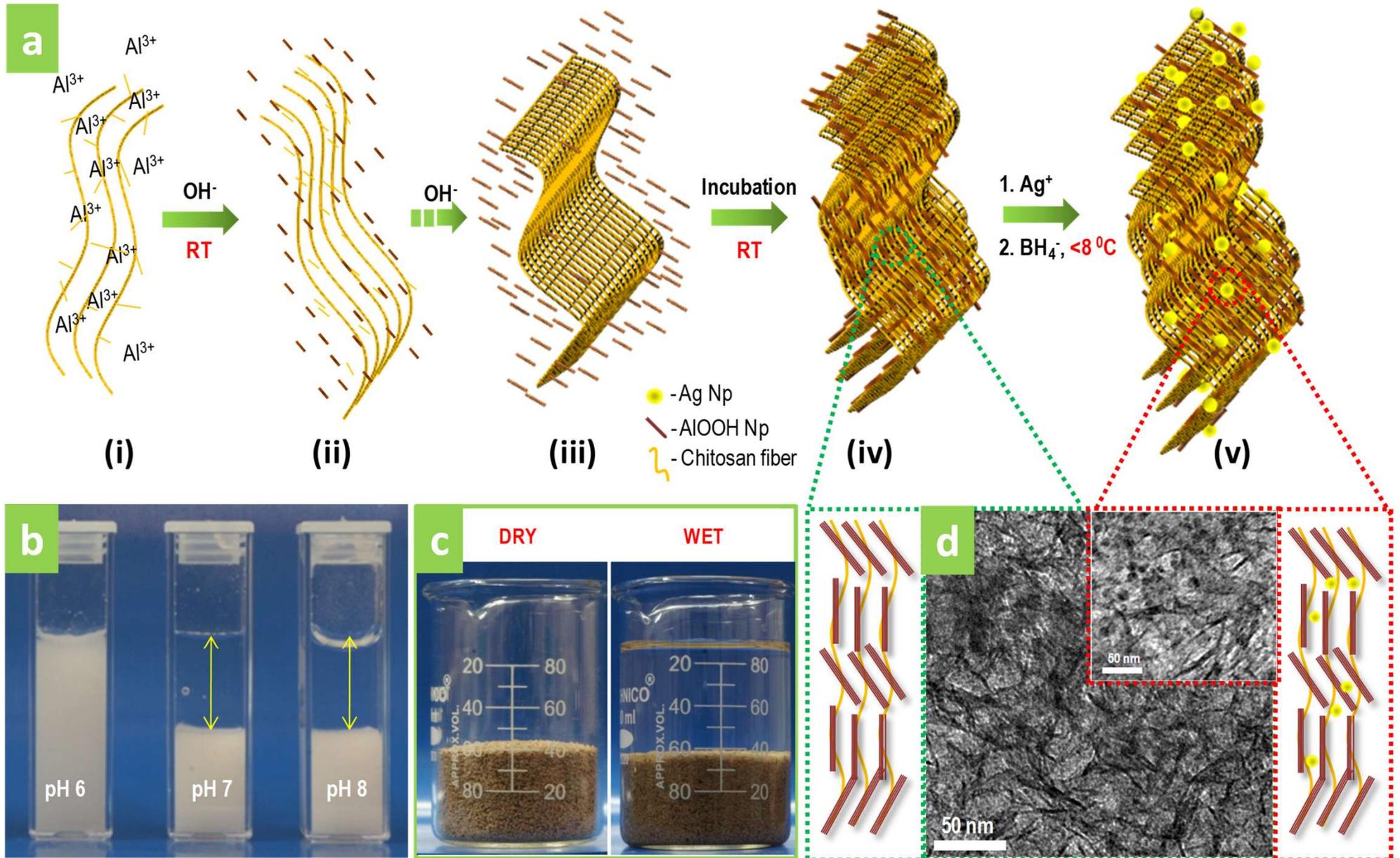


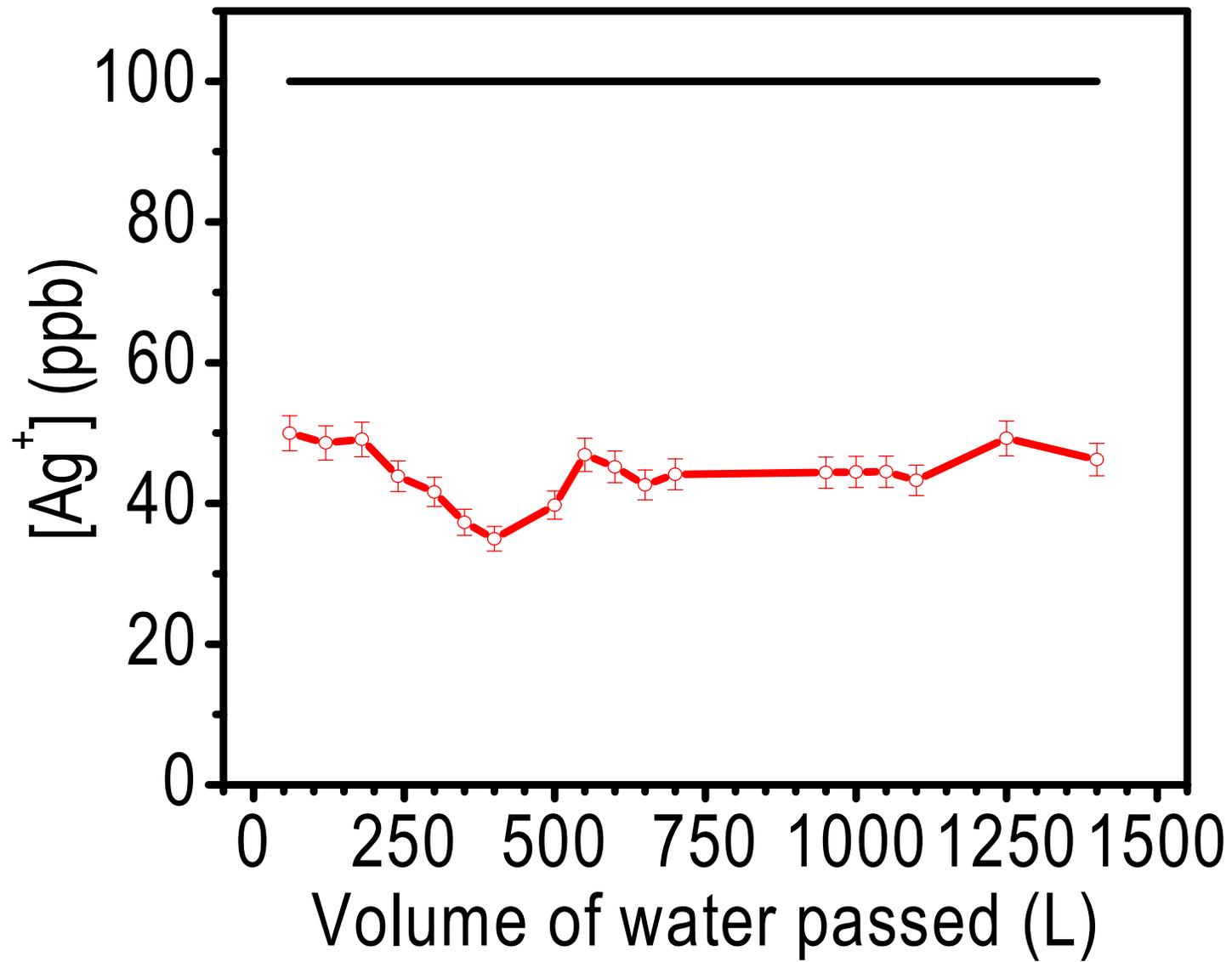
Nanomaterials can solve real problems



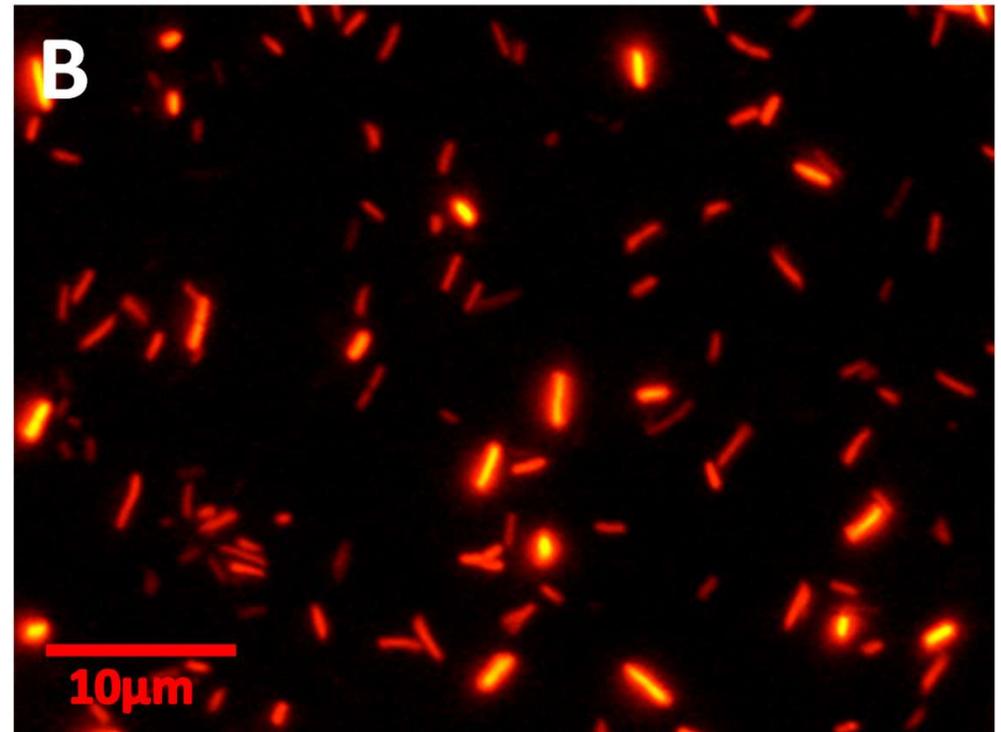
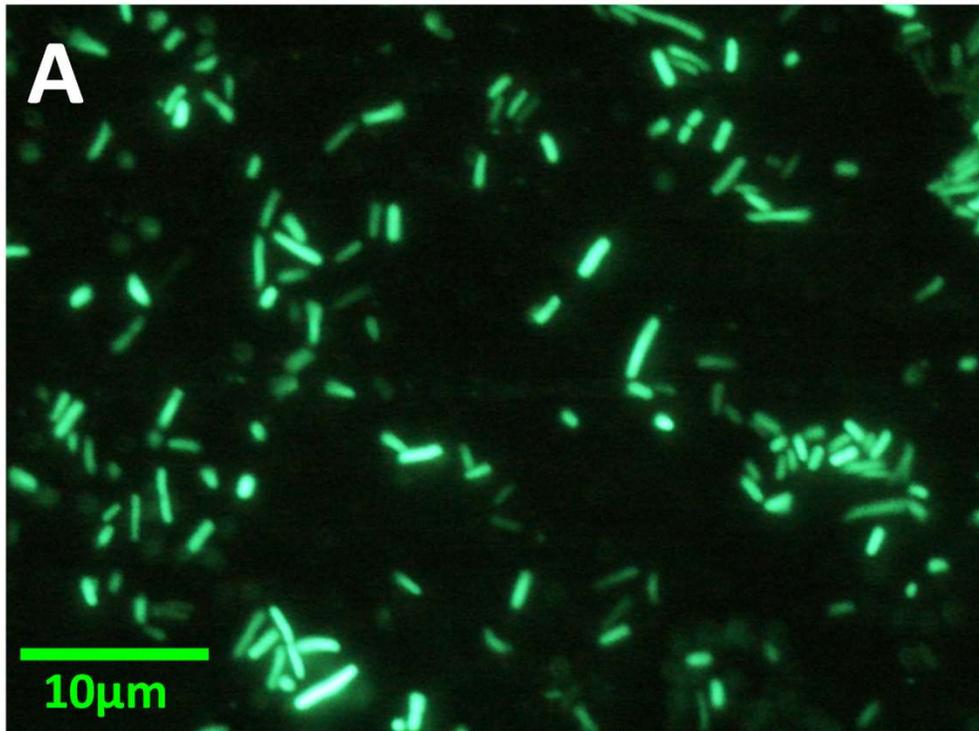
ACS Sustainable Chemistry & Engineering Editorial, December 2016

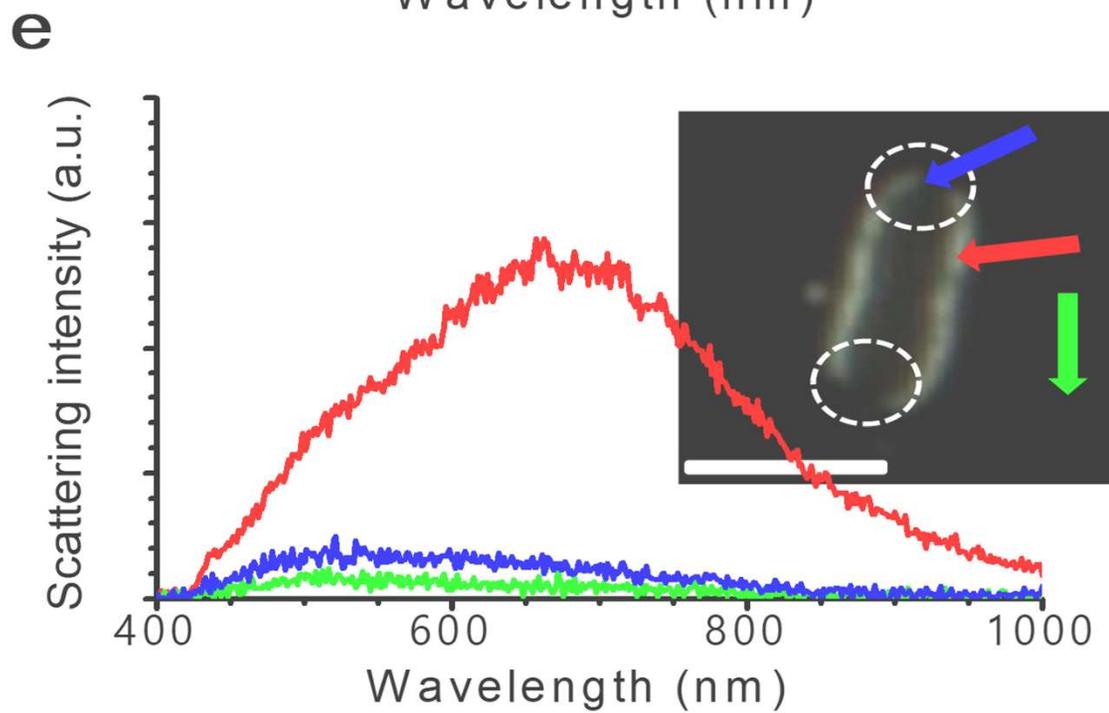
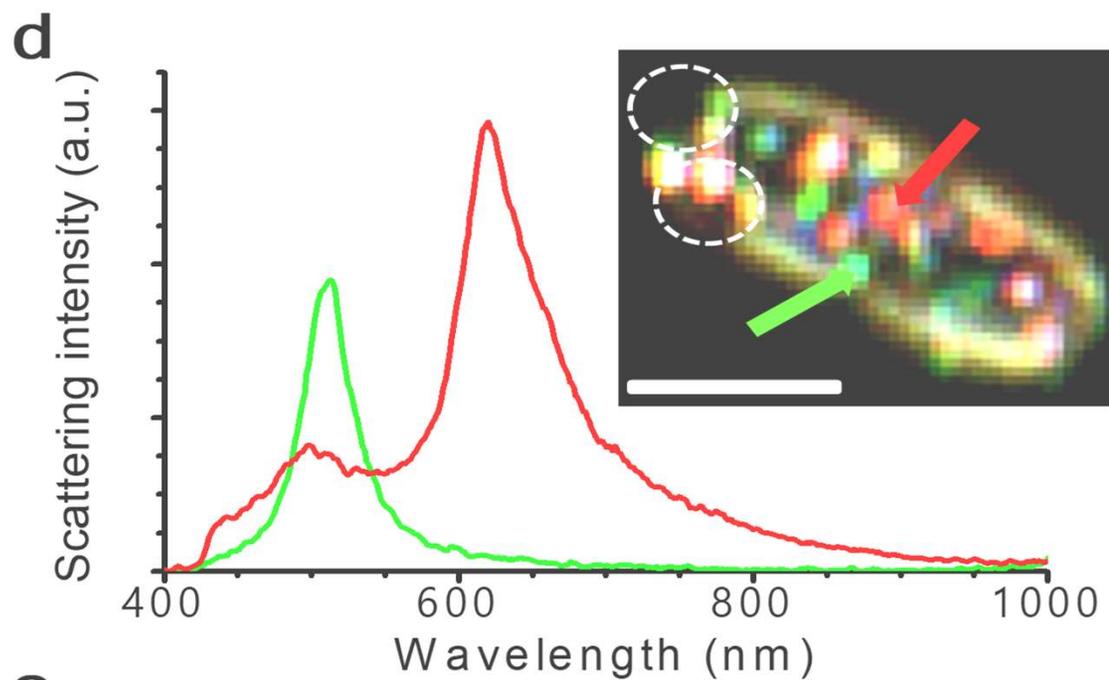
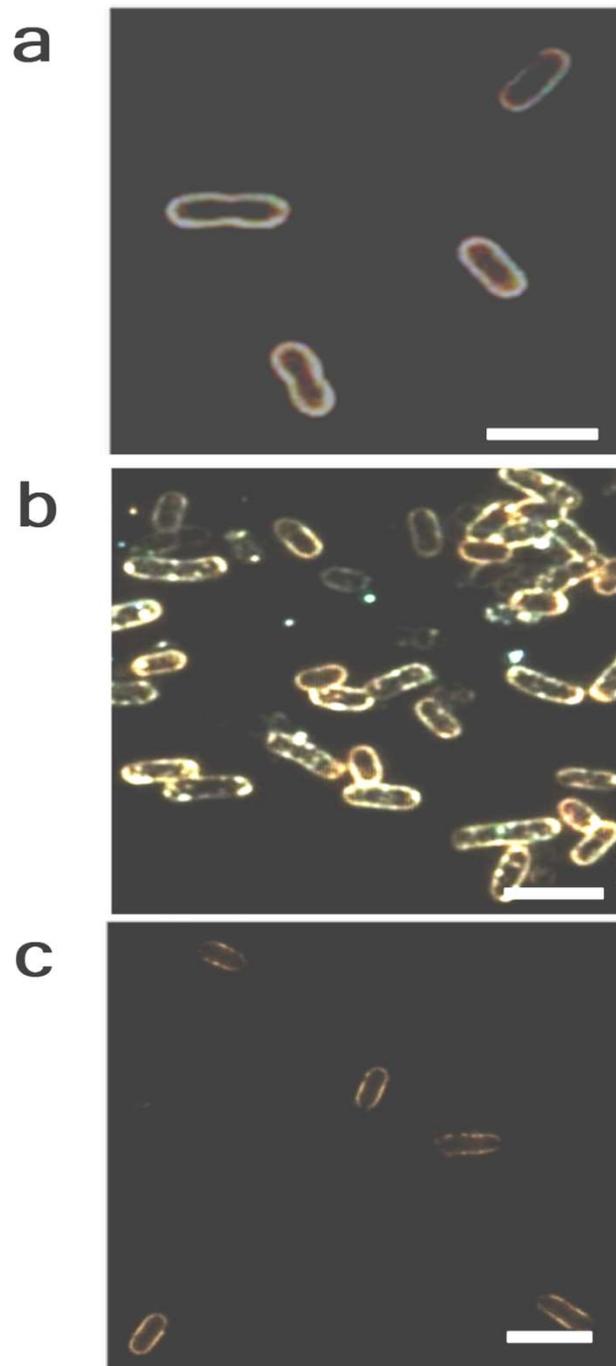
New materials

