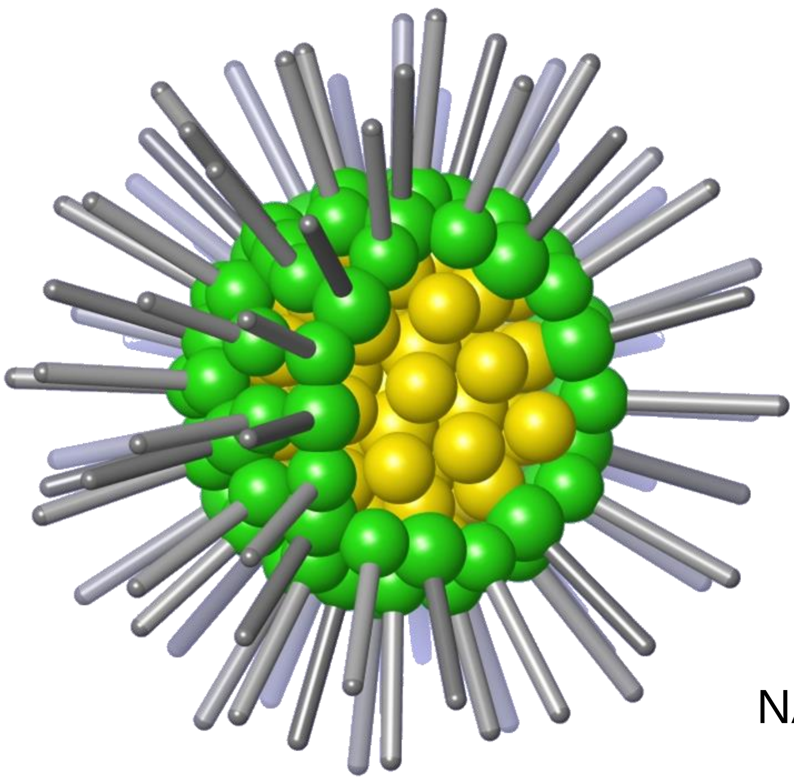
Drinking water purification for tomorrow



T. Pradeep

DST Unit of Nanoscience (DST UNS)
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Department of Chemistry
Indian Institute of Technology Madras
Chennai 600 036, India

NASI 3rd Policy Support Brainstorming on Safe Water and Sanitation, Nov. 18-20, 2014

Lab to market

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Partner agencies

Founder
InnoNano Research Pvt. Ltd.
An IIT Madras Incubated Company

Associate Editor
ACS Sustainable Chemistry & Engineering

Distinguished Professor
South African Research Chair Initiative (SARChI)

Government of India
Department of Science and Technology
State Governments
West Bengal, Bihar, Uttar Pradesh

DST Unit of Nanoscience and
Thematic Unit of Excellence, IIT Madras

www.dstuns.iitm.ac.in

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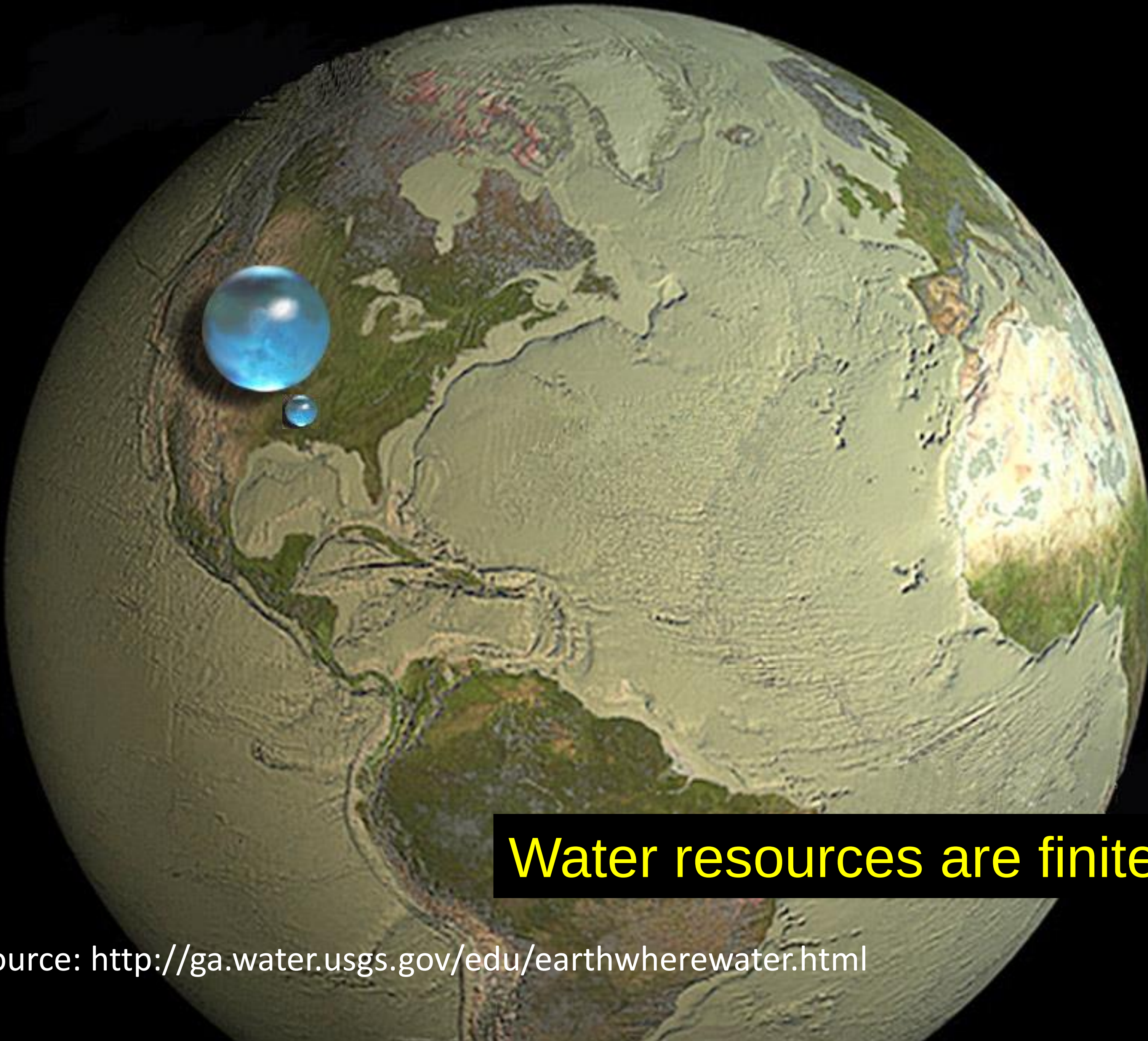
Research Private Limited
Innovative Infinity through the Infinitesimal
An IIT Madras incubated company


