Since 1959

Science, technology and innovation for sustainable clean water

T. Pradeep

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https://pradeepresearch.org

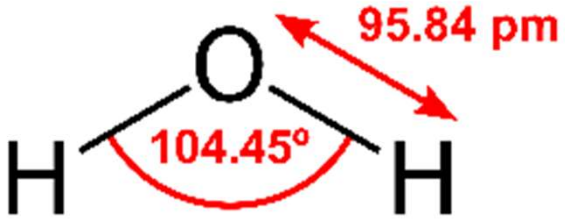
Co-founder

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. Ajit K. Chaturvedi, Director
Prof. Apurbba Kumar Sharma,
Dean of Academic Affairs



National Science Day Lecture, IIT Roorkee, 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)

WORLDS IN THE MAKING

THE EVOLUTION OF THE UNIVERSE

BY

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

TRANSLATED BY
DR. H. BORNS

ILLUSTRATED

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

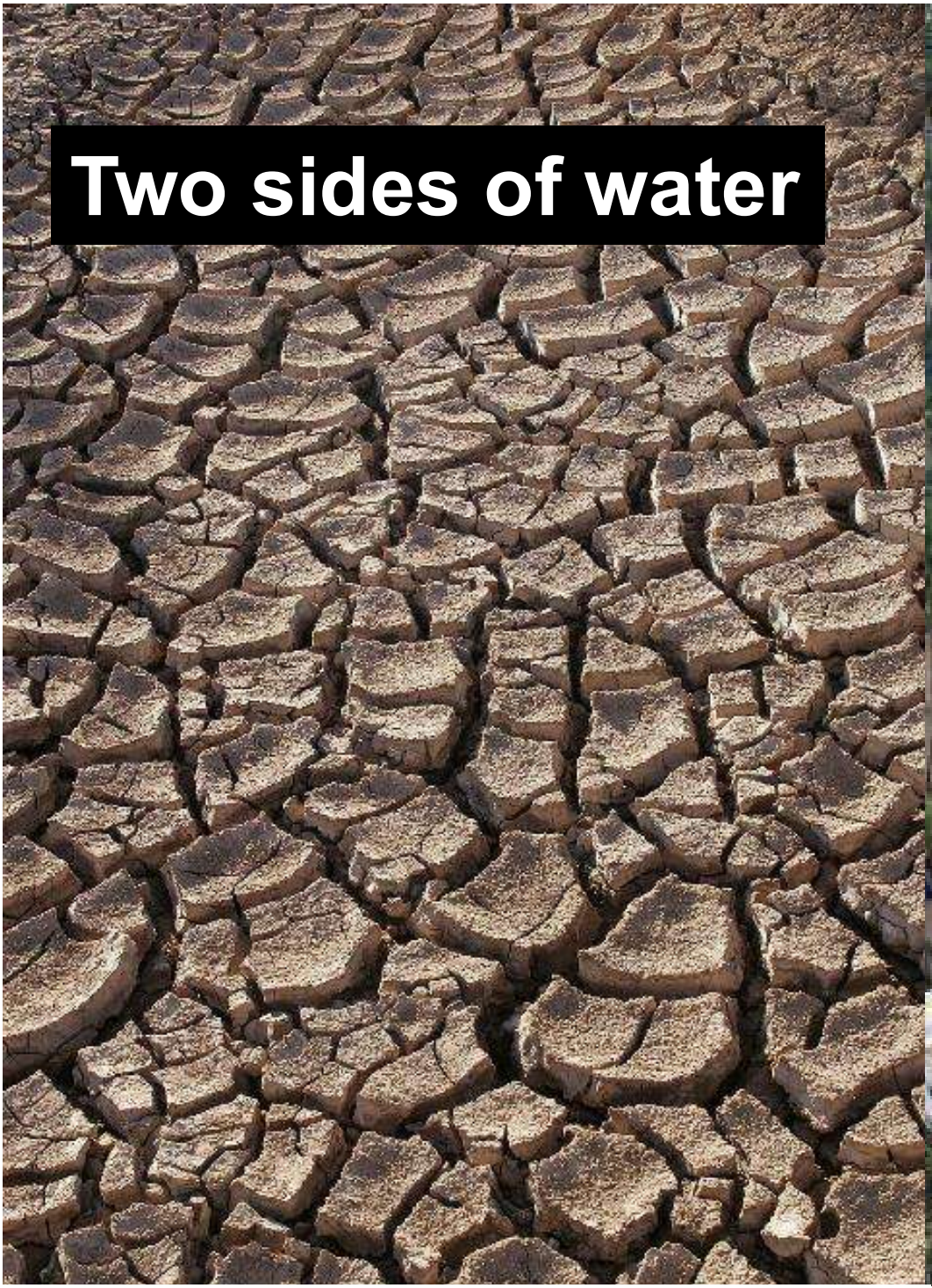
Water is the simplest and simultaneously the most complex problem of humanity.

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
Dry ground in the Sonoran Desert, Sonora, Mexico.

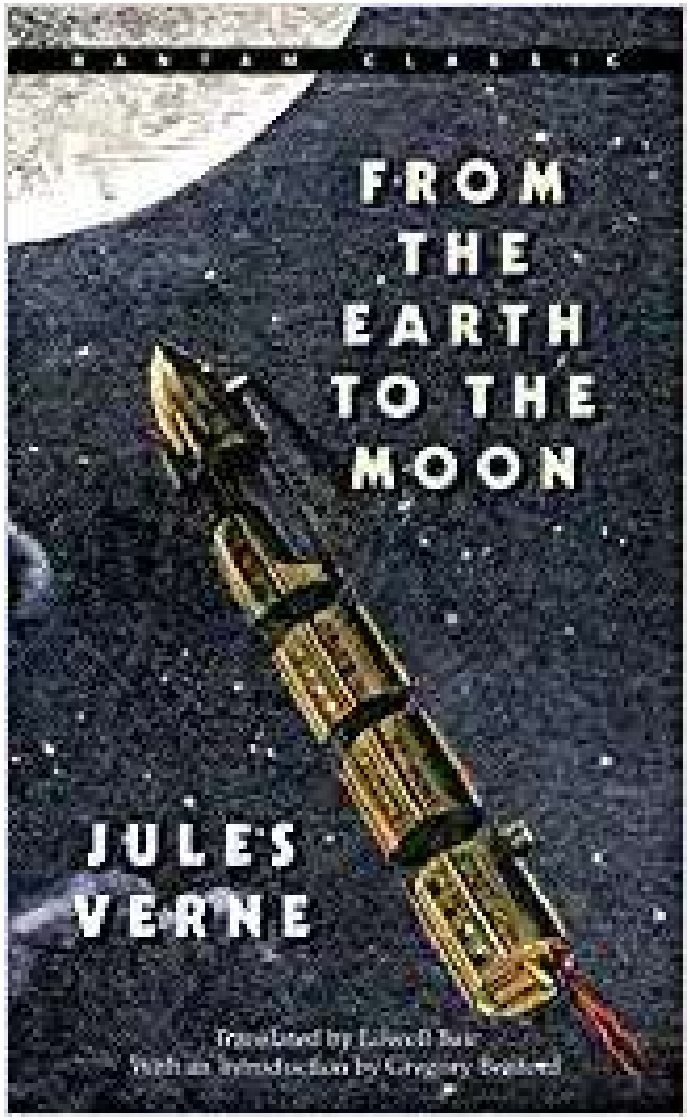
Kerala Floods, August 16, 2018, Wiki

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!

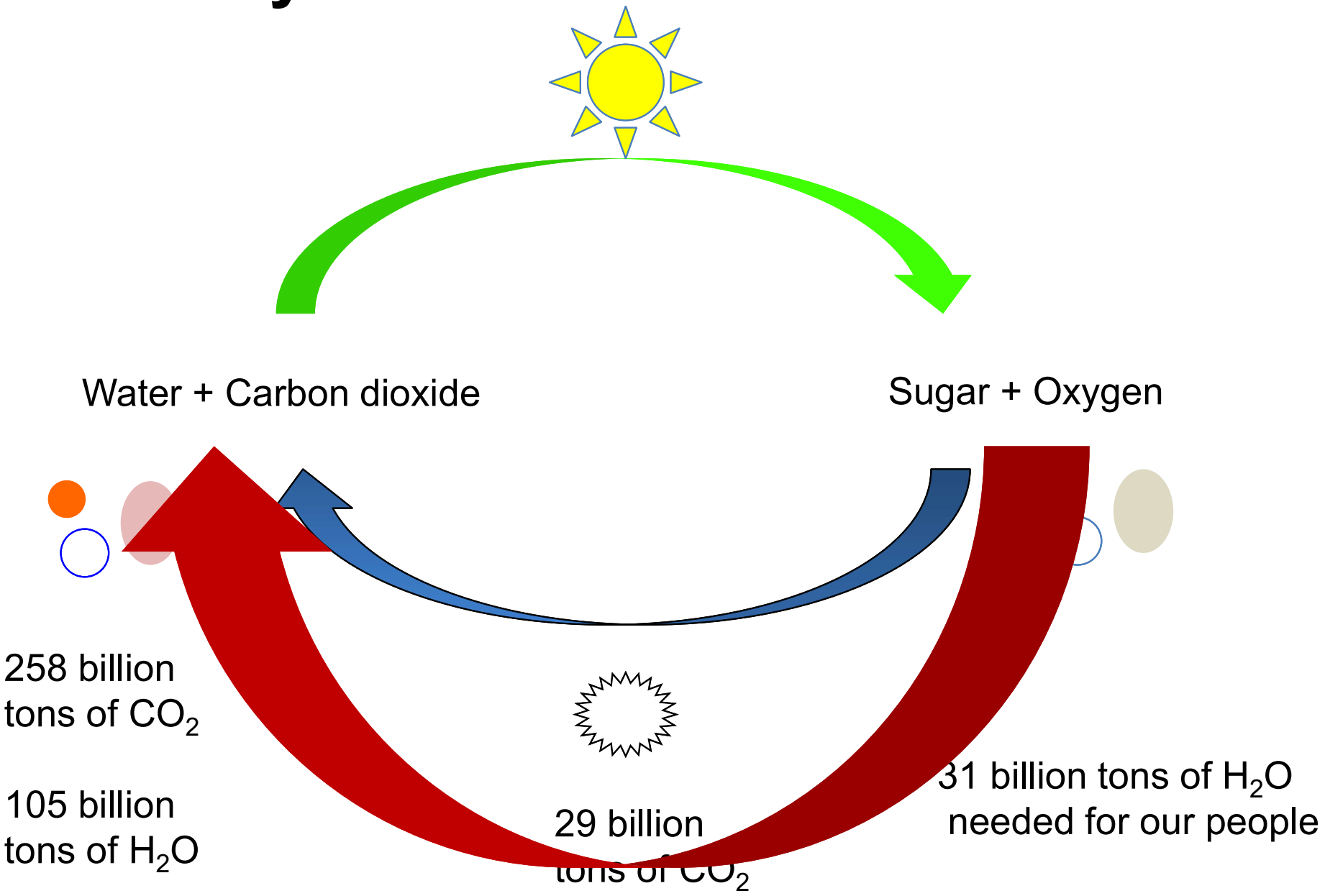
Well, add efficiency, other costs of plant, transportation, etc.

The truth

Water cycle is NetZero – we have opened the cycle

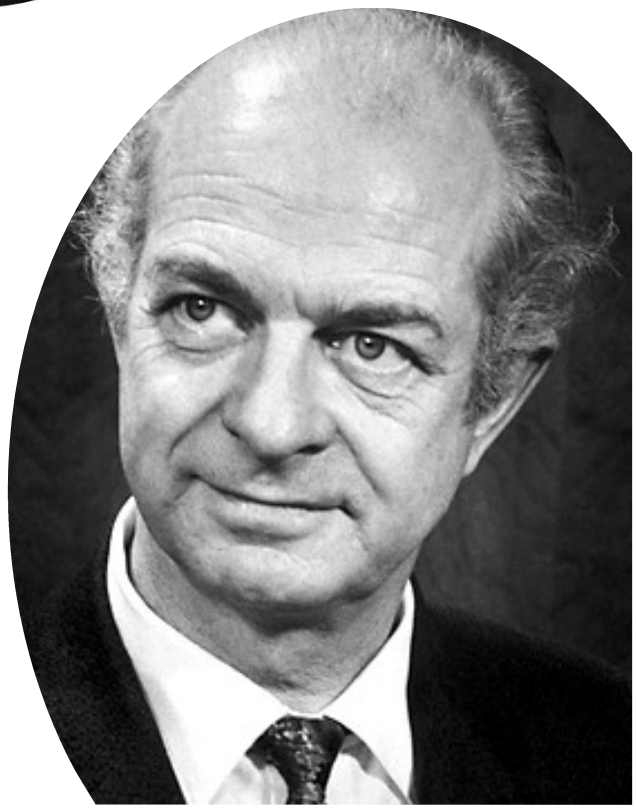
Image from Wikipedia

Circularity and threats



The earth, the air, the land and the water are not an inheritance from our forefathers but on loan from our children. So, we have to handover to them at least as it was handed over to us.

M. K. Gandhi

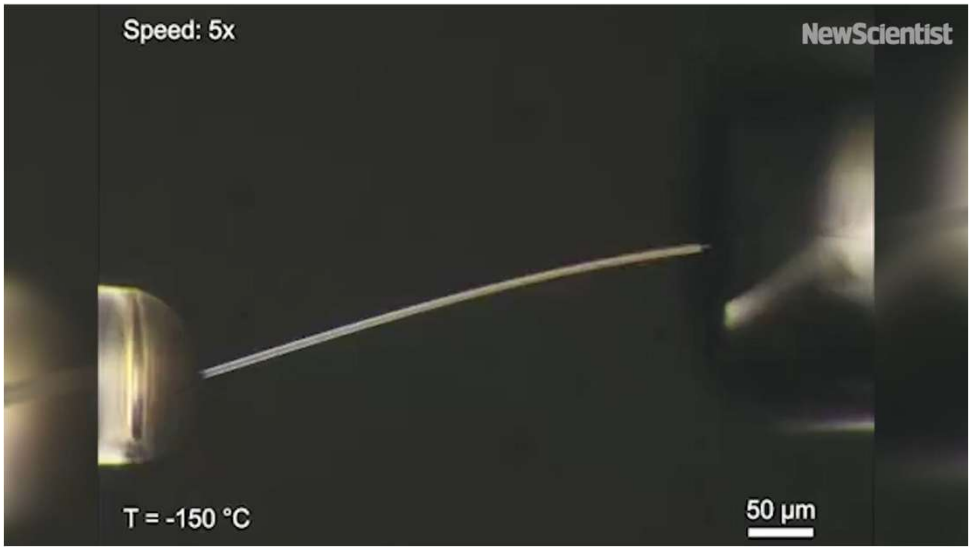


Life is a relationship among molecules and not a property of any molecule.

Linus Pauling

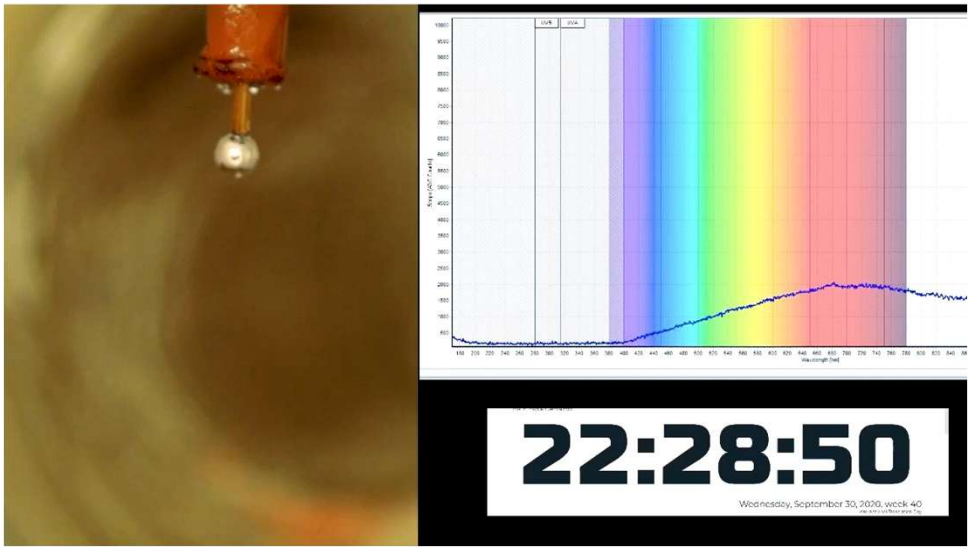
Water continues to fascinate science

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 km^3 (~1.4×10^{18} tons)
2.5% is freshwater and 0.3% surface water

Total precipitation – 505,000 BCM

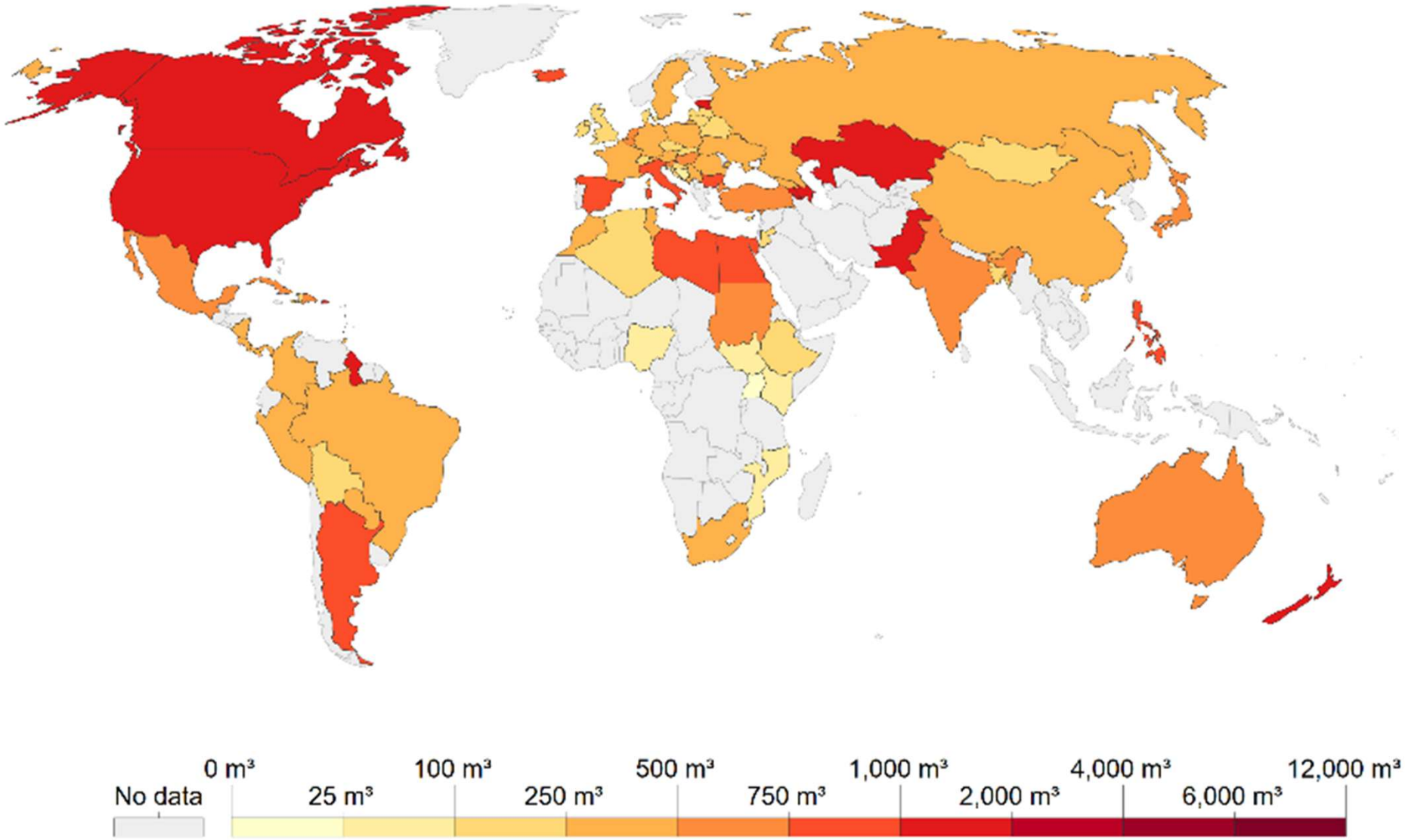
India – 4000 BCM, geographical area 328.7 million hectare

Per capita water availability – 1500 CM

Average rainfall 1085 mm, 85^{th} 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

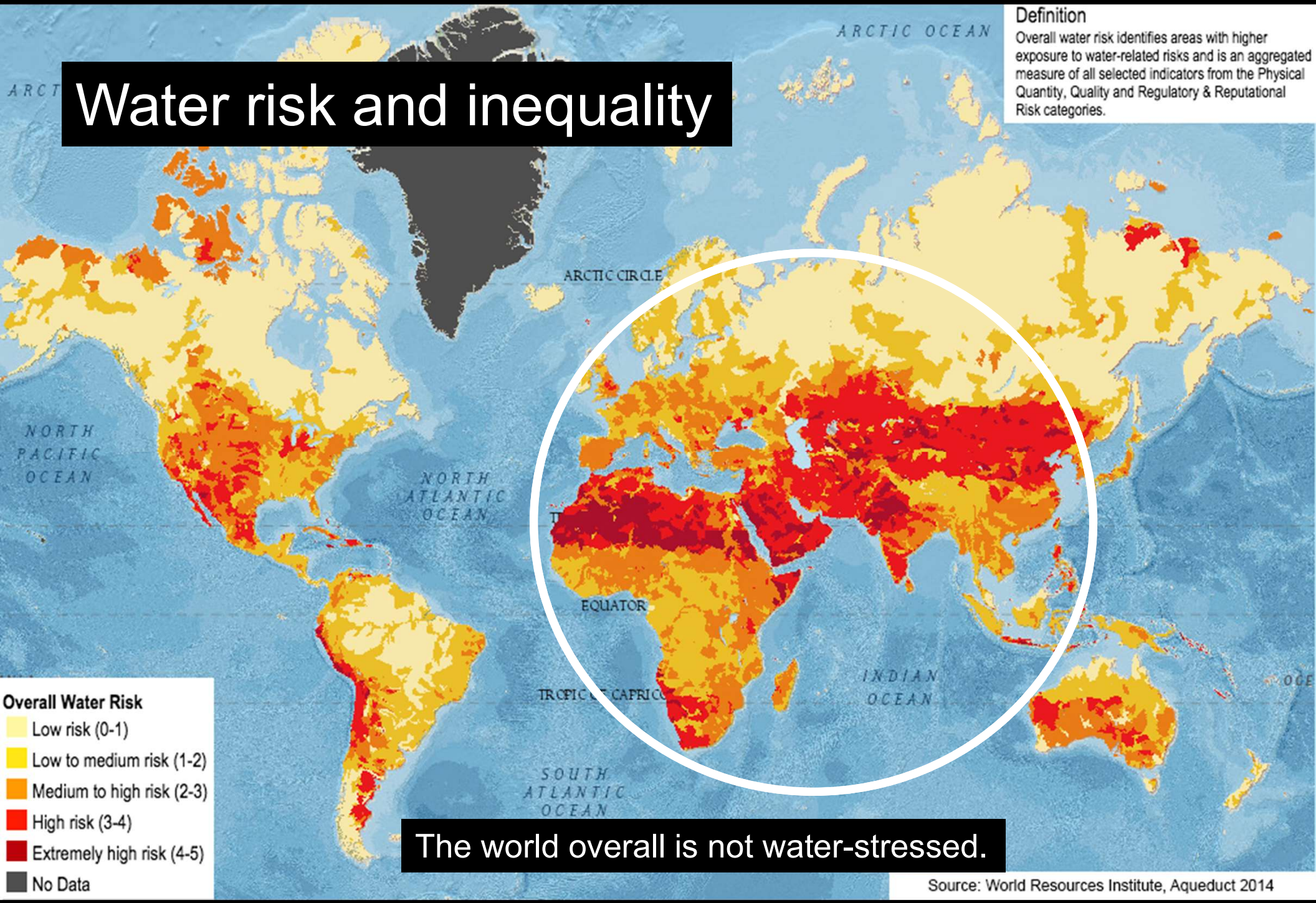
Water withdrawals per capita, 2015



Source: UN Food and Agricultural Organization (FAO) AQUASTAT

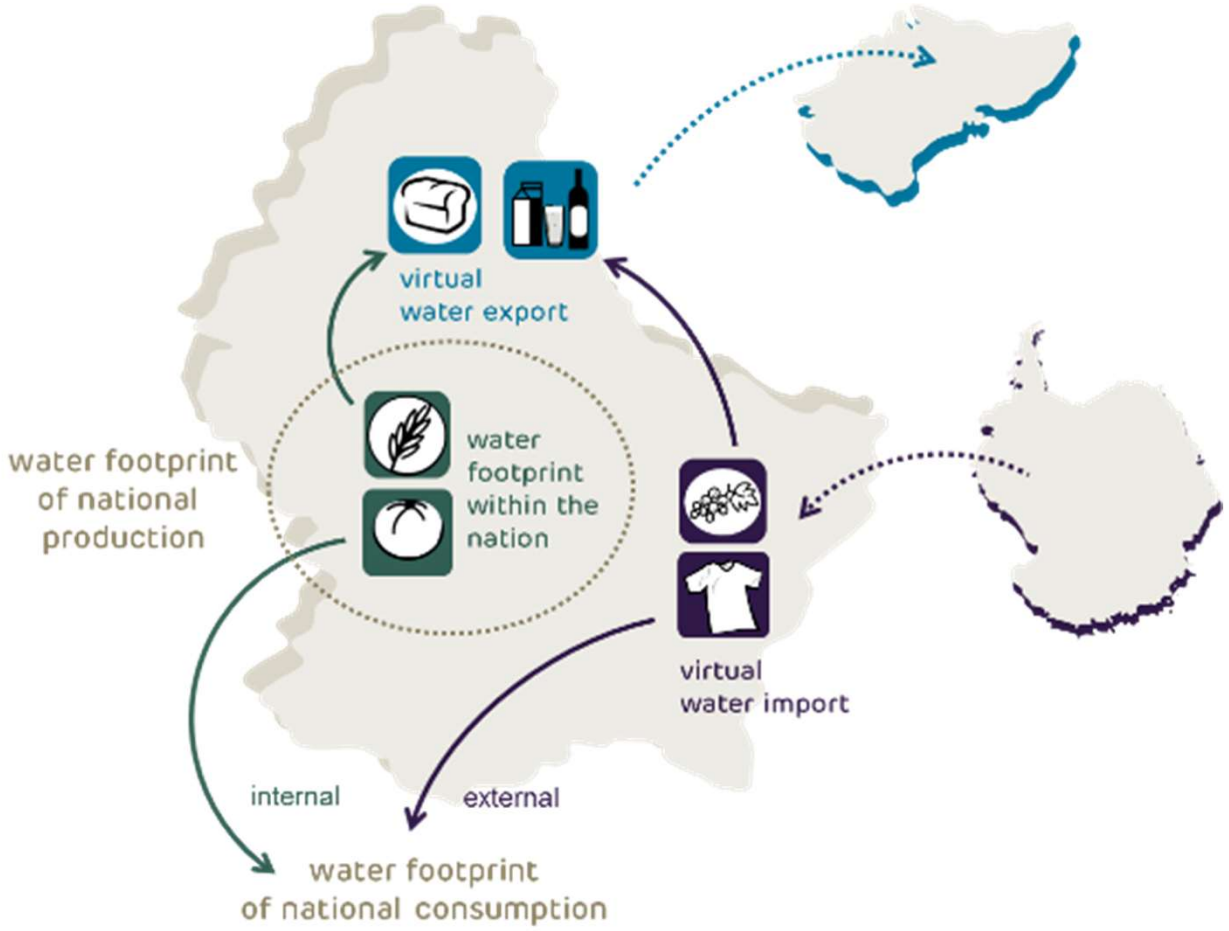
OurWorldInData.org/water-access-resources-sanitation/ • CC BY

Water risk and inequality



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/

Arjen Y. Hoekstra and Mesfin M. Mekonnen, The water footprint of humanity, PNAS, 109, 2012, 3232–3237

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


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
© Nations Online Project

http://www.un.org/sustainabledevelopment/blog/2015/12/sustainable-development-goals-kick-off-with-start-of-new-year/#prettyPhoto

India’s water challenges

21% of India’s diseases are water-related; 1 in 5 children in India die before the age of 5 as a result of contaminated water, lack of sanitation, or inadequate hygiene.