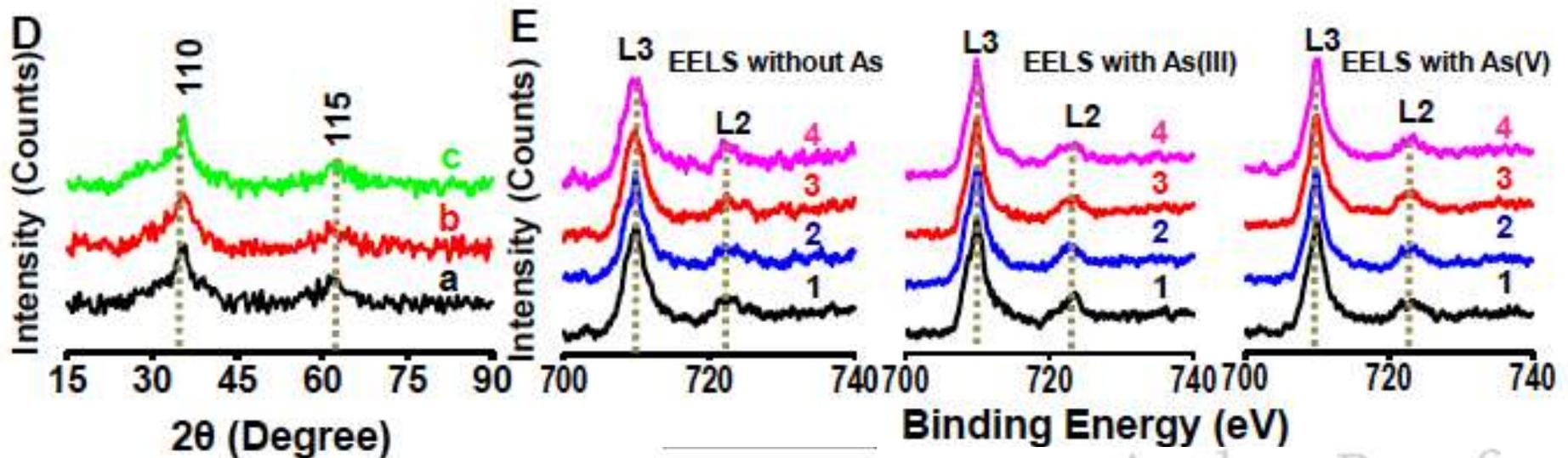
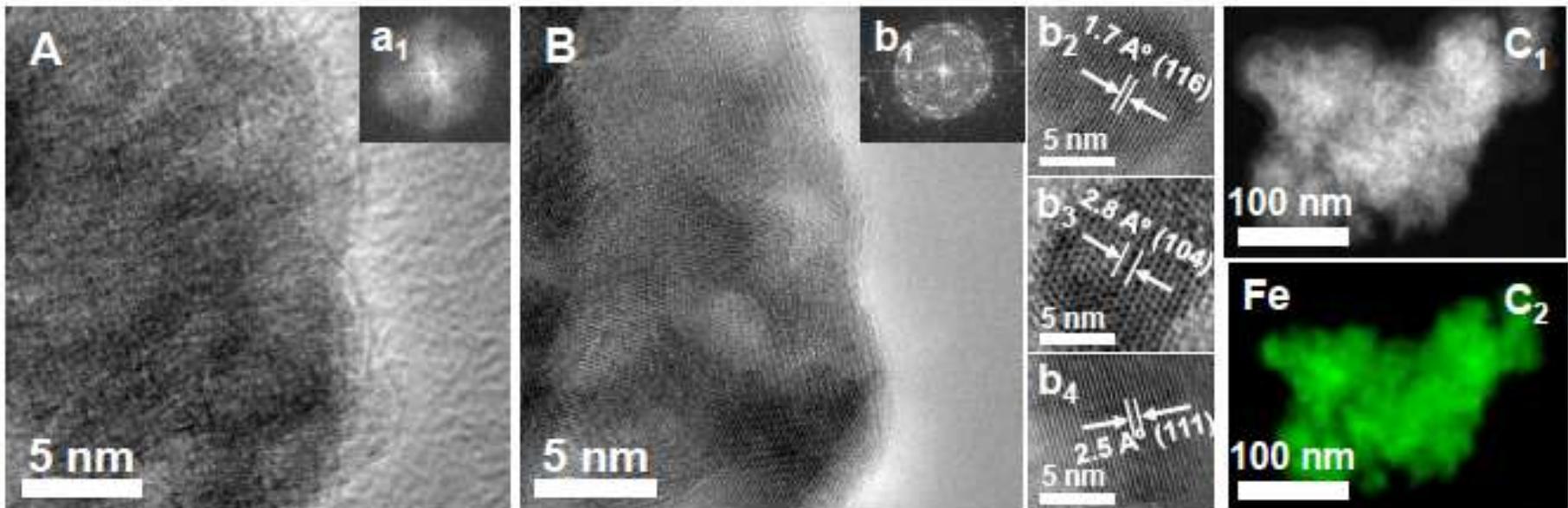




Live/dead staining experiments







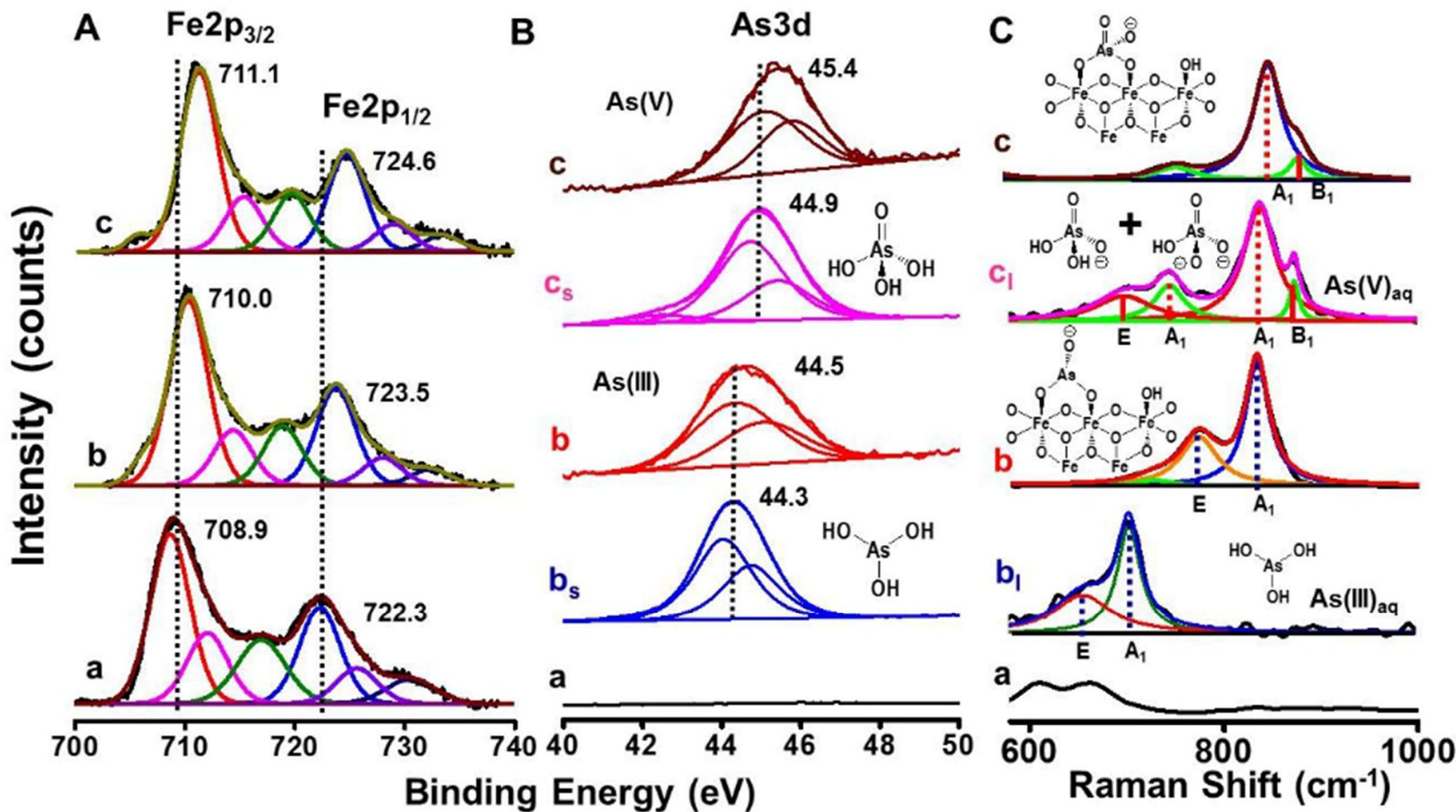
www.advmat.de

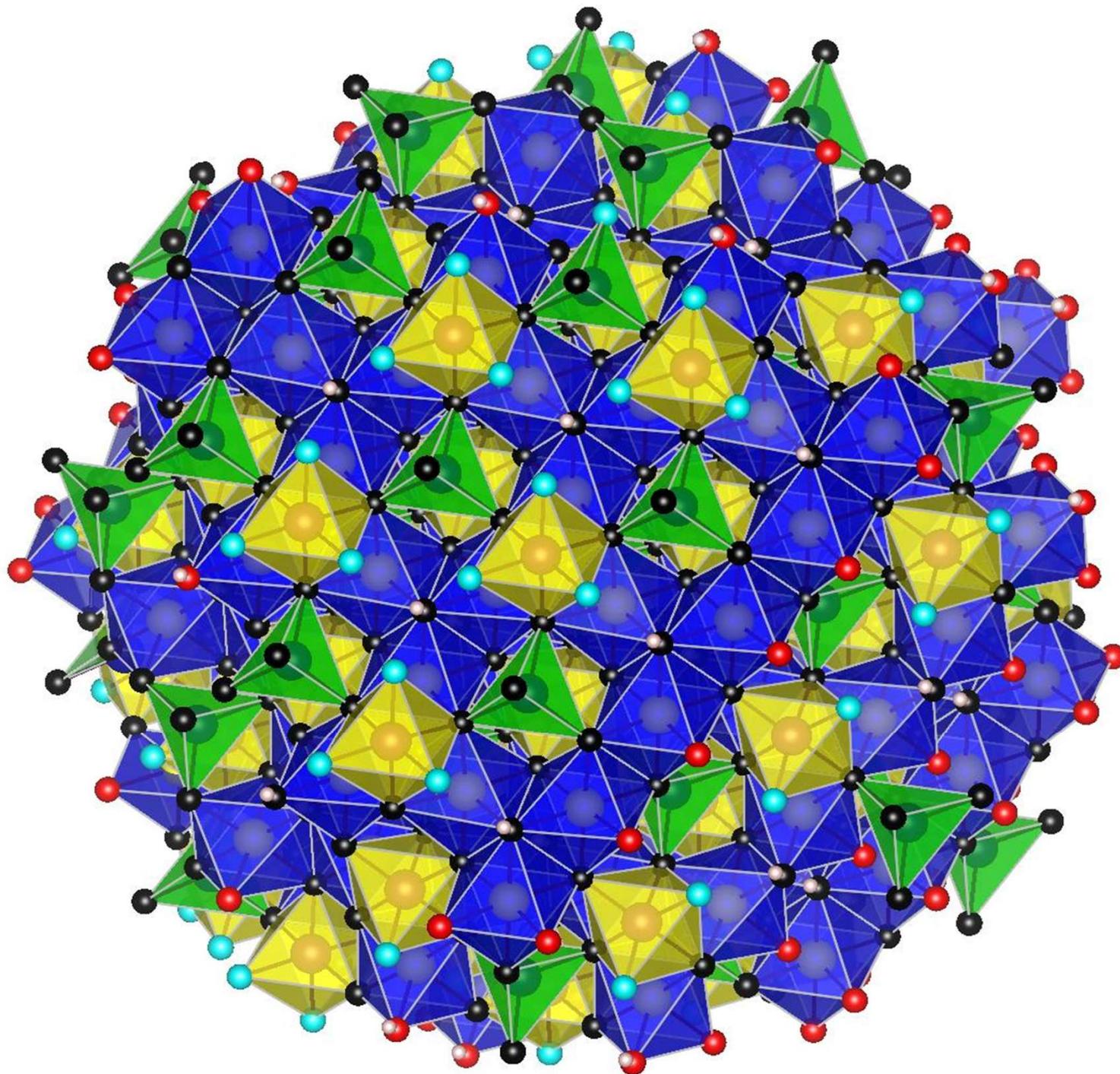
Author Pre-proof
 ADVANCED MATERIALS

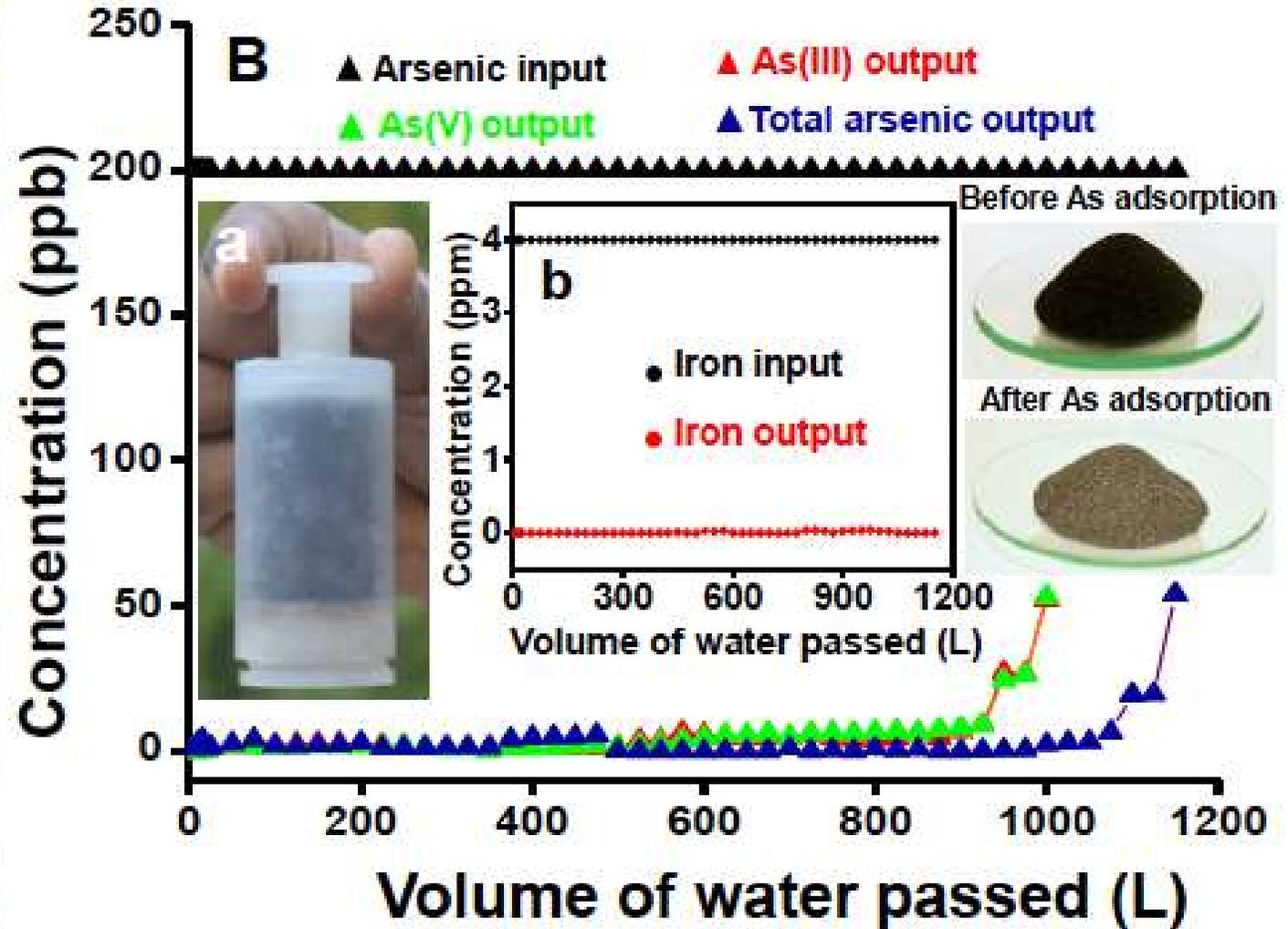
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

By Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhuin, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep*