iitmadras.org
Technologies for a sustainable world



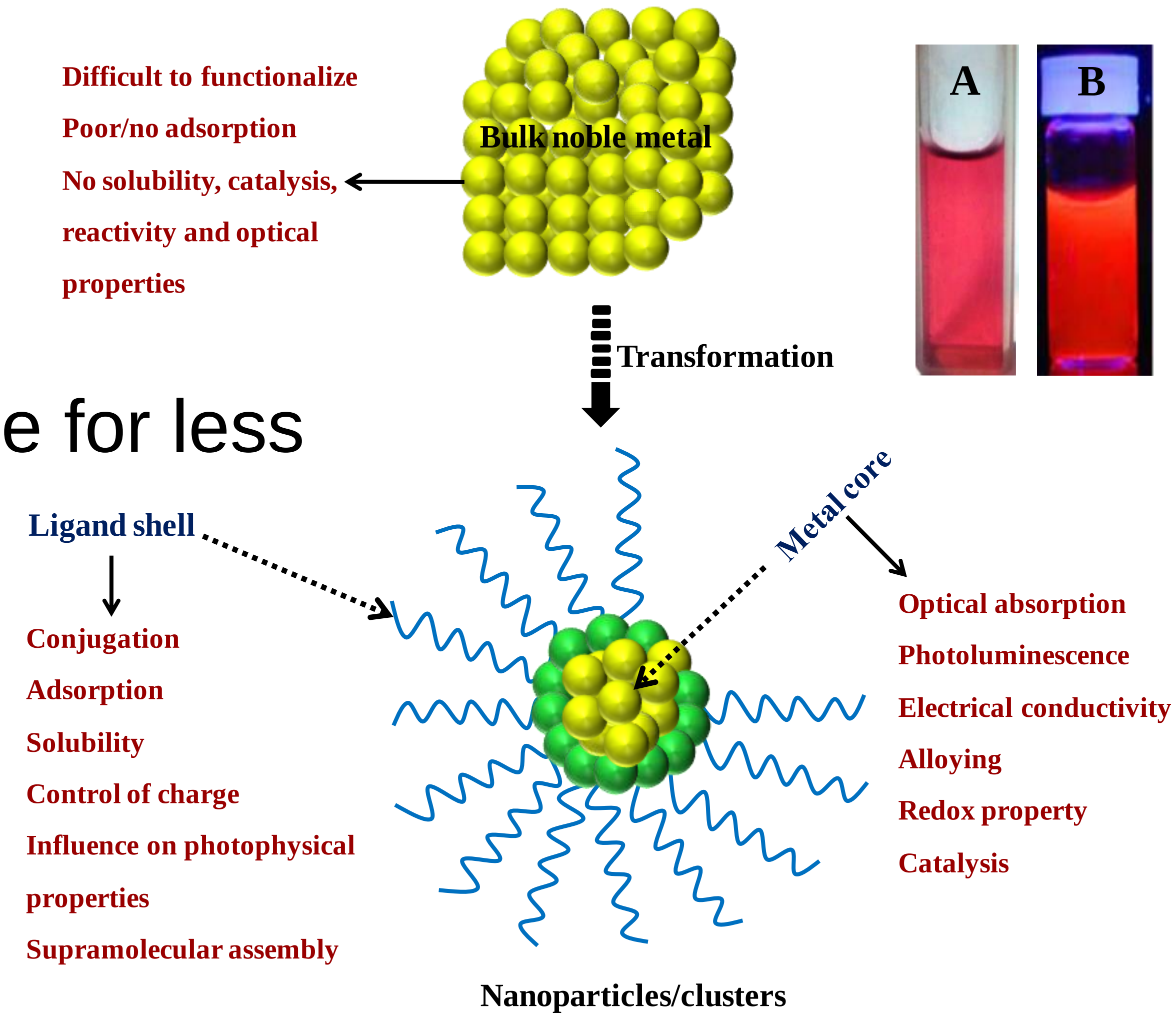
Water resources are finite

Source: http://ga.water.usgs.gov/edu/earthwherewater.html

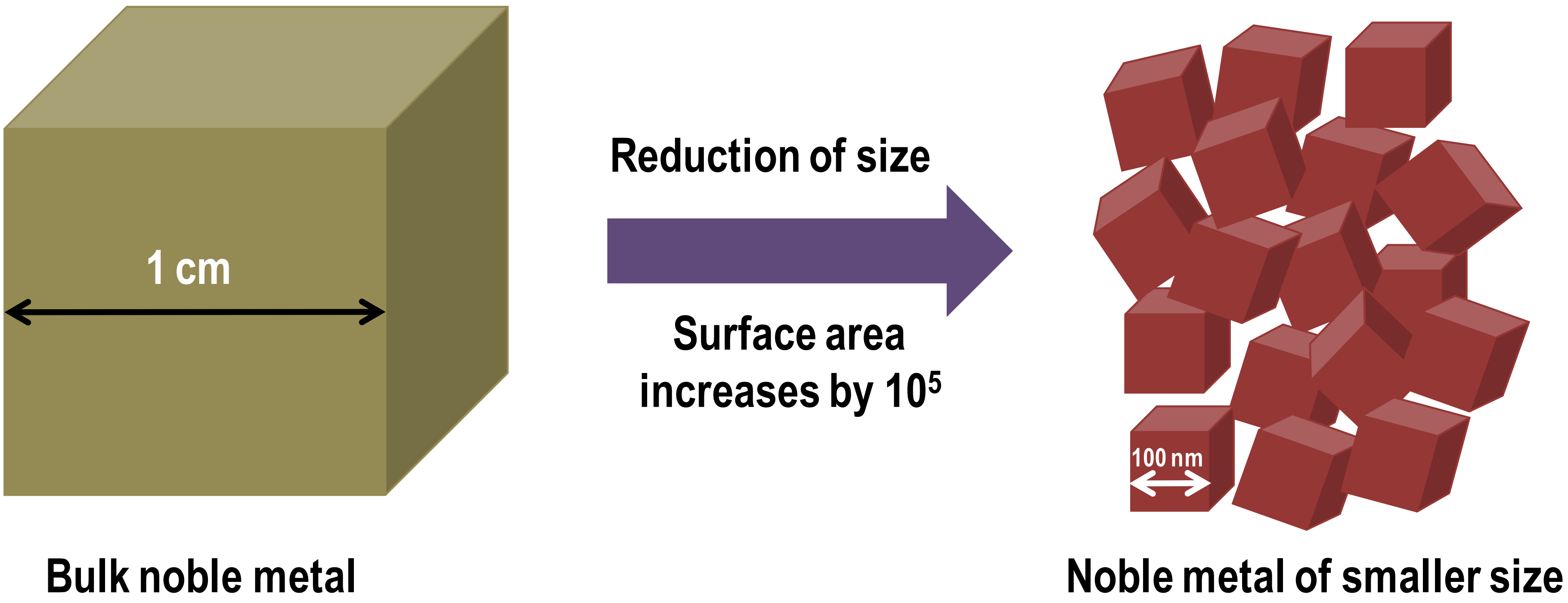
Why nanotechnology?