Almost 2 in 3 people who lack access to safe drinking water survive on less than Rs. 100 a day.

India’s sewage from major cities – 19,000 MLD (2017)
Only half is treated – 9,500 MLD (2017)

70% of the sewage is not treated – Start-up India sees this as a $420 M business, with a CAGR of 18% - estimates vary

Population will become 1.6 billion by 2050.

Drinking water

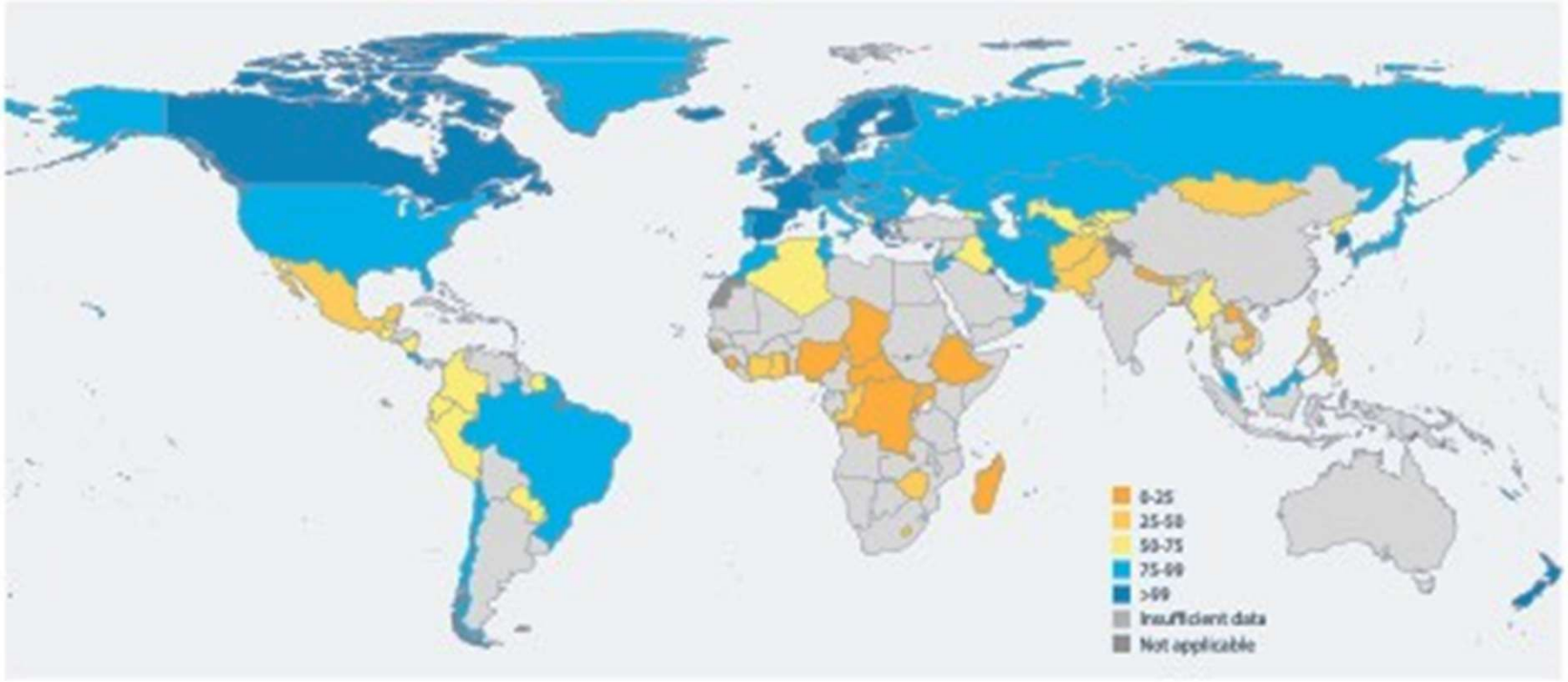
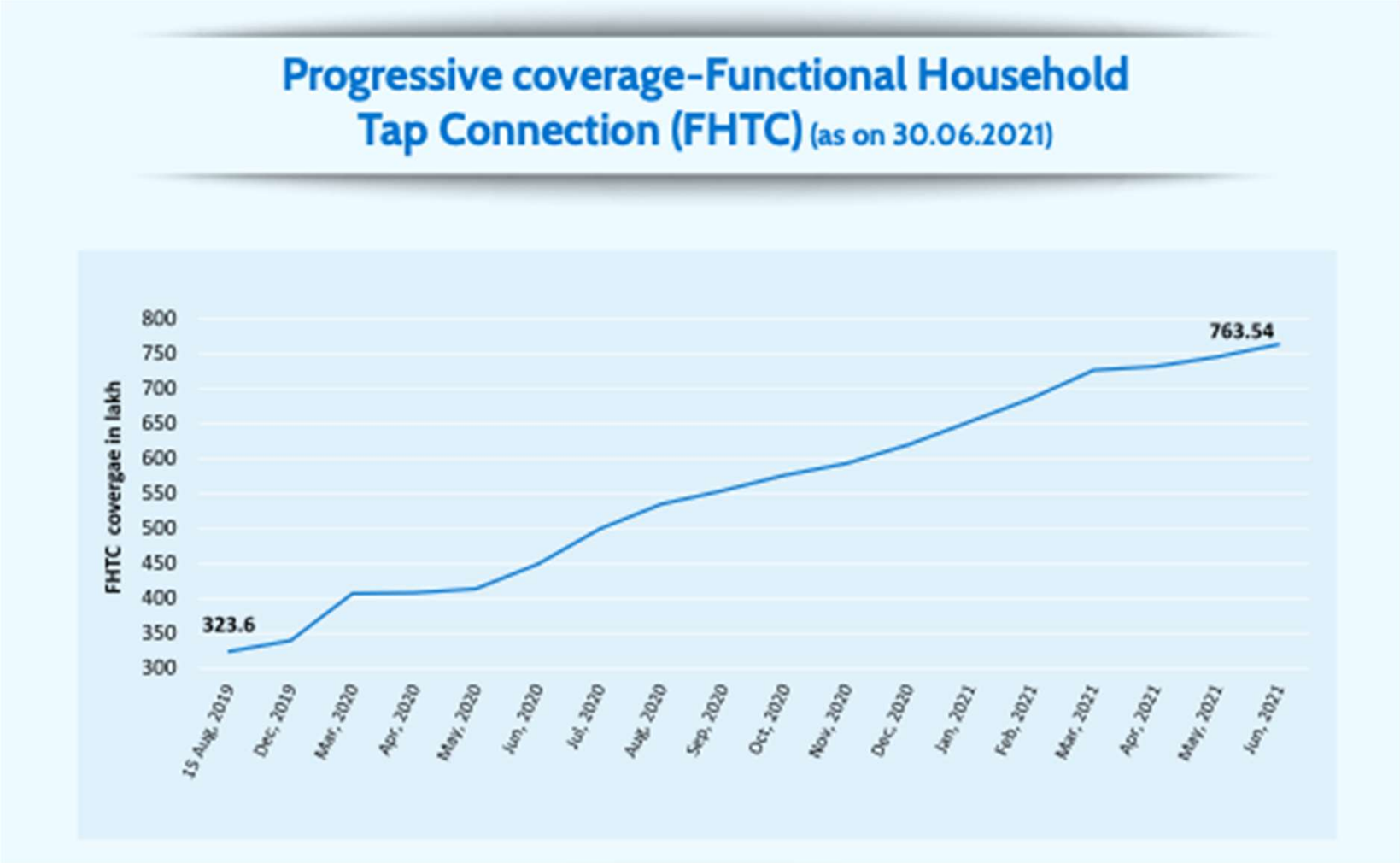


Figure 1: Proportion of population using safely managed drinking water services in 2020 (%). Only 138 countries[2] had sufficient data – on accessibility, availability and quality of drinking water – to produce a national estimate for this indicator in 2020.

UN Water SDG 6 Report 2021

Despite odds, we are making progress

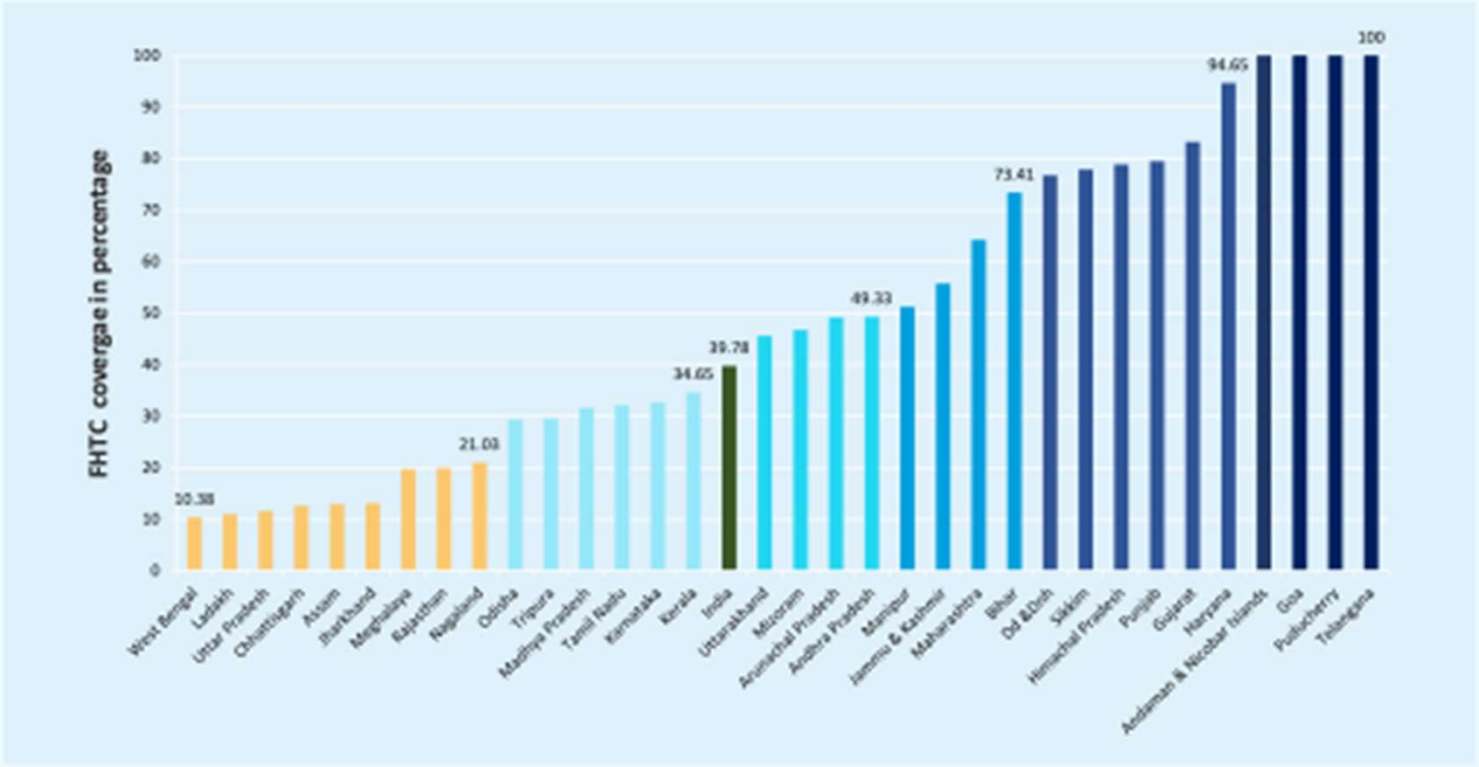


30 million new households have been provided with tap water during this period, equal to the number of households provided with taps since Independence.

From Jal Jeevan Mission

Comparative FHTC coverage status of States/ UTs

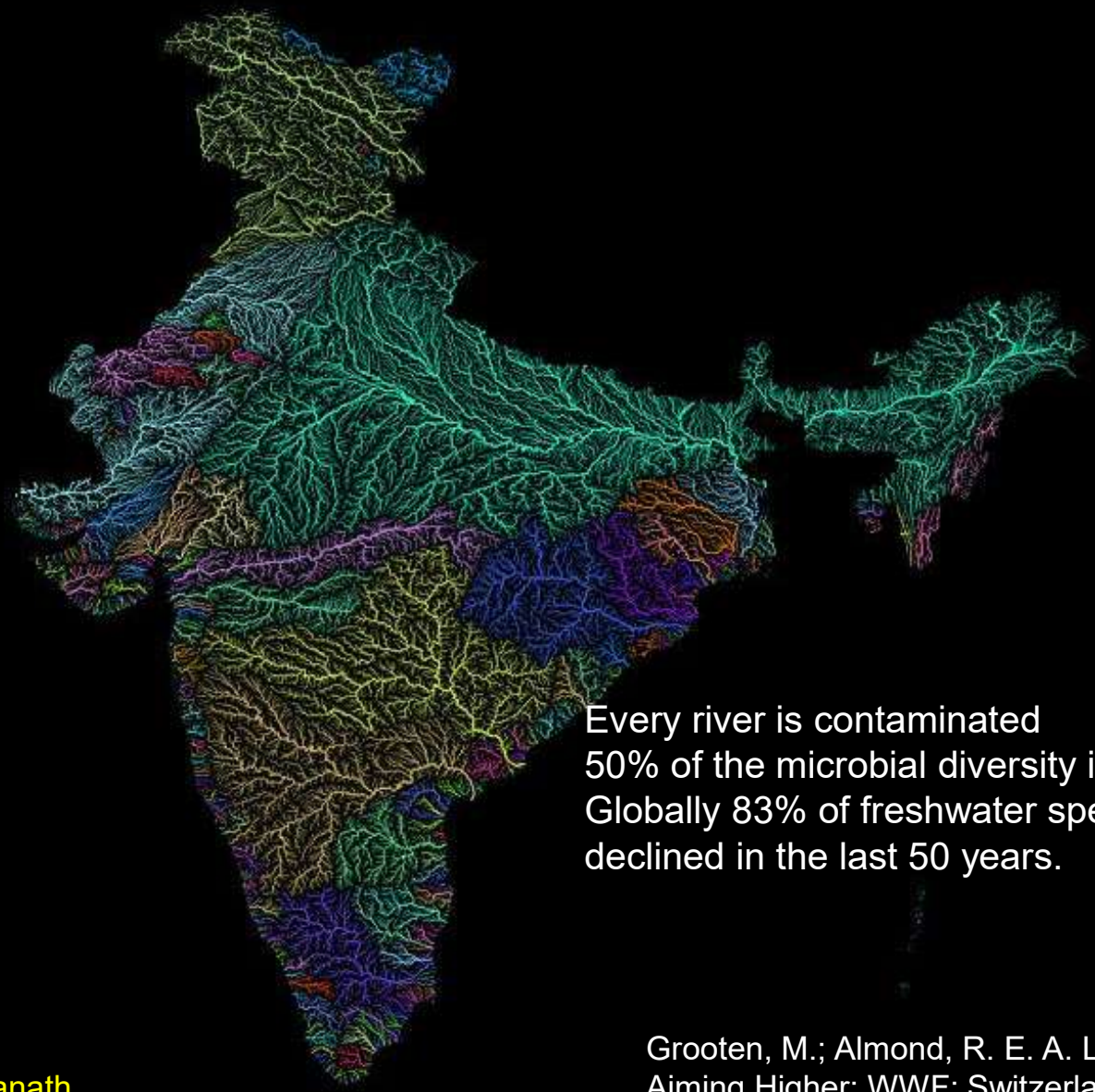
(as on 30.06.2021)



From Jal Jeevan Mission

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.

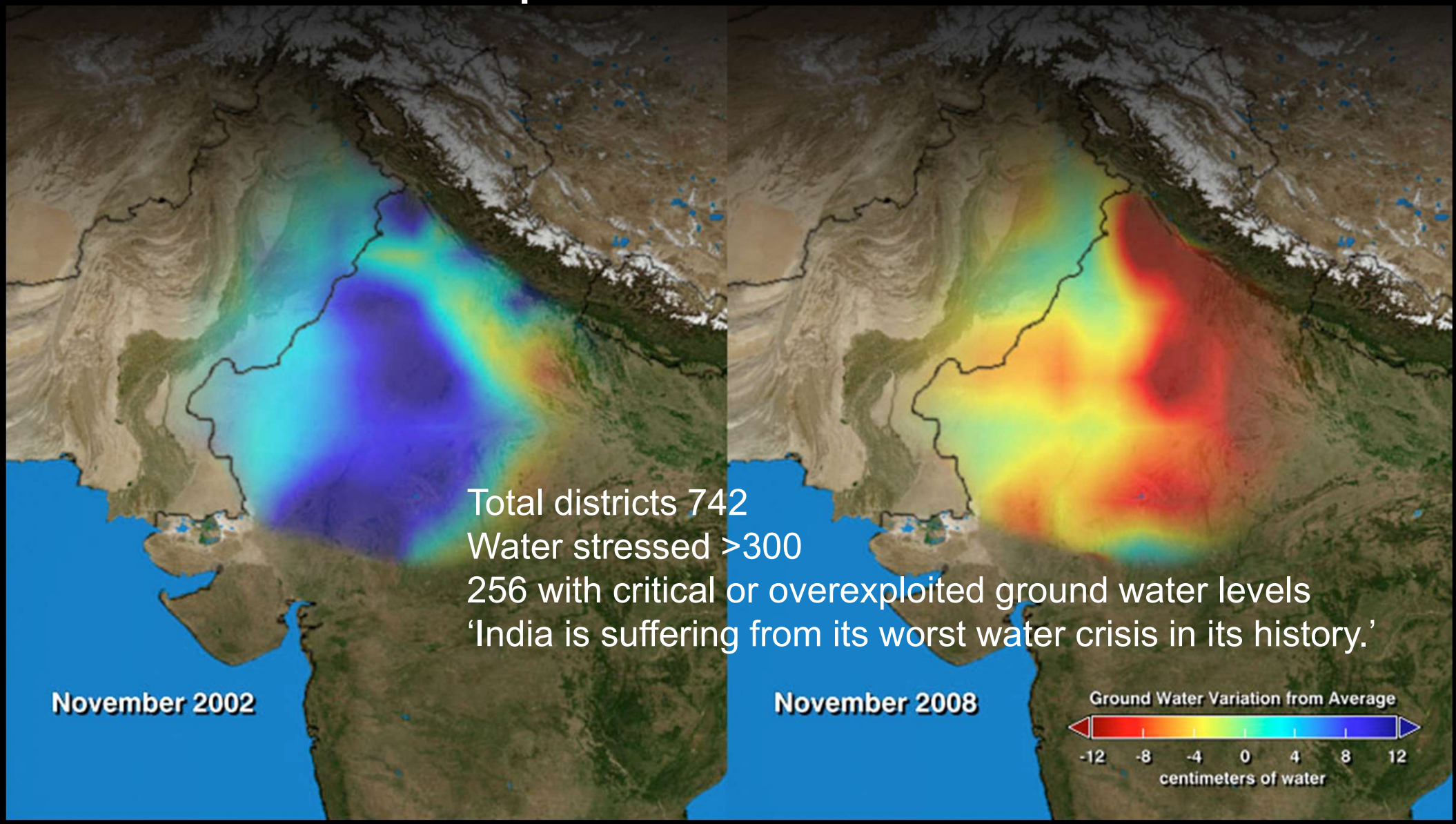
From S. Vishwanath

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

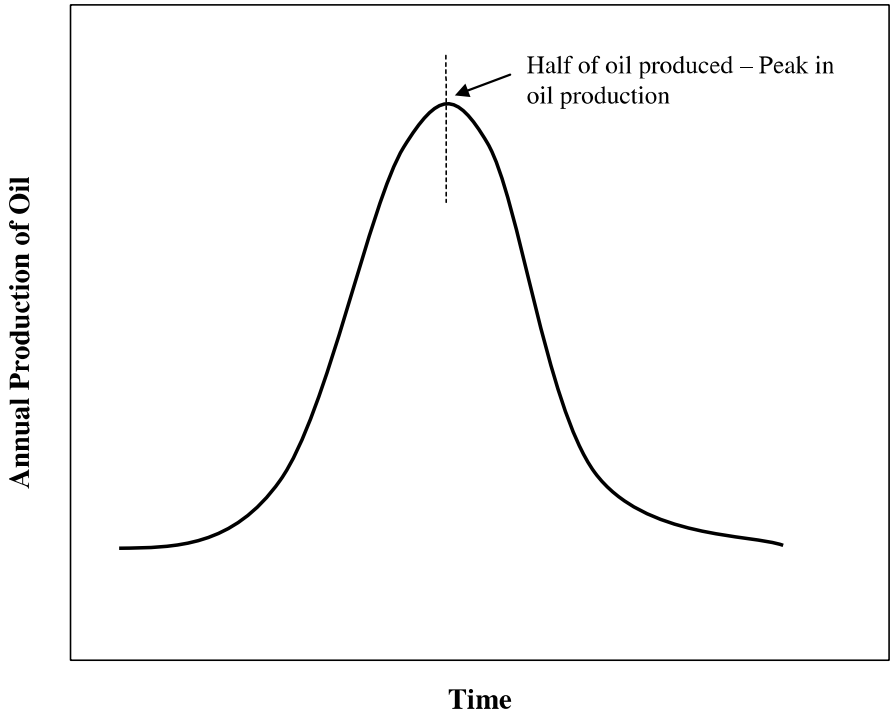
Groundwater depletion



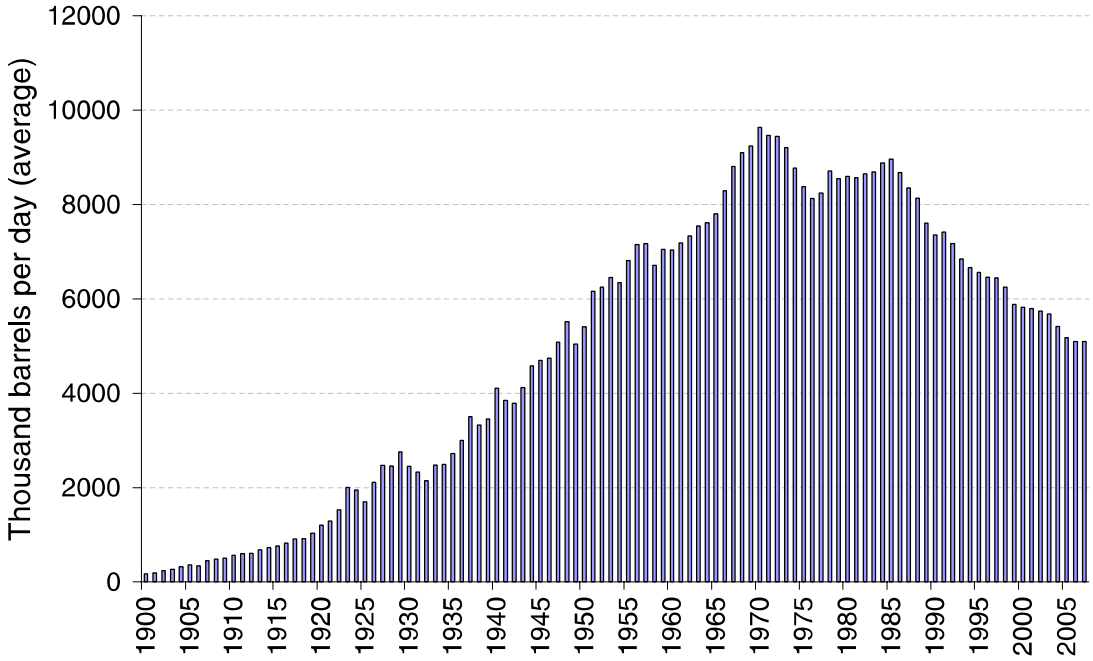
Total districts 742
Water stressed >300
256 with critical or overexploited ground water levels
‘India is suffering from its worst water crisis in its history.’

Data from NASA

Can we grow without water?
Peak water



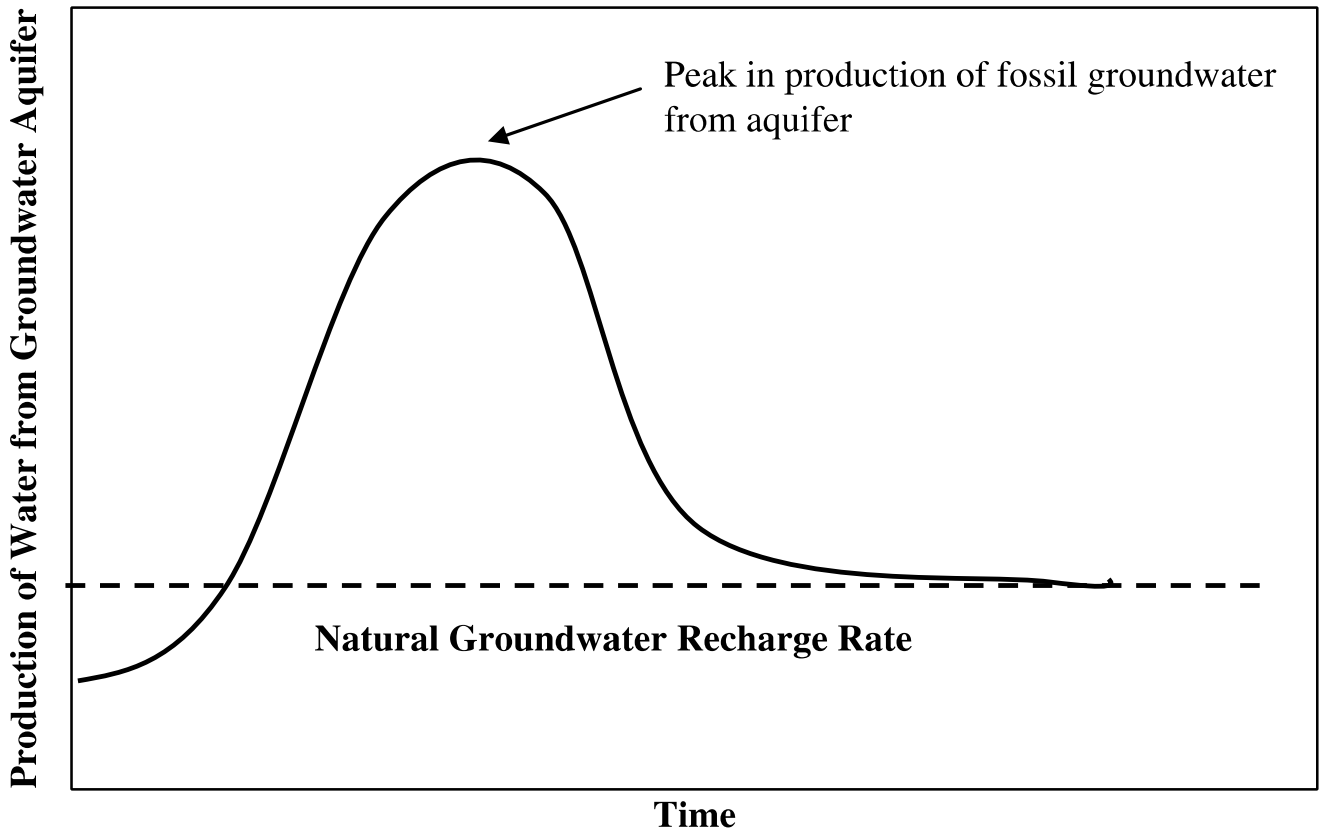
There is no reason actual peak resource curves have to follow symmetrical bell curves.