Mechanism







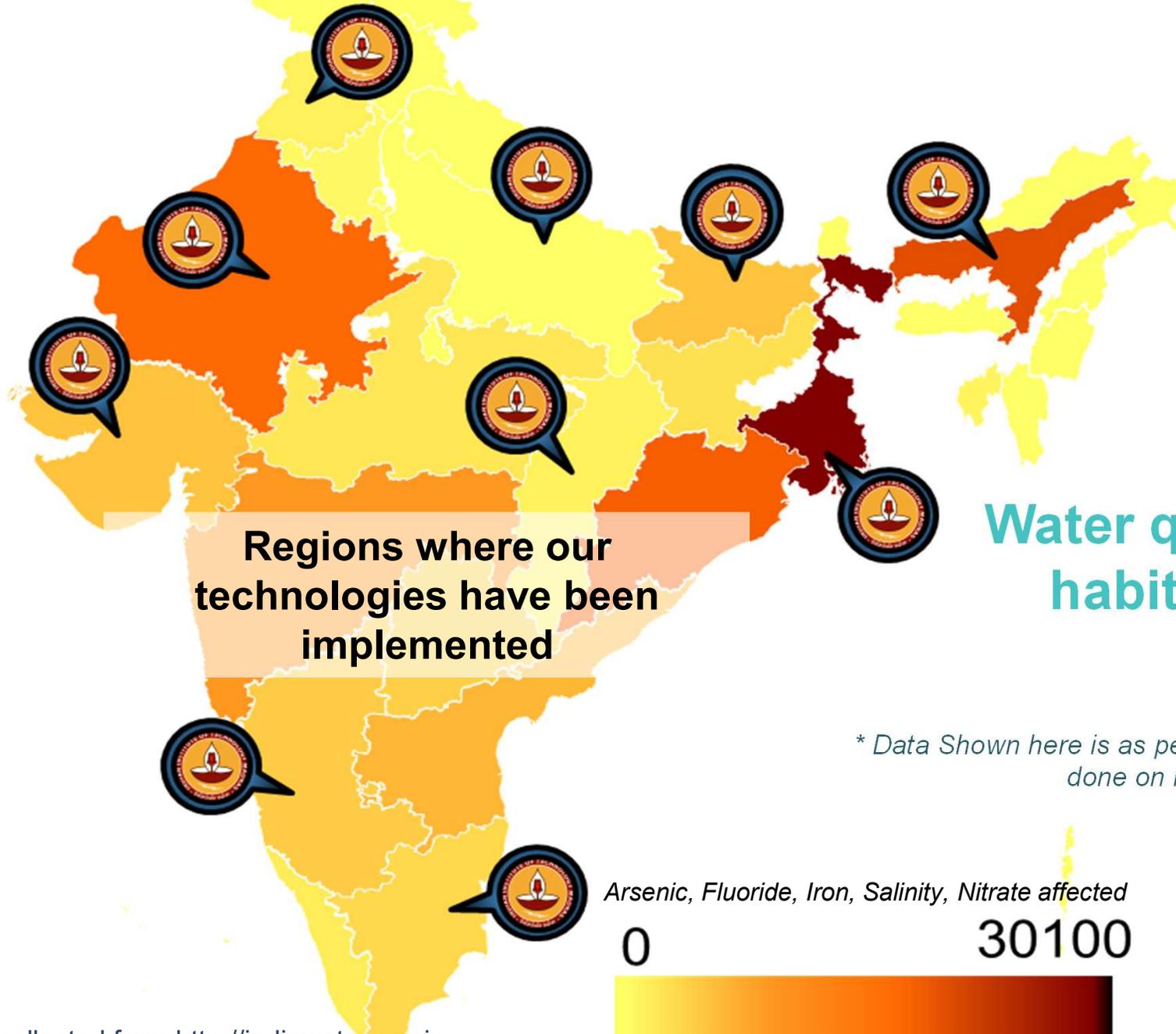
Changing the dynamics in the field



- Existing unit for iron and arsenic removal – 20 m³/h
- Uses activated alumina and iron oxide (old generation of adsorbents)

- Existing unit for iron and arsenic removal – 18 m³/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb

OUR REACH



Water quality affected habitations of India

** Data Shown here is as per laboratory testing results entry done on regular basis hence may change*

Collected on 29.05.2018

Completed 3 years maintenance (stipulated: 2 years)
for 330 bamboo unit project in Nadia, WB



Minimum uptime: 91%, Maximum: 98%
Only 4/330 have reported arsenic above 10 ppb
Benefiting over 100,000 children and villagers

Glimpse of Installed units (330 nos)



Installed in 2018, in February 2022

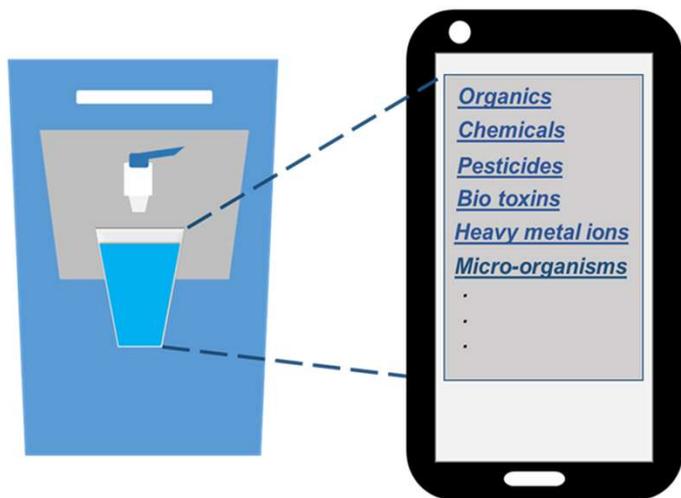
Cleanwater at 2.1 paise per litre!

Calculation for the Tariff to be collected for treated water (Revision if Required)

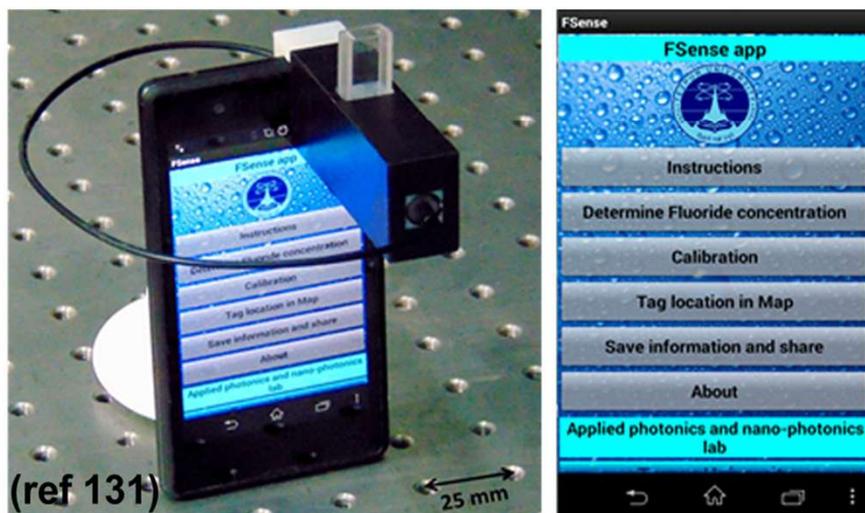
Sr.No	Item/Description	Cost / Quantity	Remarks
	Design population	1,071	Plant capacity/70 LPCD
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore media may work for 3 years also.
2	Cost of Replacement of Arsenic removal media	978660	After minimum two years if Arsenic concentration is more than 100 ppb. But arsenic concentration is more than 100 ppb at only two to three places. Therefore media may work for 3 years also.
3	Cost of replacement of Activated Carbon	28560	
4	Total cost of Replacement of media	1063620	After minimum two years.
5	Total cost of Replacement of media for one year	531810	
6	Plant capacity	75000	ltr per day
7	Design population	1,071	Plant capacity/70 LPCD
8	Cost per liter of water	2.1 Paise per ltr	
9	Cost of replacement of media	1.36	Rs. per head per day =Media replacement cost per year/365/Design population
		<u>40.80</u>	per head per month for 70 LPCD water

Smart water purifiers and big data

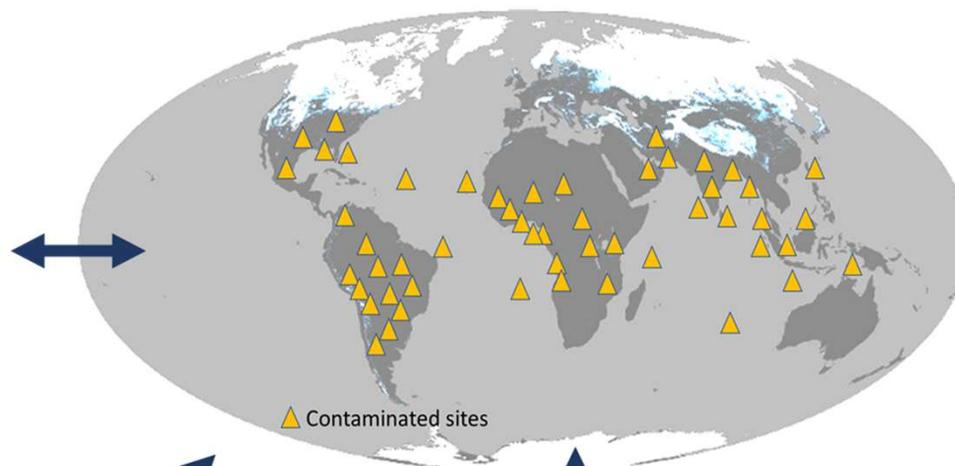
Smart Water Purifiers linked to IoT



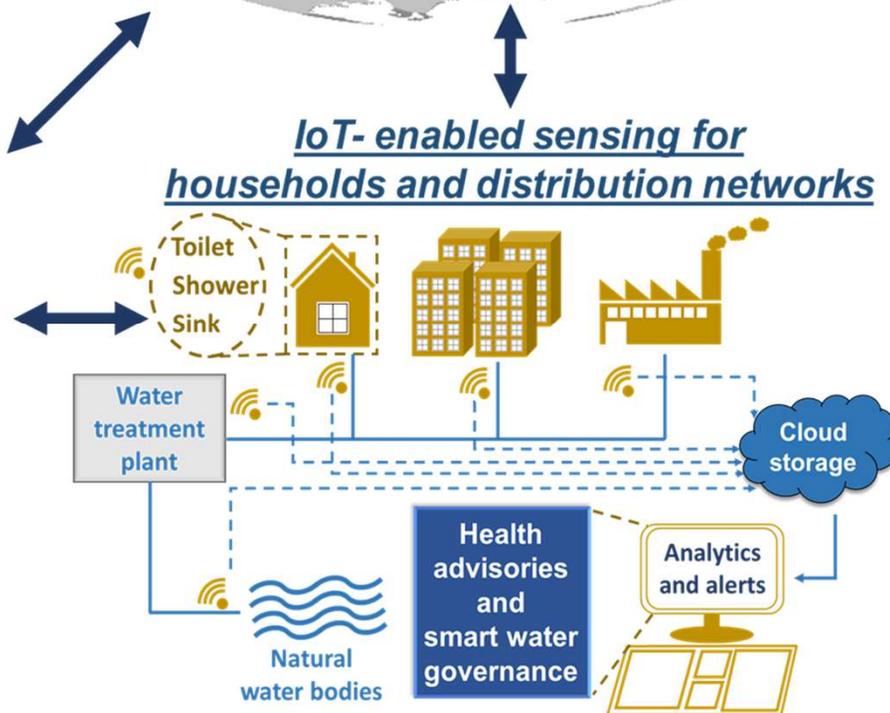
Cost-effective sensor accessory for point-of-use applications



Global Map of Water Health

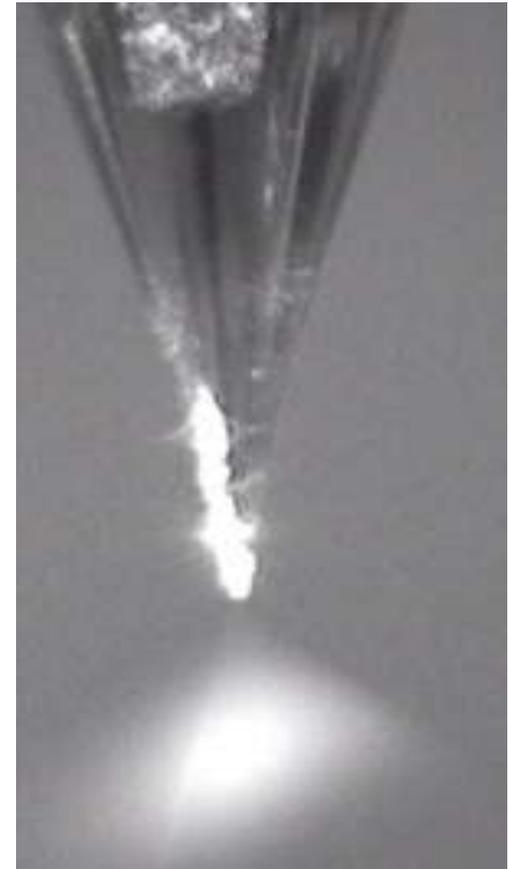
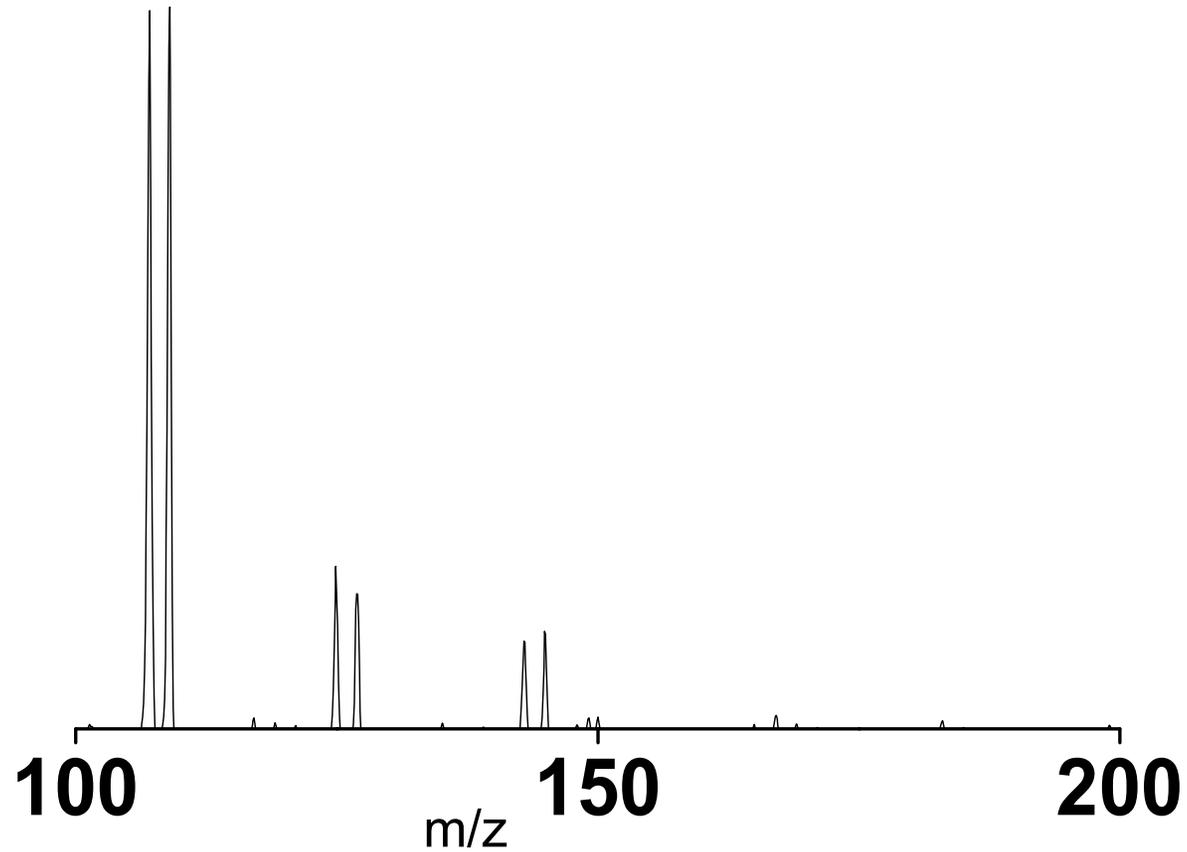


IoT-enabled sensing for households and distribution networks

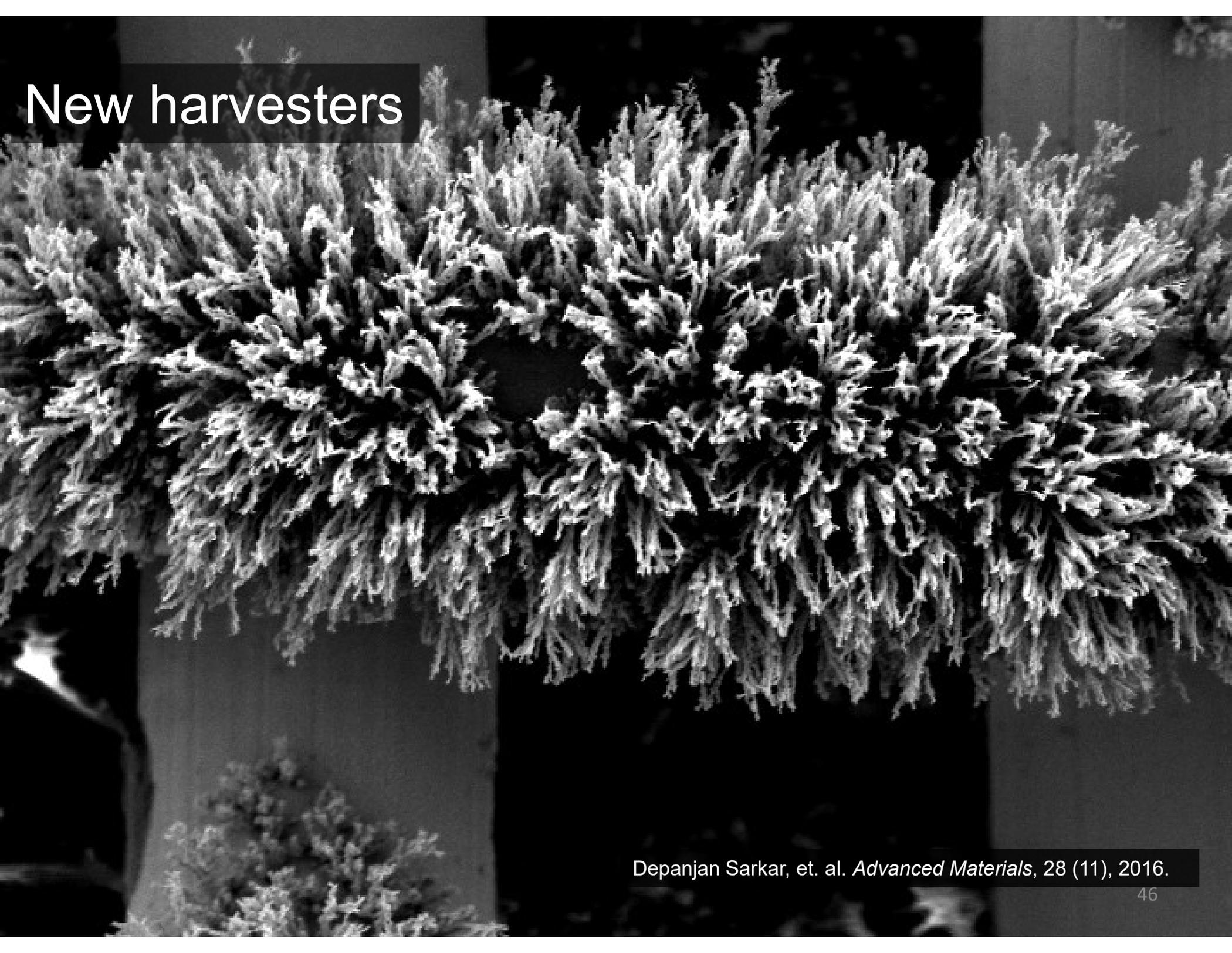




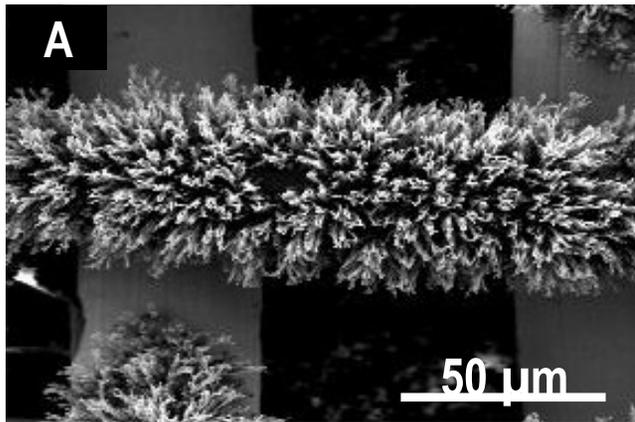
Atmospheric water harvesting



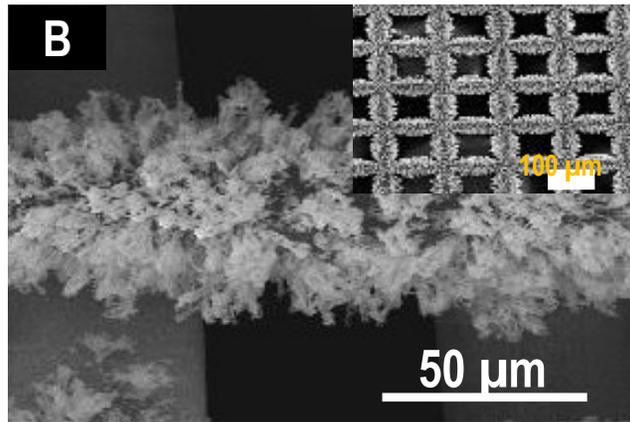
New harvesters



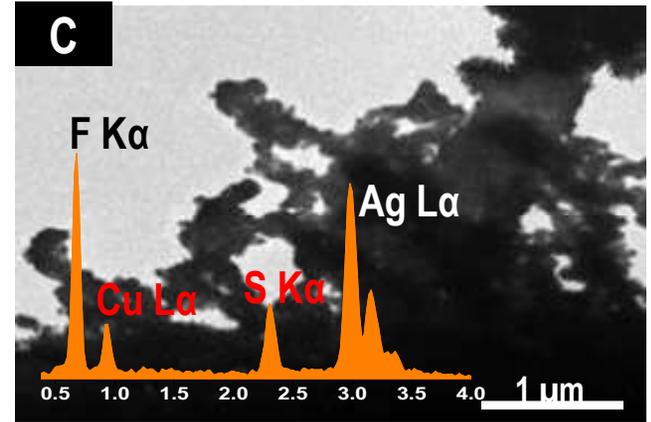
Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.