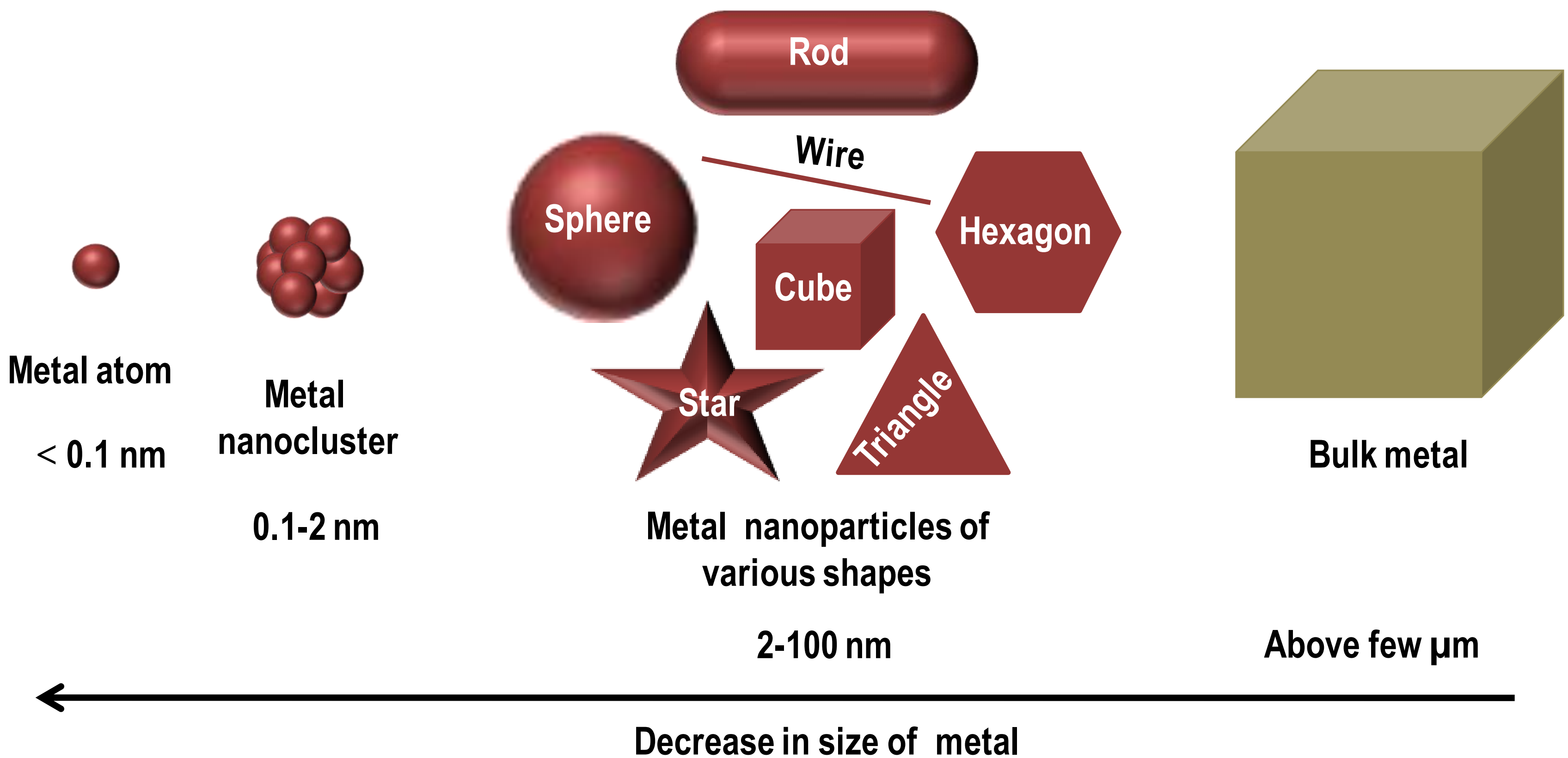
10^{-9}

1. More for less

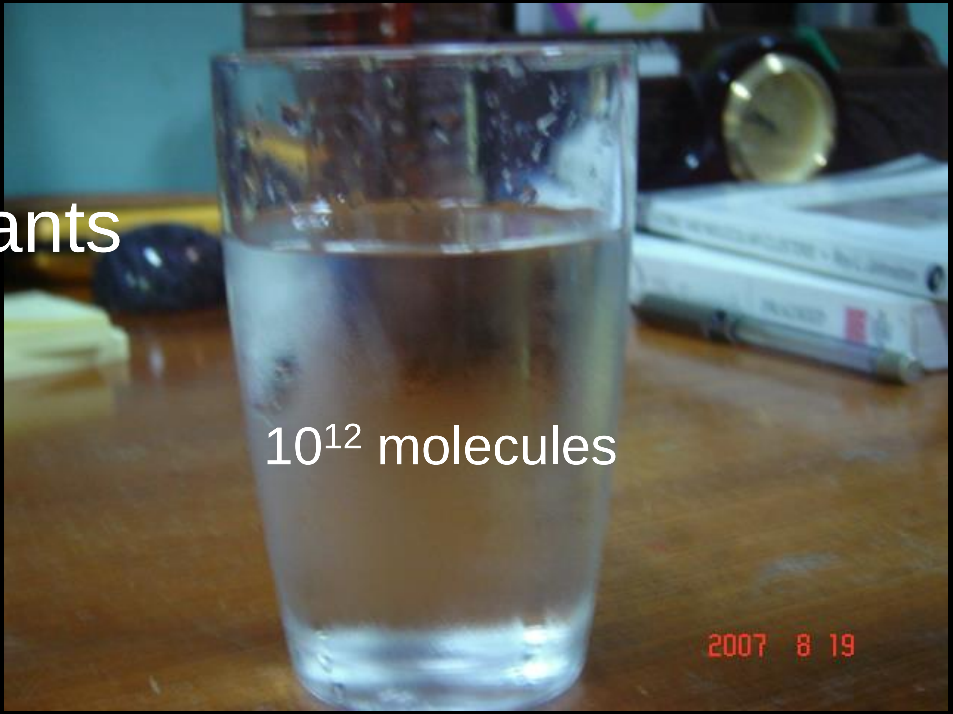


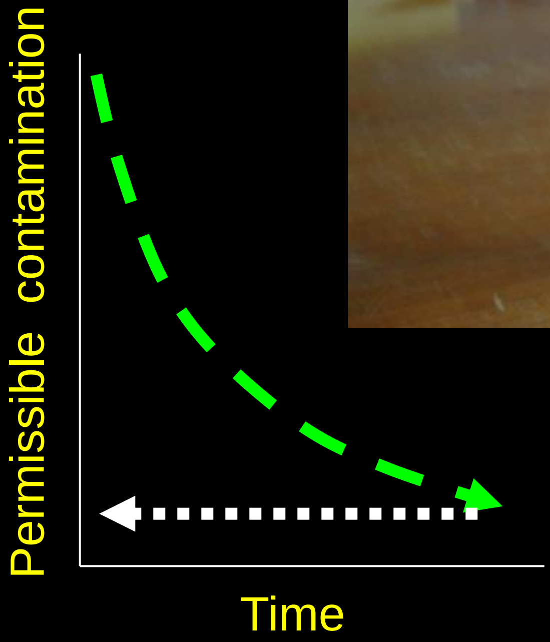
Variation in properties originating from ligand shell and metal core as bulk noble metals transform to nanoparticles/clusters. Sizes are not to scale. New properties such as color and photoluminescence arise in such size regime. Photographs of Au@citrate nanoparticles (inset A) showing intense absorption of visible light and Au@SG (SG corresponds to glutathione thiolate) clusters (inset B) showing intense photoluminescence upon ultraviolet irradiation (from the author’s work).


1 cm
Reduction of size
Surface area increases by 10^5
100 nm
Bulk noble metal
Noble metal of smaller size

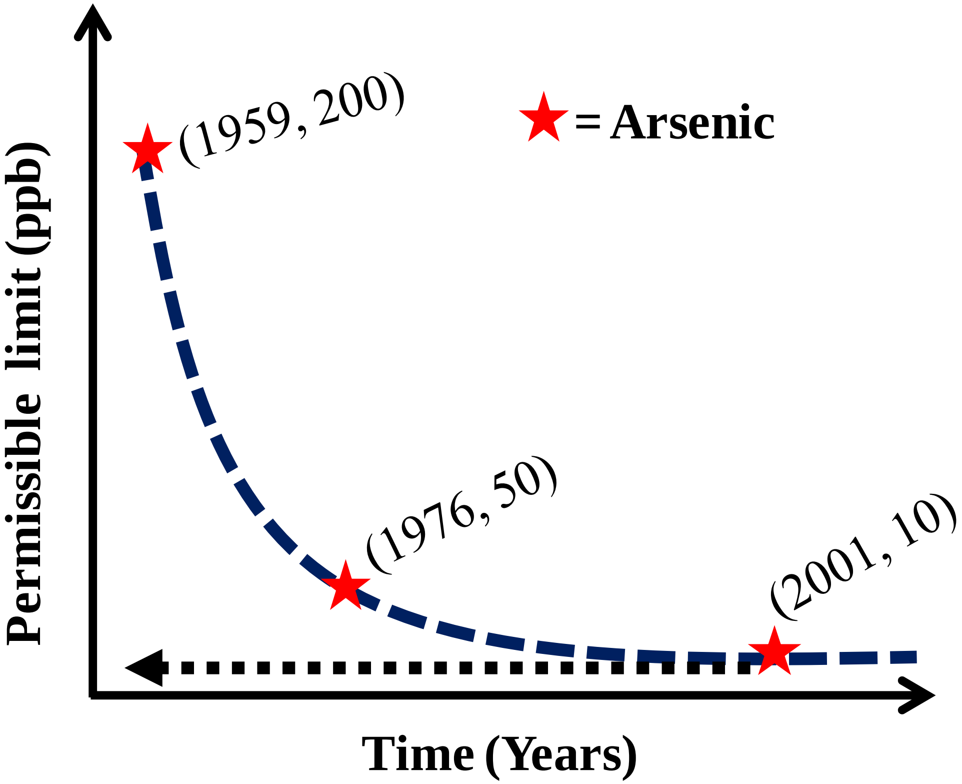

Rod
Wire
Sphere
Hexagon
Cube
Star
Triangle
Metal atom
< 0.1 nm
Metal
nanocluster
0.1-2 nm
Metal nanoparticles of
various shapes
2-100 nm
Bulk metal
Above few μm
Decrease in size of metal