Total annual US production of crude oil, 1900–2007. US production peaked in 1970 (14, 33).

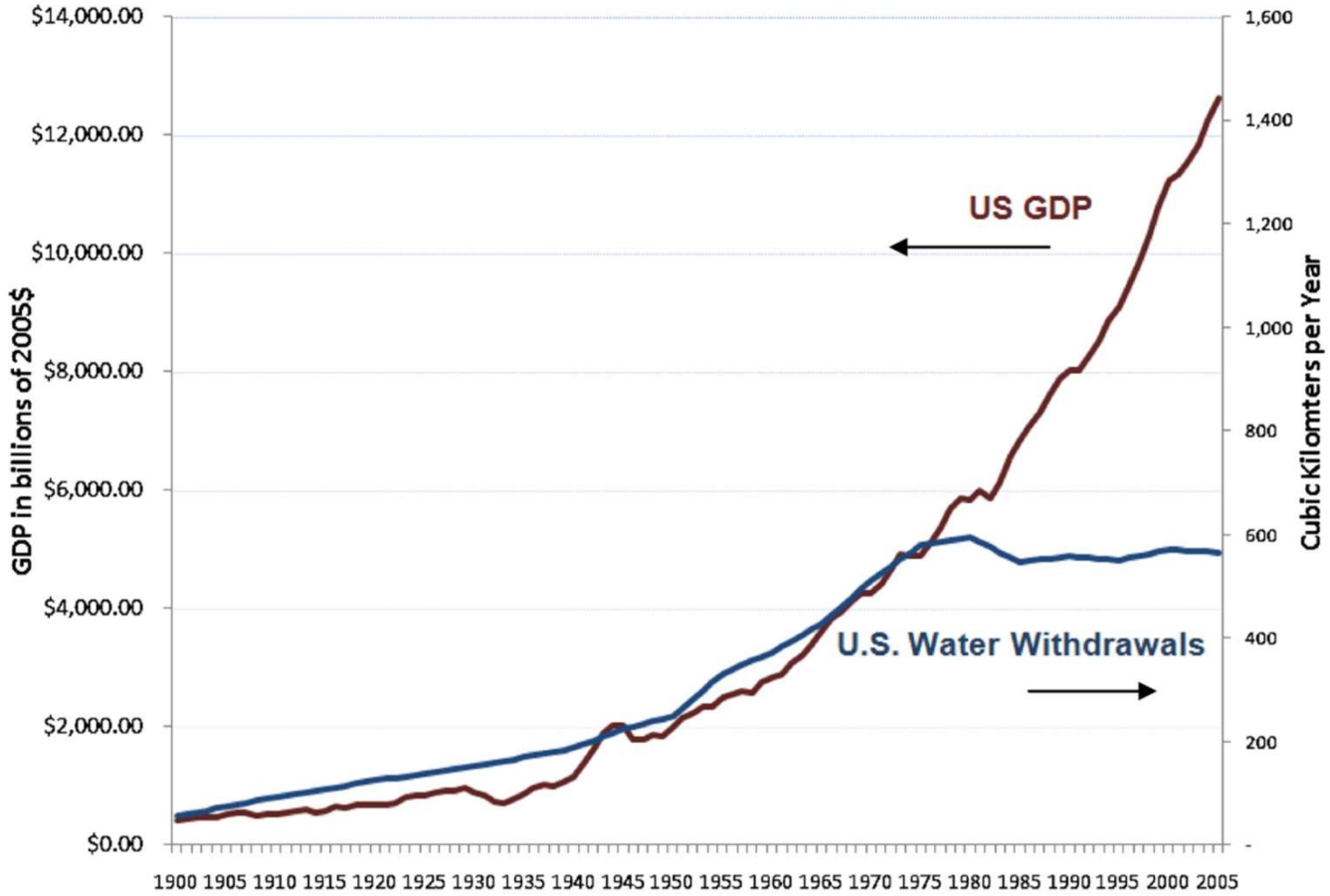
Peter H. Gleick and Meena Palaniappan, Peak water limits to freshwater withdrawal and use, PNAS, 2010, 107, 11155–11162.

Groundwater



This theoretical curve shows the progression of unsustainable water extraction from a groundwater aquifer, hypothesizing a peak-type production curve for water after the production rates surpass the natural groundwater recharge rate and production costs rise. Long-term sustainable withdrawals cannot exceed natural recharge rates.

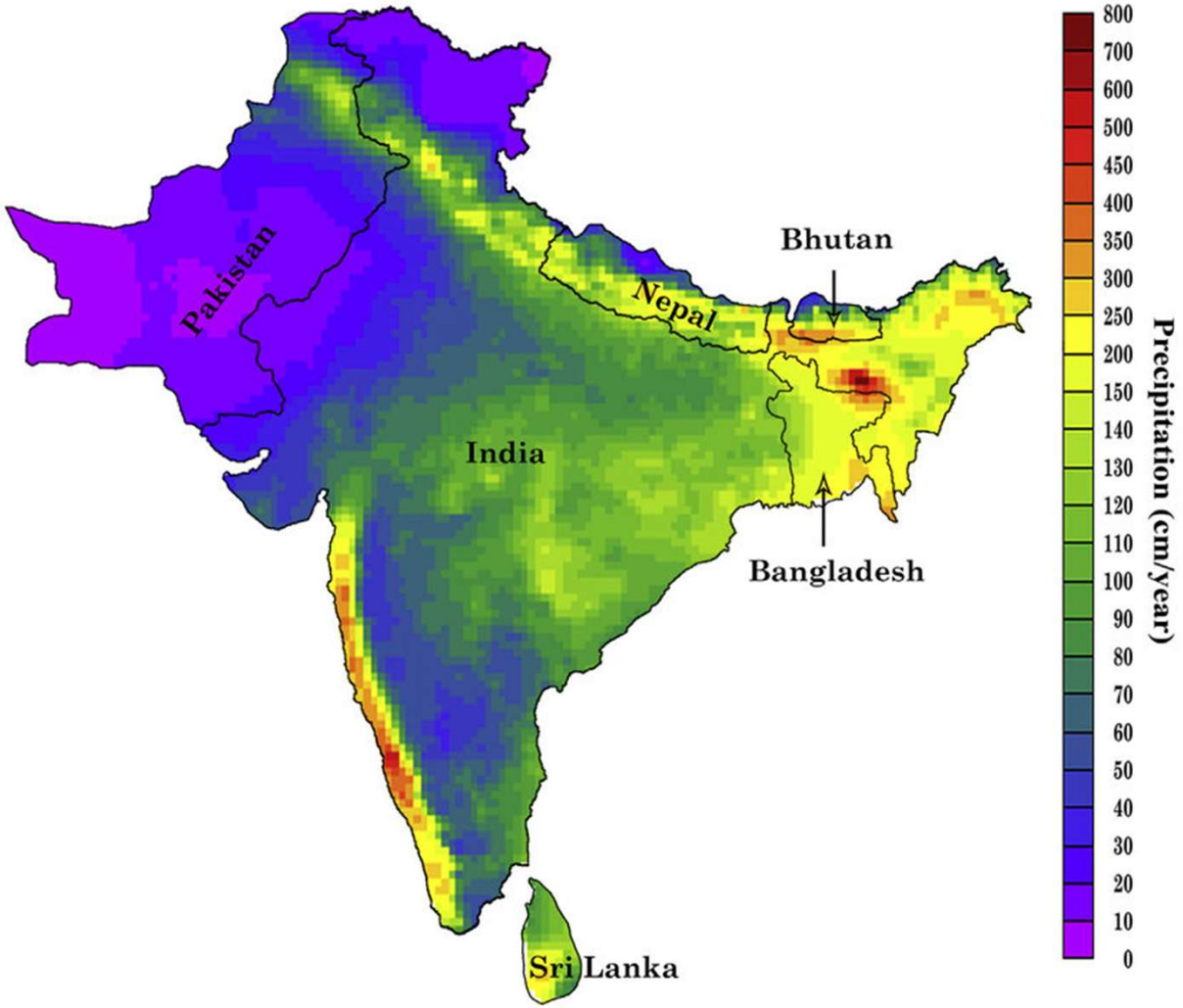
Water and GDP



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.

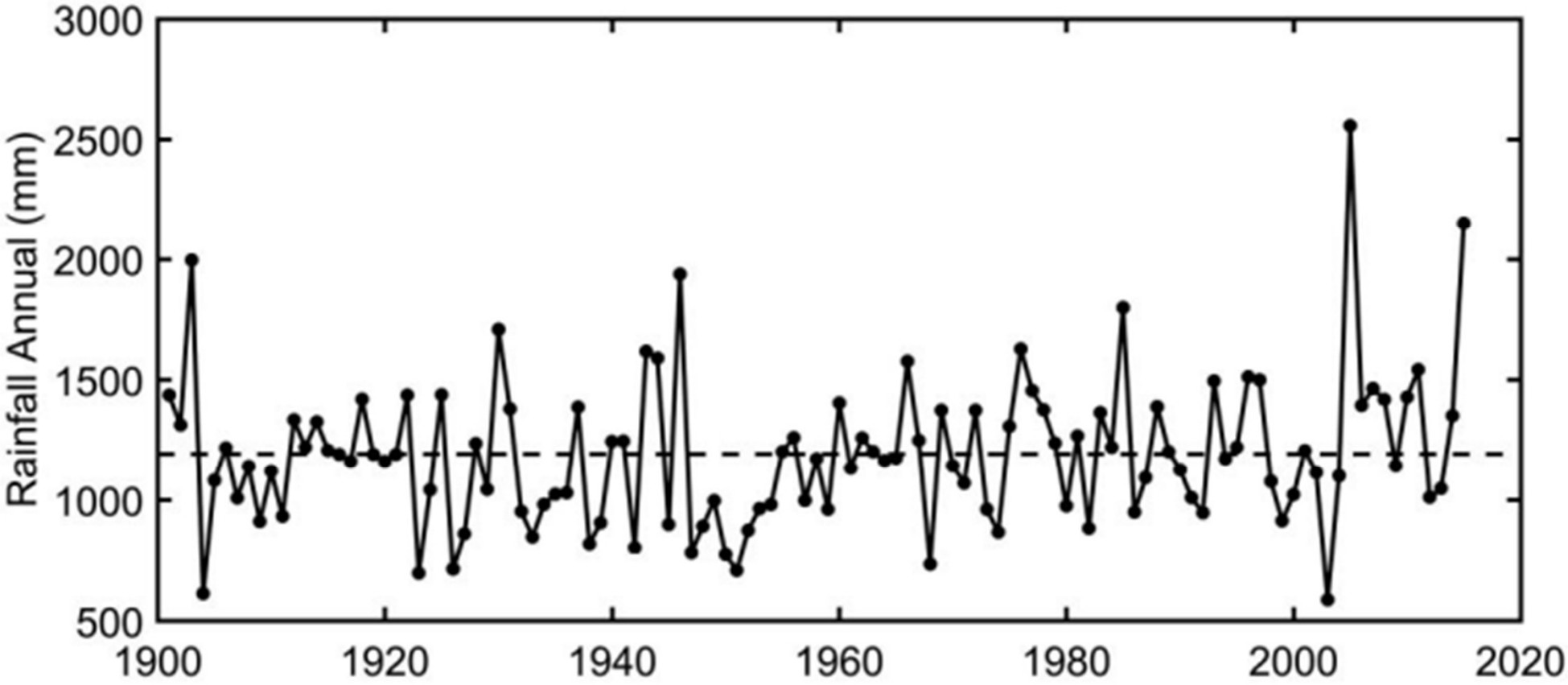
Peter H. Gleick and Meena Palaniappan, Peak water limits to freshwater withdrawal and use, PNAS, 2010, 107, 11155–11162

Precipitation 1961-2007



Groundwater systems of the IndianSub-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

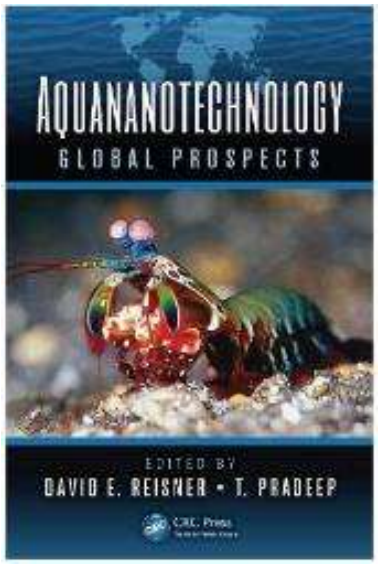
Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

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	*Silent Spring* 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)

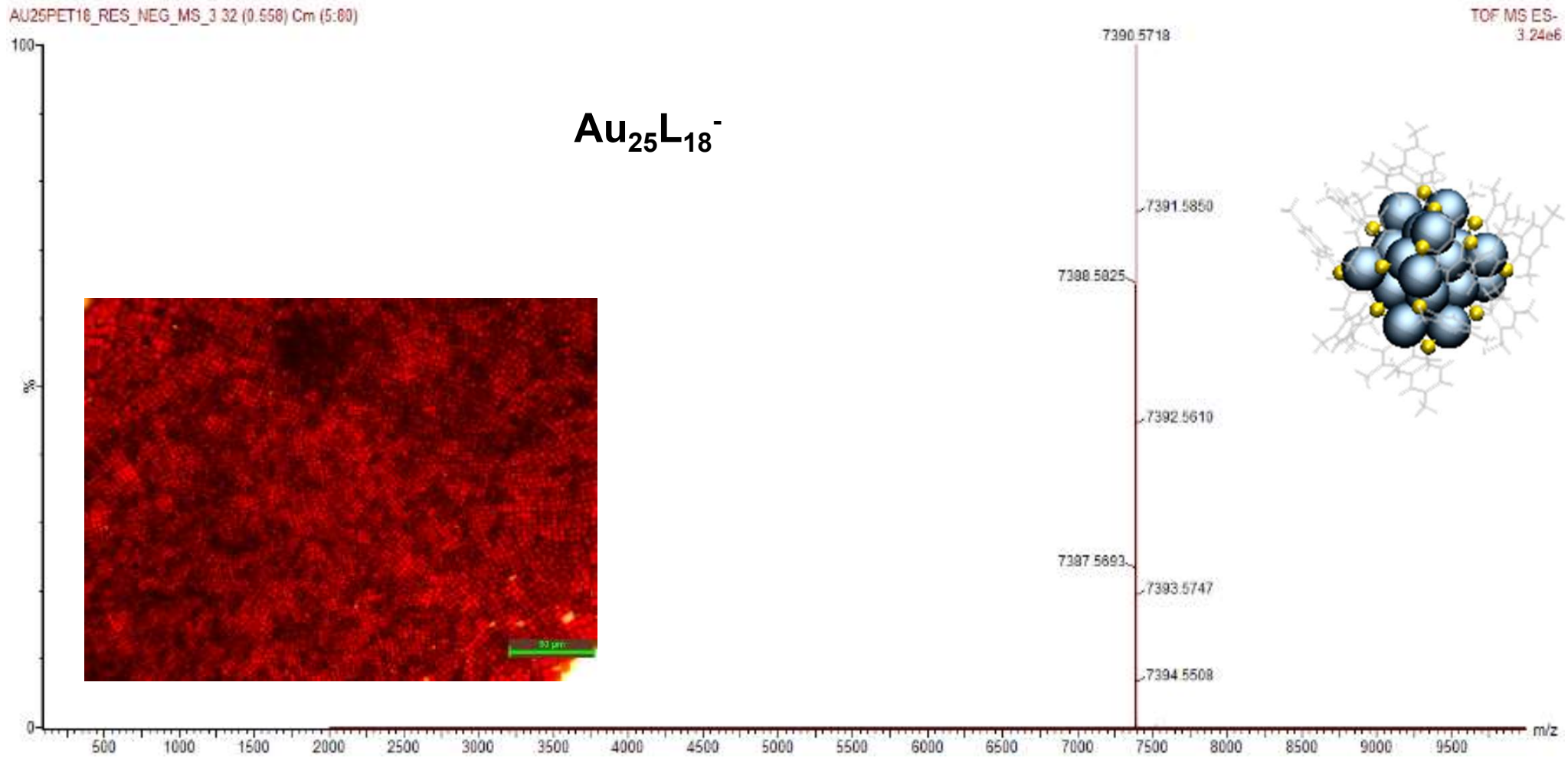
T. Pradeep and Anshup, *Thin Solid Films*, 2009

Affordable clean water is a problem of advanced materials

New adsorbents
New sensors
New catalysts
Novel phenomena
New devices



Nanomaterials are now atomically precise



$Au_{25}L_{18}^-$

T. Pradeep et. al. *Acc. Chem. Res.* 2018; 2019.

Nanomaterials can solve real problems

ACS Sustainable Chemistry & Engineering Editorial, December 2016

Biopolymer-reinforced synthetic granular nanocomposites for affordable point-of-use water purification

Mohan Udhaya Sankar[1], Sahaja Aigal[1], Shihabudheen M. Maliyekkal[1], Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep[2]

Unit of Nanoscience and Thematic Unit of Excellence, Department of Chemistry, Indian Institute of Technology Madras, Chennai 600 036, India

Edited by Eric Hoek, University of California, Los Angeles, CA and accepted by the Editorial Board April 4, 2013 (received for review November 21, 2012)

Creation of affordable materials for constant release of silver ions in water is one of the most promising ways to provide microbially safe drinking water for all. Combining the capacity of diverse nano-

composites to
other contami
affordable, all-
without electr
synthesis of st
uously in the
drinking wate
surfaces. Here
be synthesized
out the use of
sand-like prope
forms. These n
water purifier t
ily. The ability
ambient temp
water purifica

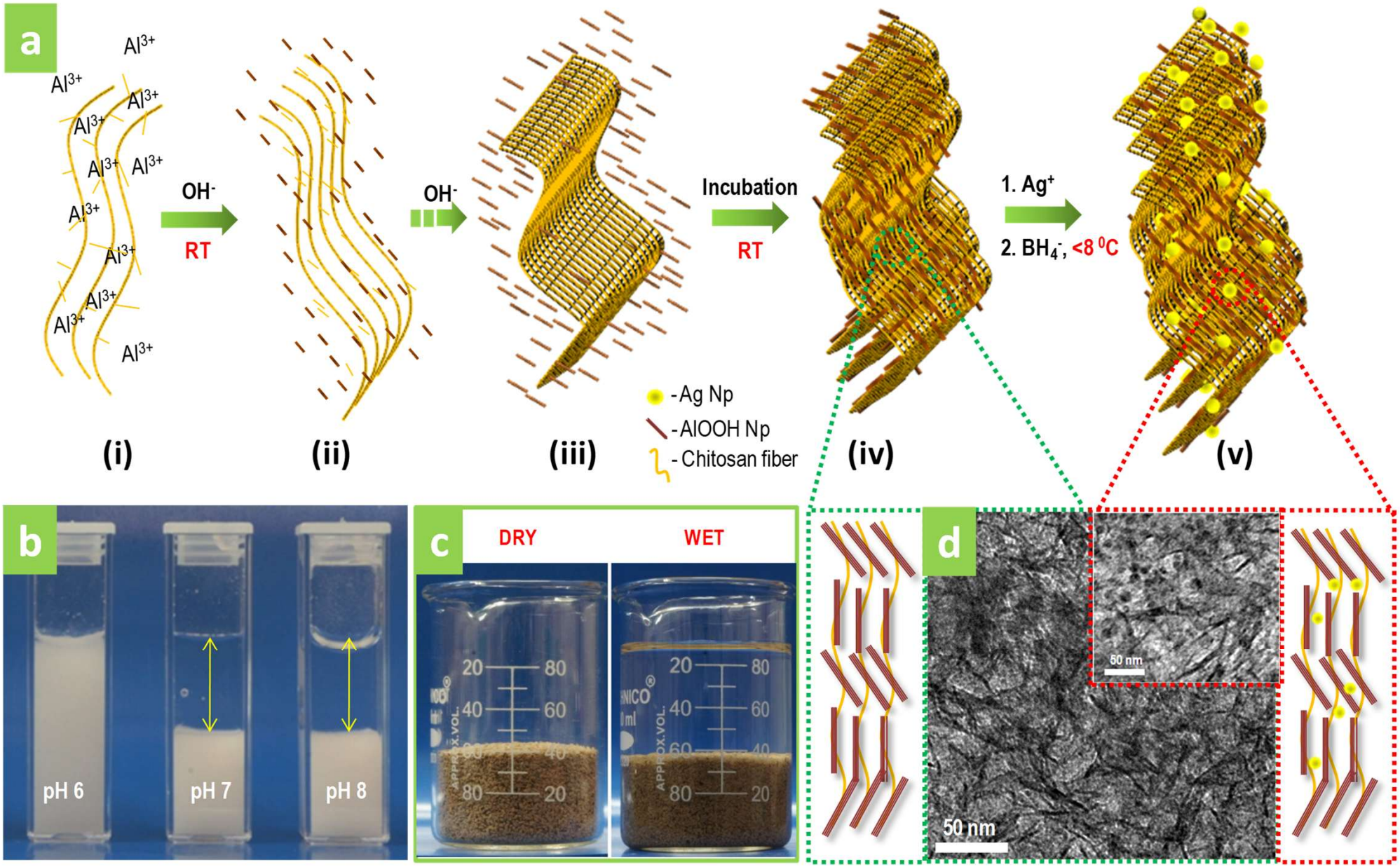
hybrid | green |

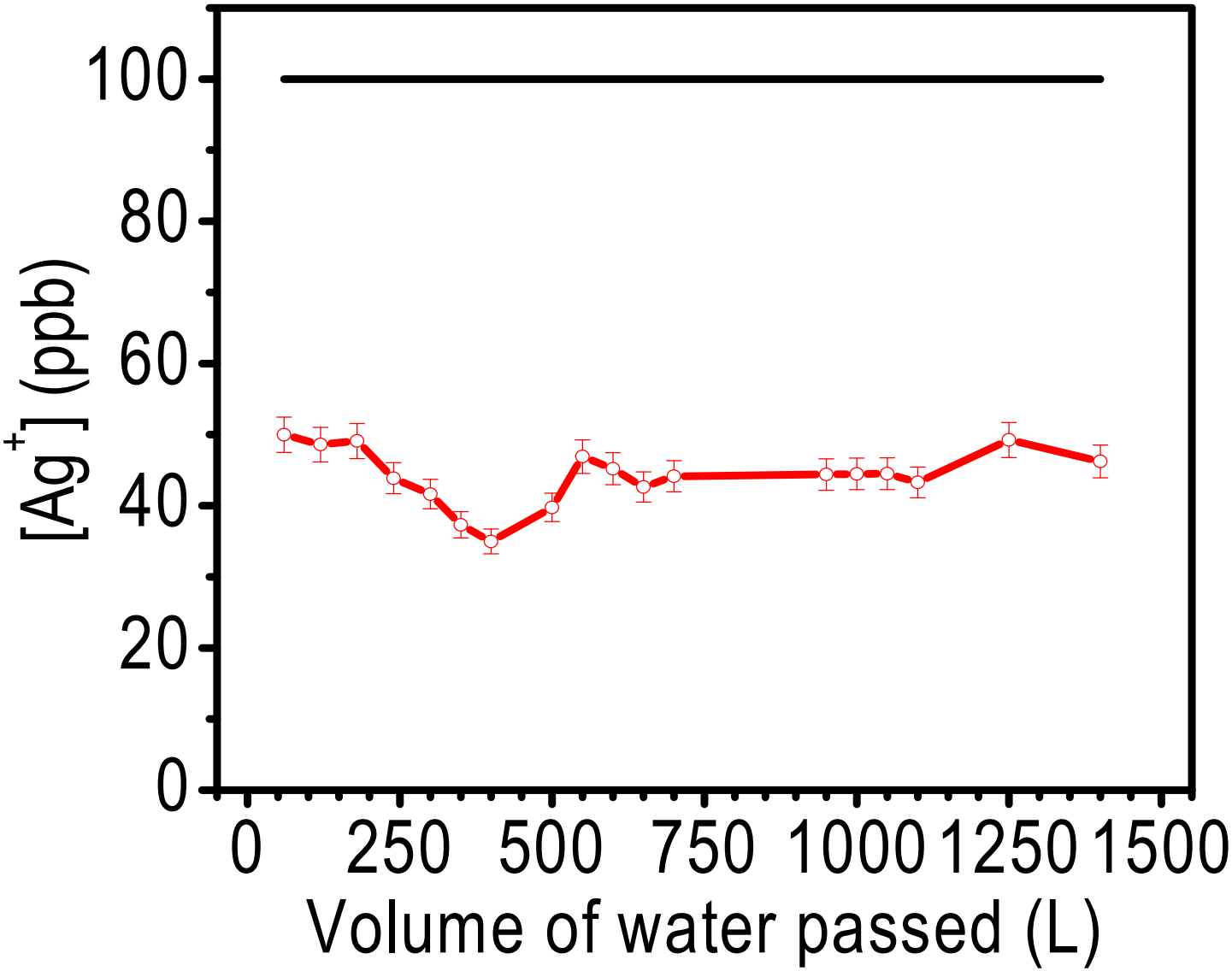
release into water are not available; and (*c*) continued retention of the nanoparticles in the matrix is difficult.

In this work, we demonstrate a unique family of nanocrystalline tal oxyhydroxide-chitosan granular composite materials pre-ed at near room temperature through an aqueous route. The gin of crystallinity in the composition is attributed to abundant -O- l -OH functional groups on chitosan, which help in the crys-ization of metal oxyhydroxide and also ensure strong covalent ding of the nanoparticle surface to the matrix. X-ray photo-tron spectroscopy (XPS) confirms that the composition is rich h surface hydroxyl groups. Using hyperspectral imaging, the ence of nanoparticle leaching in the water was confirmed. ther, a unique scheme to reactivate the silver nanoparticle face is used for continual antimicrobial activity in drinking ers. Several other composites have been developed that can venge other contaminants in water. We demonstrate an af-dable water purification device based on such composites de-oped over several years and undergoing field trials in India, as otential solution for widespread eradication of the waterborne ease burden.