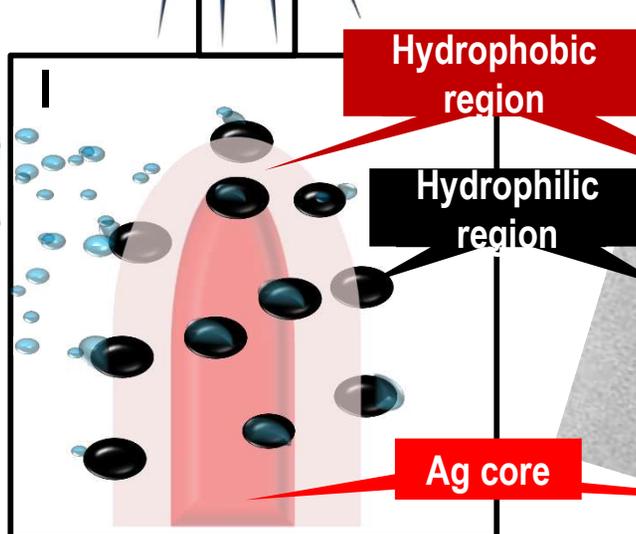
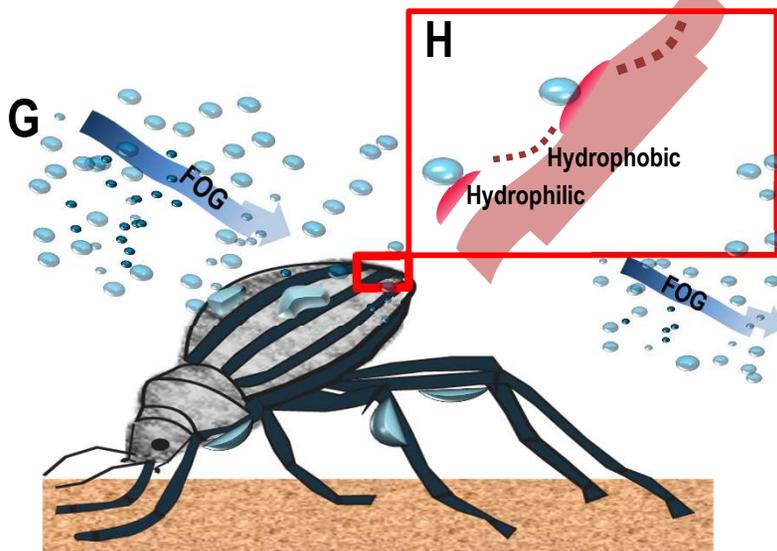
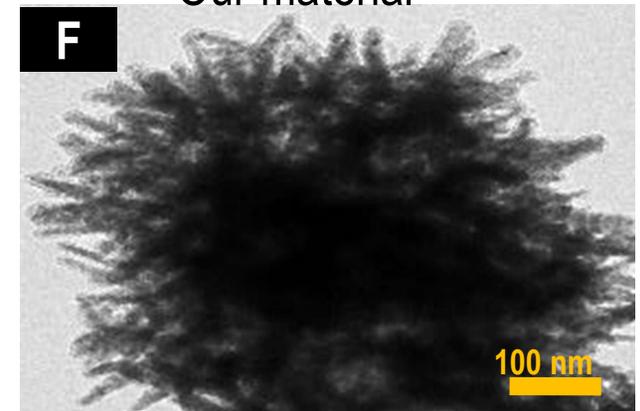
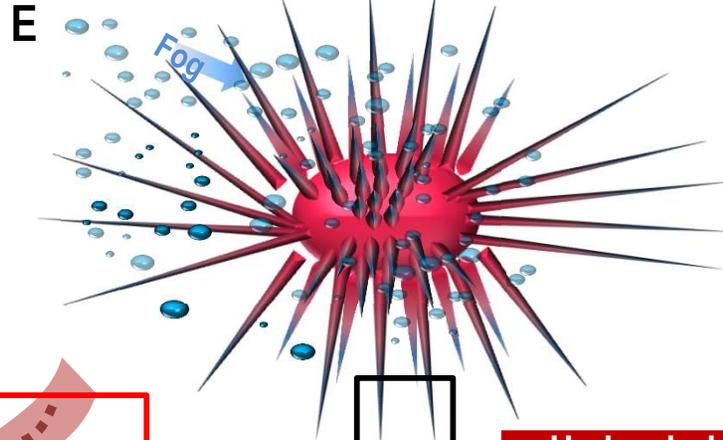
Nature



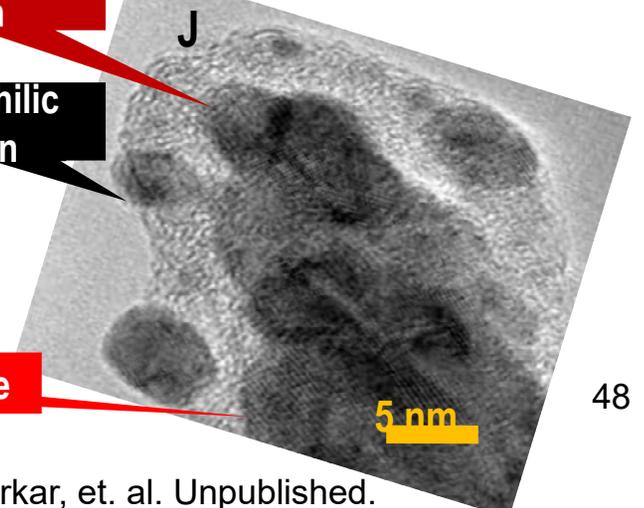
Schematic

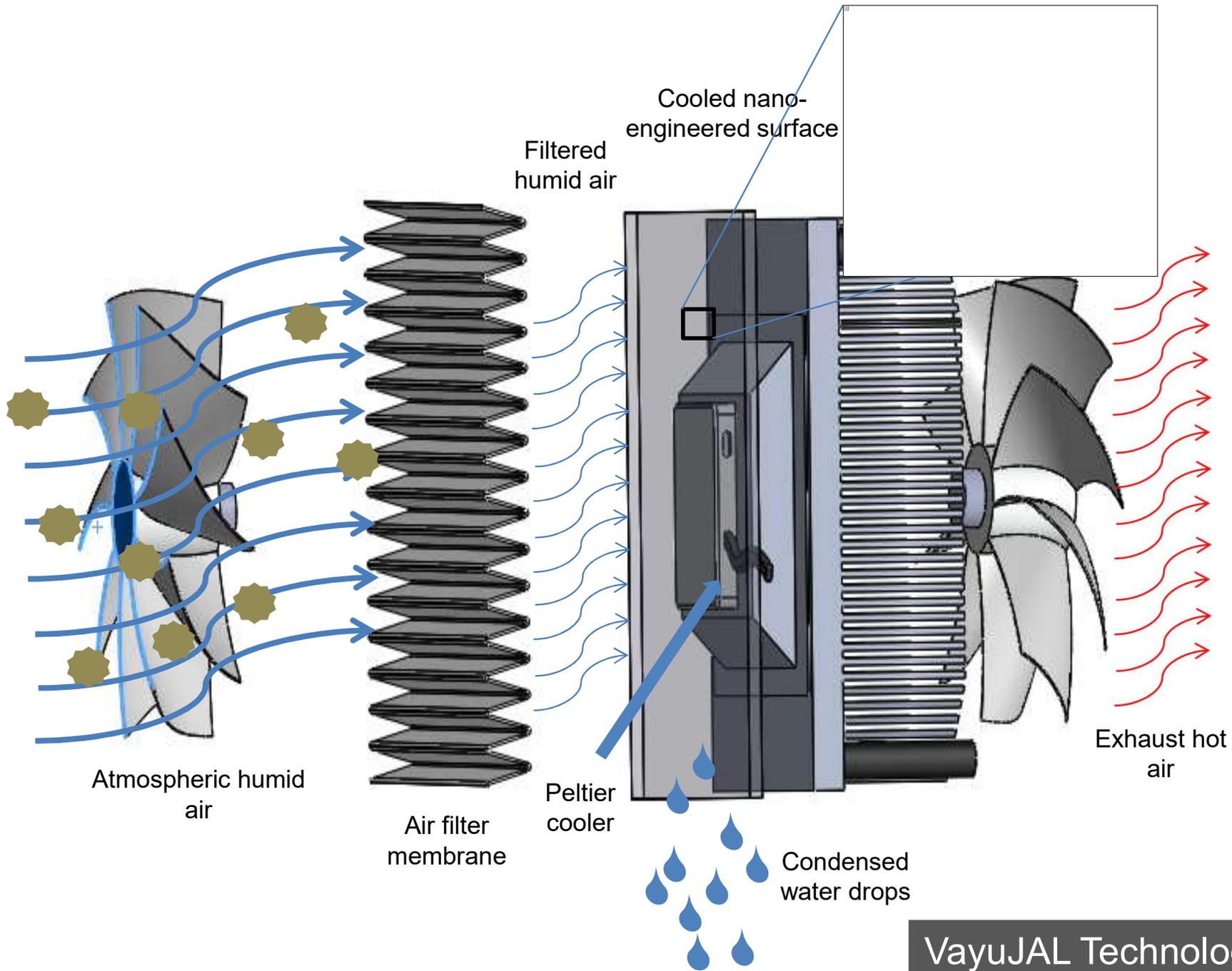


Our material



Combination of cactus and Namib desert beetle effect





VayuJAL Technologies Pvt. Ltd.
Ramesh Kumar Soni and Ankit Nagar

Products in the field



35 LPD 120 LPD

400 LPD

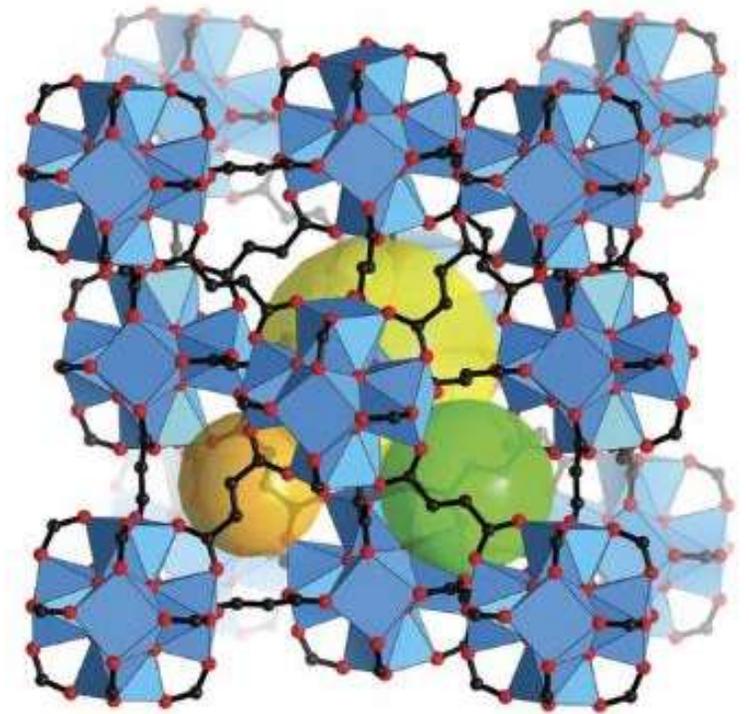
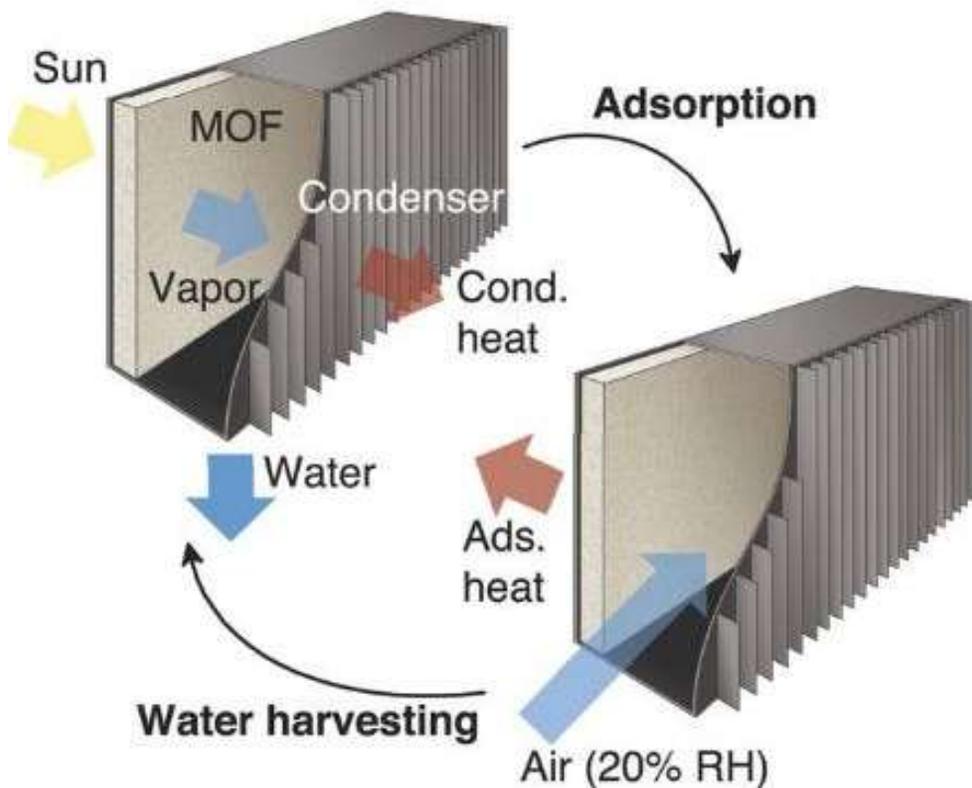
1000 LPD

2000 LPD

(LPD: Litres per day)

Sustainable atmospheric water harvesting

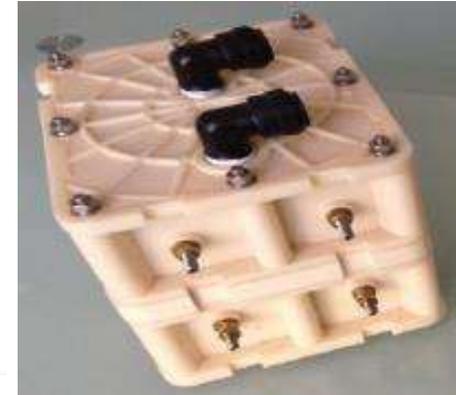
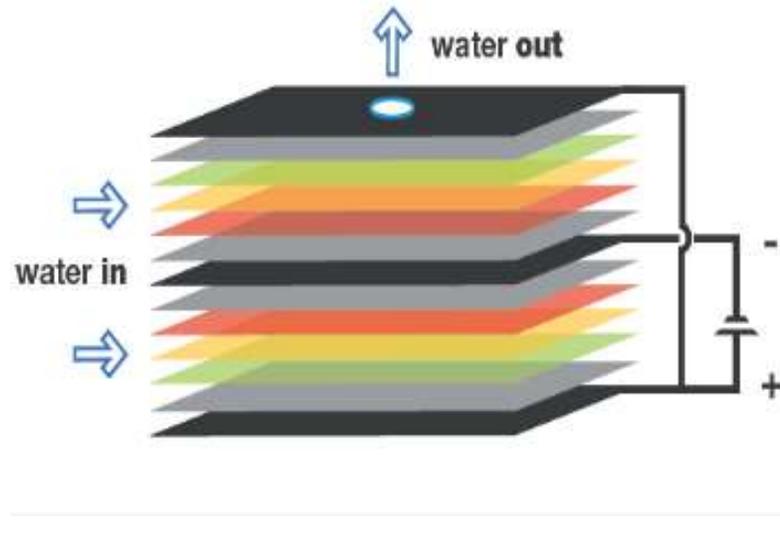
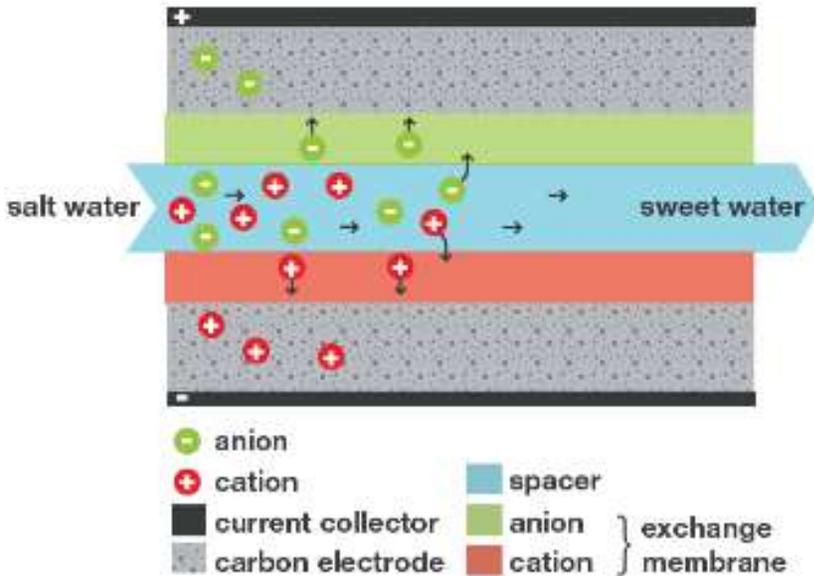
Solar- heat-enabled atmospheric water capture at a relative humidity as low as 20%



Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(\text{fumarate})_6$)

Kim Hyunho, et al. *Science*, 356 (6336) 2017

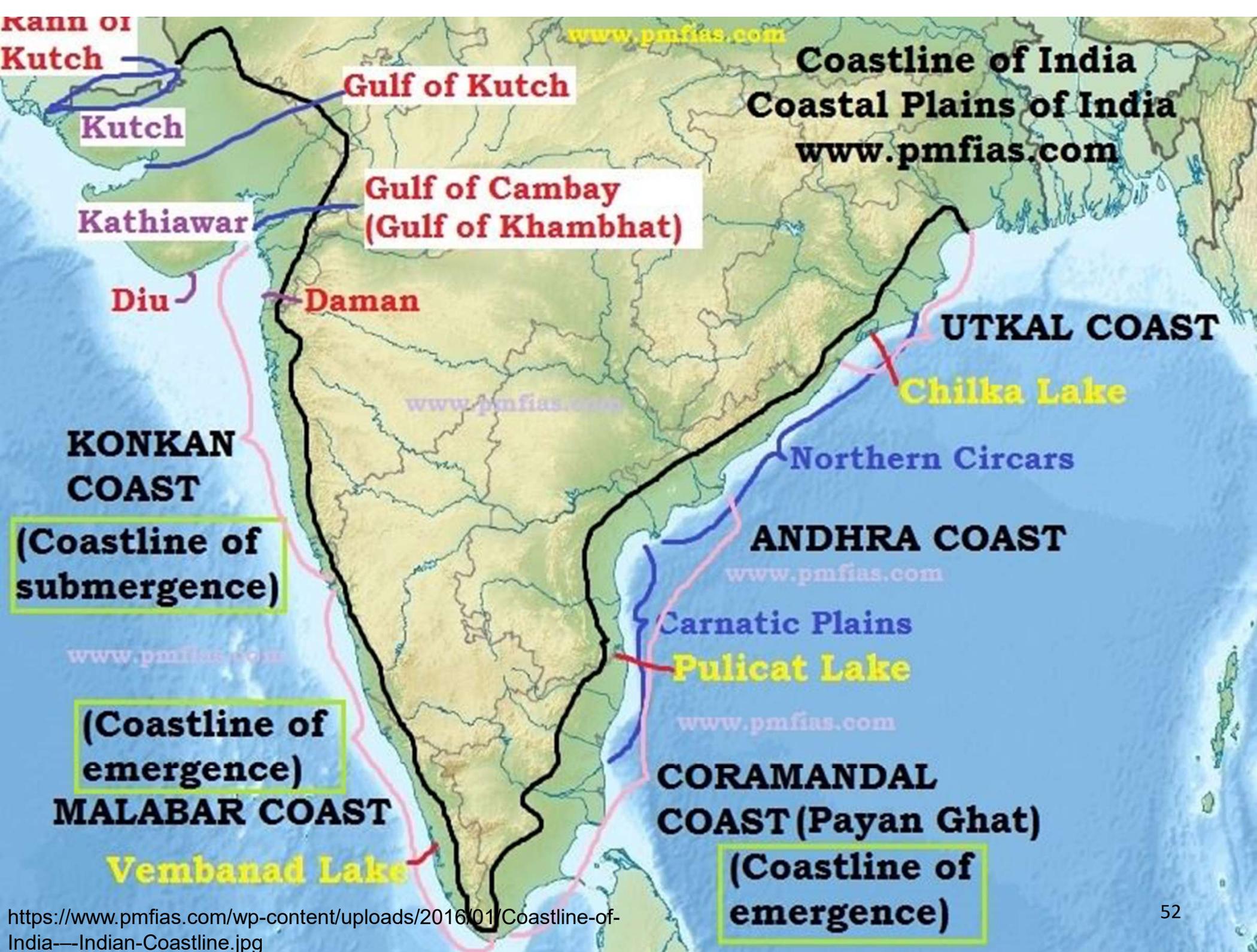
Capacitive Desalination (CDI)



imODI

Our new company

Soujit Sengupta, Rabiul Islam and others



Kann of Kutch

www.pmfias.com

Gulf of Kutch

Kutch

Coastline of India
Coastal Plains of India
www.pmfias.com

Kathiawar

Gulf of Cambay (Gulf of Khambhat)

Diu

Daman

UTKAL COAST

Chilka Lake

KONKAN COAST

Northern Circars

(Coastline of submergence)

ANDHRA COAST

www.pmfias.com

www.pmfias.com

Carnatic Plains

(Coastline of emergence)

Pulicat Lake

www.pmfias.com

MALABAR COAST

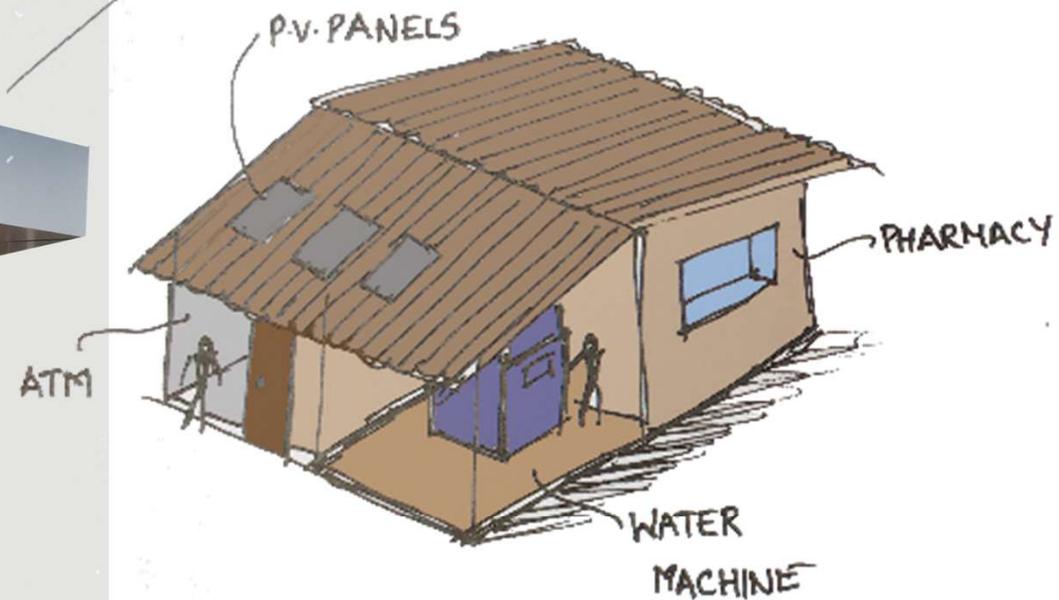
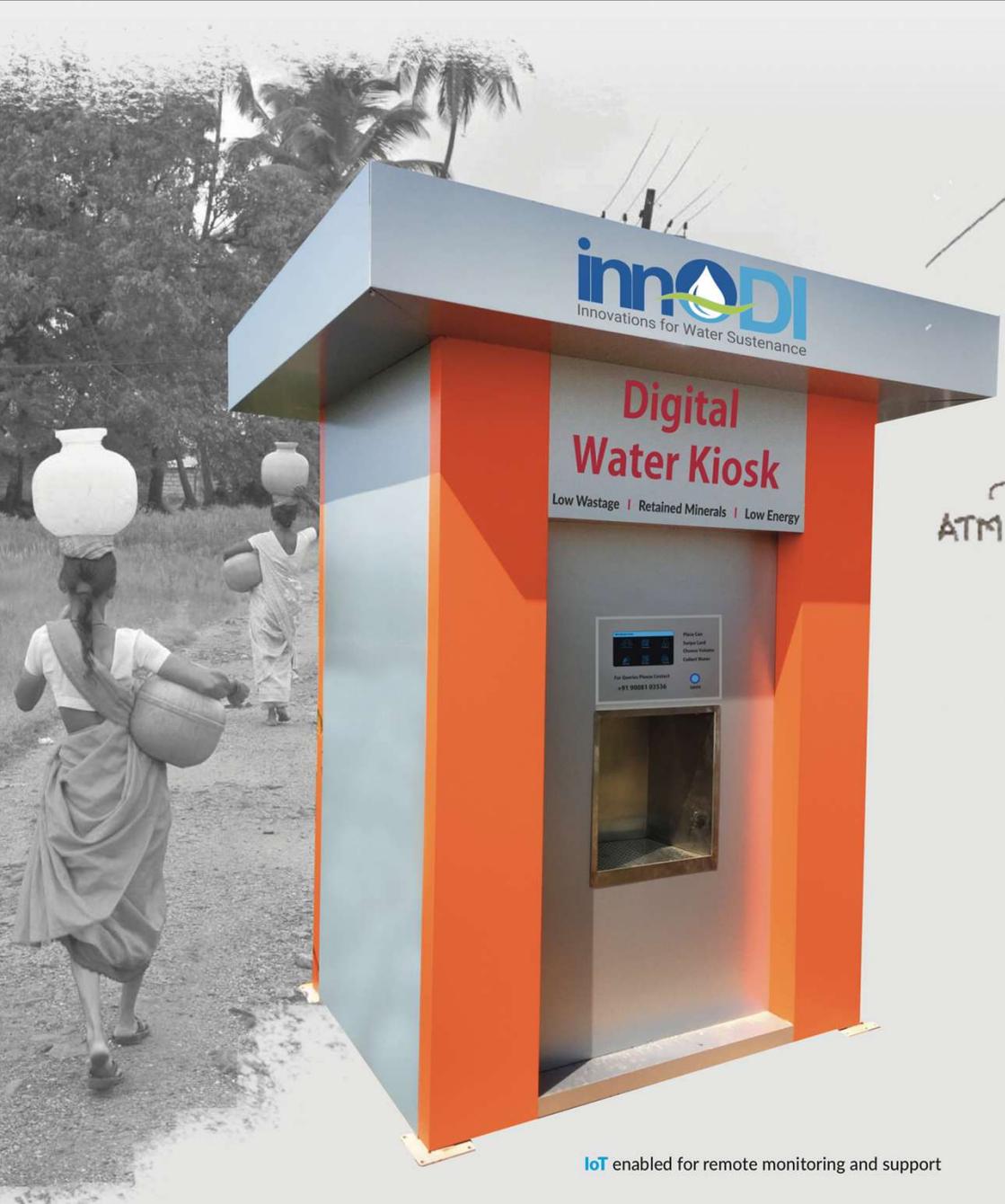
CORAMANDAL COAST (Payan Ghat)

Vembanad Lake

(Coastline of emergence)

DIGITAL WATER KIOSK

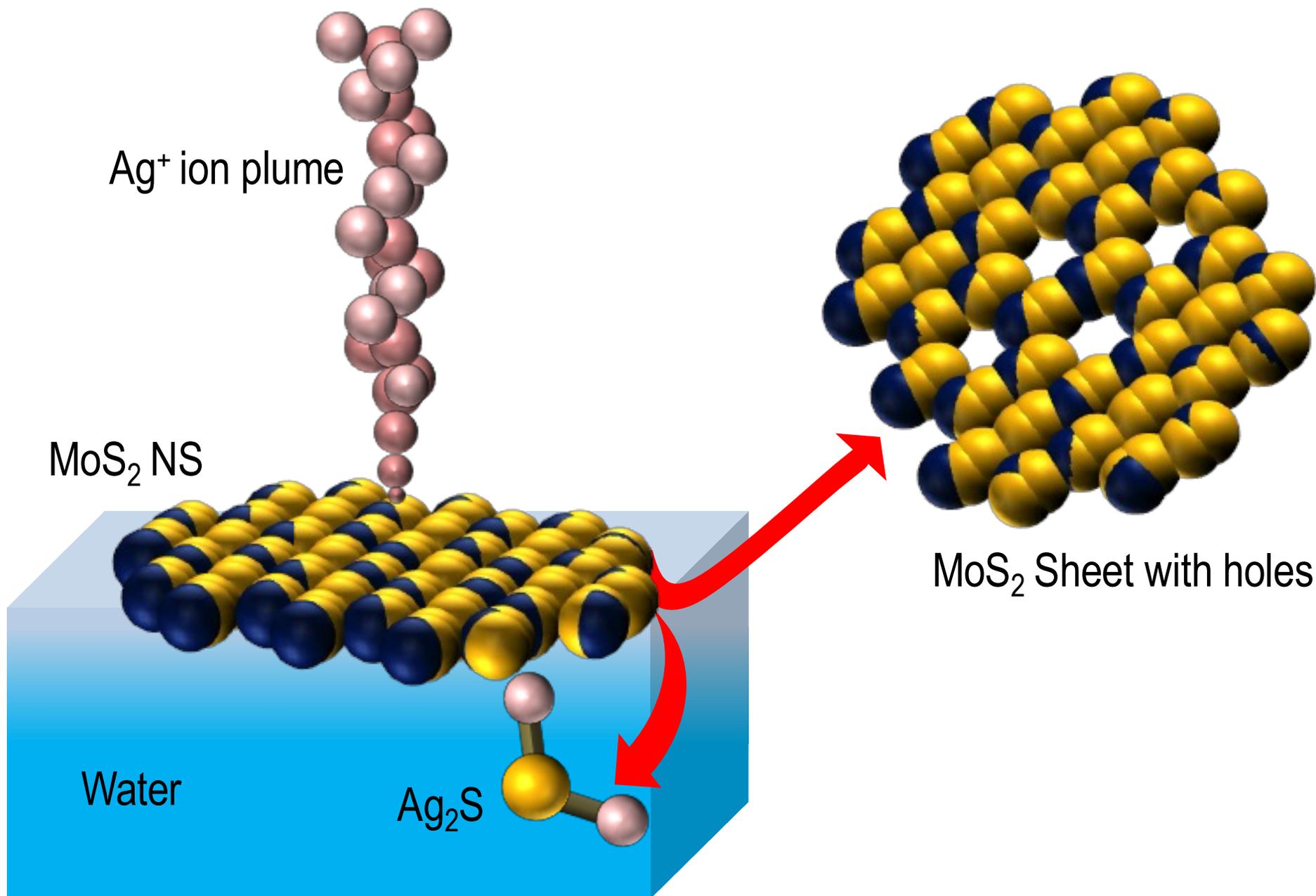
for community drinking using CDI Technology