2. Limits of contaminants



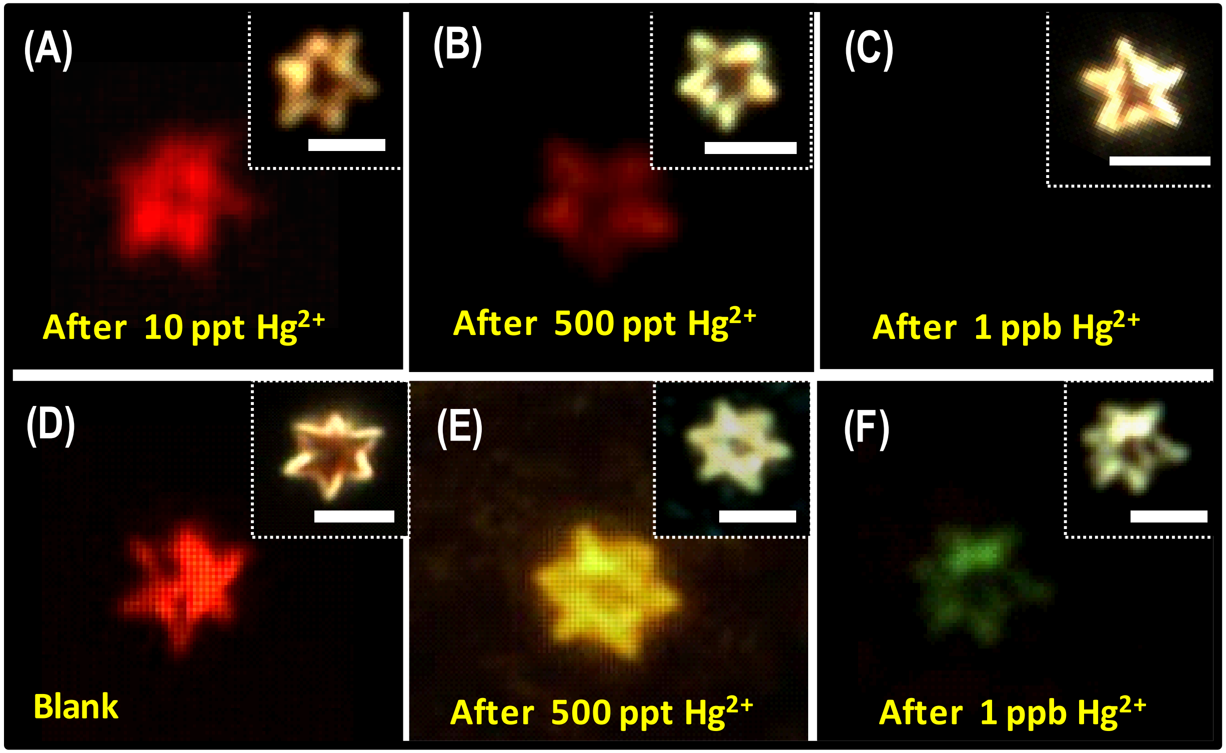


Permissible contamination reaches limits of detection



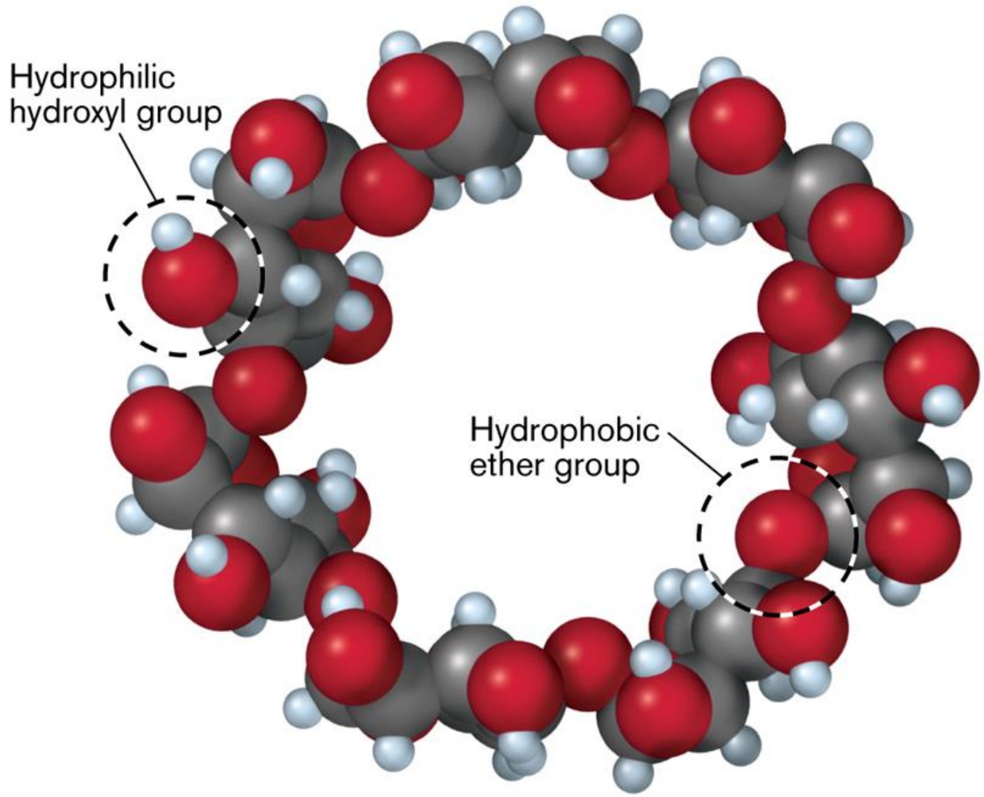
Decrease in the permissible limit of arsenic in drinking water, according to US EPA, with time. The graph indicates a general trend.