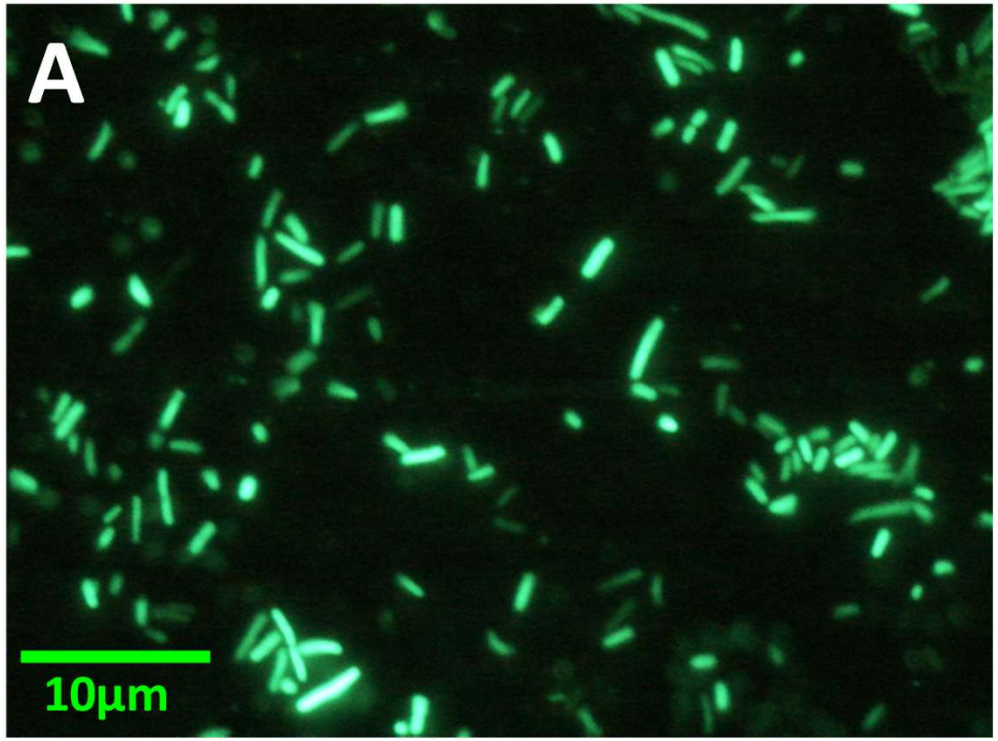
ults and Discussion

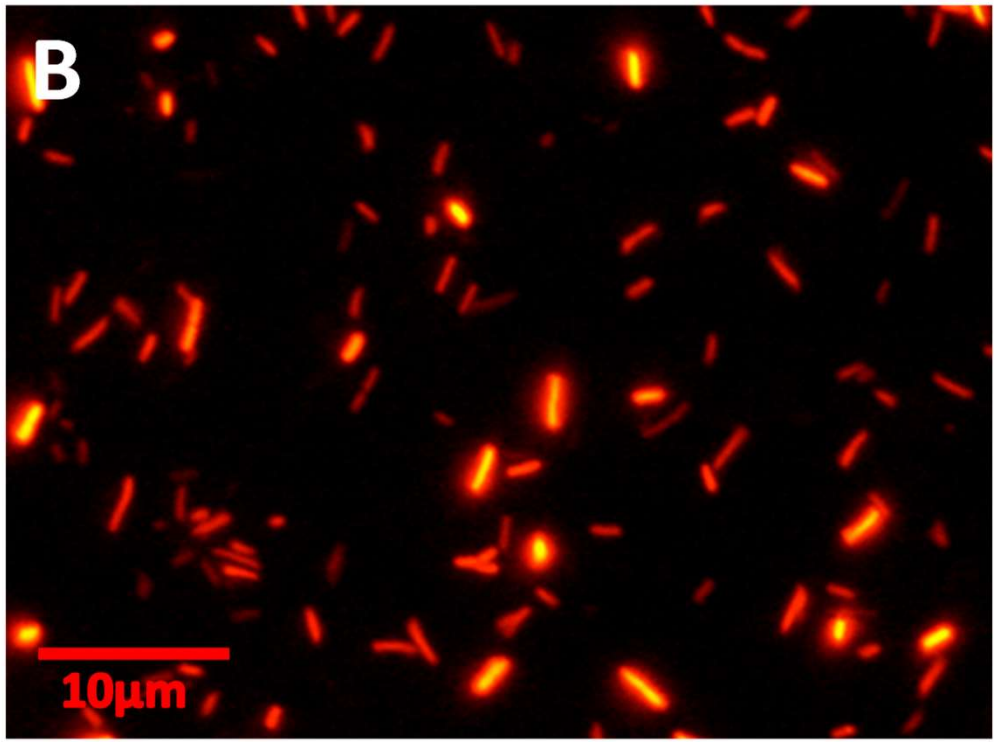
New materials

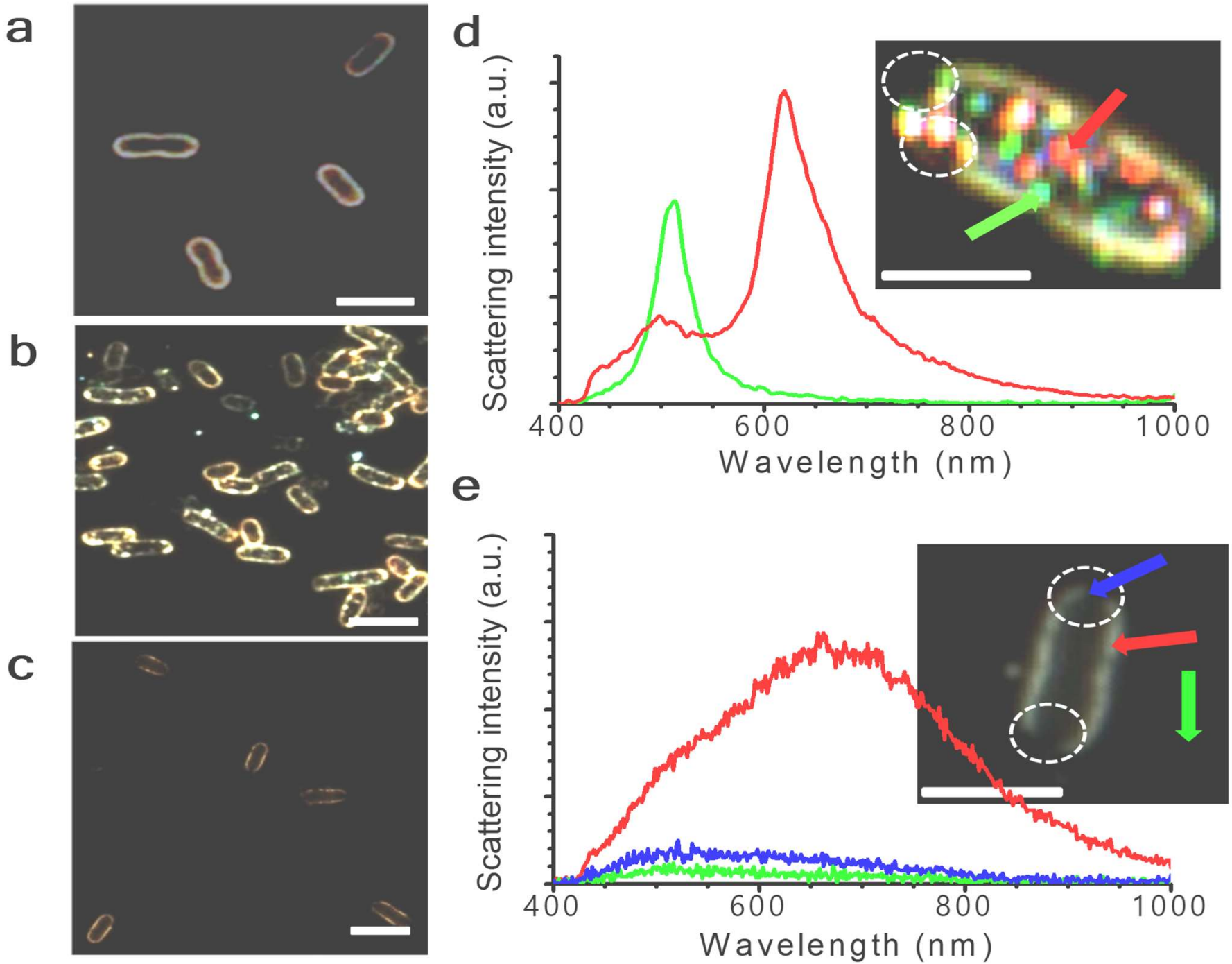



100
80
60
40
20
0
[Ag+] (ppb)
0
250
500
750
1000
1250
1500
Volume of water passed (L)

Live/dead staining experiments






a
b
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Scattering intensity (a.u.)
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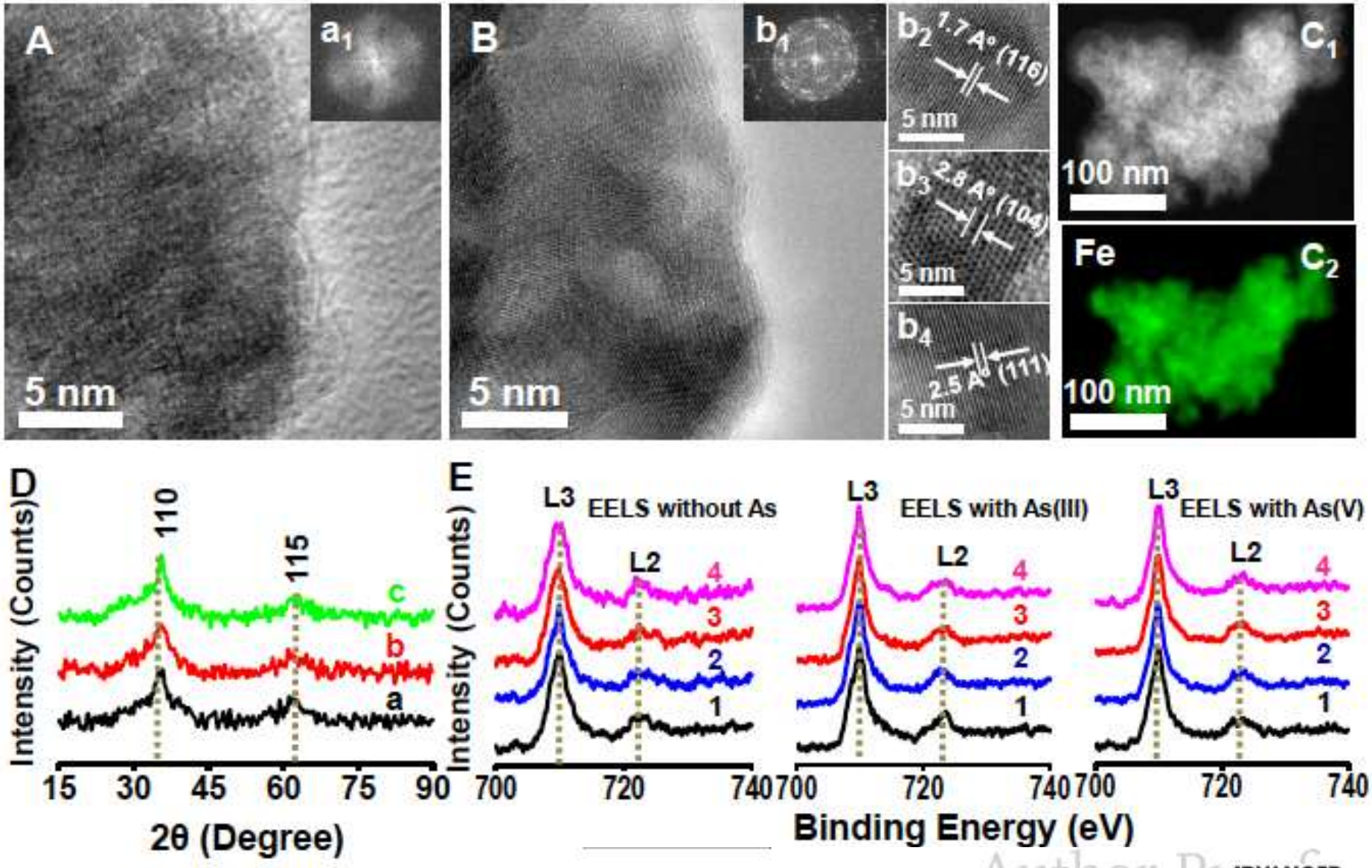
e
Scattering intensity (a.u.)
400
600
800
1000
Wavelength (nm)



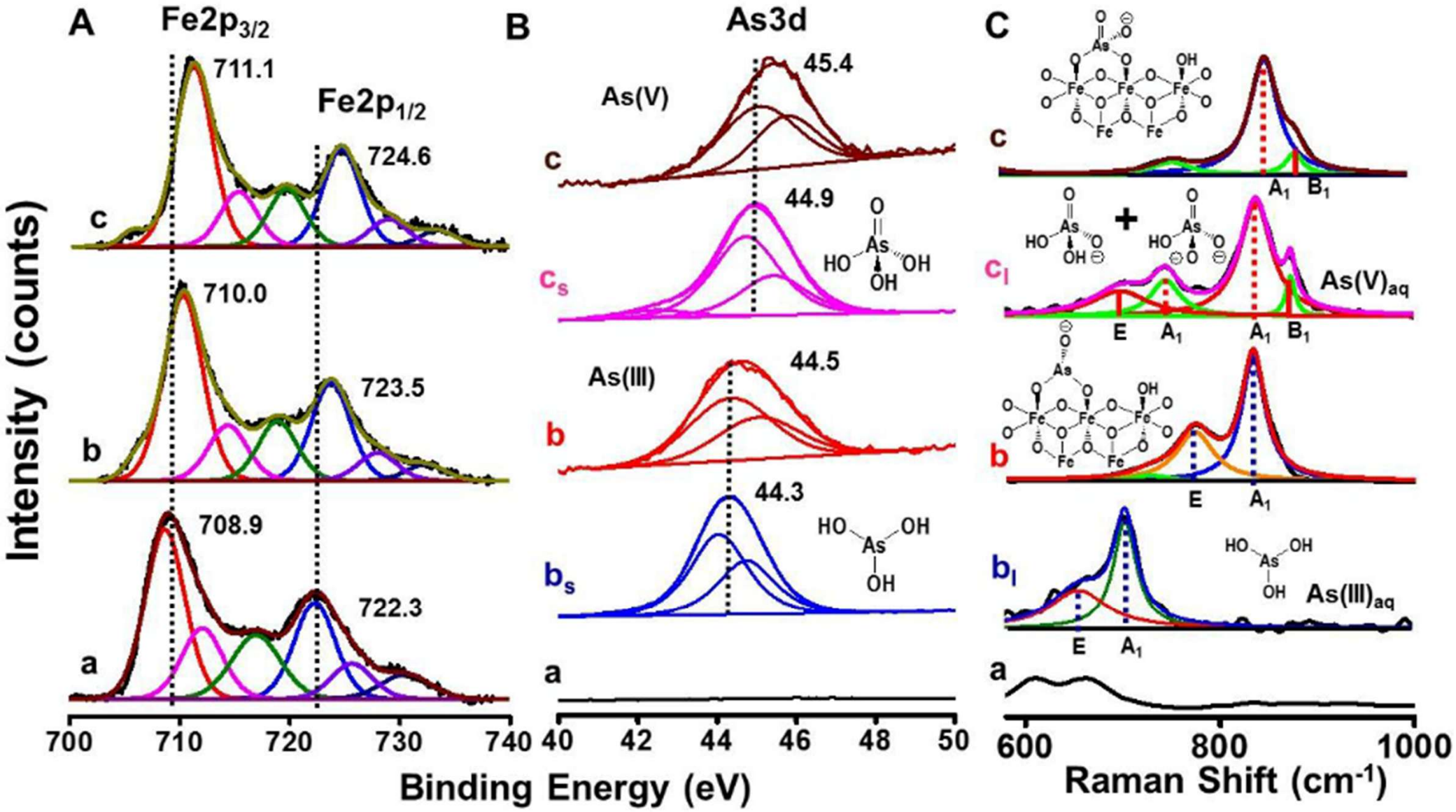
www.advmat.de ADVANCED MATERIALS

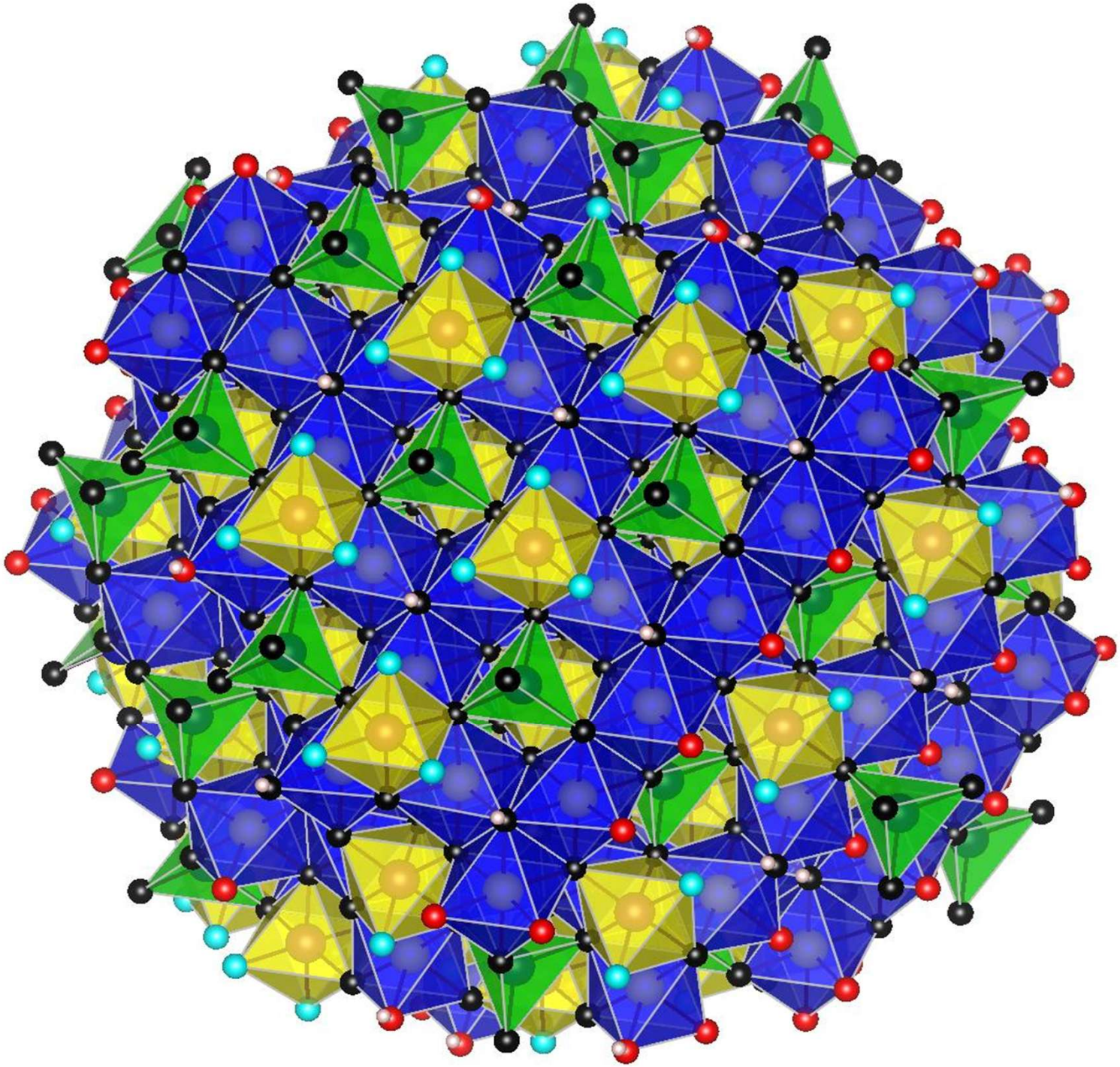
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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**

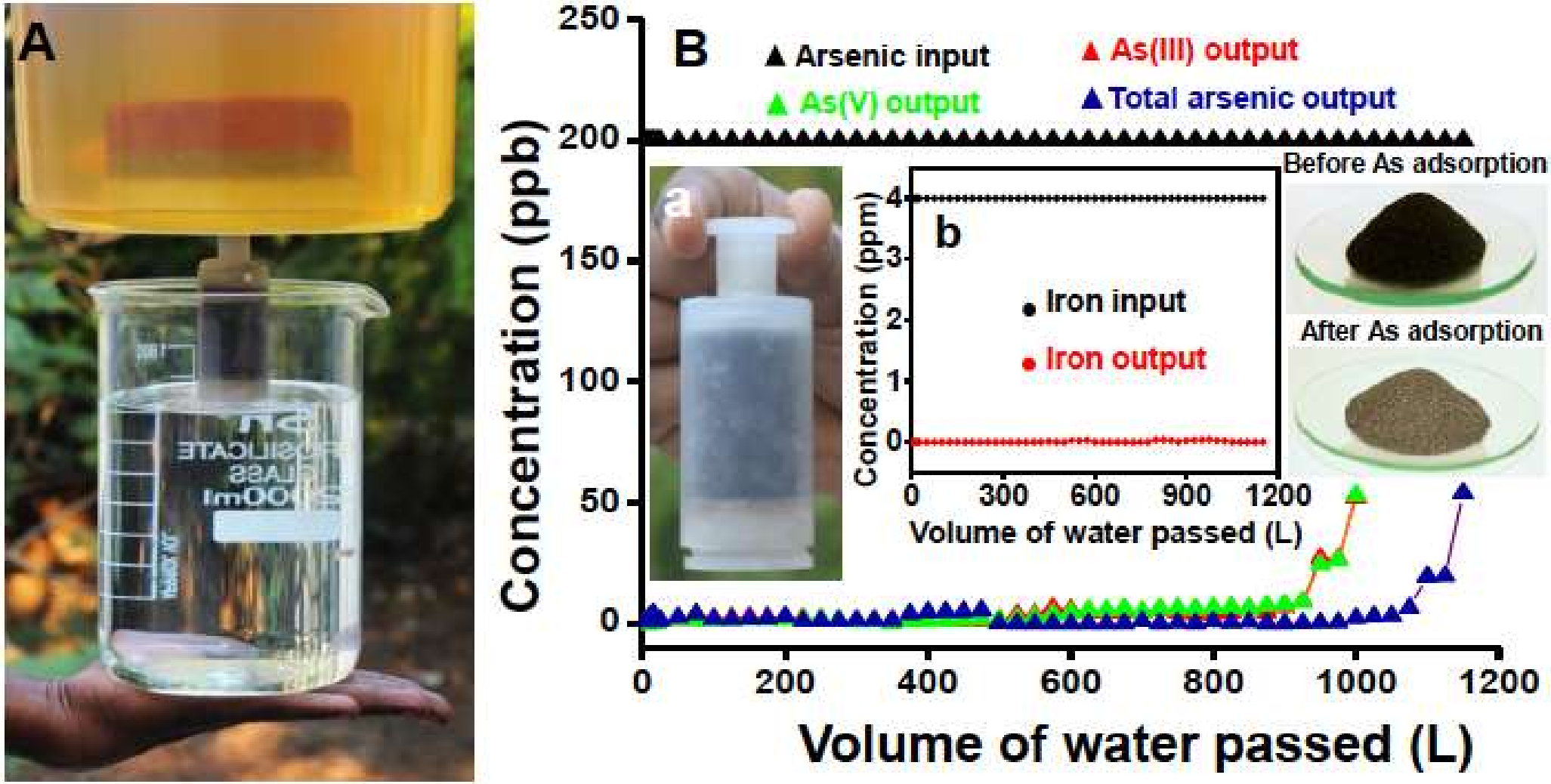
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Mechanism


A
Fe2p3/2
711.1
Fe2p1/2
724.6
c
710.0
723.5
b
708.9
722.3
a
Intensity (counts)
700
710
720
730
740
B
As3d
As(V)
45.4
c
44.9
cs
As(III)
44.5
b
44.3
bs
a
40
42
44
46
48
50
Binding Energy (eV)
C
c
A1
B1
cl
As(V)aq
E
A1
b
bl
As(III)aq
a
600
800
1000
Raman Shift (cm-1)



Chennu Sudhakar, et al. *ACS Sustainable Chemistry & Engineering*, 6 (2018) 9990-10000



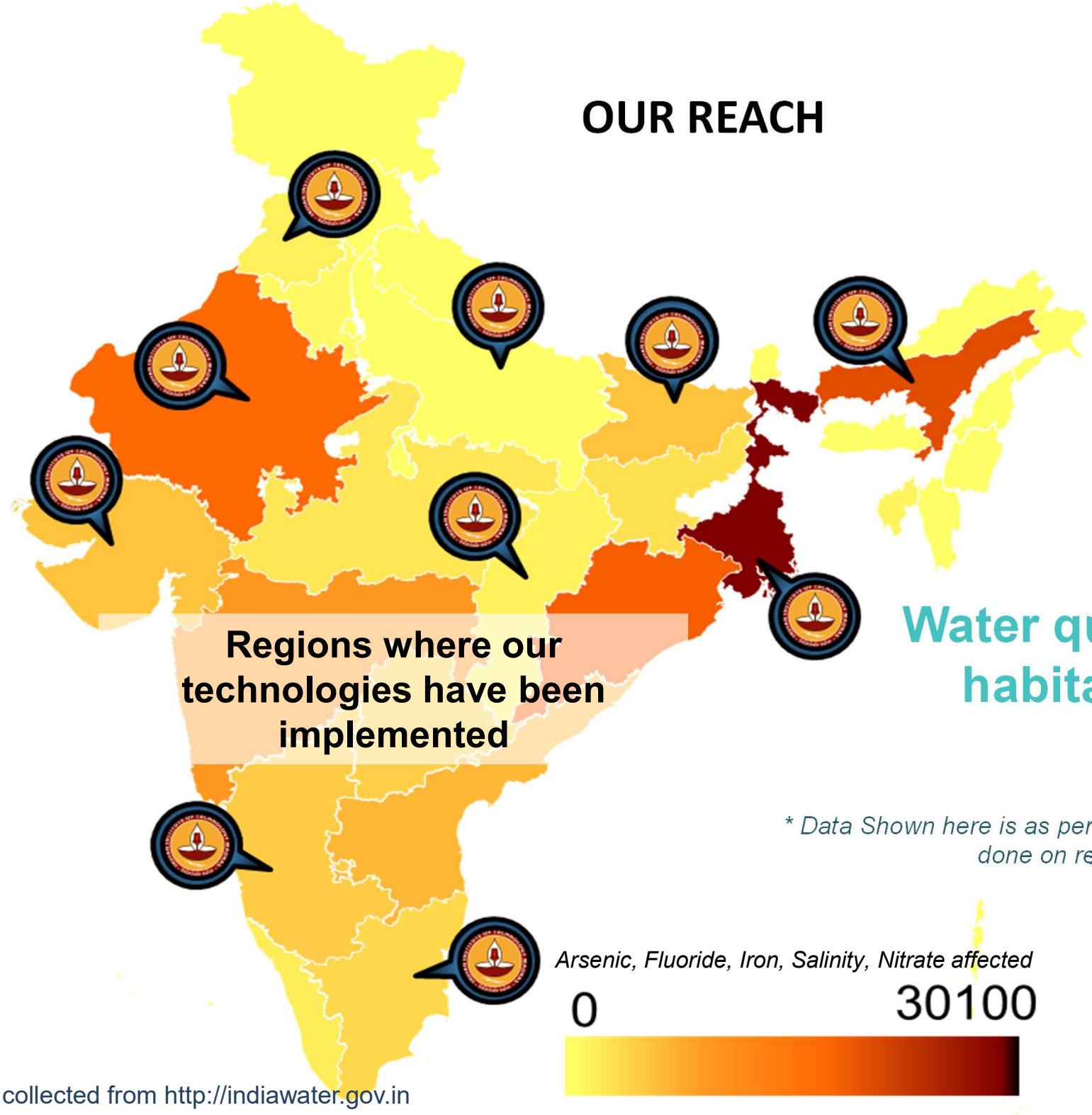
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Changing the dynamics in the field

- Existing unit for iron and arsenic removal – 20 m^3/h
- Uses activated alumina and iron oxide (old generation of adsorbents)

- Existing unit for iron and arsenic removal – 18 m^3/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb

OUR REACH



Data collected from http://indiawater.gov.in


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)

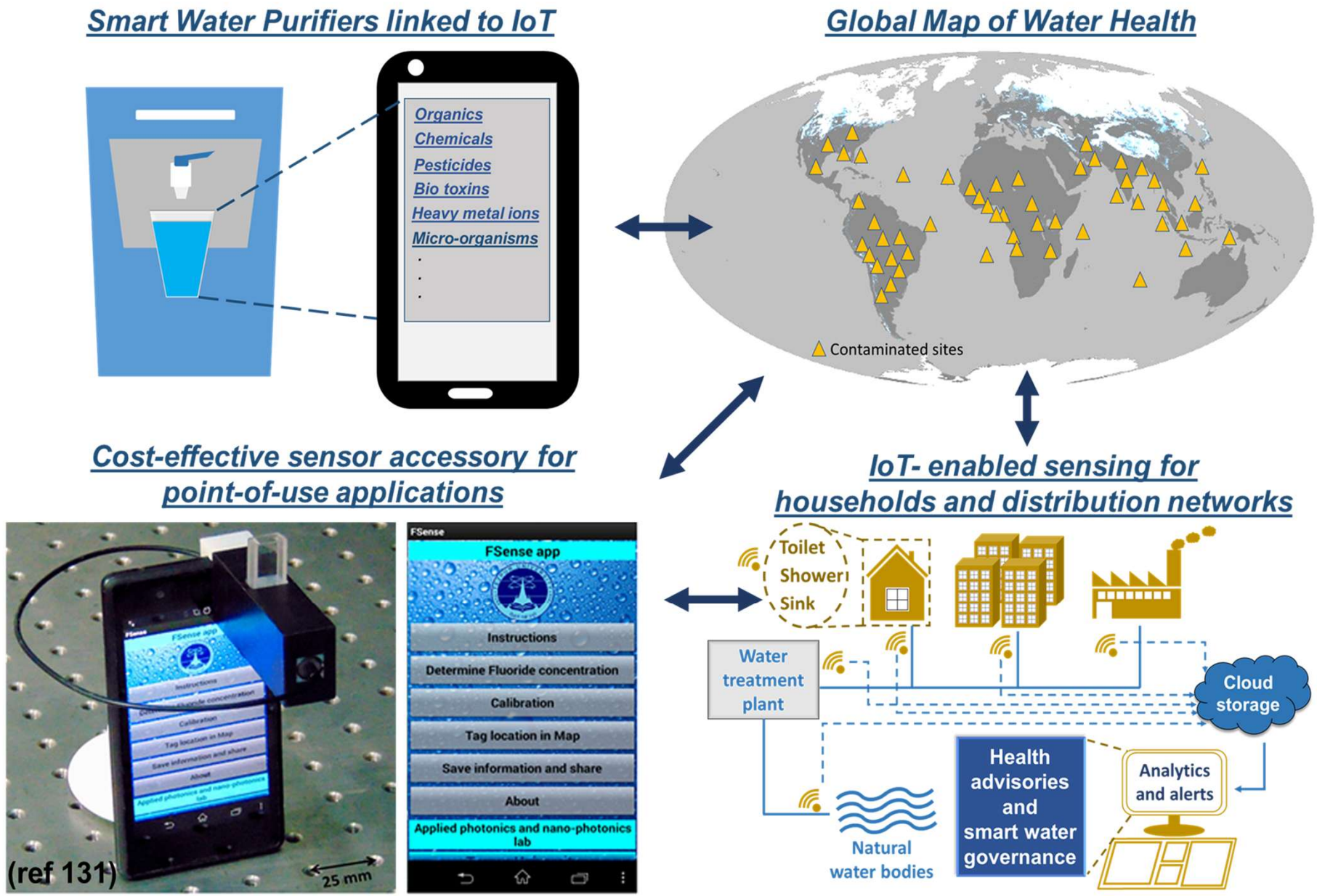
Installed in 2018, in February 2022

Cleanwater at 2.1 paise per litre!