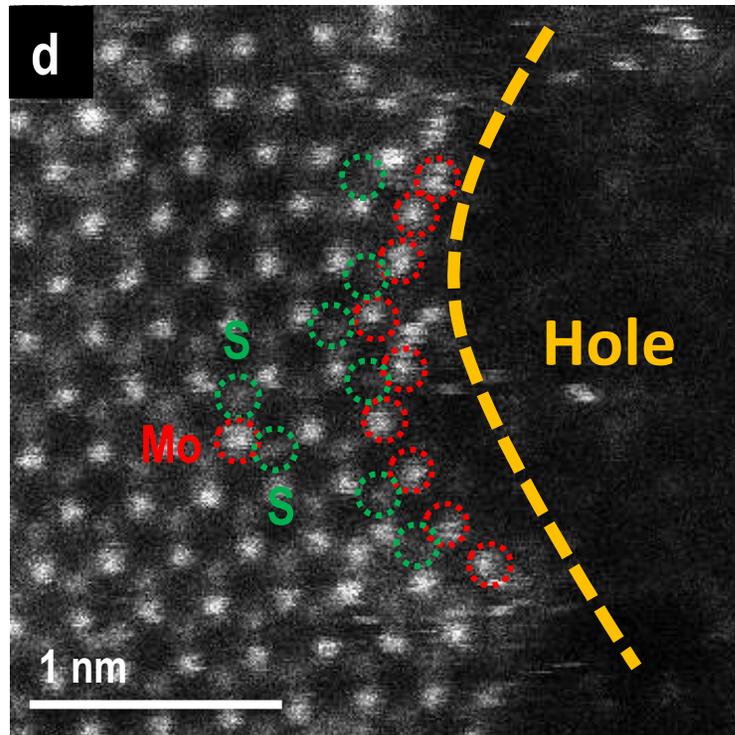
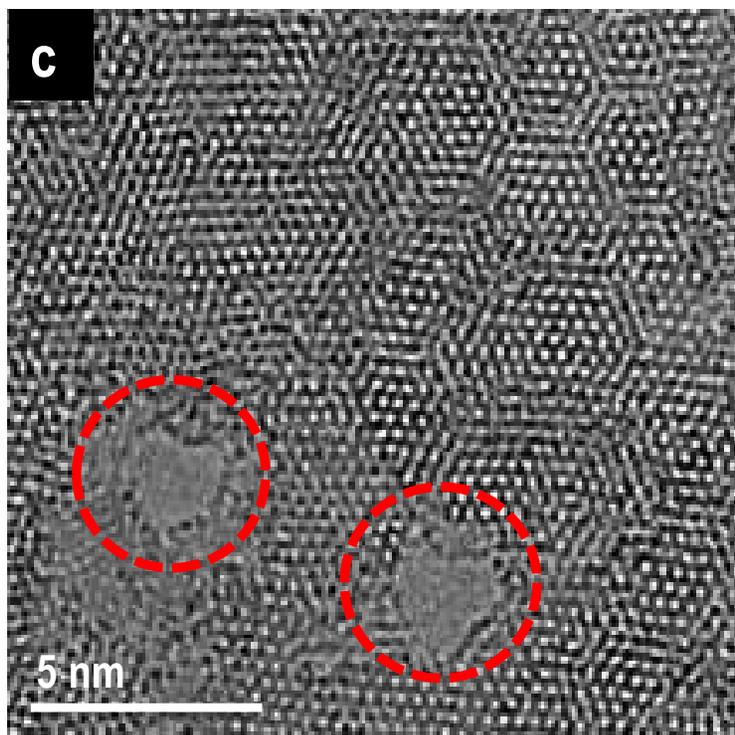
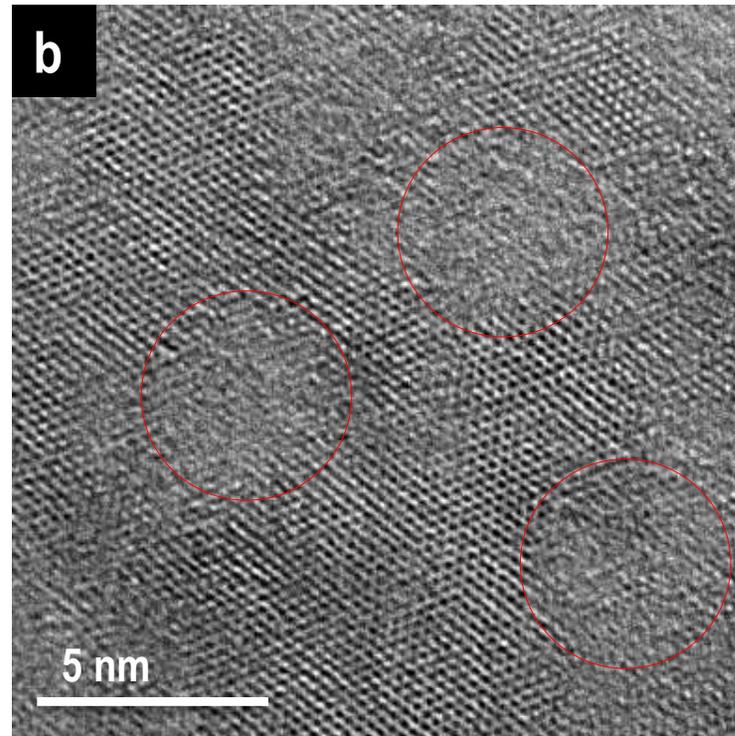
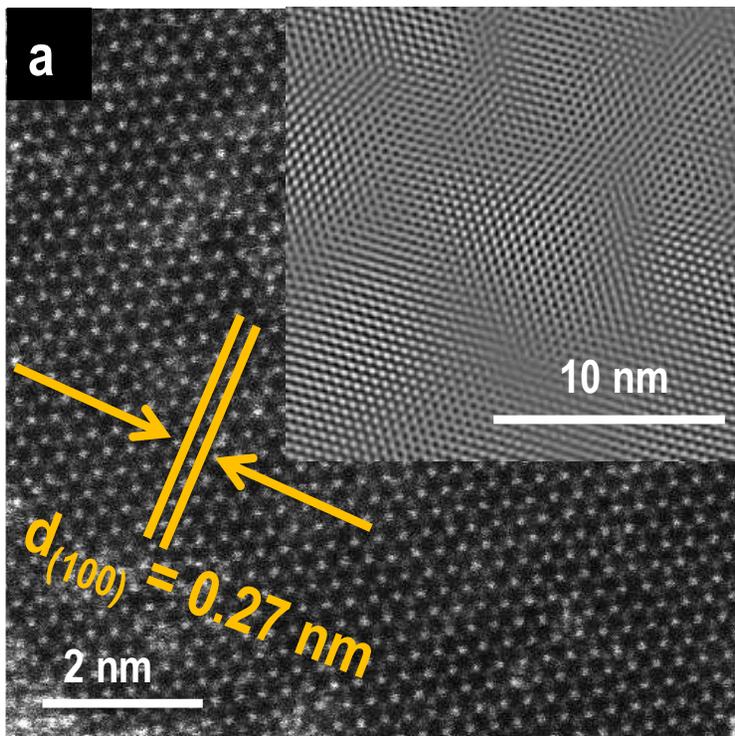


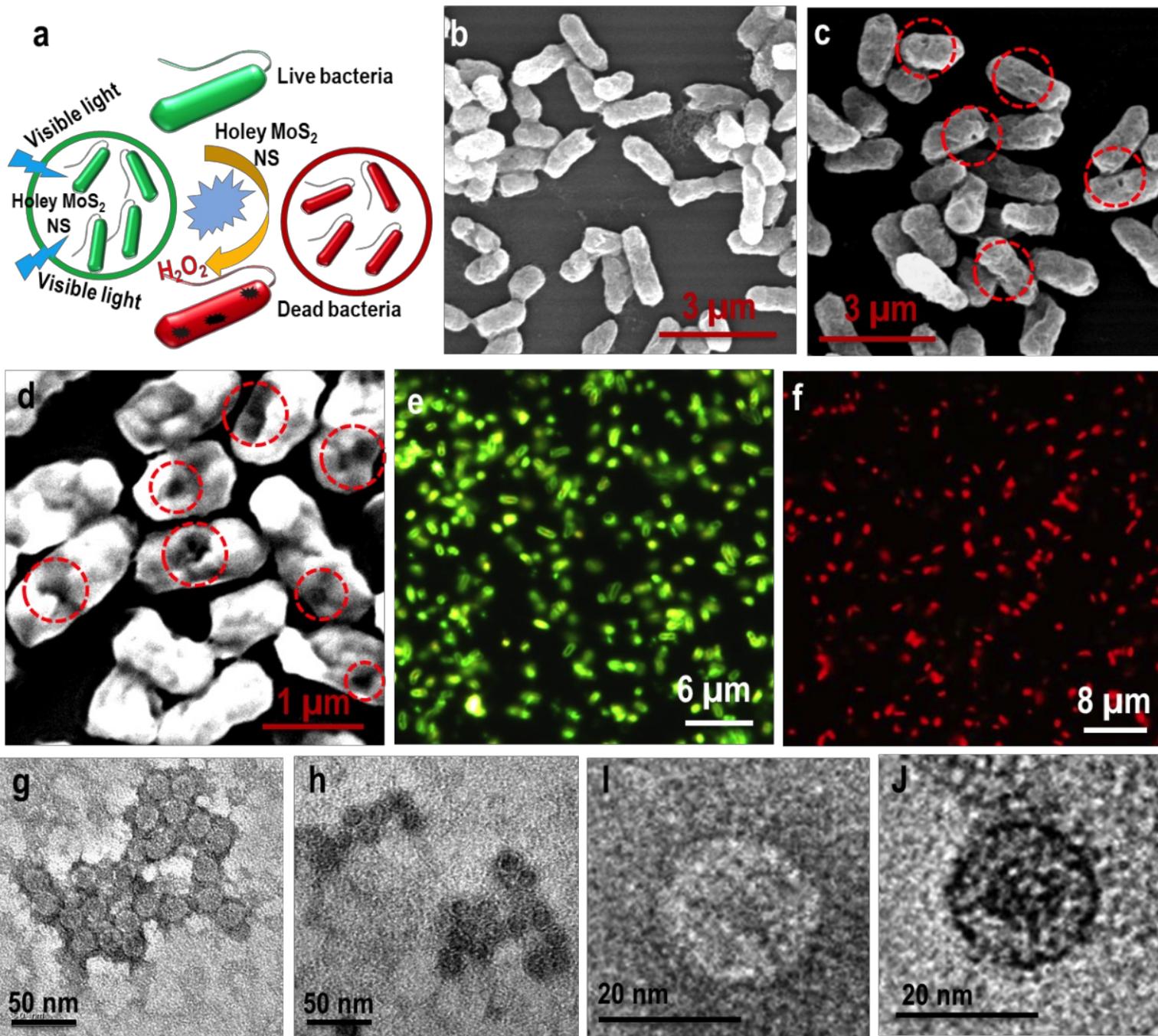
Products under implementation

Vijay Sampath and Tullio Servida

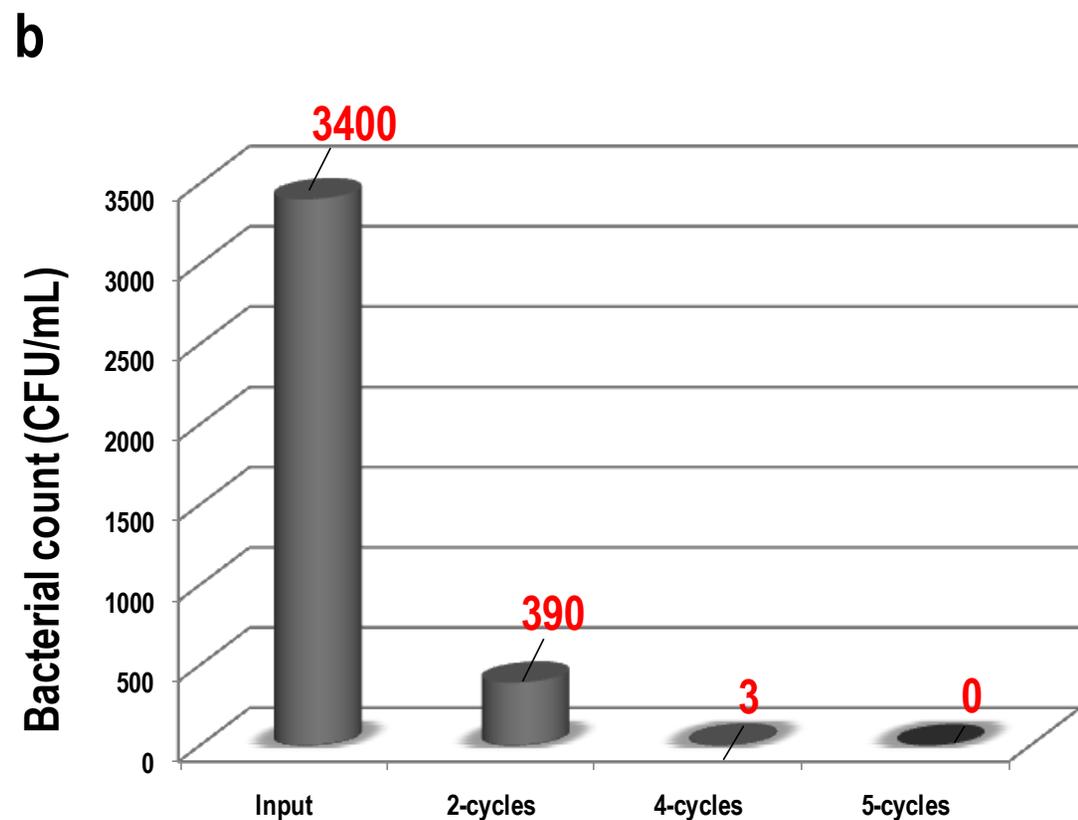
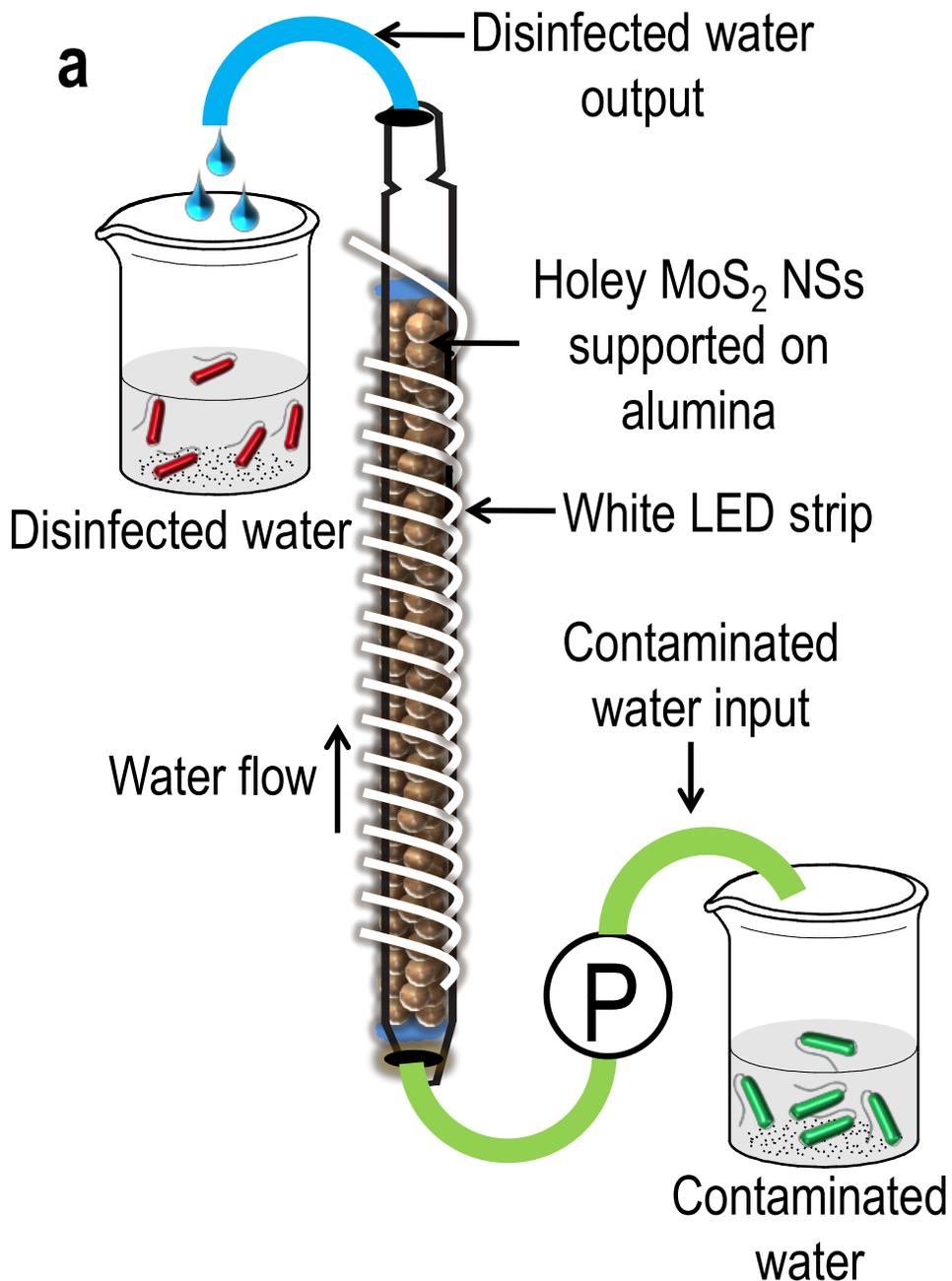
2D materials, nanopores