3. Can we reach limits?

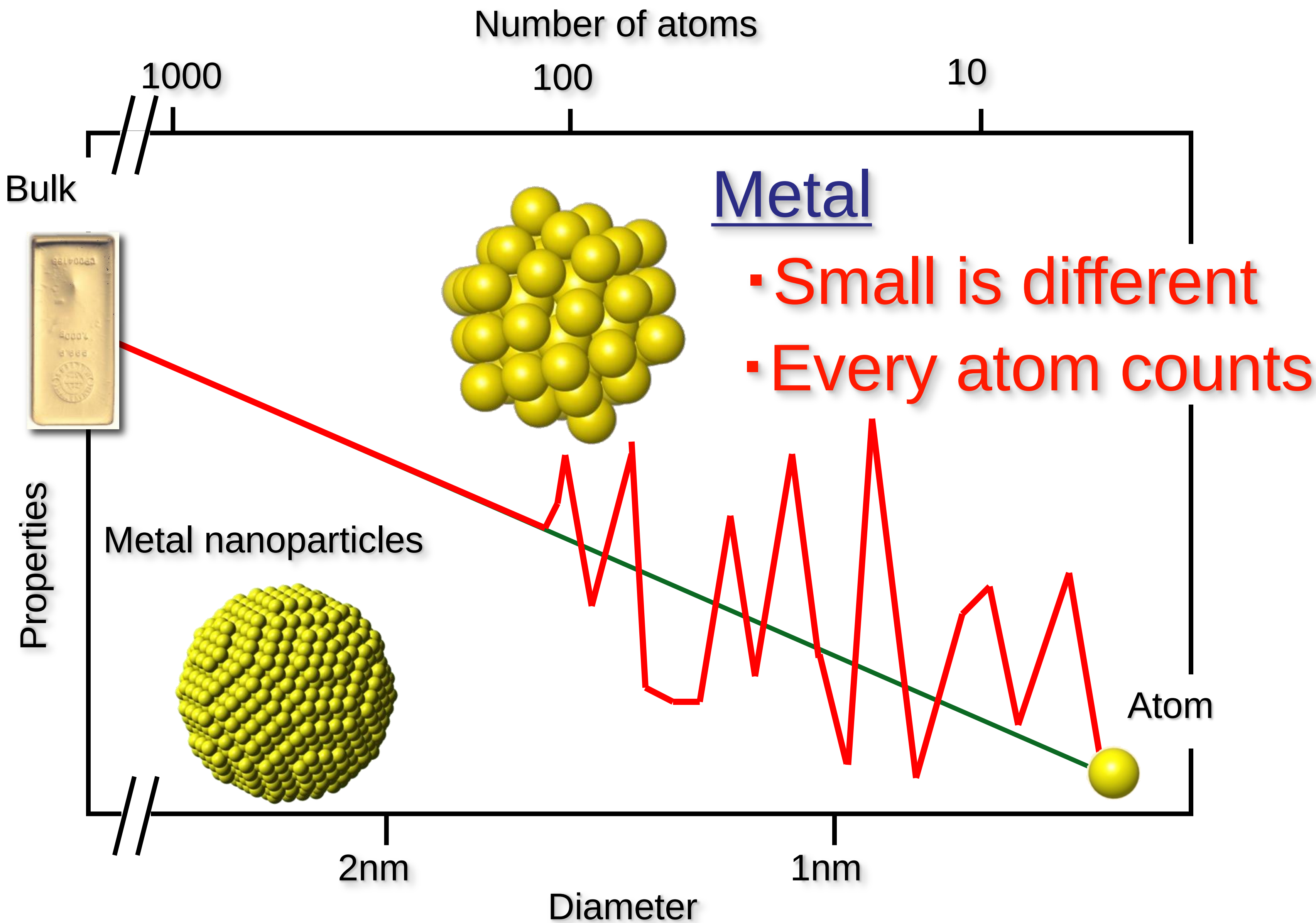


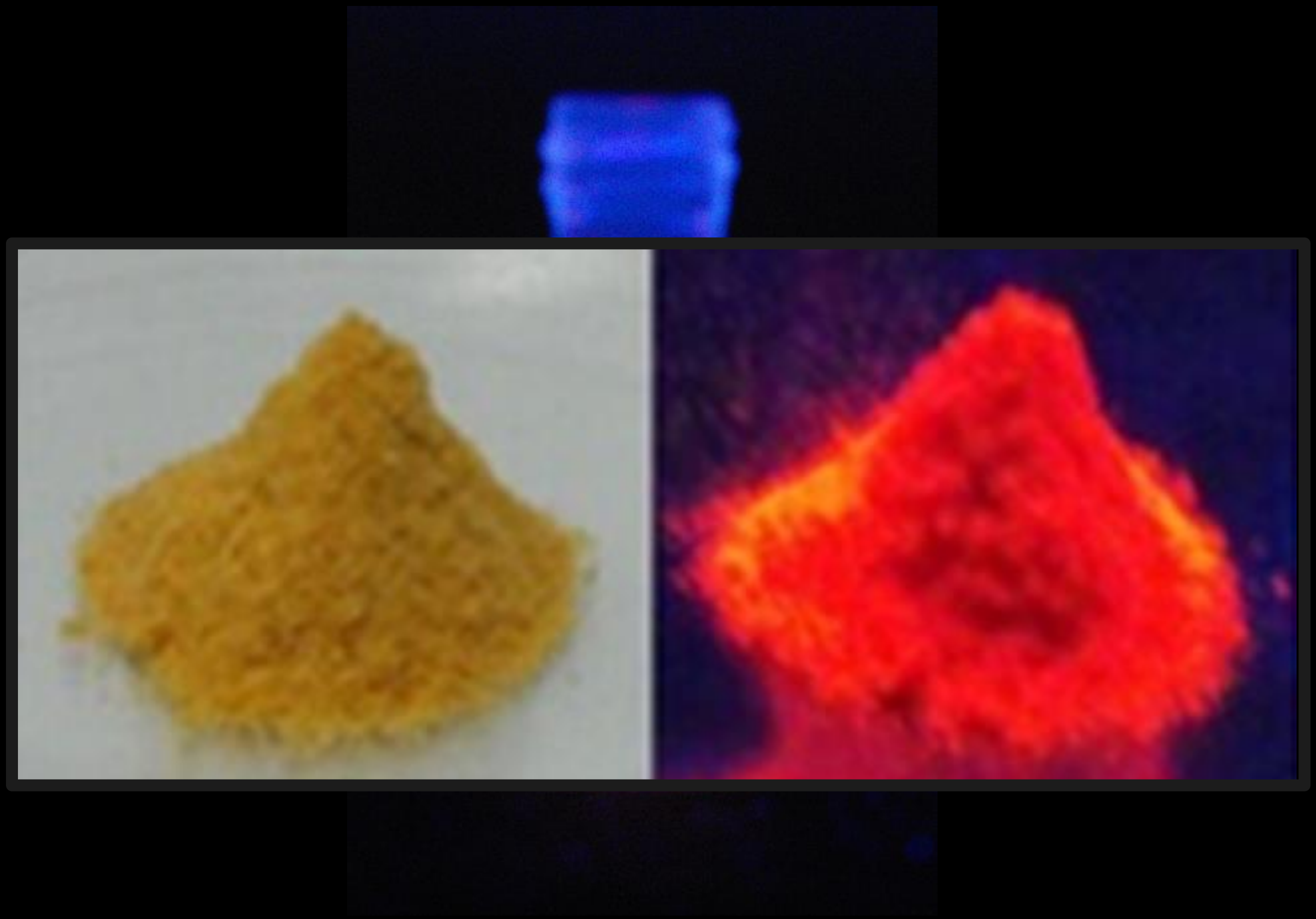
(A)–(C) Dark field fluorescence images of $Au@SiO_2@Ag_{15}$ MFs showing the gradual disappearance of luminescence with increasing Hg^{2+}. (D)–(F) Fluorescence images showing variation in color during the addition of Hg^{2+} of different concentrations to $Au@SiO_2$-FITC@Ag_{15} MFs. Insets in all images show the corresponding optical images of the MFs; scale bars are 3 μm.

Cavities, channels, imprints, assemblies, fibres, ……

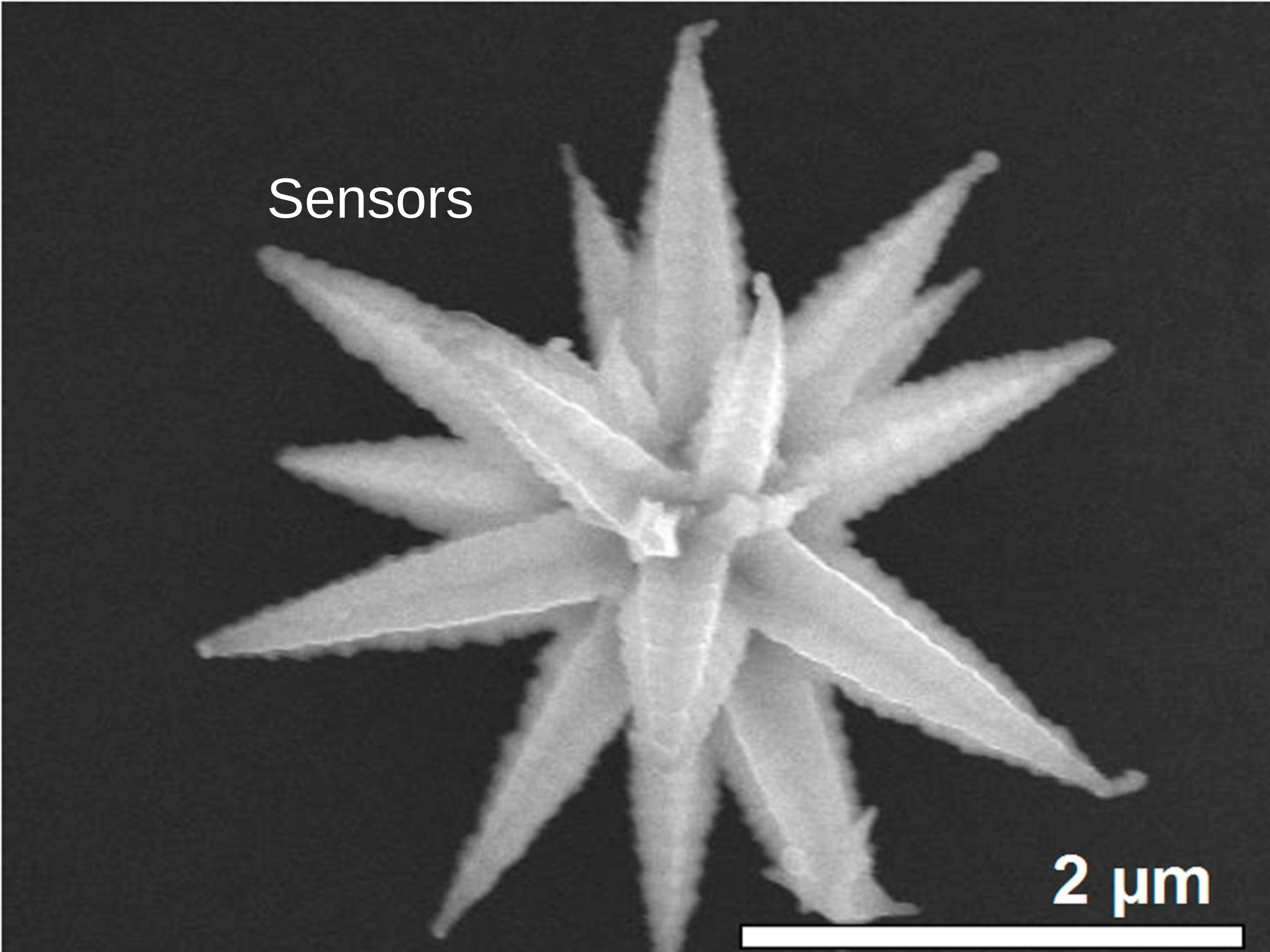


Metal Clusters





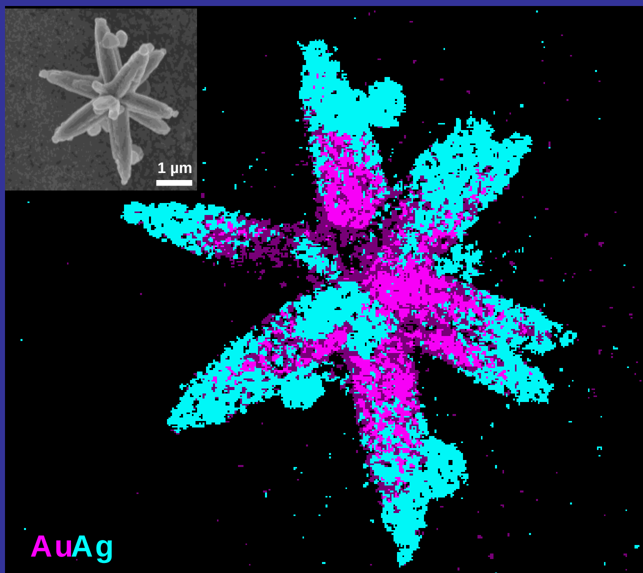
Shibhu, Habeeb, Uday, Kamalesh, Lourdu, Ammu, Ananya, Indranath, Atanu,….