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

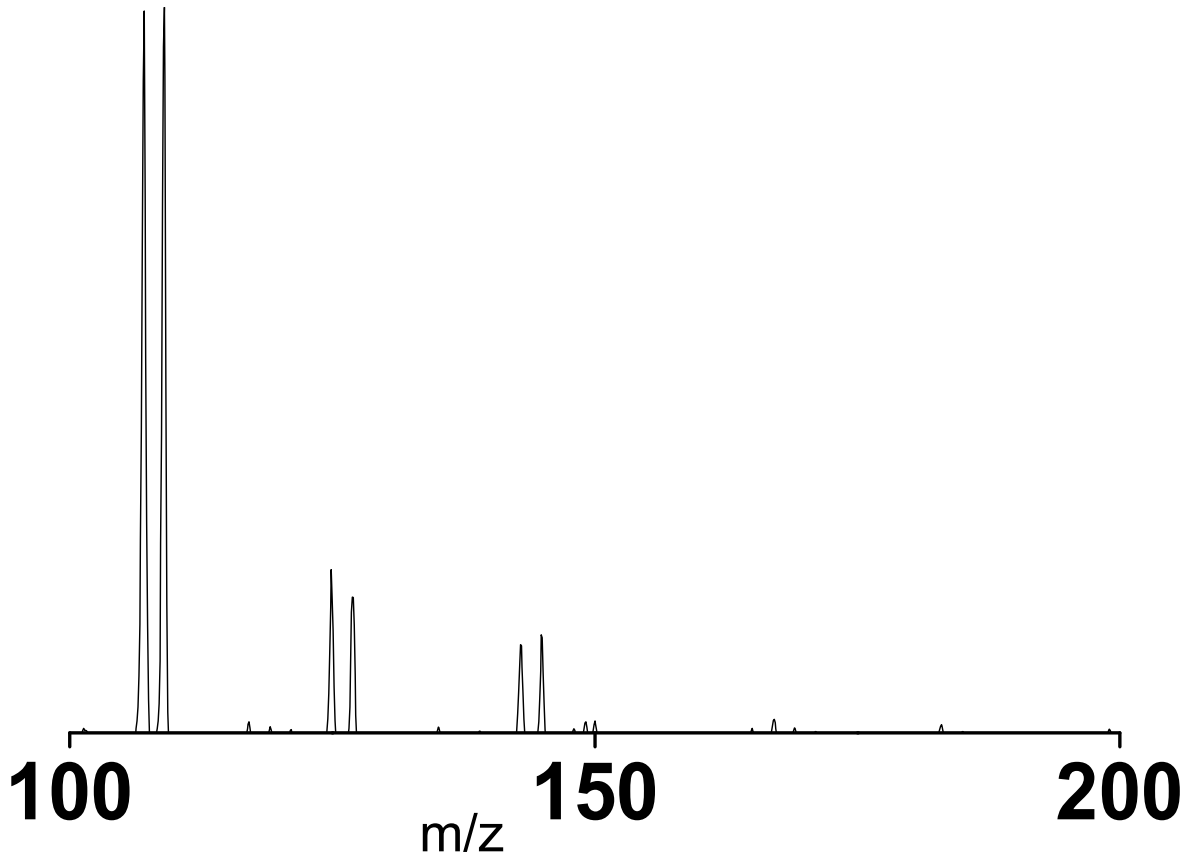
	Design population	1,071	Plant capacity/70 LPCD
Sr.No.	**Item/Description**	**Cost / Quantity**	**Remarks**
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore 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 litr of water	2.1 Paise per ltr	
9	Cost of replacement of media	**1.36** **40.80**	Rs. per head per day =Media replacement cost per year/365/Design population per head per month for 70 LPCD water

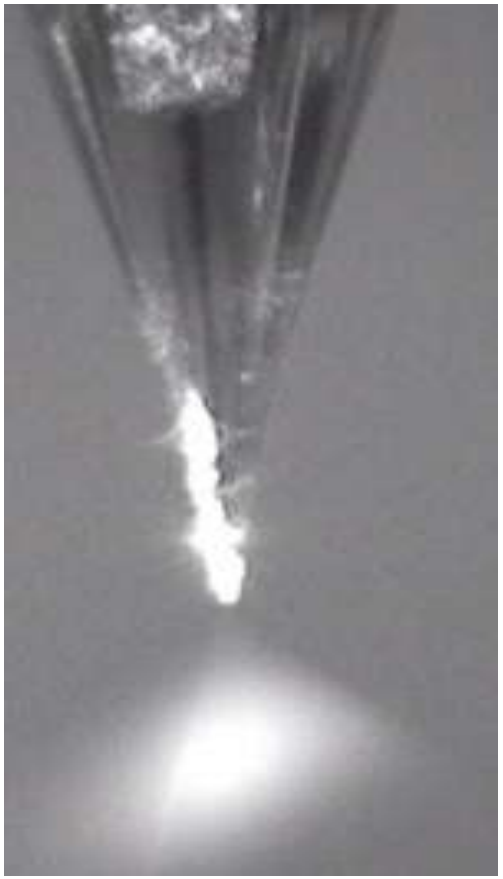
Smart water purifiers and big data



Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

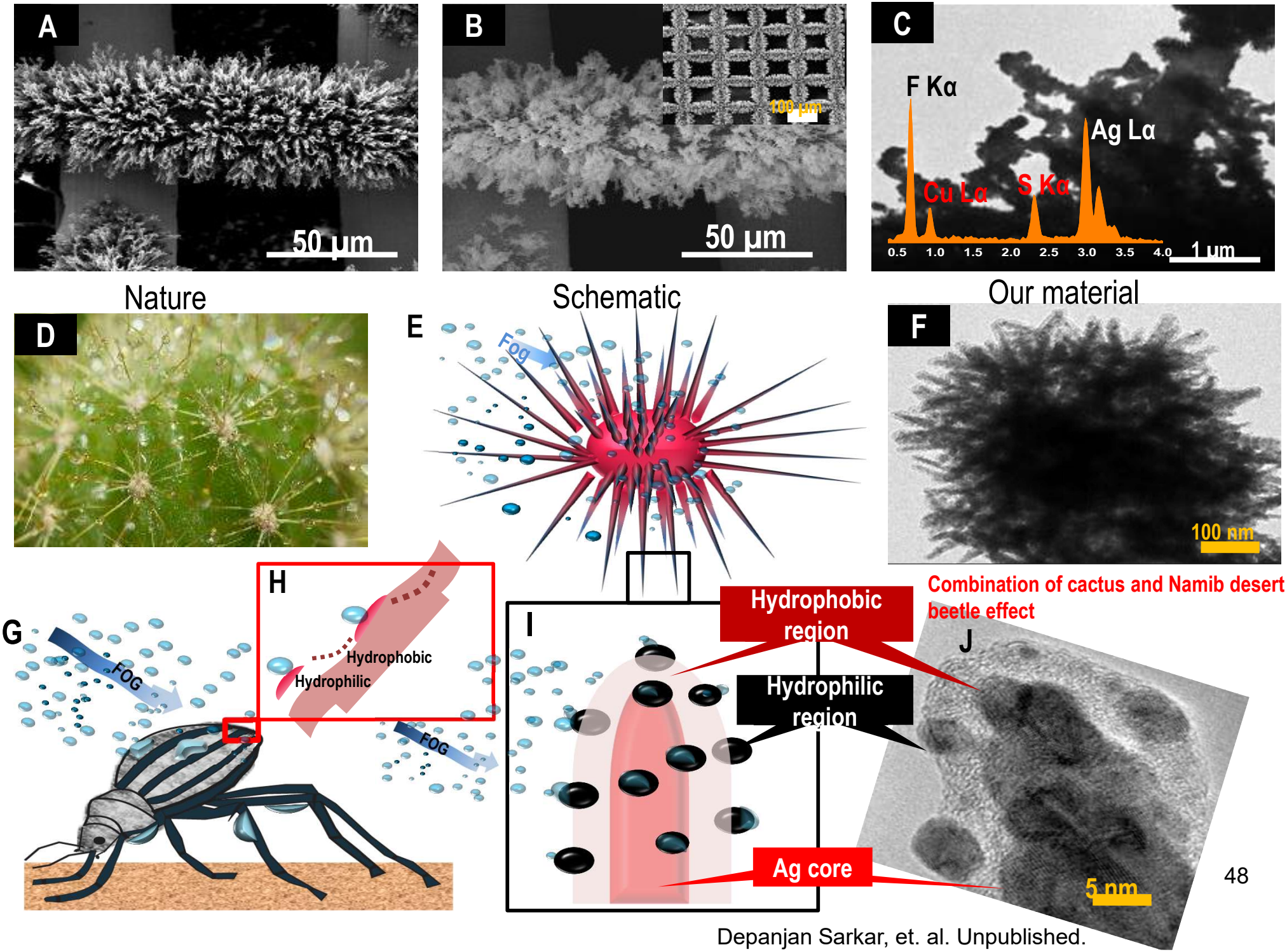
Atmospheric water harvesting



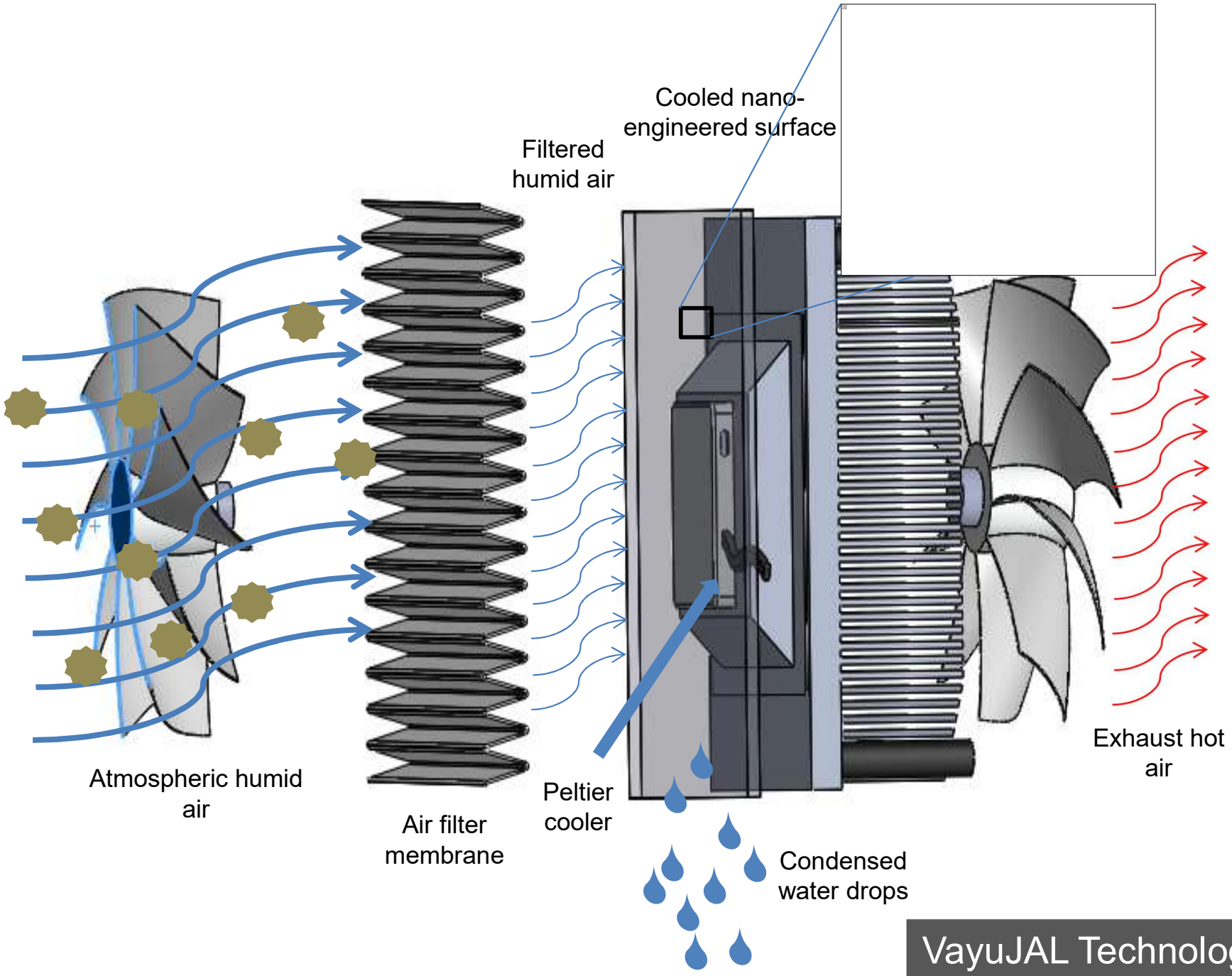


New harvesters

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



Depanjan Sarkar, et. al. Unpublished.

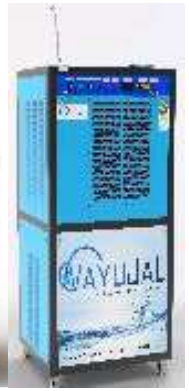


VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

Products in the field

35 LPD



120 LPD

400 LPD

1000 LPD

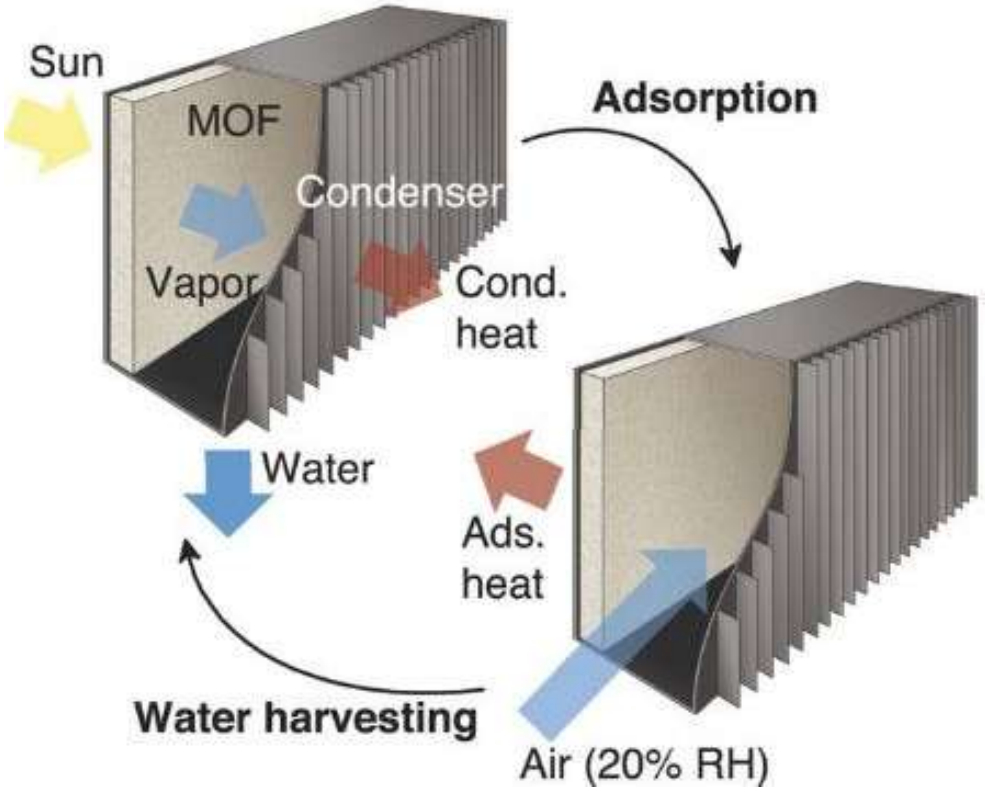
2000 LPD

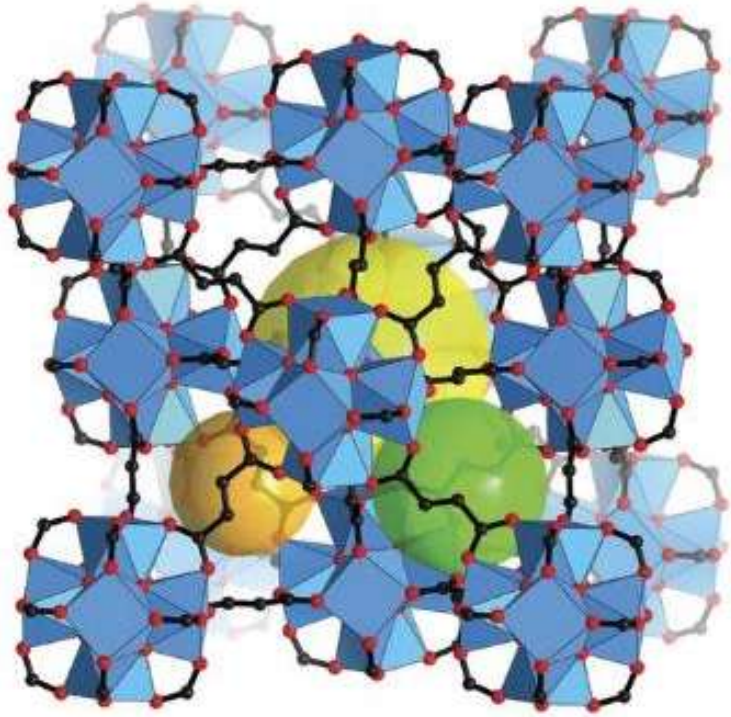
(LPD: Litres per day)


THE HINDU
NEWS 18
'VAYUJAL MISSION OF
IIT-MADRAS IS SIGNIFICANT'
VAYUJAL
AN IIT MADRAS INCUBATED COMPANY
WATER FROM AIR - ANYTIME, ANYWHERE
PROF. K. VIJAYRAGHAVAN
Principal Scientific Advisor
Govt of India
CHENNAI
Mandir celebrated their golden jubilee reunion
an atmospheric water generator (AWG) to their
potable water with the moisture in the air.

Sustainable atmospheric water harvesting

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

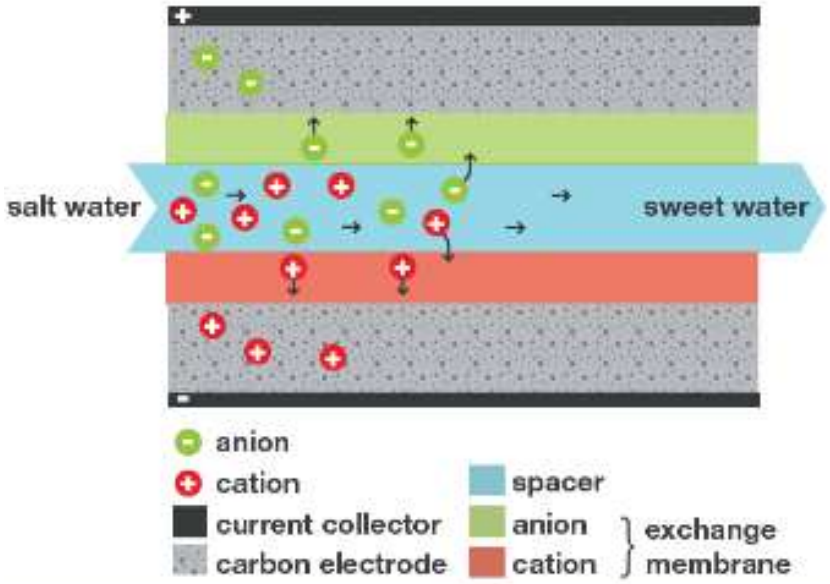


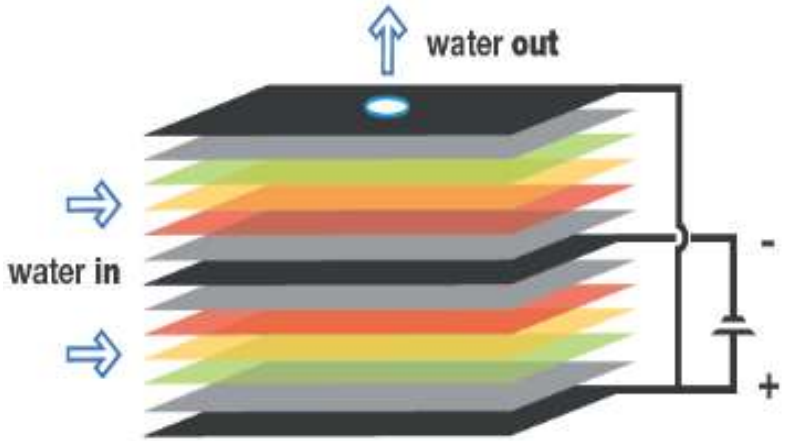


Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(fumarate)_6$)

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

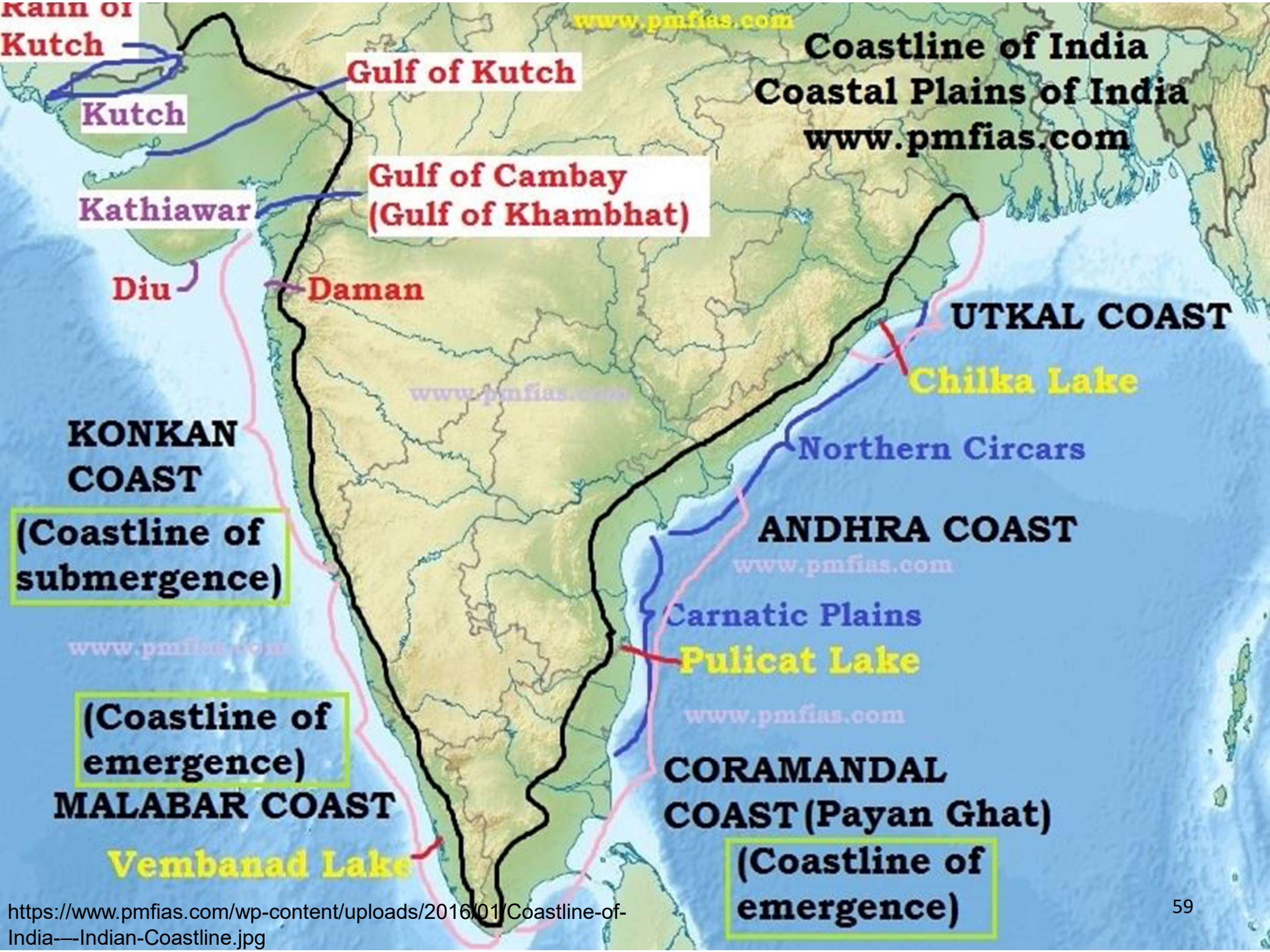
Capacitive Desalination (CDI)