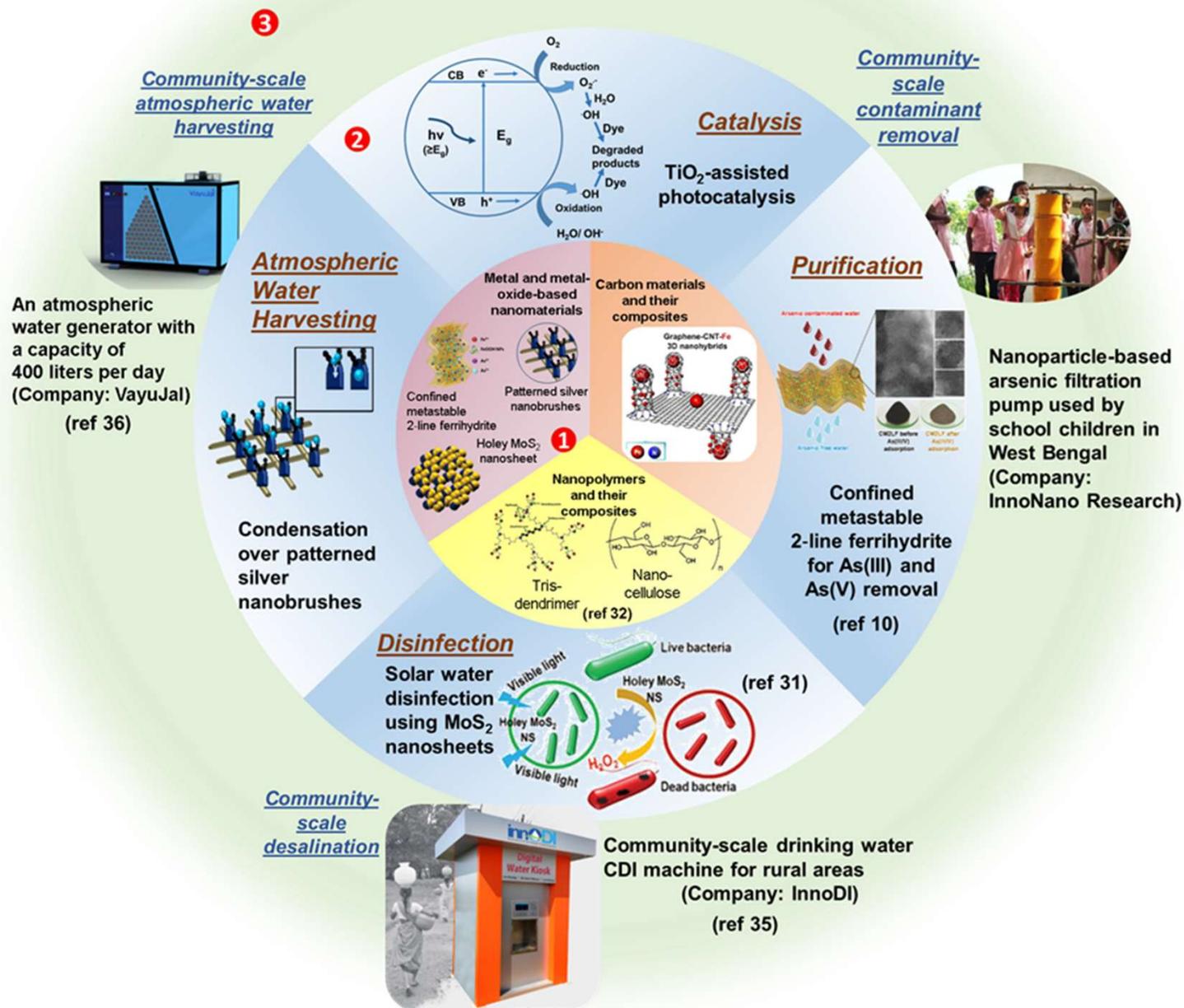




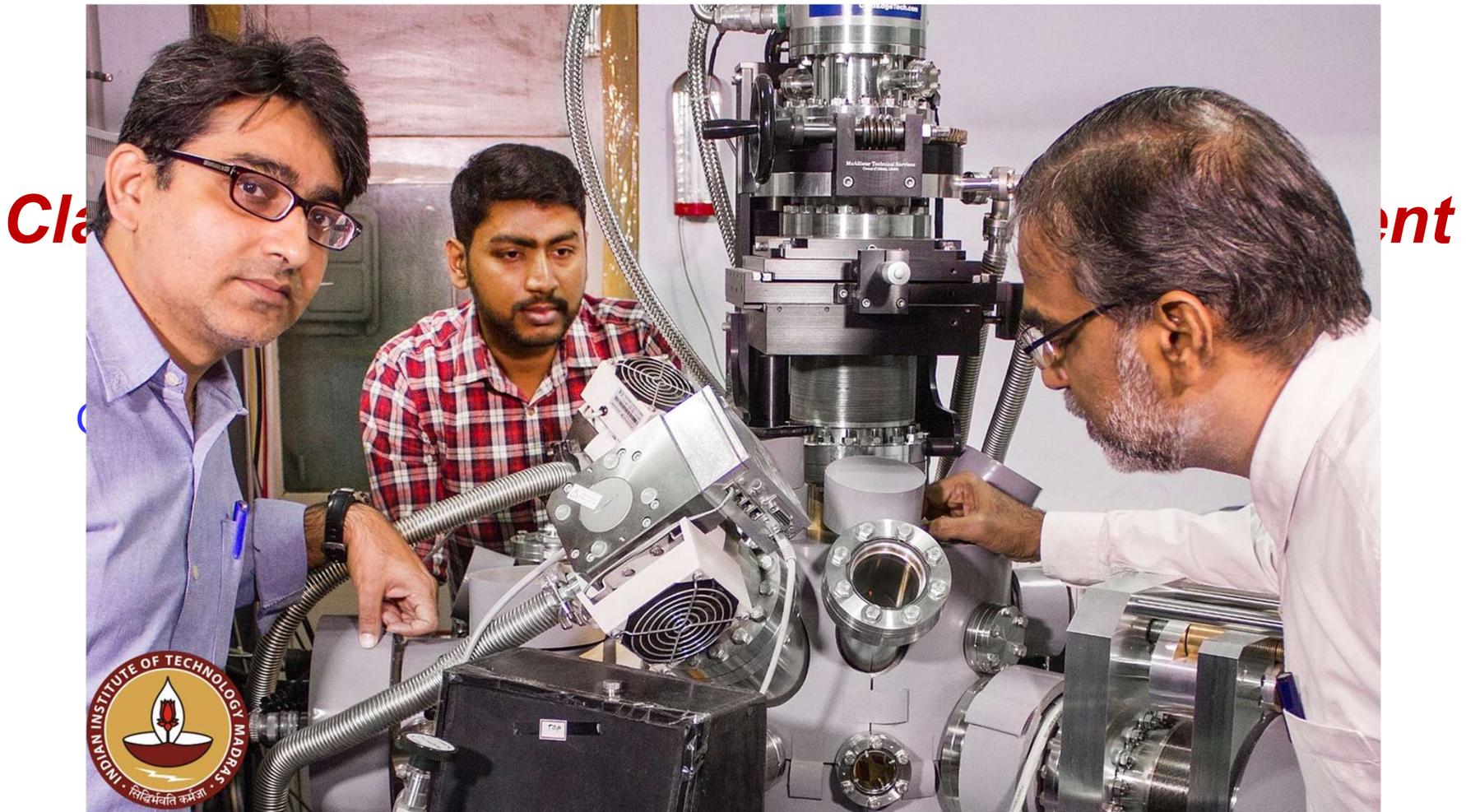
Prototype



Evolution of materials to products

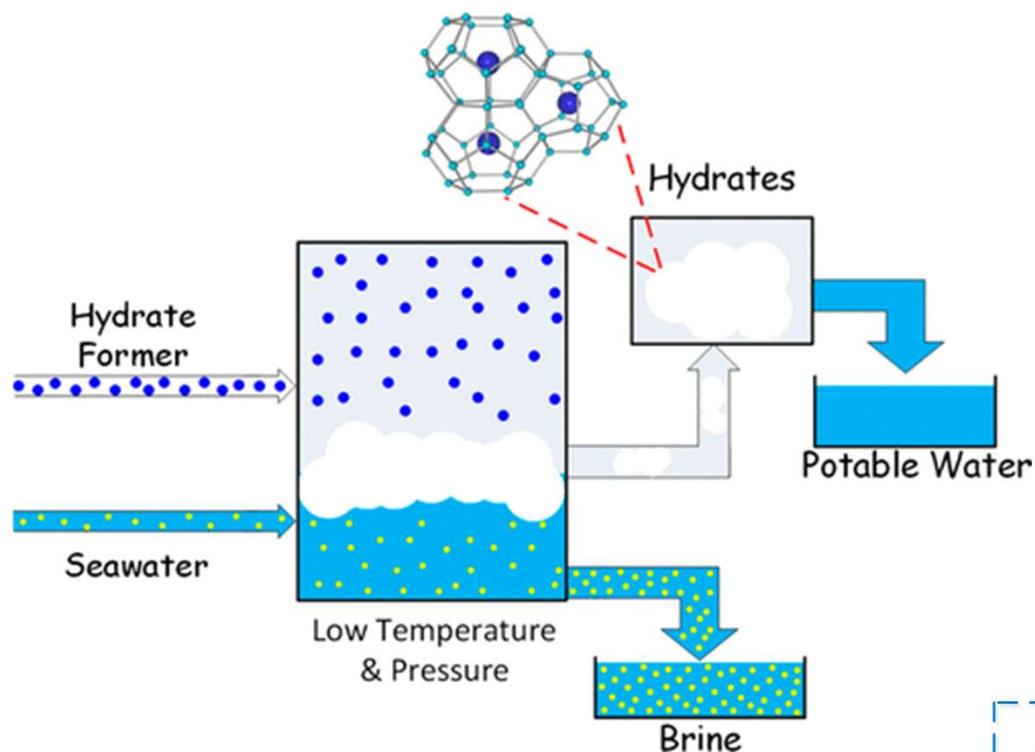


New phenomena



With Rajnish Kumar

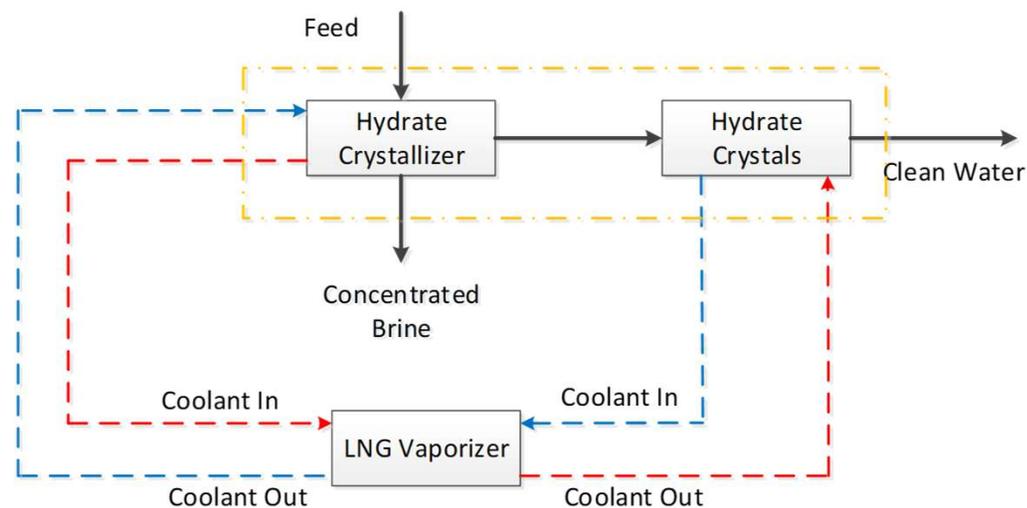
Hydrate-based desalination (HyDesal)



Water dissociated from hydrate is pure

HyDesal process advantages

- ✓ Salts get occluded
- ✓ No chemical reaction, recovery of water is very easy
- ✓ Hydrates consist of 85% water and rest guest gas
- ✓ Not sensitive to impurities or salt concentration



Cold Energy in LNG terminals can be harvested to produce water

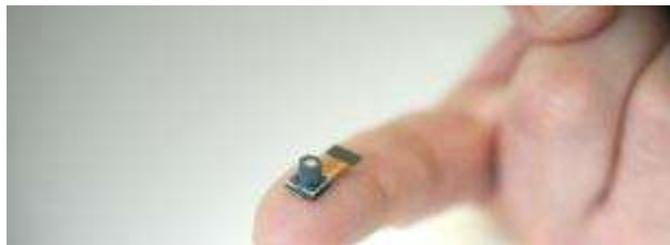
Sensors and new opportunities



Analog/Grating
Equipment
\$ 5~6 Billion (2017)
a few **100k units (2017)**

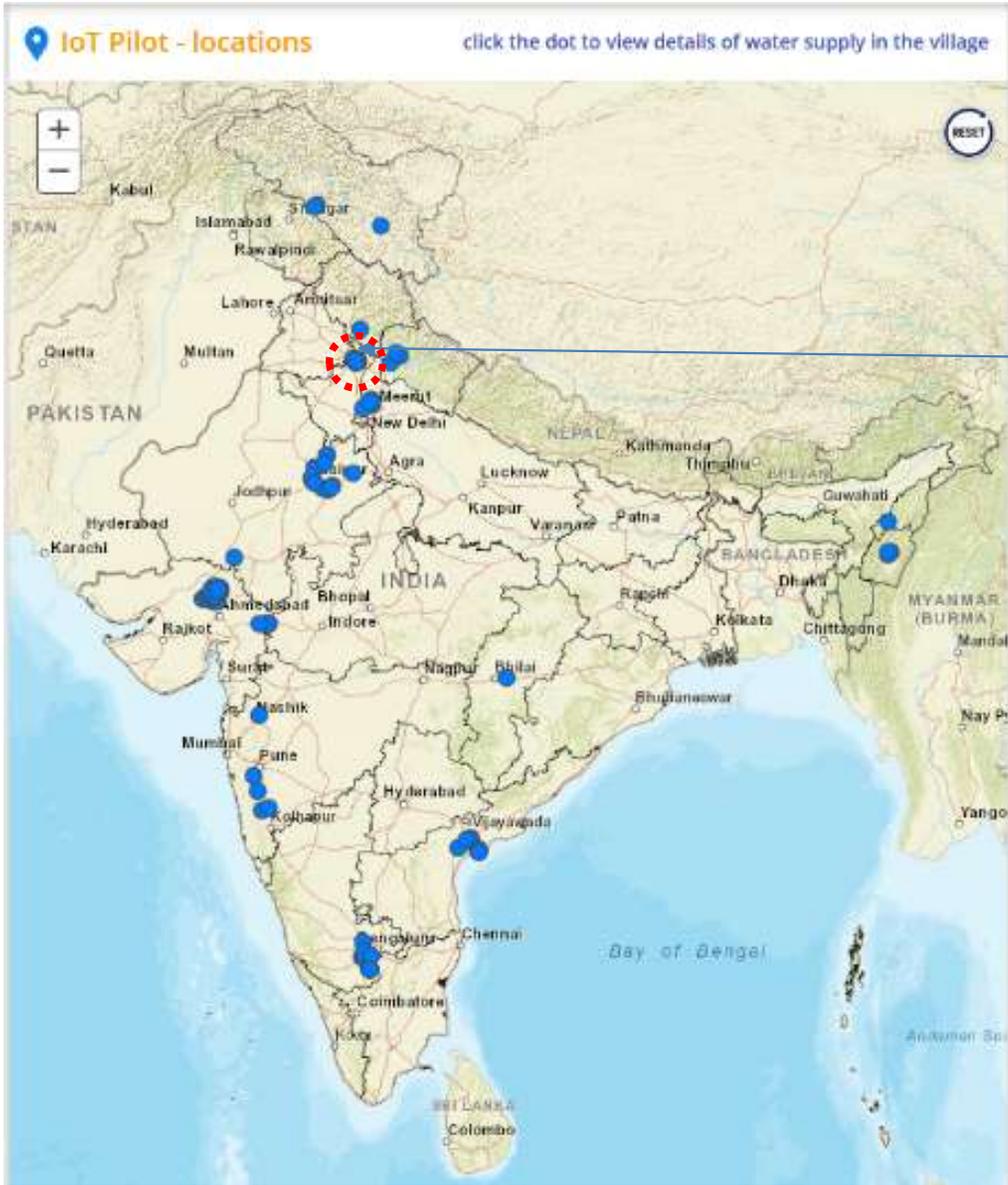


**Ultra compact Low Cost
Spectral Sensor Module**
~ **Billions units (? 2027)**



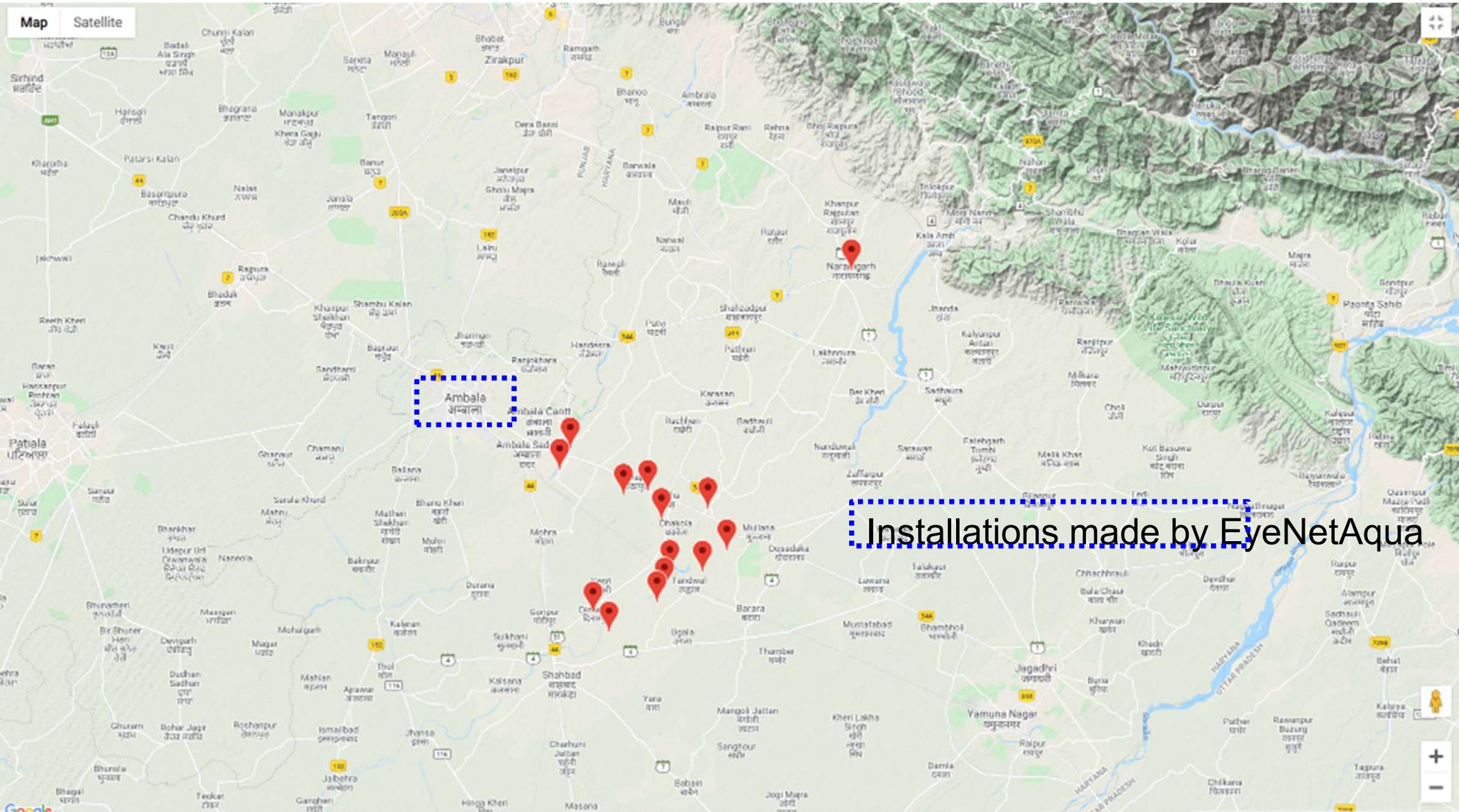
Water quality measurement – In the pipeline

nano λ



Installations made by EyeNetAqua

Installations made by four companies



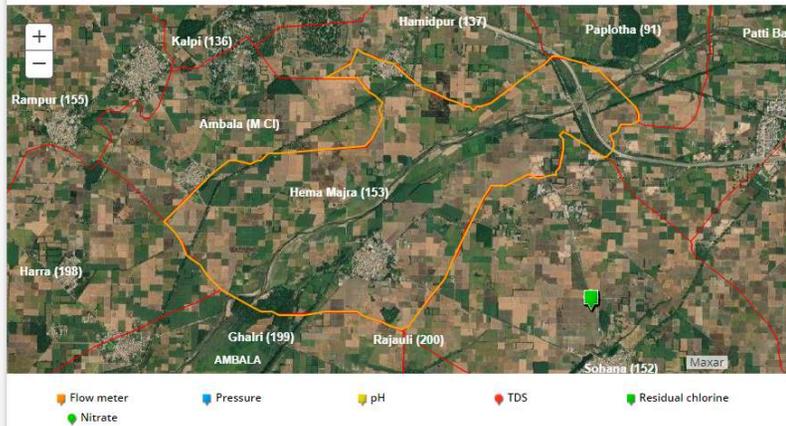
Installations made by EyeNetAqua

Jal Jeevan Mission - Har Ghar Jal

Pilot for IoT-based smart water supply monitoring system



Hema Majra Village in Ambala District, Haryana



Basic Information

[Back](#)

State : Haryana	District : Ambala
Block : Barara	Panchayat : Hema Majra
Village : Hema Majra	Nos. of habitations : 1
Population served through schemes : 1,445	
Agency : EyeNetAqua Solutions Pvt. Ltd. (Under ICT Grand Challenge)	
Location (Water Sources) : Near Govt School	
Scheme : Hema Majra (Igdws)	
Year of commissioning : 2009-2010	

Average water supply (LPCD)

Last 7 Days
12 Feb 2022-18 Feb 2022

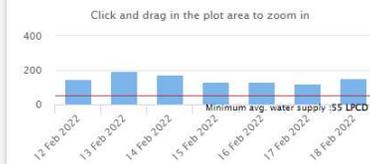
149.69 L

Water Supplied

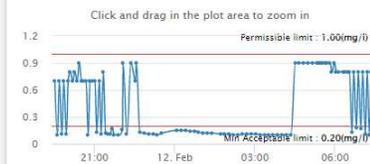
Yesterday
As on 18 Feb 2022

9,076 L

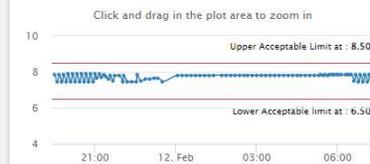
Daily water supply trend (LPCD)



Residual chlorine (mg/l)



pH



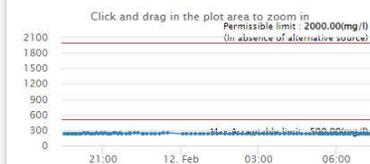
Pressure (meter)