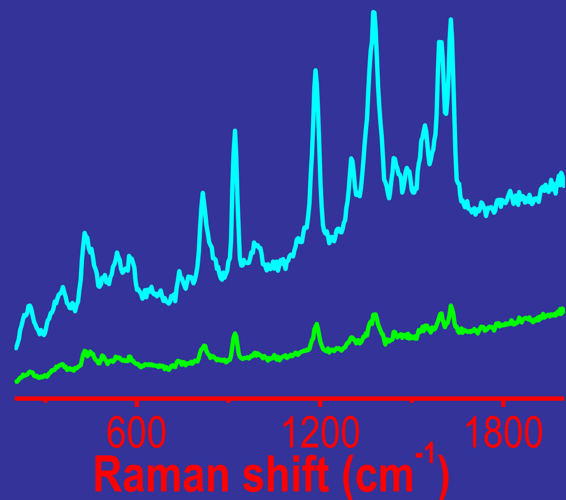
Sensors
2 µm

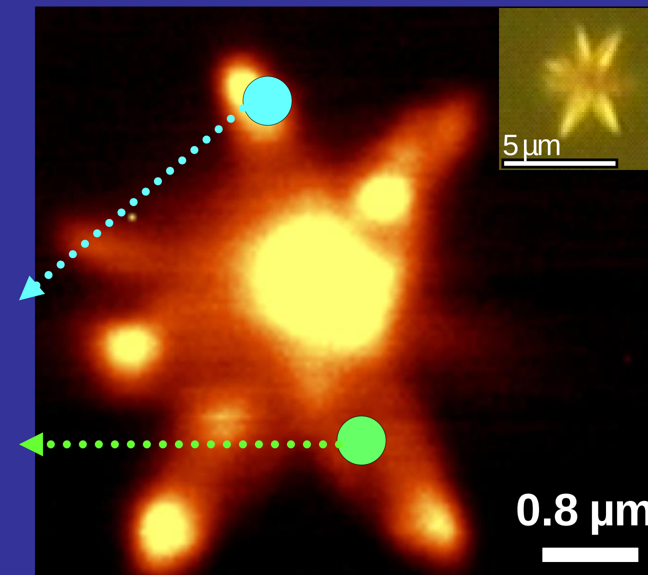
Region-specific SERS activity

Decreasing order of SERS activity → Au/Ag MFs> Au MFs> Au/Pt MFs



EDAX image of Au/Ag MF





Raman image of Au/Ag MF

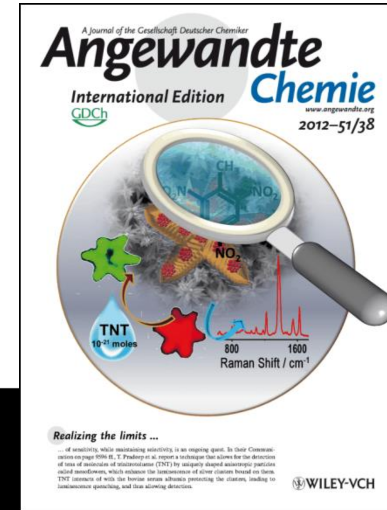
SERS intensity is higher at the tip compared to the body of the stem.

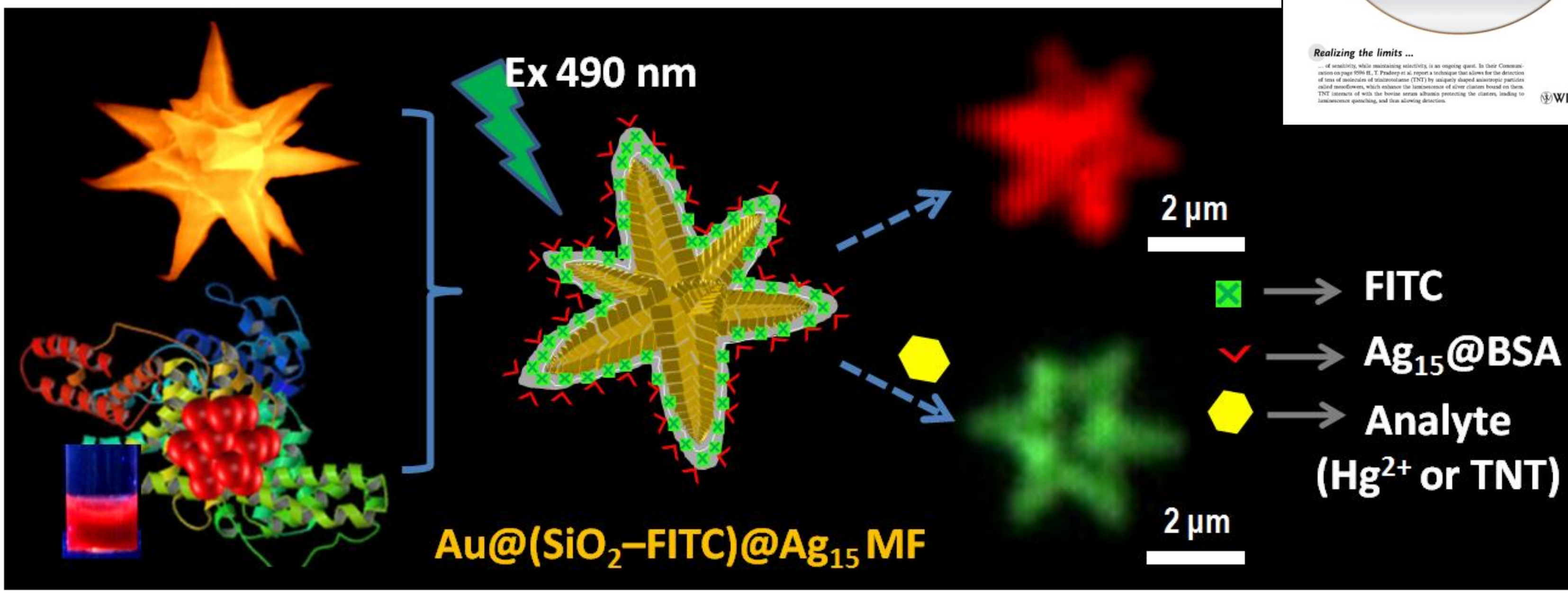
Au/Ag mesoflowers

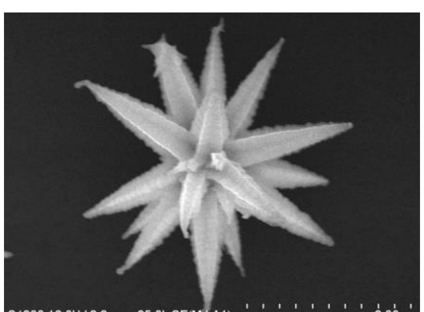
- **show high SERS activity than Au mesoflowers.**
- **show ten-fold increase in the SERS enhancement factor than Au mesoflowers.**
- **capable of detecting biomolecules and explosives at very low concentrations.**