Our new company

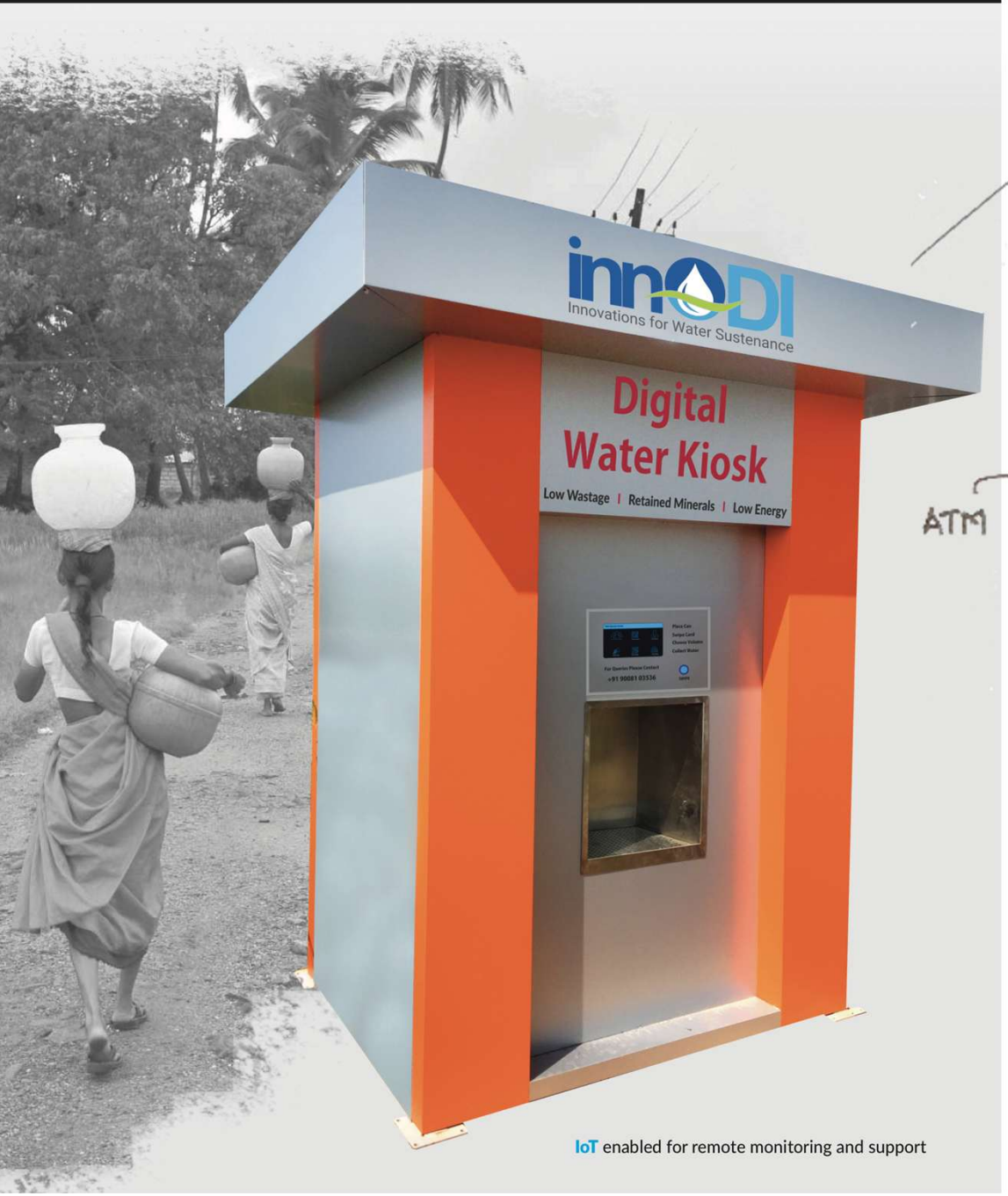
Soujit Sengupta, Rabiul Islam and others

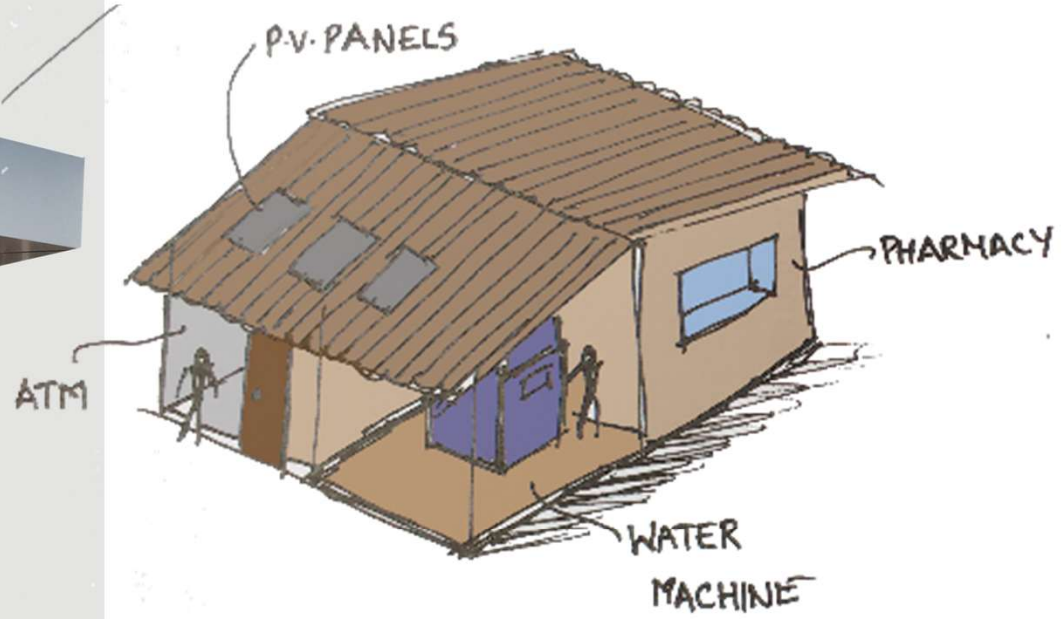


https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India-–-Indian-Coastline.jpg

DIGITAL WATER KIOSK

for community drinking using CDI Technology

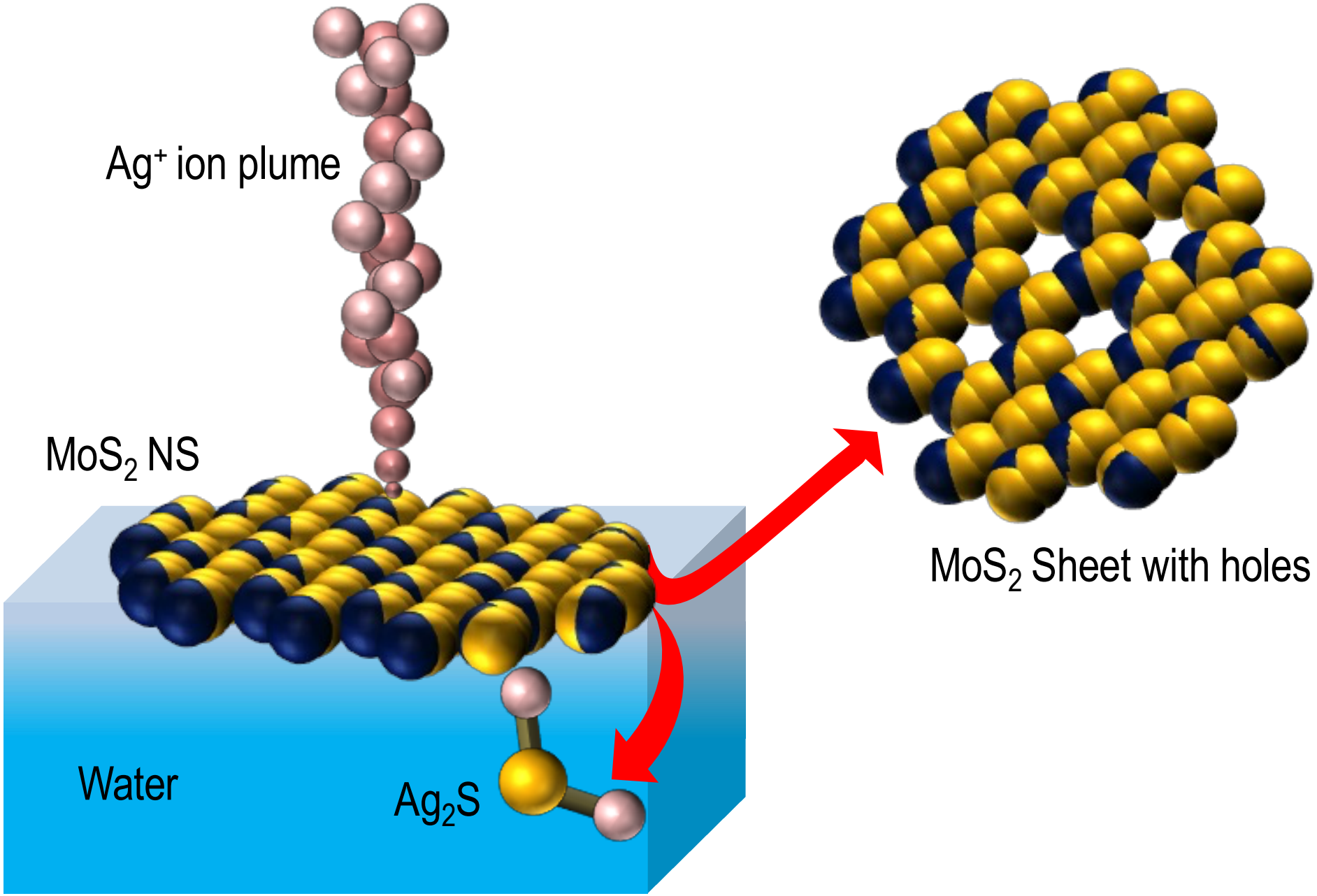




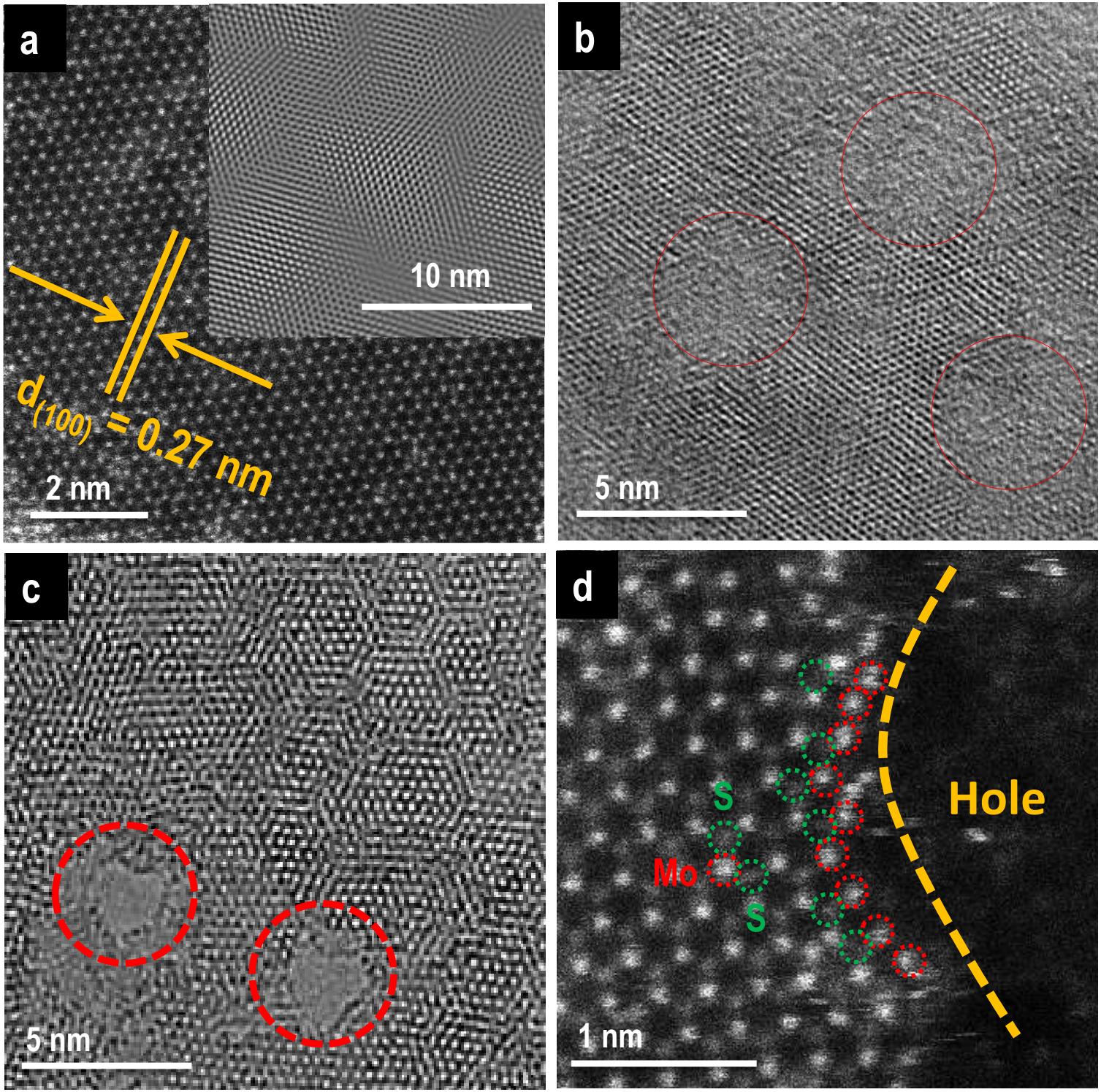
Products under implementation

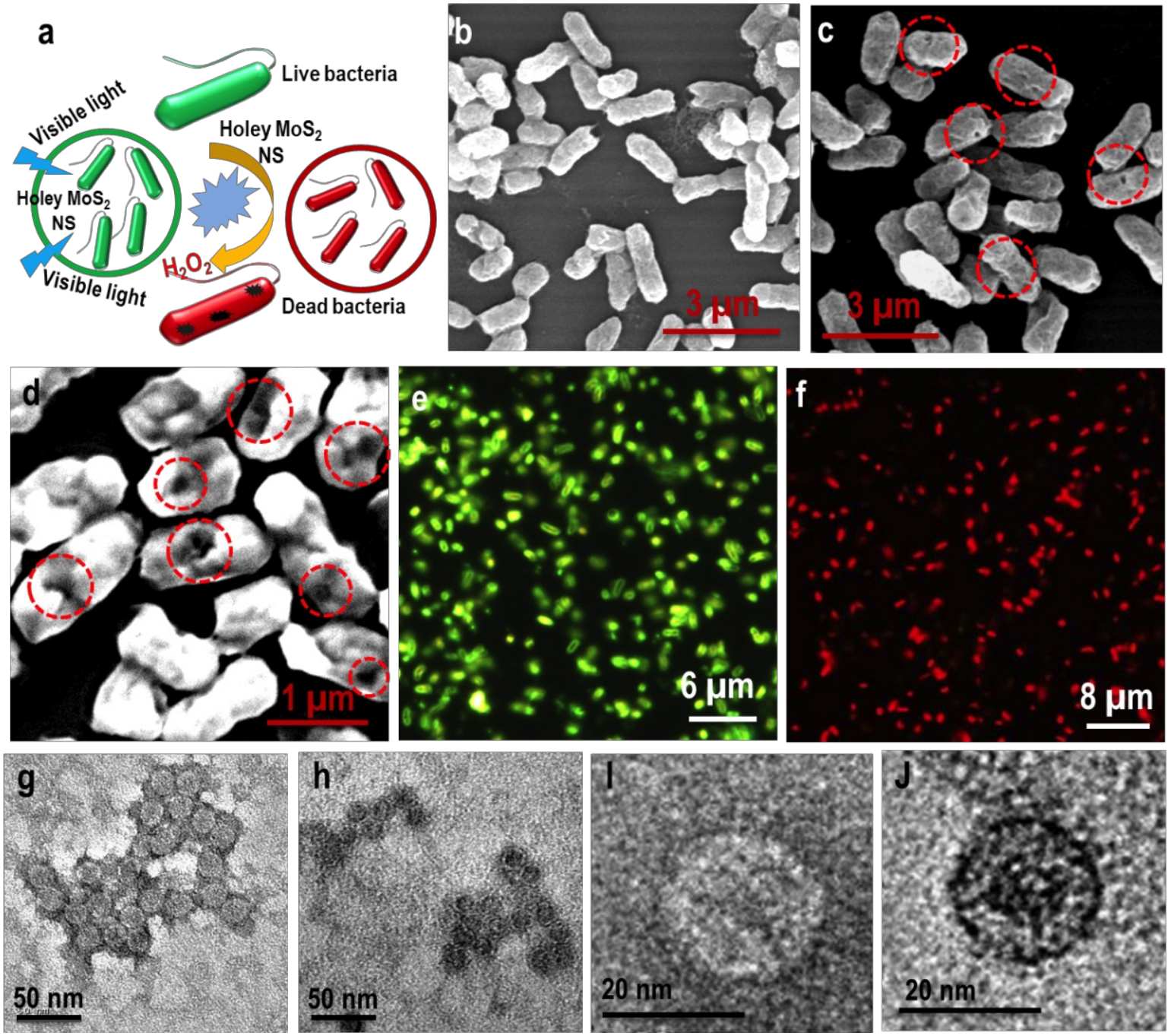
Vijay Sampath and Tullio Servida

2D materials, nanopores

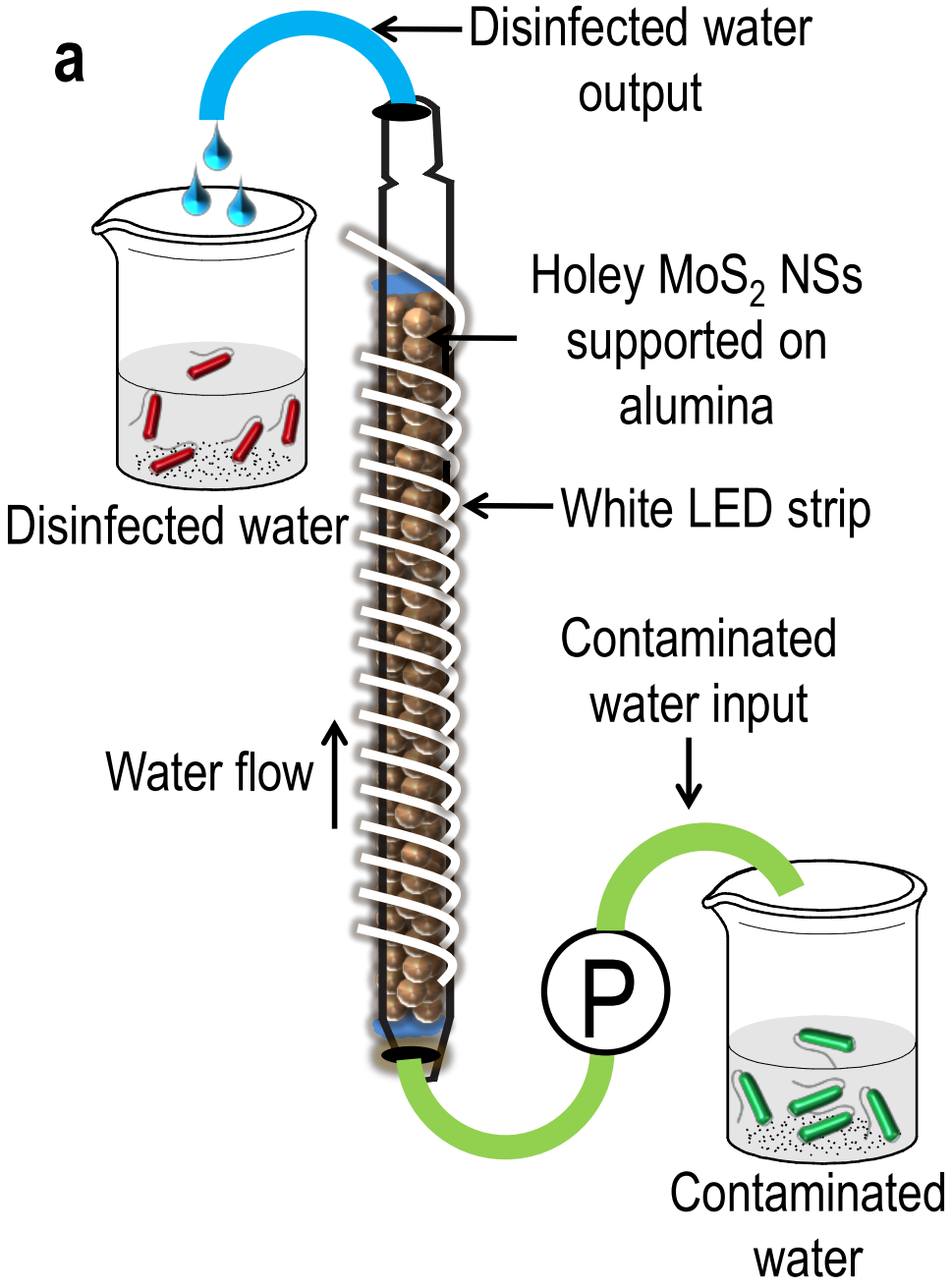


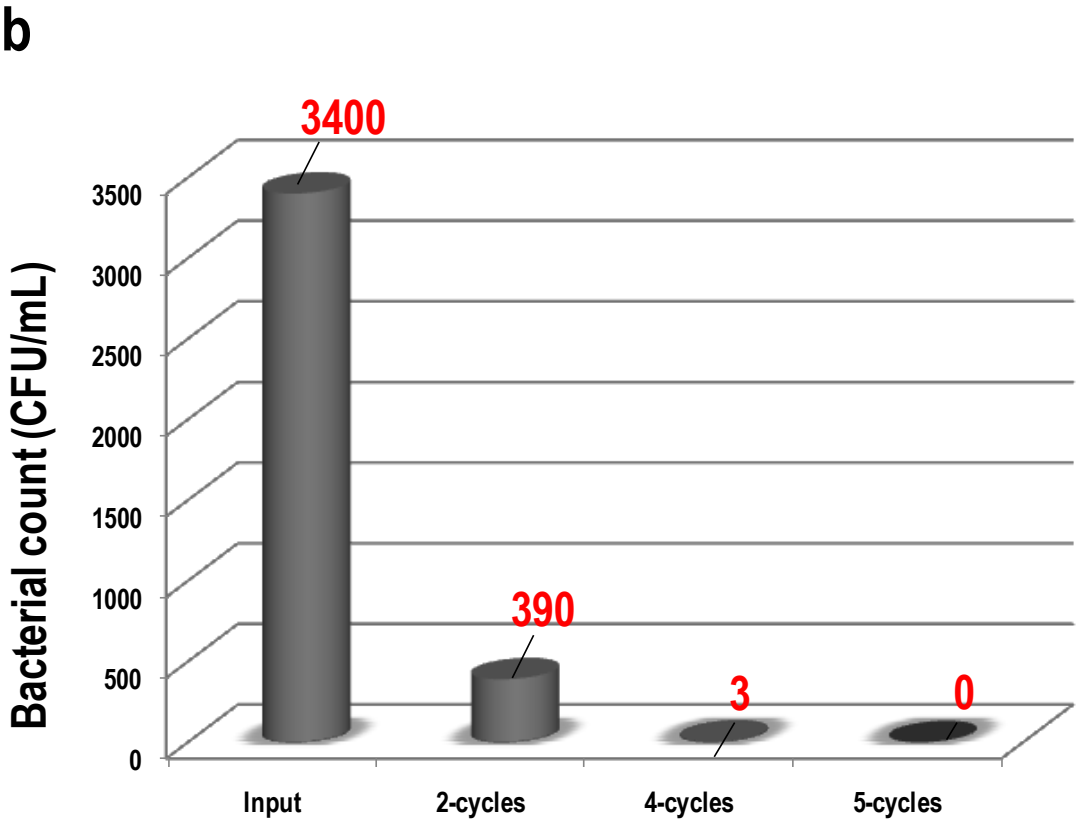
Depanjan Sarkar, Biswajit Mondal, et. al., *Global Challenges, 2* (12), 2018


a
10 nm
$d_{(100)}$ = 0.27 nm
2 nm
b
5 nm
c
5 nm
d
S
Mo
S
Hole
1 nm

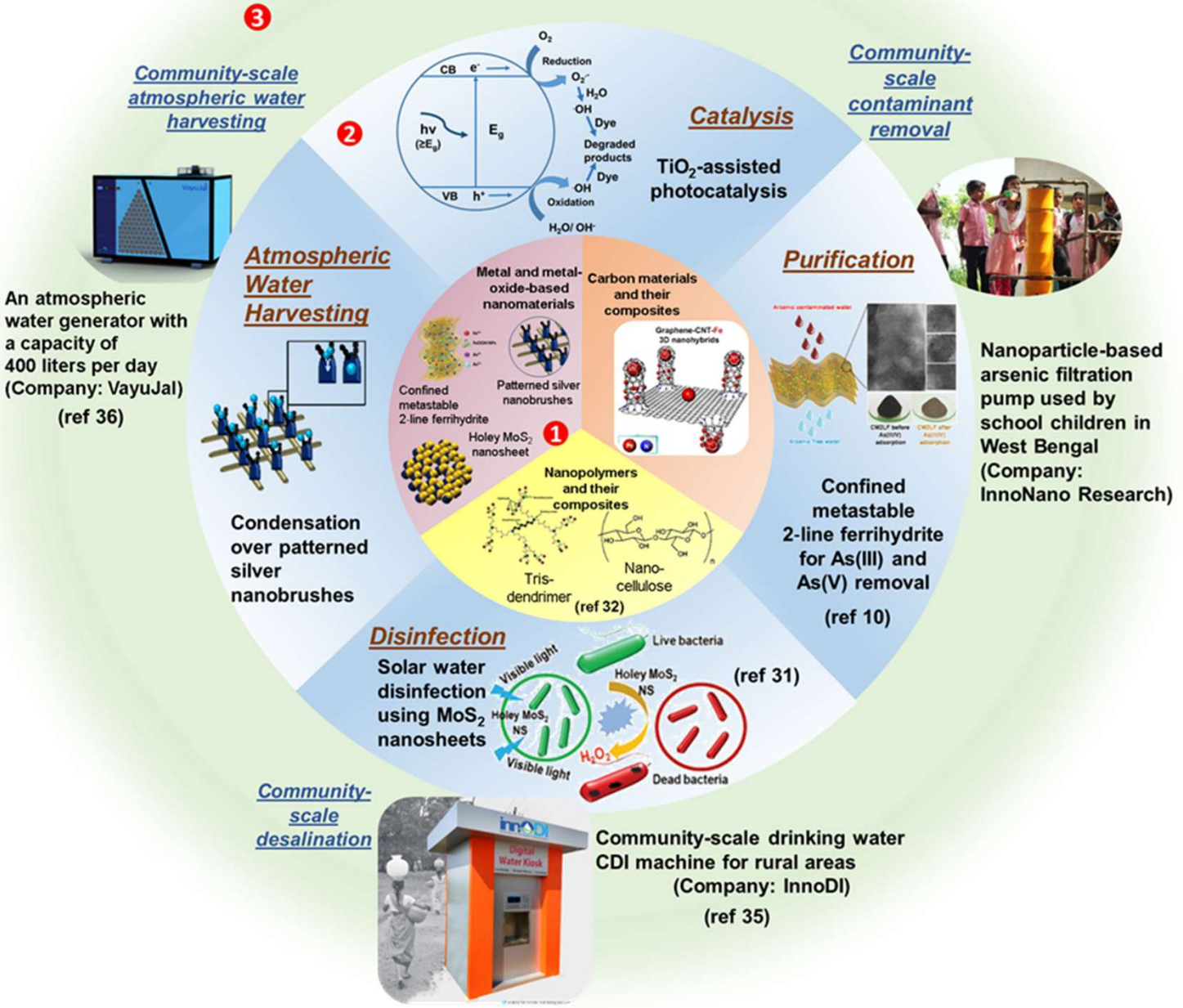

a
Live bacteria
Visible light
Holey MoS_2 NS
Holey MoS_2 NS
H_2O_2
Visible light
Dead bacteria
b
3 μm
c
3 μm
d
1 μm
e
6 μm
f
8 μm
g
50 nm
h
50 nm
I
20 nm
J
20 nm