Nitrate (mg/l)



TDS (mg/l)



VWSC/ Pani Samiti Member

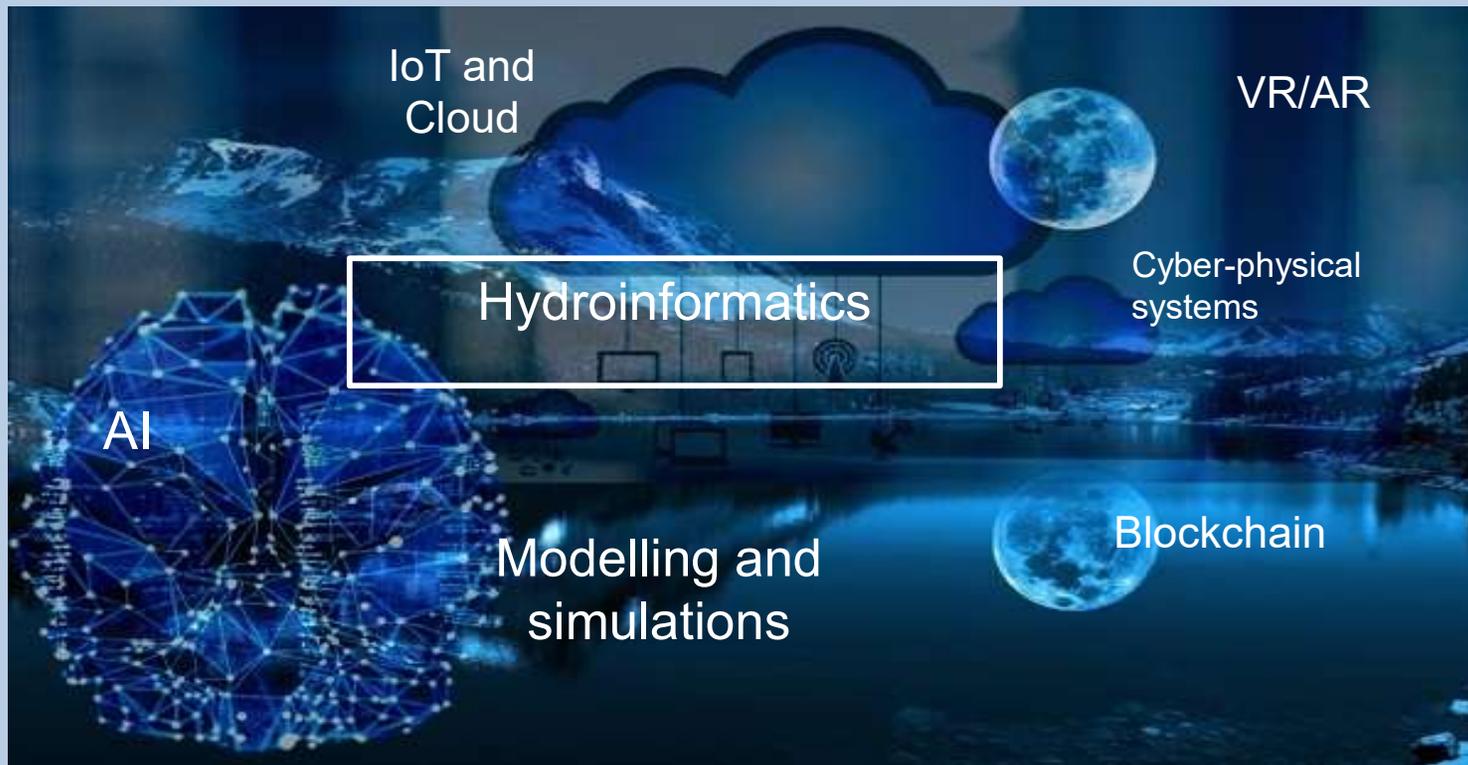
Name	Designation	Gender
Usha Rani	Chairperson	Female

Operation & Maintenance Personnel

Name	Designation	Gender
Anil Kumar	Pump Operator	Male
Ramji Lal	Pump Operator	Male

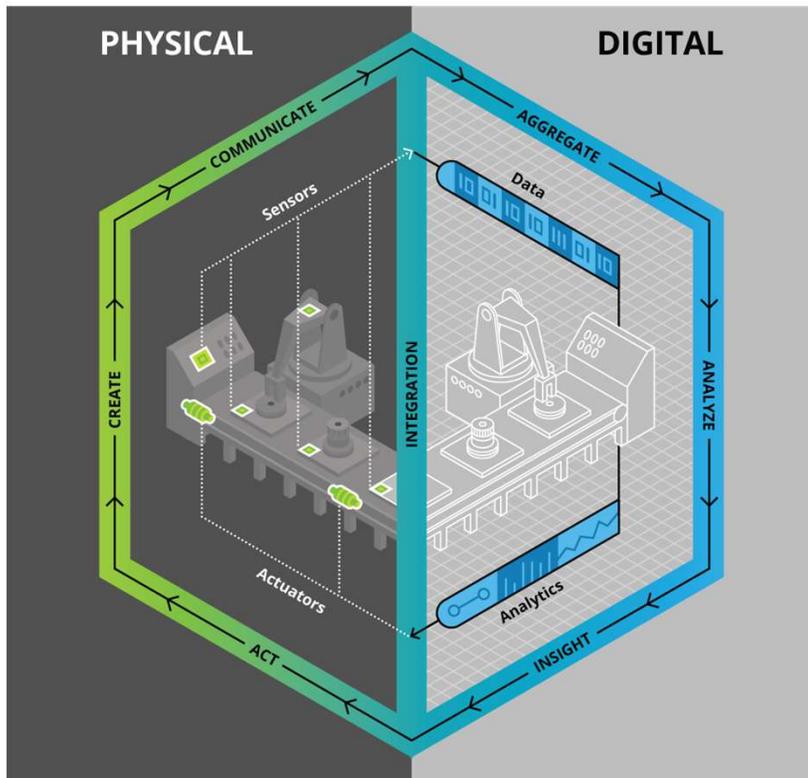
Hydroinformatics

Application of computing technologies for efficient, sustainable and equitable water management.



Digital water or water 4.0 will revolutionize water management.

Digital twin of water resources



Digital twin is the digital visualization and representation of a physical or natural system, which may gather data continuously from its physical counterpart and interact with it via a control system.

Create a digital twin of different elements of hydrologic environment – surface water bodies, ground water, rivers, and urban water utilities.

Data-driven modelling of events such as flood inundation of rural and urban areas with 3D visualization using the digital twin representation of the landscape.

Integration of real-time modelling of groundwater and surface water, water supply networks and utilities combined with analytics platform more accurate decision making.



Policy

Traditional knowledge



<https://www.unnatisilks.com/blog/naturally-colored-cottons-a-regain-in-popularity/>

Arsenic free rice



So much is happening on the ground

What science can offer - Innovations

Solve at source – Green/sustainable chemistry

Water in agriculture, energy, construction,.....

Water in materials – Detergents, plastics, antibiotics,...

Wearable sensors and big data

Water on the central stage

Clean water for India

What should we do?

Care for future: Sustainability planning – industry, ecosystem

Learn from the past: Water security, rainwater harvesting, conservation, nature

Education: Water literacy, critical knowledge in specific areas

Action: Recycling, protection, cap freshwater withdrawals at 2020 levels

New initiatives: Water cost in products and services, National detergent policy – an example

What do the opportunities in water amount to?

Towards NetZero

Reduced energy processes

RO vs CDI

RO with aquaporins

RO vs NF

Adsorption vs filtration

2D materials

Energy zero processes

Adsorption

AWG

Carbon zero materials

RT synthesis

Aqueous processes

Sustainability metrics

Water positive materials

Solar pumping & gravity fed solutions

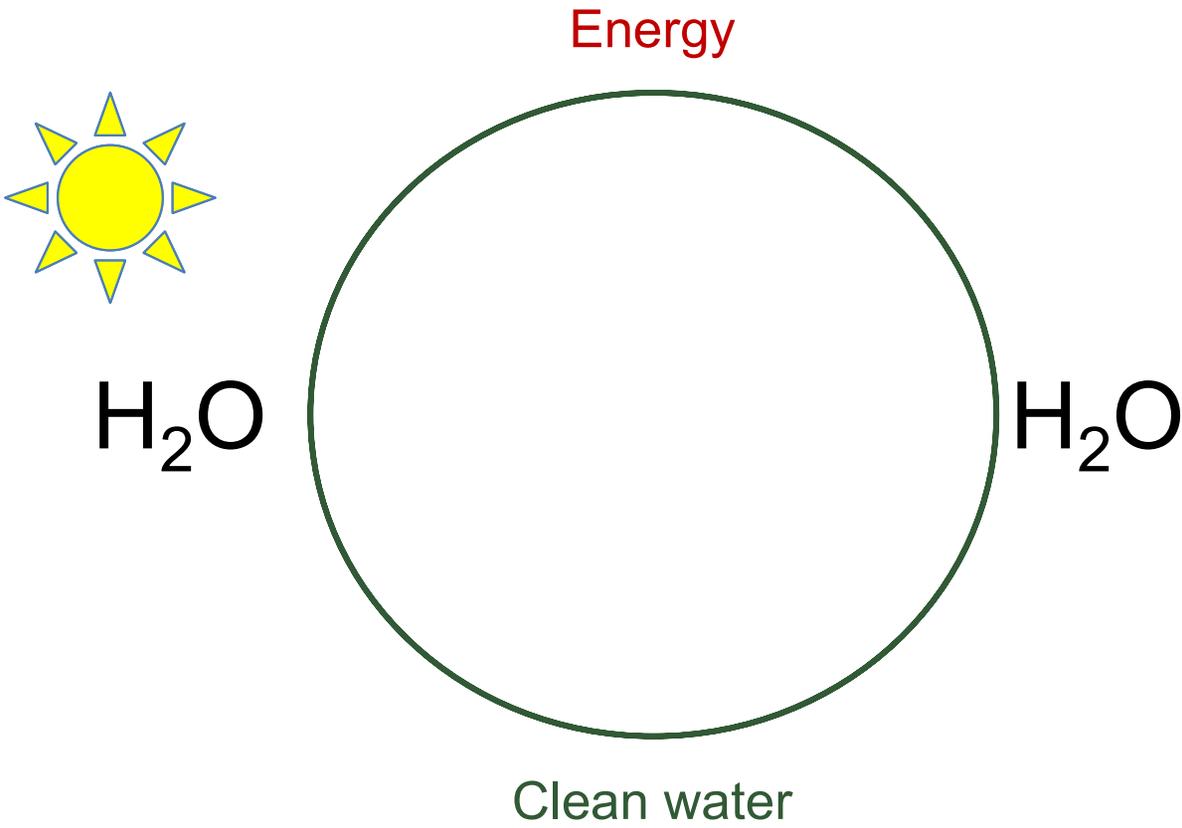
Traditional wisdom

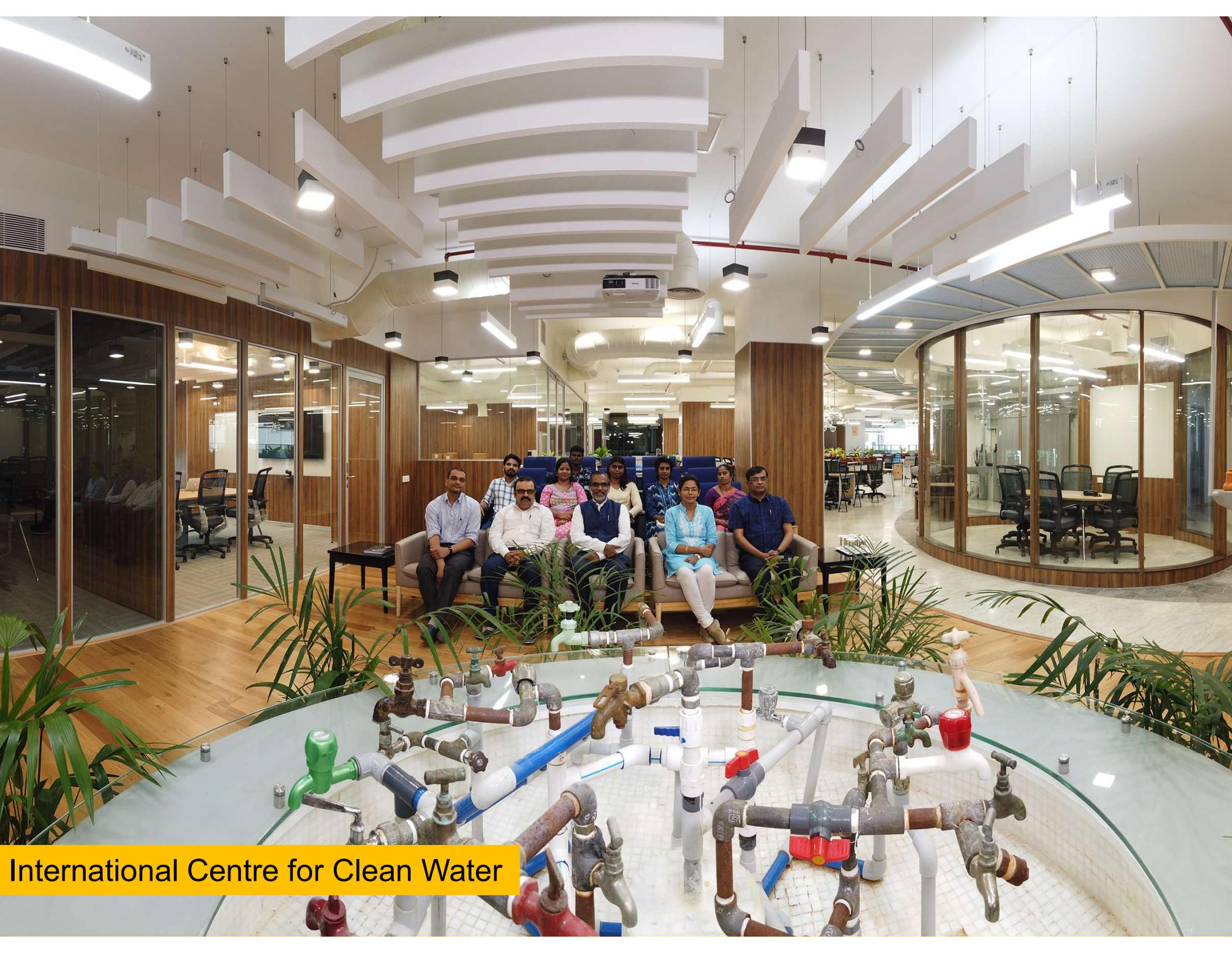
Water harvesting – we do around 8%

Preserve water bodies

Dig wells, maintain them

Plant trees – 14 trees per person

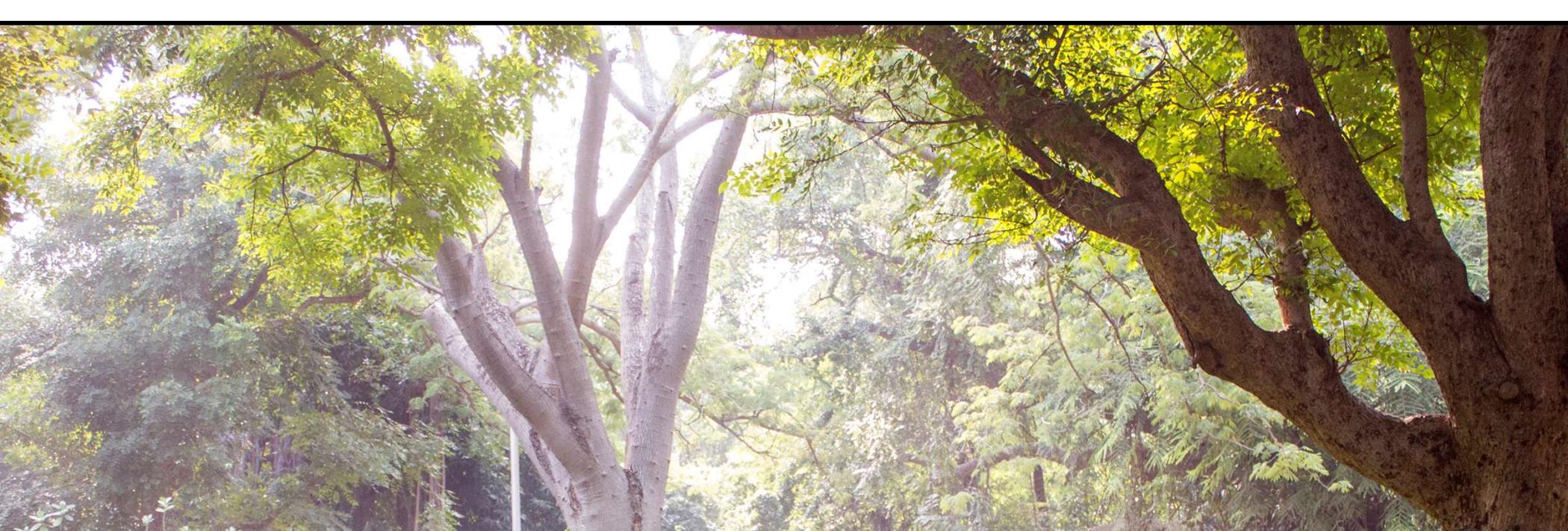




International Centre for Clean Water



IIT Madras Research Park



The AMRIT Team, 2013



Group during 2018, along with Prof. Graham Cooks

People: A. Sreekumaran Nair, Anshup, M. Udhaya Sankar, Amrita Chaudhary, Renjis T. Tom, T. S. Sreeprasad, Udayabhaskararao Thumu, M. S. Bootharaju, K. R. Krishnadas, Kalamesh Chaudhari, Soujit Sengupta, Depanjan Sarkar, Avijit Baidya, Swathy Jakka Ravindran, Abhijit Nag, S. Vidhya, Biswajit Mondal, Krishnan Swaminathan, Azhardin Gnayee, Sudhakar Chennu, A. Suganya, Rabiul Islam, Sritama Mukherjee, Tanvi Gupte, Jenifer Shantha Kumar, A. Anil Kumar, Ankit Nagar, Ramesh Kumar Soni, Tanmayaa Nayak, Shihabudheen M. Maliyekkal, G. Velmurugan, Wakeel Ahmed Dar, Ganapati Natarajan, N. Pugazhenthiran, A. Leelavathi, Sahaja Aigal, S.Gayathri, Bibhuti Bhusan Rath, Ananthu Mahendranath, Harsh Dave, Erik Mobegi, Egor Moses, Hemanta R. Naik

Funding: Department of Science and Technology, Government of India

Start-ups and partners:



Our collaborators



Ministry of Drinking Water and Sanitation, Govt. of India



IndianOil





Indian Institute of Technology Madras



Directors - past and present

Thank you all



Associate Editor

ACS
Sustainable
Chemistry & Engineering