P. R. Sajanlal and T. Pradeep, *Langmuir*, 26 (2010) 8901- 8907.

Sub-zeptomolar detection



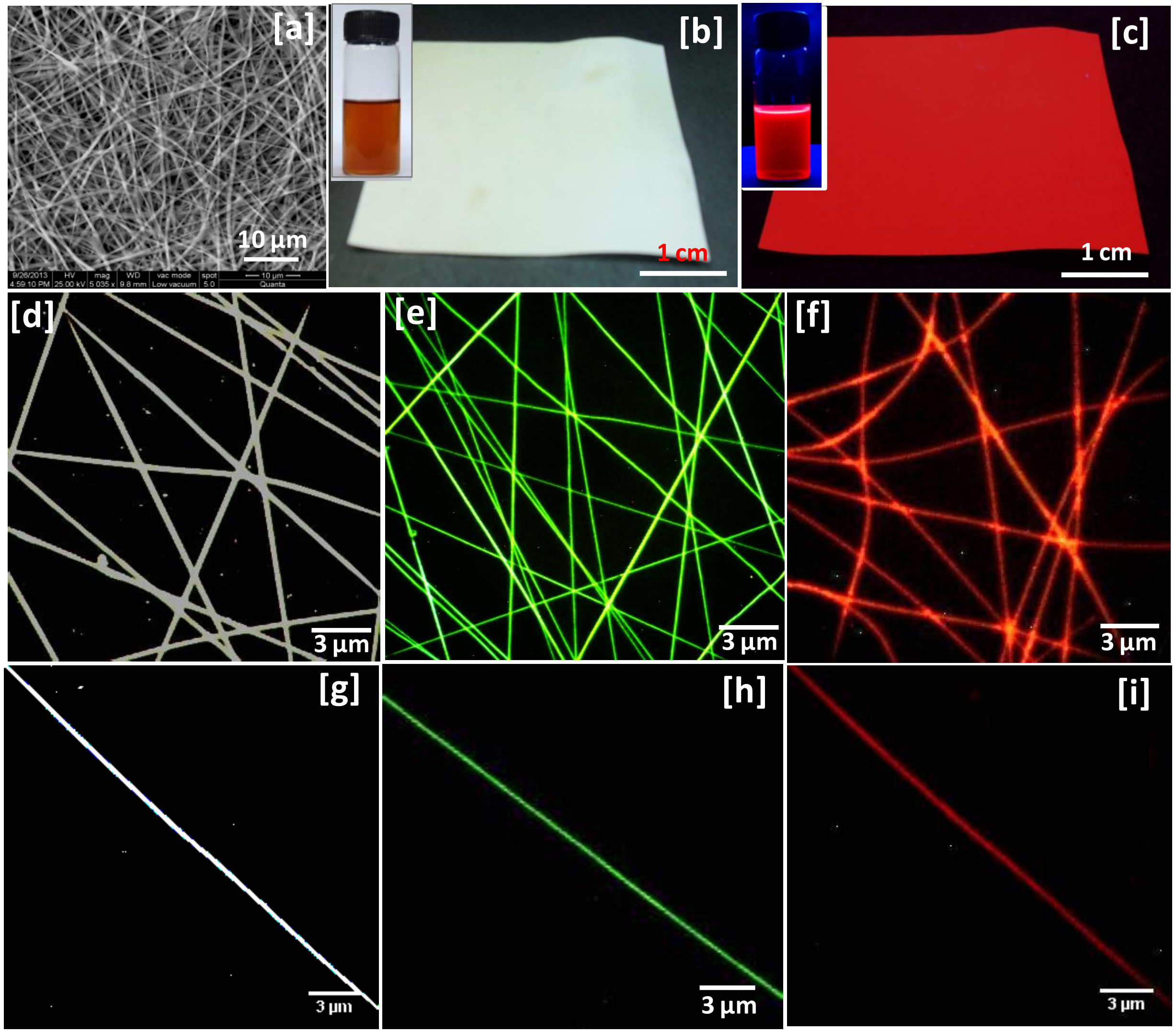




Featured in:
The Hindu, Telegraph, Times of India, etc.
C&E News
and many others

Ammu Mathew, et al. Angew. Chem. Int. Ed. 2012

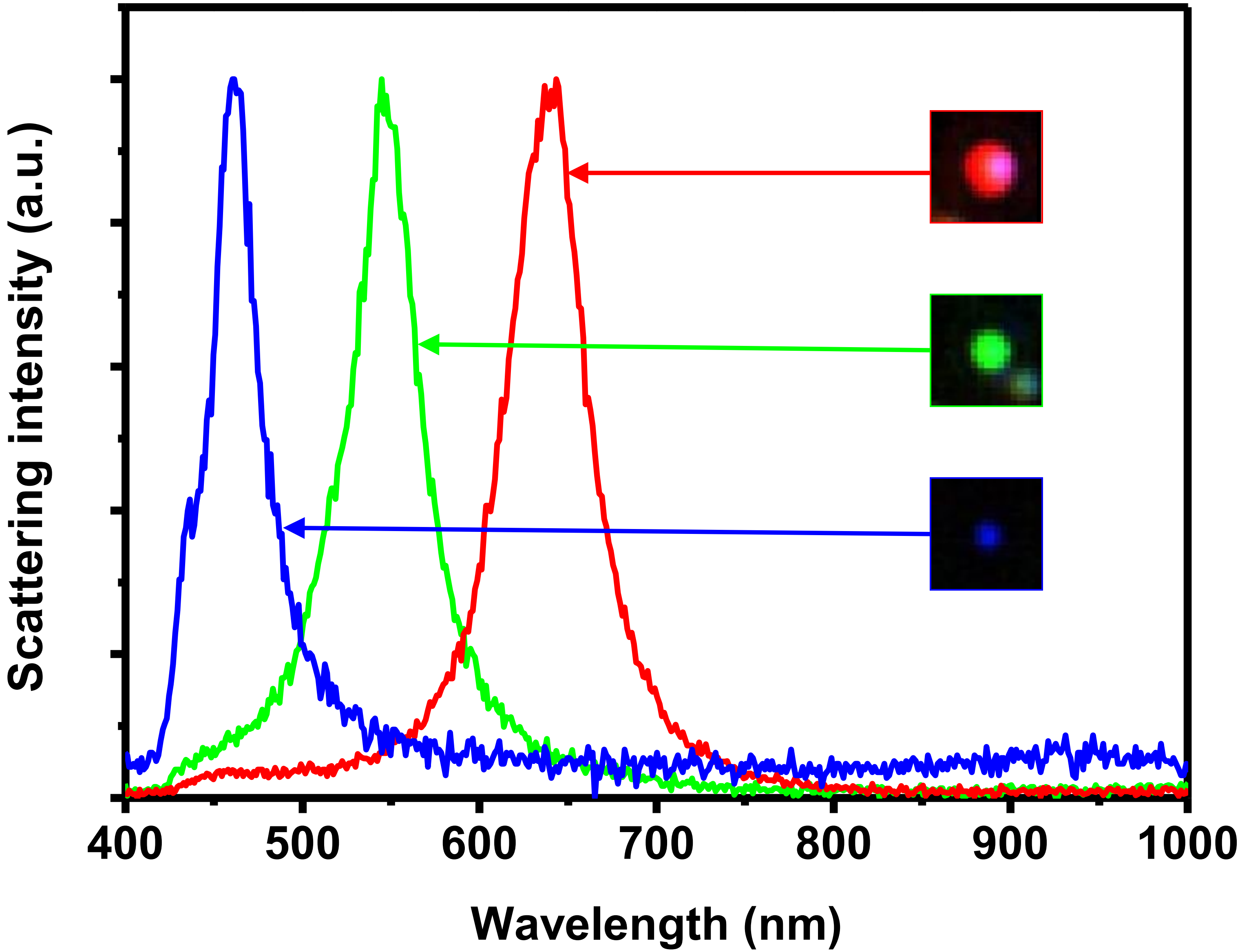
Approaching detection limits of tens of Hg^{2+}