Prototype


a
Disinfected water output
Holey MoS_2 NSs supported on alumina
White LED strip
Disinfected water
Contaminated water input
Water flow
P
Contaminated water

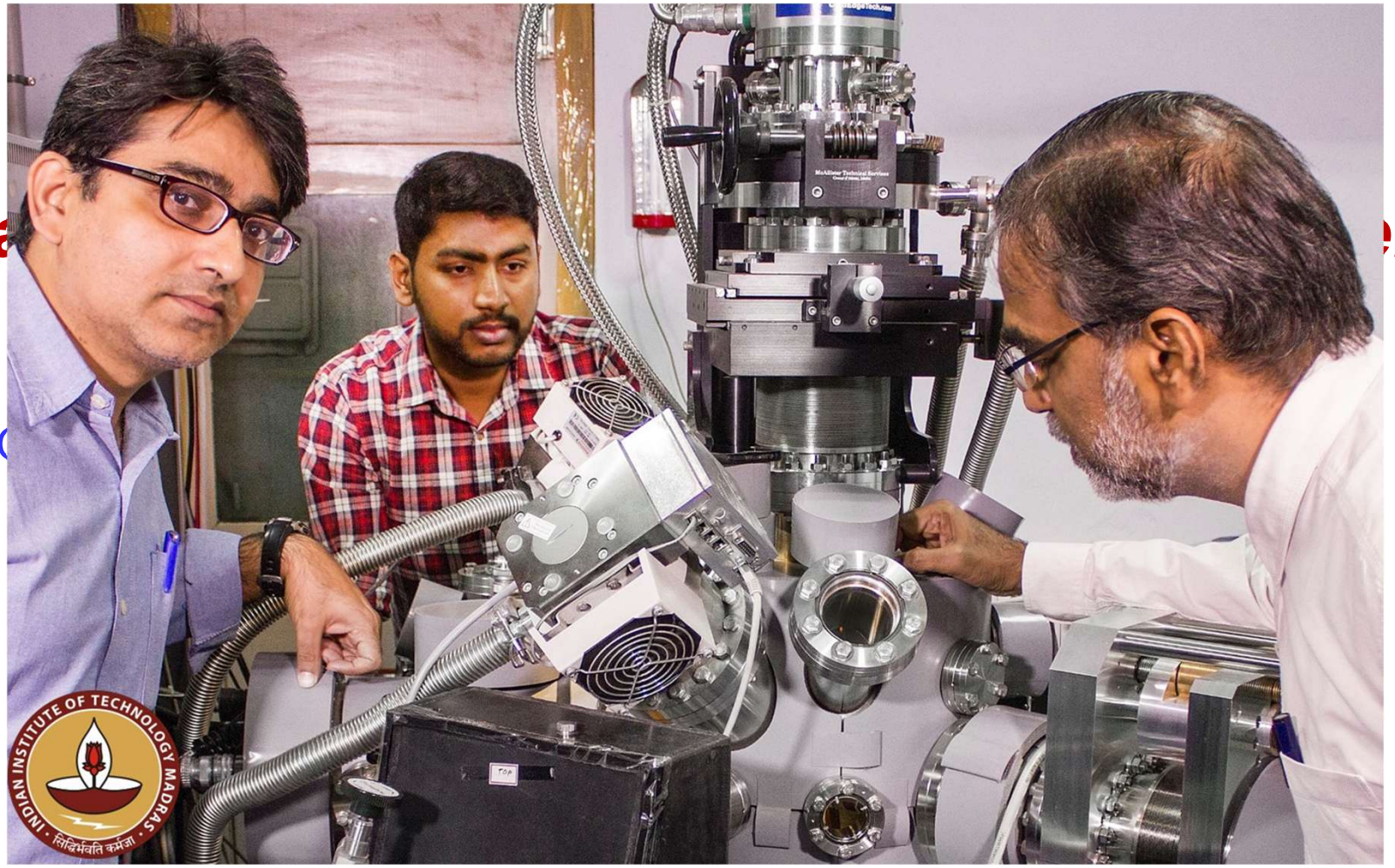

b
Bacterial count (CFU/mL)
3400
390
3
0
3500
3000
2500
2000
1500
1000
500
0
Input
2-cycles
4-cycles
5-cycles

Evolution of materials to products



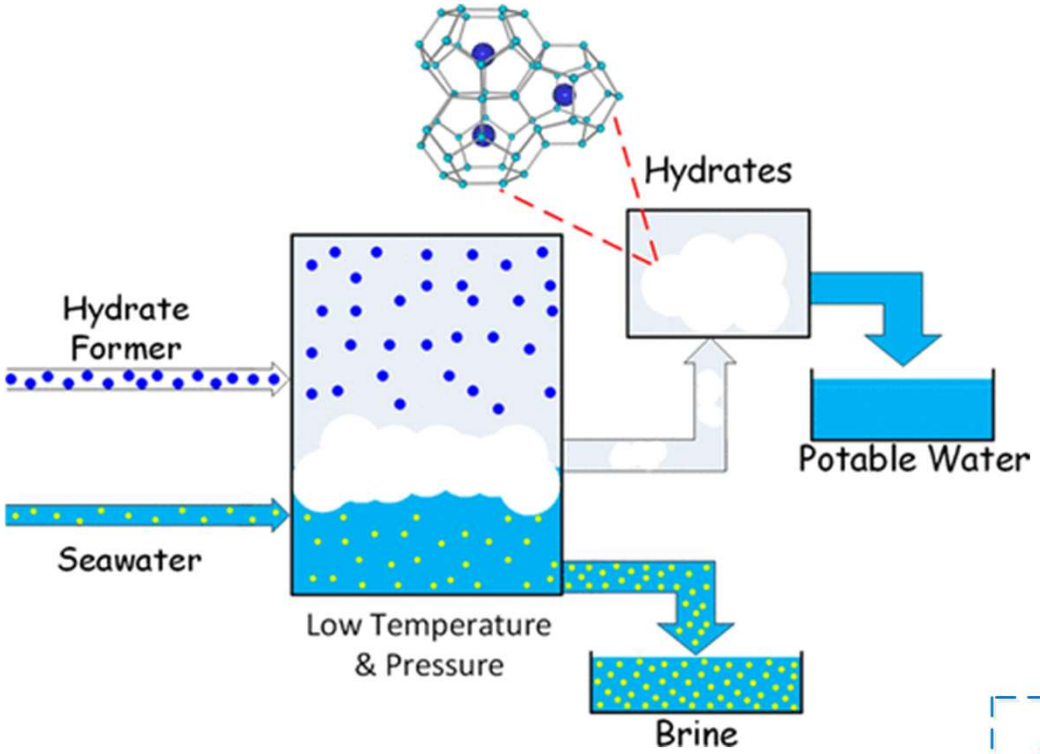
Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

New phenomena



With Rajnish Kumar

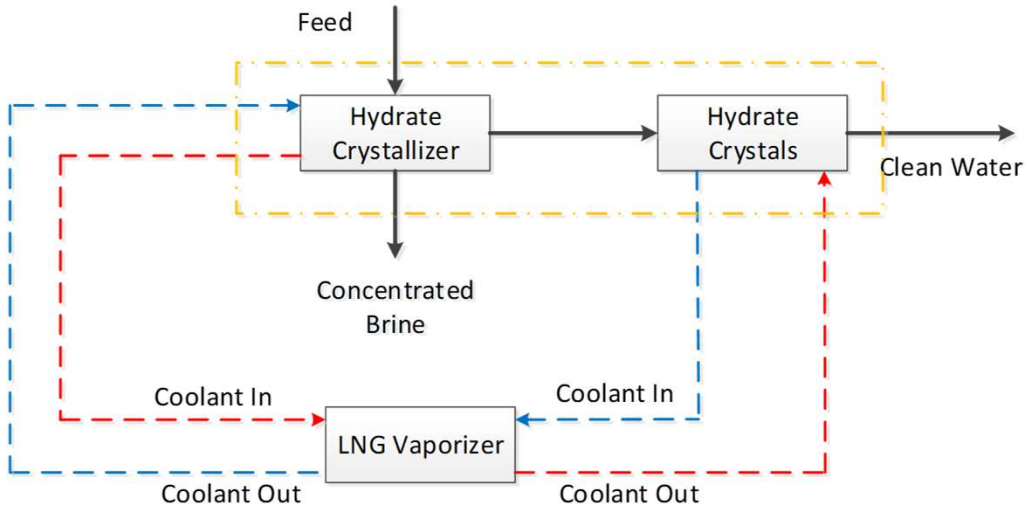
Hydrate-based desalination (HyDesal)



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

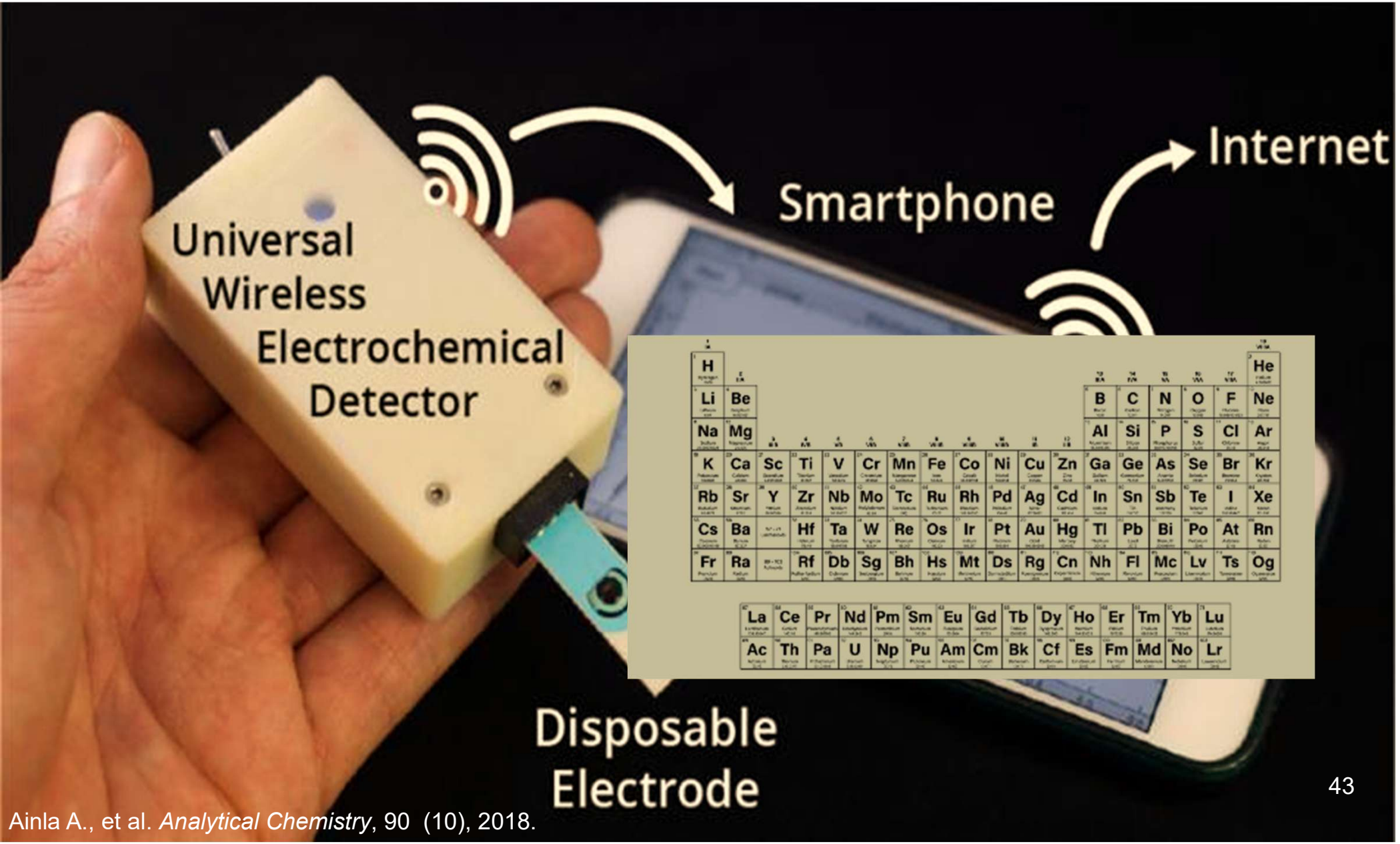


Cold Energy in LNG terminals can be harvested to produce water

Babu et al. ACS Sustainable Chemistry and Engineering (2018), 6 (7), 8093-8107

Slide from Prof. Praveen Linga, NUS

Analytical devices

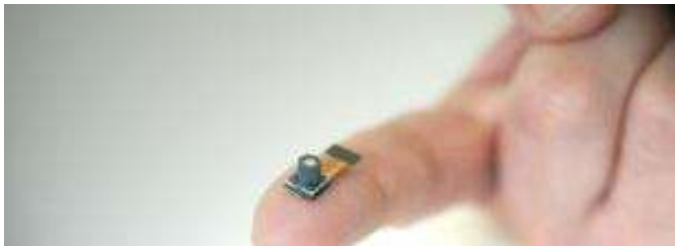


Ainla A., et al. *Analytical Chemistry*, 90 (10), 2018.

Sensors and new opportunities

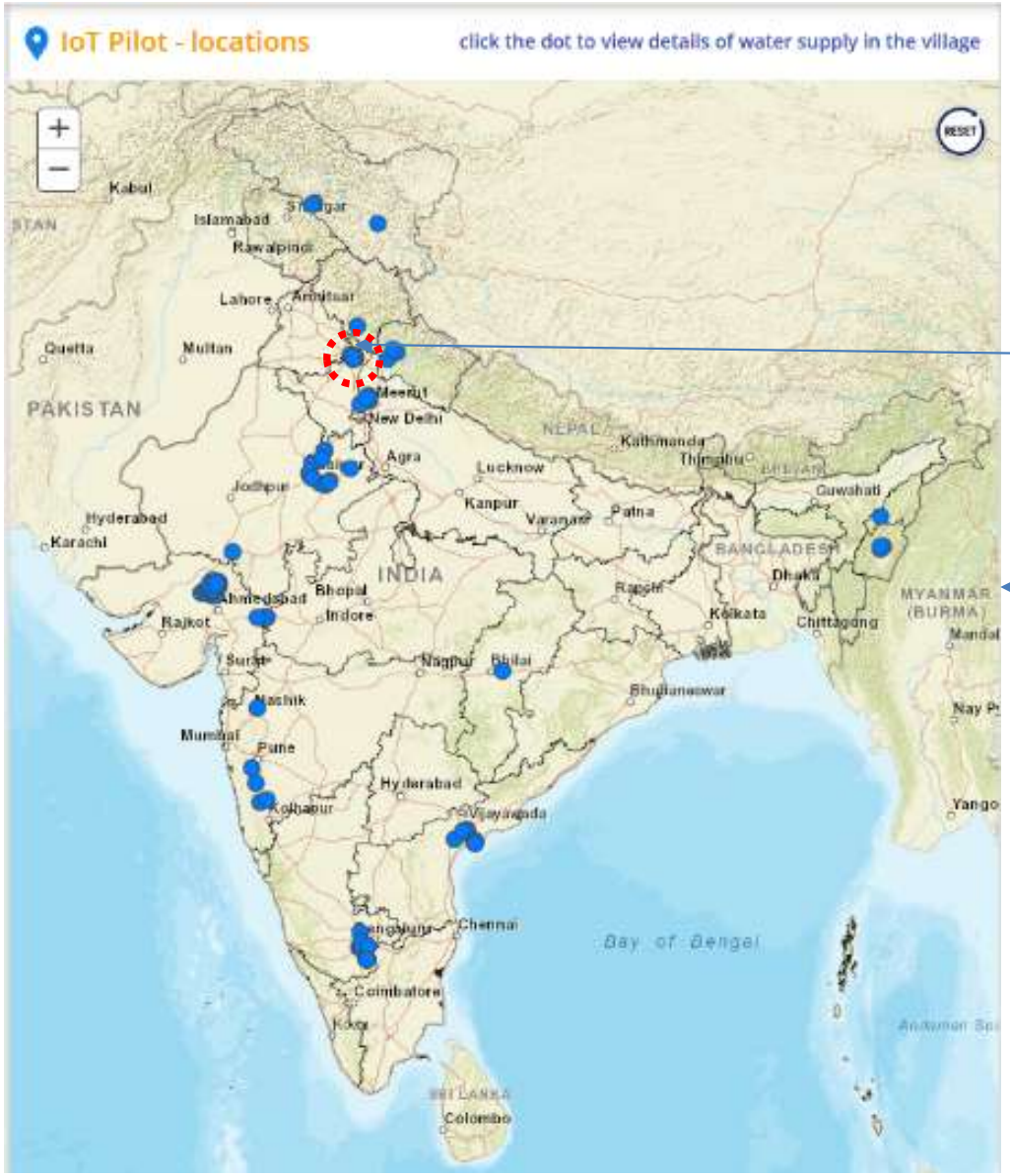
Analog/Grating
Equipment
$ 5~6 Billion (2017)
a few **100k units (2017)**

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



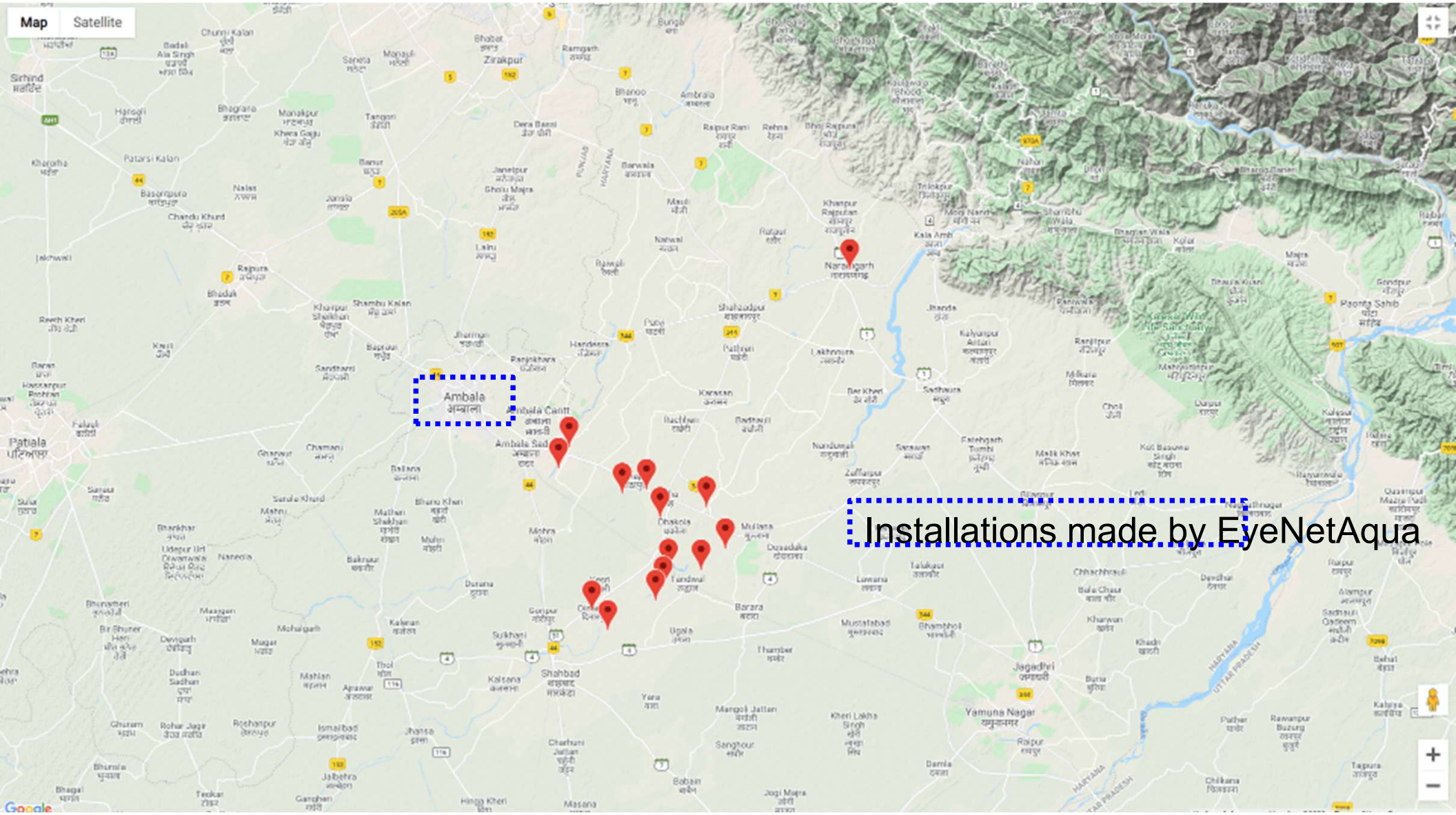
Water quality measurement – In the pipeline

nanoλ



Installations made by EyeNetAqua

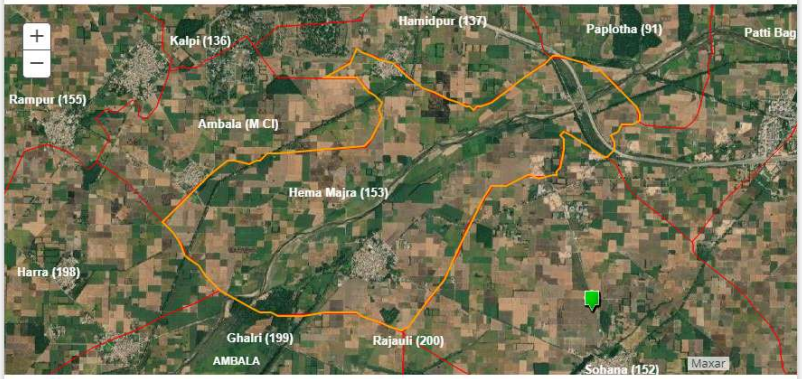
Installations made by four companies


Map
Satellite
Ambala
अम्बाला
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



Flow meter | Pressure | pH | TDS | Residual chlorine | Nitrate

Basic Information

Back

State : Haryana	**District :** Ambala
Block : Barara	**Panchayat :** Hema Majra
Village : Hema Majra	**Nos. of habitations :** 1
Population served though 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

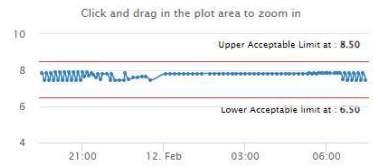
Yesterday
As on 18 Feb 2022

9,076 L

Daily water supply trend (LPCD)

Residual chlorine (mg/l)

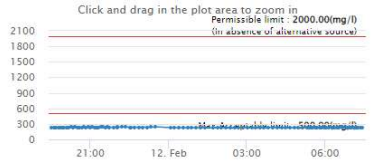
pH



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

Jal Jeevan Mission - Har Ghar Jal

Pilot for IoT-based smart water supply monitoring system

Rampur Village in Ambala District, Haryana

Flow meter | Pressure | pH | TDS | Residual chlorine | Nitrate

Basic Information

Back

State : Haryana	**District :** Ambala
Block : Saha	**Panchayat :** Rampur
Village : Rampur	**Nos. of habitations :** 1
Population served though schemes : 2,823	
Agency : EyeNetAqua Solutions Pvt. Ltd. (Under ICT Grand Challenge)	
Location (Water Sources) : Rampur	
Scheme : Rampur (Saha) Village, Drilling Of Additional Tube	
Year of commissioning : 2018-2019	

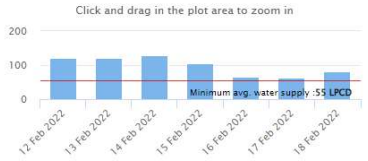
Average water supply (LPCD)

Last 7 Days
12 Feb 2022-18 Feb 2022
98.58 L

Water Supplied

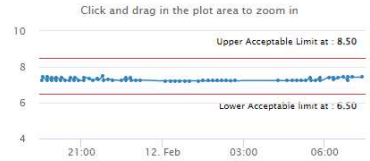
Yesterday
As on 18 Feb 2022
22,563 L

Daily water supply trend (LPCD)



Residual chlorine (mg/l)

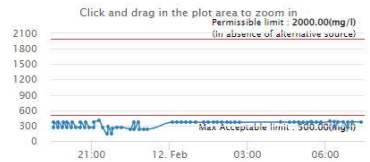
pH



Pressure (meter)

Nitrate (mg/l)

TDS (mg/l)



VWSC/ Pani Samiti Member

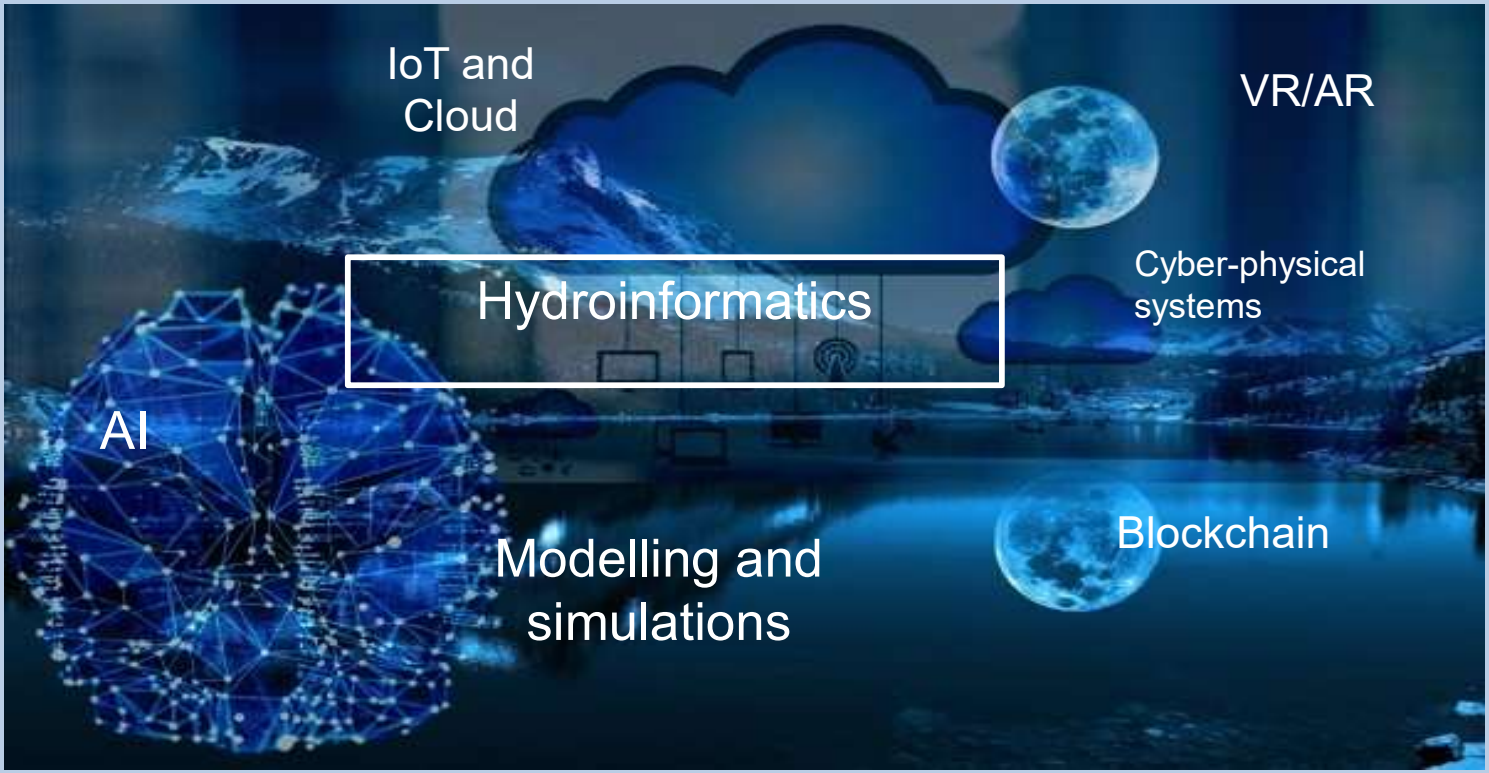
Name	Designation	Gender
Satish Kumar	Chairperson	Male
Shublata	Member Secretary	Female

Operation & Maintenance Personnel

Name	Designation	Gender
Rishipal	Pump Operator	Male
Ramparkash	Pump Operator	Male

Hydroinformatics

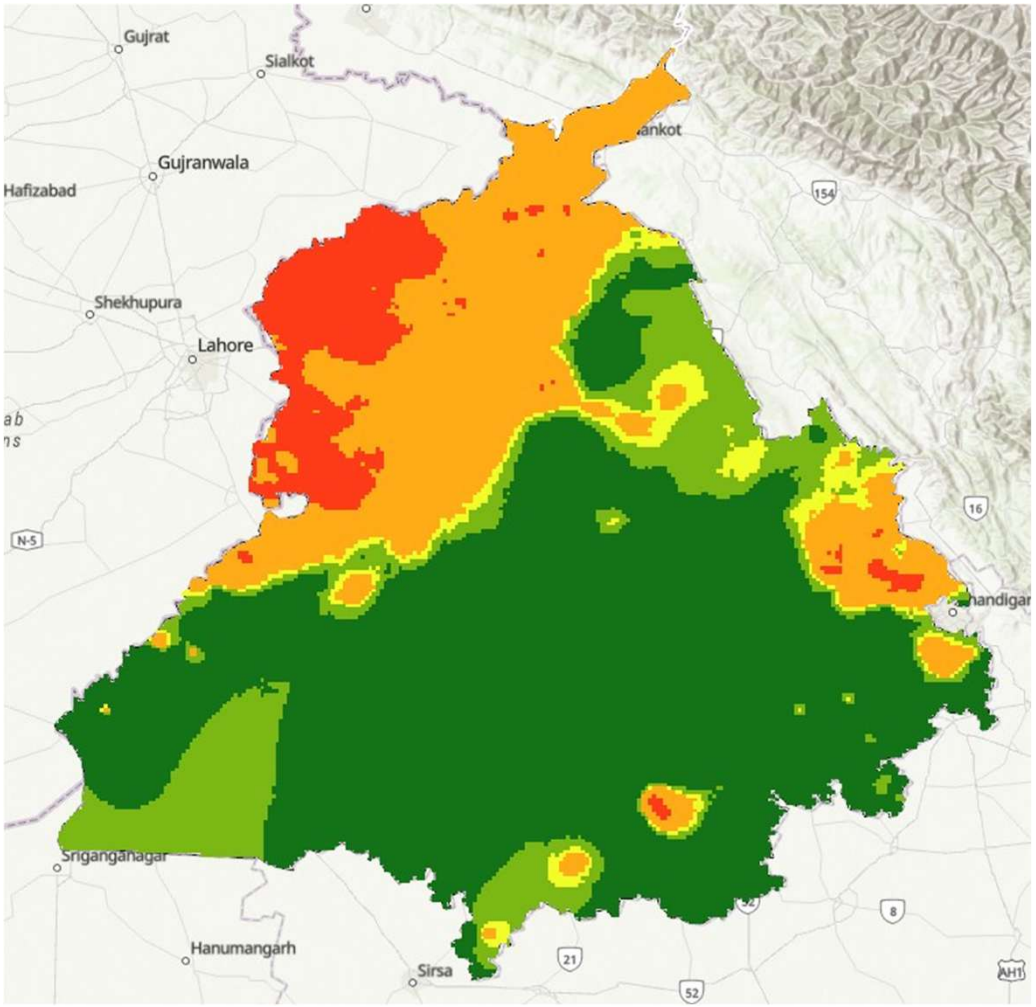
Application of computing technologies for efficient, sustainable and equitable water management.



Digital water or water 4.0 will revolutionize water management.

Average of arsenic at 7000 locations

2017-2020



Arsenic in mg/L

- 0 - 0.001
- 0.001 - 0.002
- 0.002 - 0.004
- 0.004 - 0.006
- 0.006 - 0.008
- 0.008 - 0.01
- 0.01 - 0.02
- 0.02 - 0.04
- 0.04 - 0.06
- 0.06 -0.2

Wastewater, rainwater, runoff,…

About 1000 billion litres a day - 1000,000 MLD!

With increasing urbanisation, wastewater must be consider as - used water and must be reused.

Most of the global urban area of 658,760 km^2 is non-porous.

This leads to faster runoff and quick flooding.

Urban flooding demands adequate investments.

Cont…Energy

There is large amounts of energy in wastewater (Table 1).
Yet, wastewater management consumes additional energy.
We cannot recover most of the nutrients.

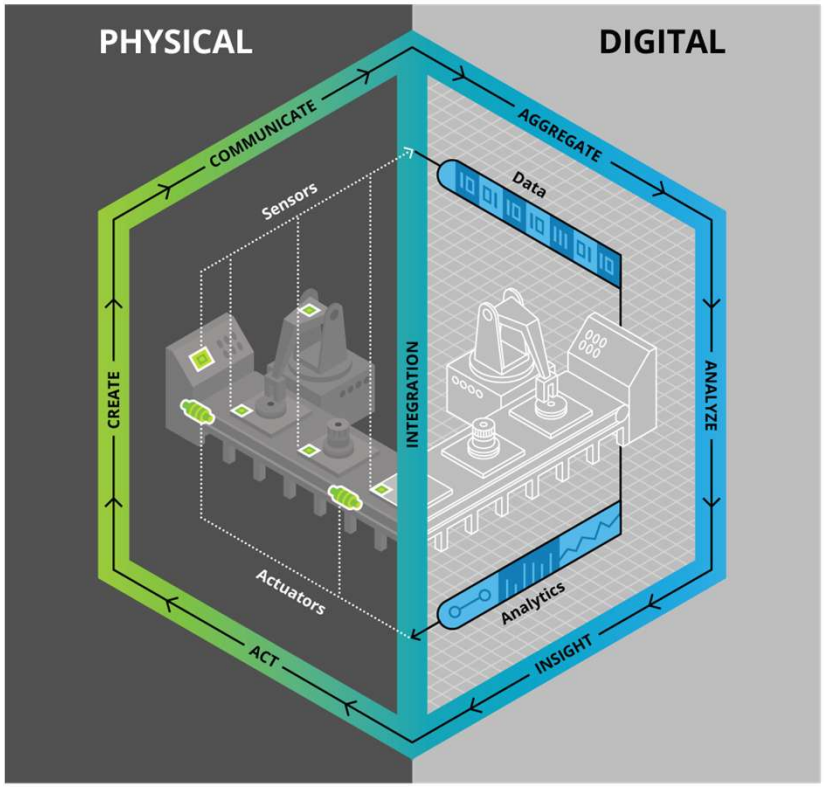
With 9 billion population, nitrogen in wastewater would be of the same order as the anthropogenic production of reactive nitrogen

Table 1. Resources in wastewater. For nutrients and water, global averages are given. No global information is available concerning warm water and organic matter in wastewater. Local loads depend inter alia on nutritional status, household devices, water availability, and habits.

Water (liters person^{-1} day^{-1})		
Domestic	184	Global average (69)
Industrial	300	Industrial global average (69)
Energy (MJ person^{-1} year^{-1})		
Heat contained in warm water	2800	Typical European country (11)
Chemical energy contained in organic matter	540	Typical European country (11)
Chemical energy "embedded" in N and P	180	Global average, year 2000 (11, 17)
Nutrients from human metabolism (g person^{-1} day^{-1})		
Nitrogen (N)	10	Global average, year 2000 (17)
Phosphorus (P)	2	Global average (17)

Tove A. Larsen, Sabine Hoffmann, Christoph Lüthi, Bernhard Truffer and Max Maurer, Science, 352 (2016) 6288 928-933.

Digital twin of water resources



Source: Deloitte University Press.

Deloitte University Press | dupress.deloitte.com

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

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

Should we continue to eat rice and cultivate the way we have been doing for ages?
Urban farming
Aquaponics/hydroponics

Should we do agriculture on ground water?

All these will not change soon

We need to use all the water we get from the heavens – in a country which is increasingly urban

Wastewater – all that must be recycled – micro/nano recycling

Restructure cultivation – where water is rich, there is no farming!

Technology enabled farming, enabling cultivation in every bit of land

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

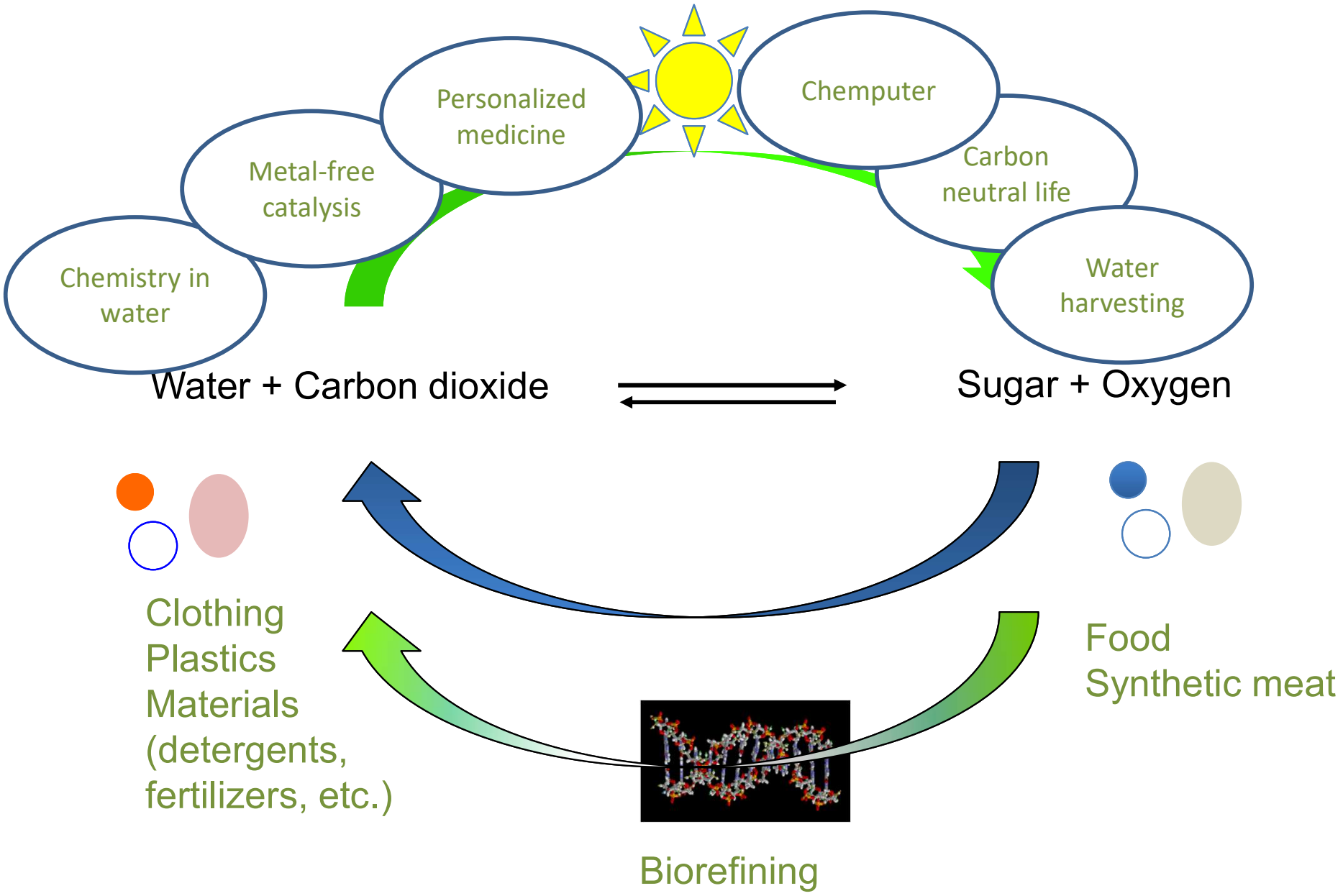
Sustainability metrics

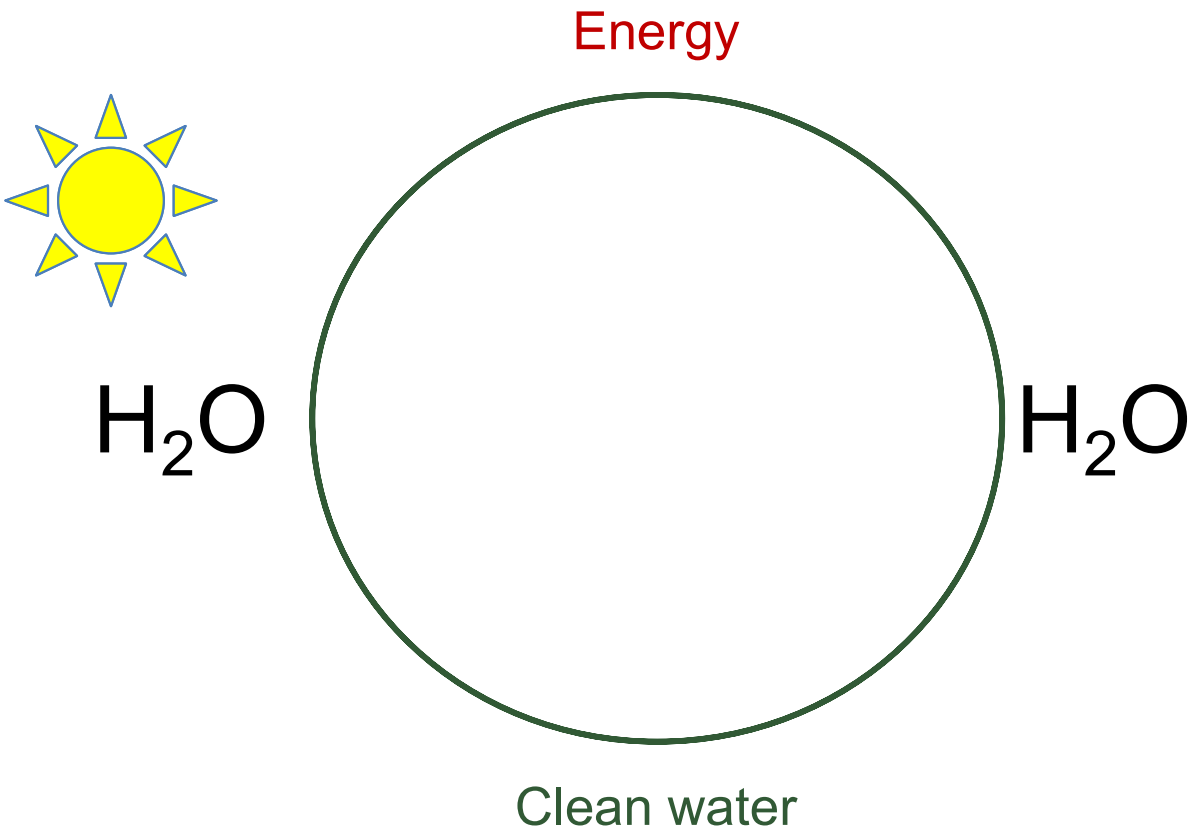
Water positive materials
Solar pumping &
gravity fed solutions

Traditional wisdom

Water harvesting – we do around 8%
Preserve water bodies
Dig wells, maintain them
Plant trees – 14 trees per person

Sustainability and a host of opportunities




Energy
H_2O
H_2O
Clean water


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

सत्यमेव जयते

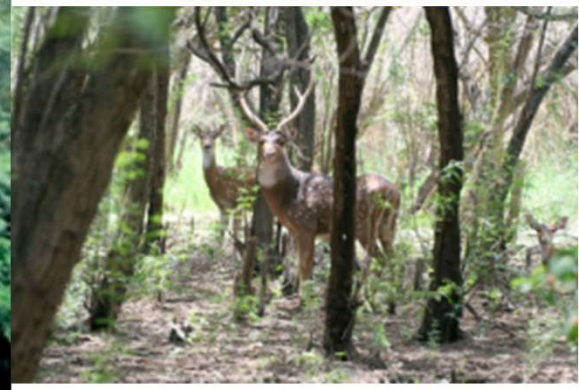
Start-ups and partners:

Mahindra WORLD CITY

Our collaborators

Ministry of Drinking Water and Sanitation, Govt. of Indi

Indian Institute of Technology Madras



Directors - past and present

Associate Editor

ACS Sustainable Chemistry & Engineering

Pradeep Research Group

Thematic Unit of Excellence

Thank you all

Table 3: Sector-wise expenditure under Kerala Budget 2021-22 (in Rs crore)
Note: BE: Budget Estimates; RE: Revised Estimates.
Sources: Kerala Budget Documents 2021-22; PRS.

Sector	2019-20 Actuals	2020-21 BE	2020-21 RE	2021-22 BE	Annualised Change (2019-20 to 2021-22 BE)
Education, Sports, Arts, and Culture	18,771	20,862	16,487	23,662	12%
Social Welfare and Nutrition	4,010	7,790	10,180	11,058	66%
Health and Family Welfare	7,539	7,856	7,971	10,354	17%
Agriculture and allied activities	5,172	7,407	8,574	8,983	32%
Rural Development	2,158	6,389	3,369	6,893	79%
Roads and Bridges	3,708	5,084	4,340	4,883	15%
Police	3,542	3,781	3,137	4,406	12%
Welfare of SC, ST, OBC, and Minorities	2,060	3,045	2,021	3,202	25%
Urban Development	1,071	2,346	1,680	2,083	39%
Water Supply and Sanitation	606	1,440	937	1,525	59%
% of total expenditure on all sectors	**43%**	**46%**	**46%**	**48%**	**-**

Molecular scavengers

Multi-recognition sensors

Table 5: Ministry-wise expenditure in 2021-22 (Rs crore)

Note: Expenditure is net of recoveries such as fines, and ticket sales.

Sources: Expenditure Budget, Union Budget 2021-22; PRS.

	Actuals 2019-20	Budgeted 2020-21	Revised 2020-21	Budgeted 2021-22	Change (Annualised) (Actuals 2019-20 to BE 2021-22)
Defence	4,52,996	4,71,378	4,84,736	4,78,196	3%
Consumer Affairs, Food and Public Distribution	1,17,096	1,24,535	4,50,687	2,56,948	48%
Home Affairs	1,34,978	1,67,250	1,49,388	1,66,547	11%
Rural Development	1,23,622	1,22,398	1,98,629	1,33,690	4%
Agriculture and Farmers' Welfare	1,01,775	1,42,762	1,24,520	1,31,531	14%
Road Transport and Highways	78,249	91,823	1,01,823	1,18,101	23%
Railways	69,972	72,216	1,11,234	1,10,055	25%
Education	89,437	99,312	85,089	93,224	2%
Chemicals and Fertilisers	82,063	71,897	1,35,559	80,715	-1%
Communications	43,939	81,957	61,060	75,265	31%
Health and Family Welfare	64,258	67,112	82,928	73,932	7%
Jal Shakti	25,683	30,478	24,286	69,053	64%
Housing and Urban Affairs	42,054	50,040	46,791	54,581	14%
Other Ministries	12,60,209	14,49,071	13,93,577	16,41,398	14%
Total Expenditure	**26,86,330**	**30,42,230**	**34,50,305**	**34,83,236**	**14%**

Rich tend to be healthy – although it is not simple

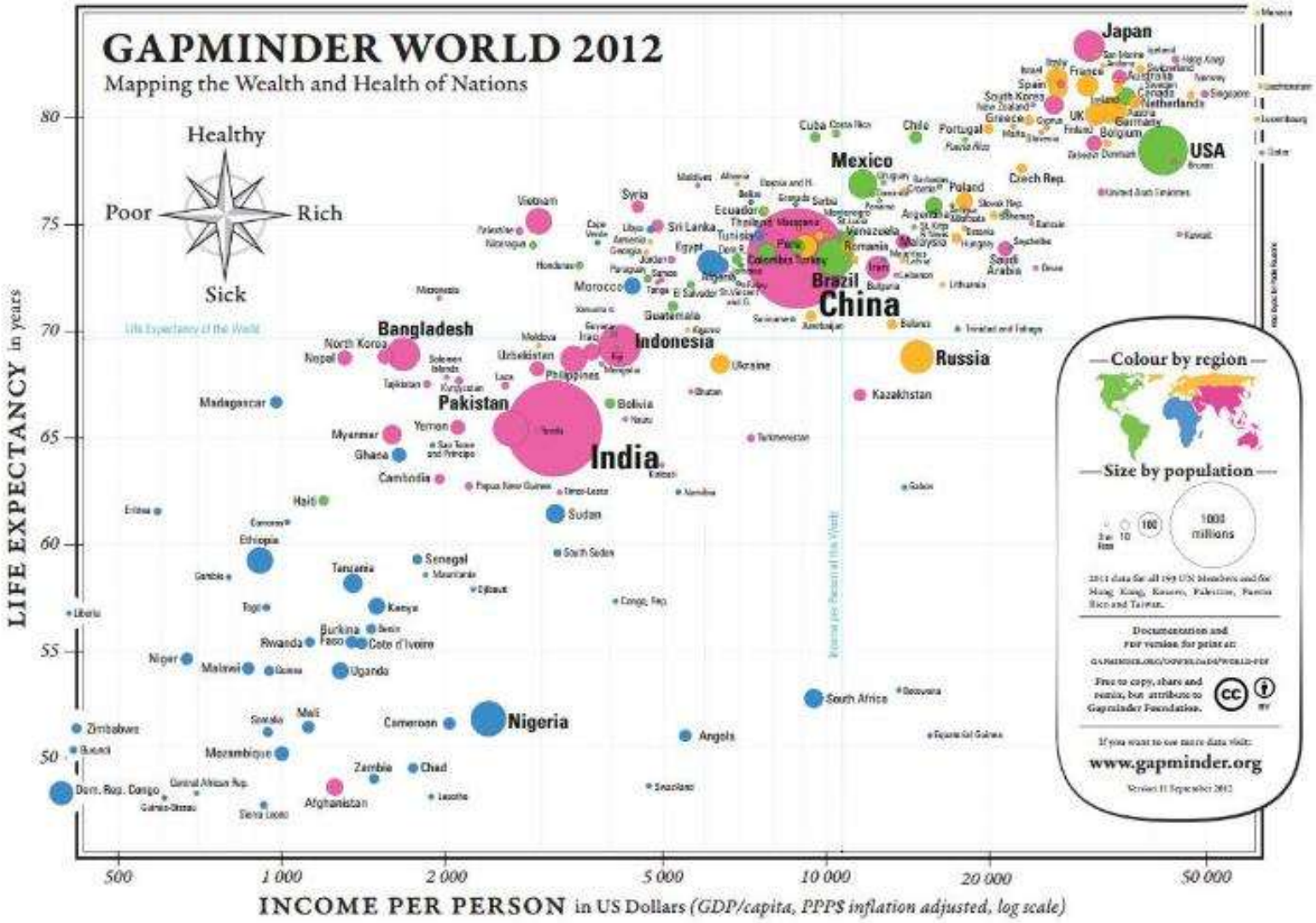
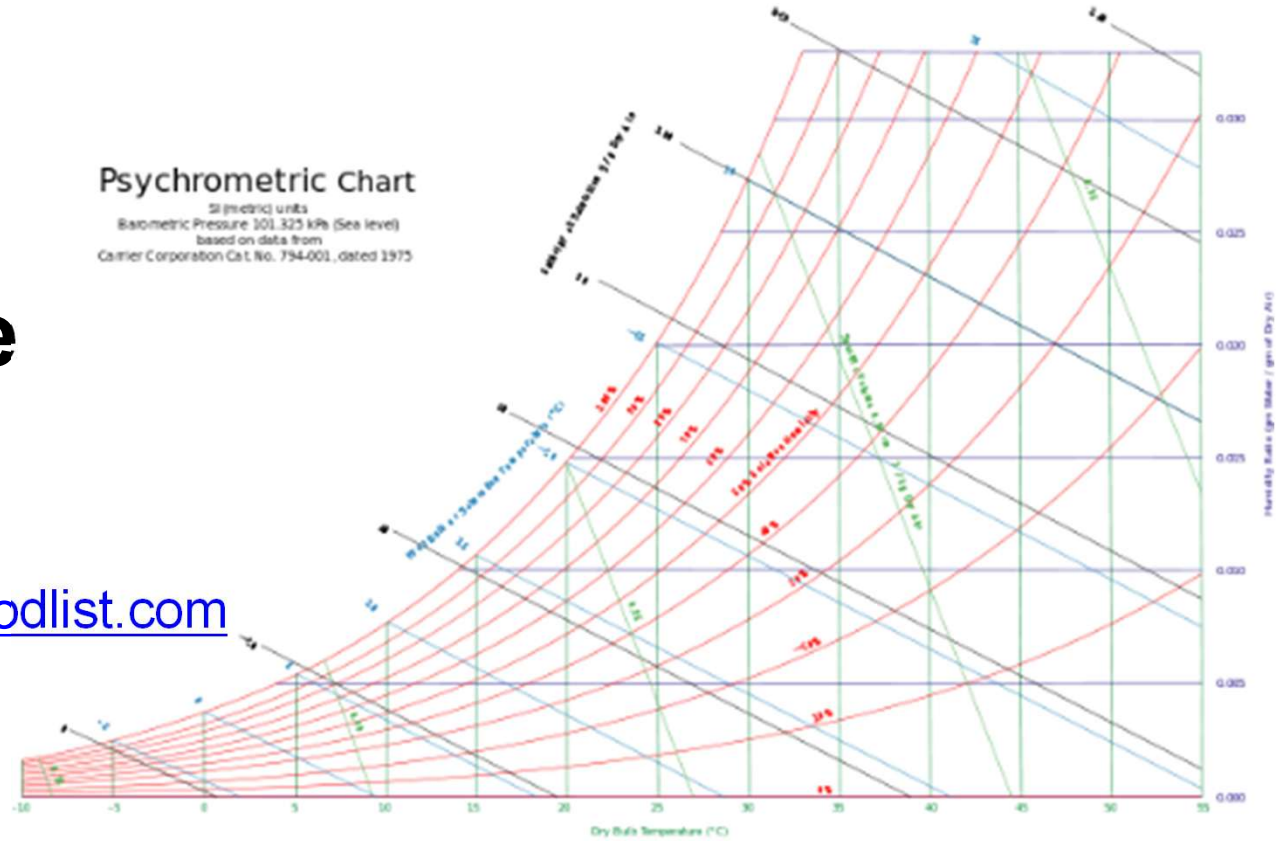
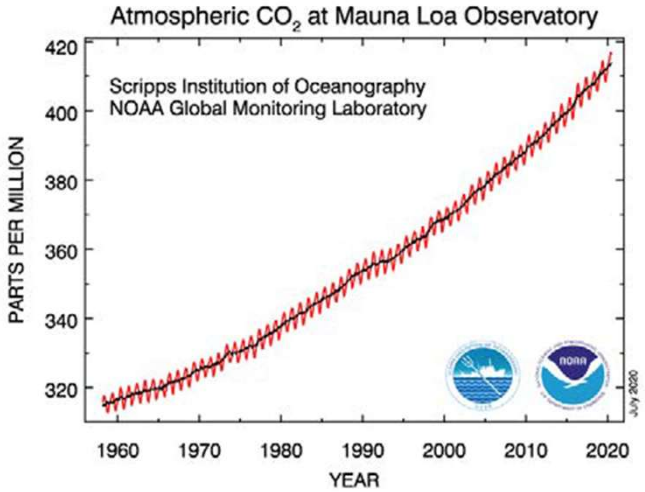


Image from: Dr. François Sestier, https://lifeexpectancyexpertise.com

Threats
Climate change

Floods every day - https://floodlist.com





United in Science 2020, UNESCO Report

From: Wikimedia