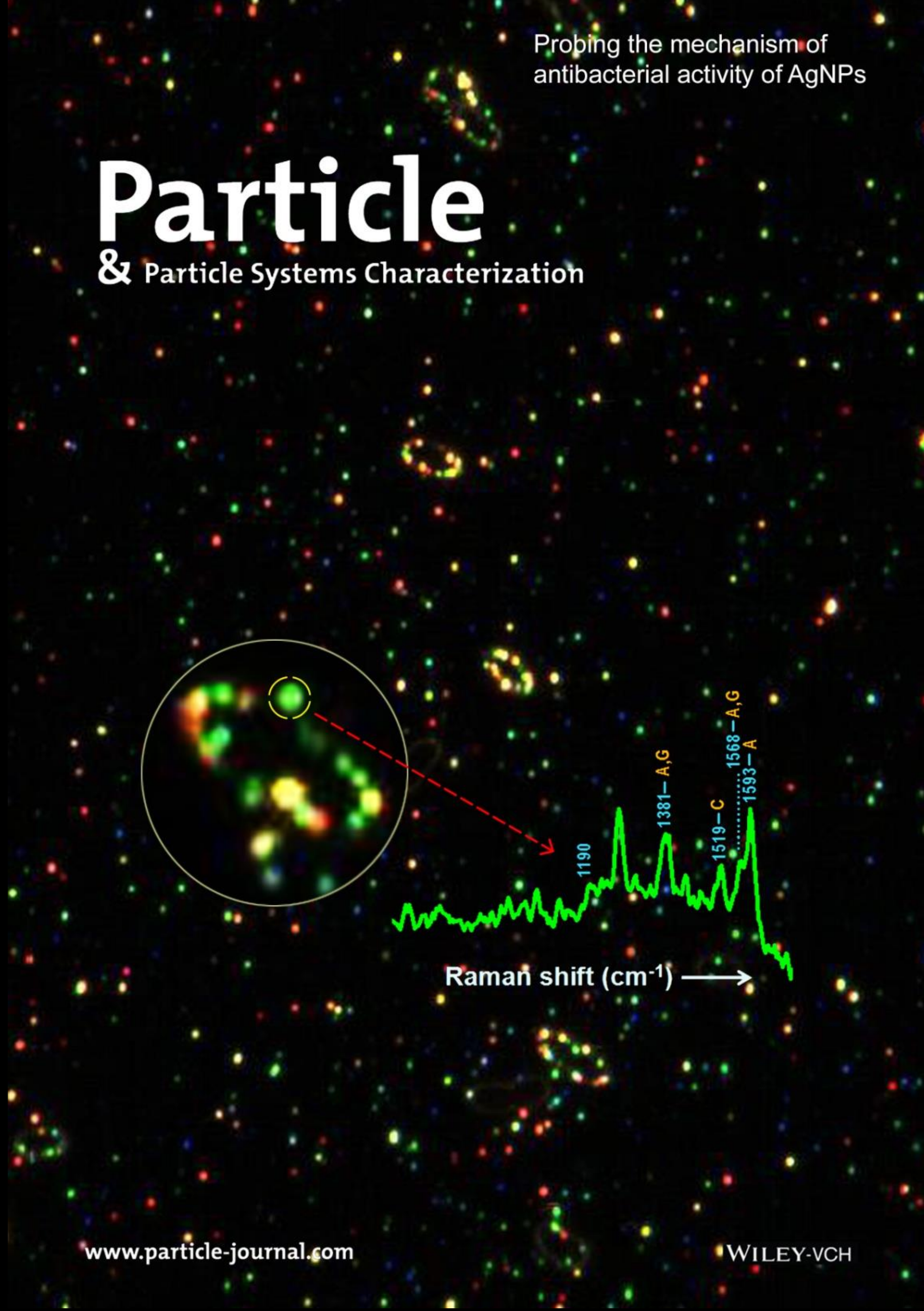
Atanu Ghosh et al. Anal. Chem.2014 (in press)

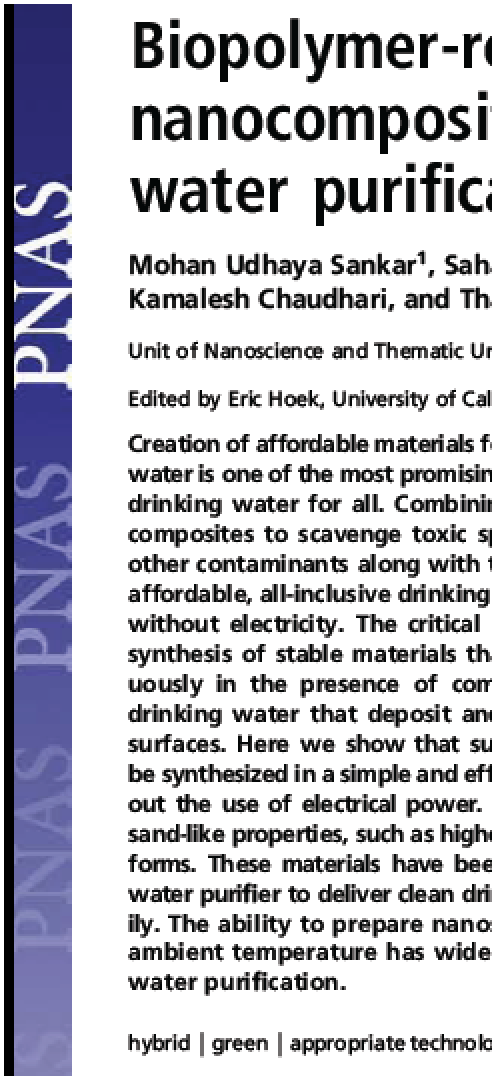
Observing nanochemistry in real time

Mechanism of action



Scattering intensity (a.u.)
400
500
600
700
800
900
1000
Wavelength (nm)


Probing the mechanism of
antibacterial activity of AgNPs
Particle
& Particle Systems Characterization
1190
1381—A,G
1519—C
1568—A,G
1593—A
Raman shift (cm-1)
www.particle-journal.com
WILEY-VCH



PNAS PNAS PNAS PNAS

Biopolymer-r
nanocomposi
water purifica

Mohan Udhaya Sankar[1], Sah
Kamalesh Chaudhari, and Th

Unit of Nanoscience and Thematic Ur

Edited by Eric Hoek, University of Cal

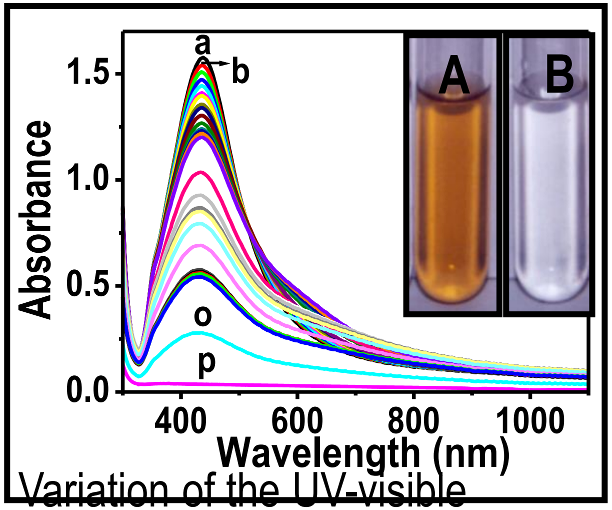
Creation of affordable materials f
water is one of the most promisin
drinking water for all. Combinin
composites to scavenge toxic s
other contaminants along with
affordable, all-inclusive drinking
without electricity. The critical
synthesis of stable materials th
uously in the presence of con
drinking water that deposit an
surfaces. Here we show that su
be synthesized in a simple and eff
out the use of electrical power.
sand-like properties, such as high
forms. These materials have bee
water purifier to deliver clean dri
ily. The ability to prepare nano
ambient temperature has wide
water purification.

hybrid | green | appropriate technolo

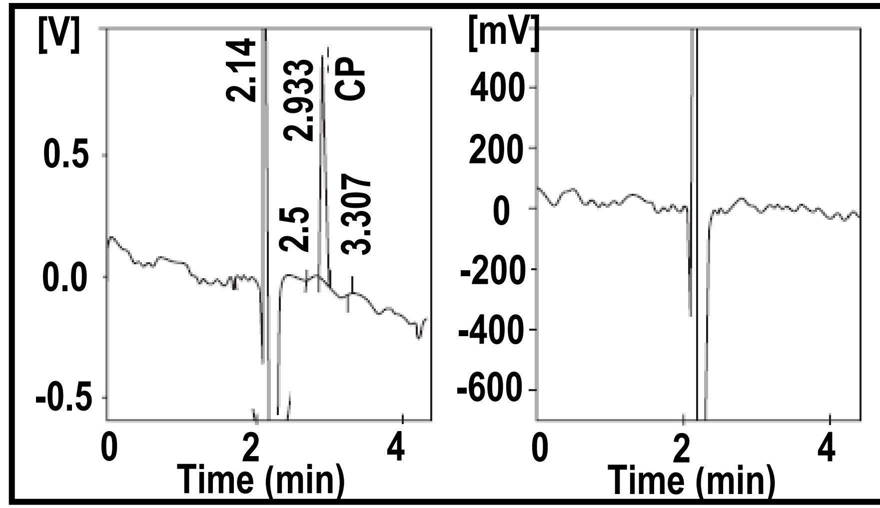
Featured in:
The Guardian, UK
The Hindu, Telegraph, Times of India, etc.
Scientific American
New Scientist
and many others

Noble metal nanoparticles: removal of pesticides from water

A.S. Nair, T. Pradeep, Curr. Sci. 84 (2003) 1560



Variation of the UV-visible absorption spectrum of silver nanoparticles upon the addition of CCl_4



Gas chromatogram of chlorpyrifos solution (L) and after treatment with silver nanoparticles (R)

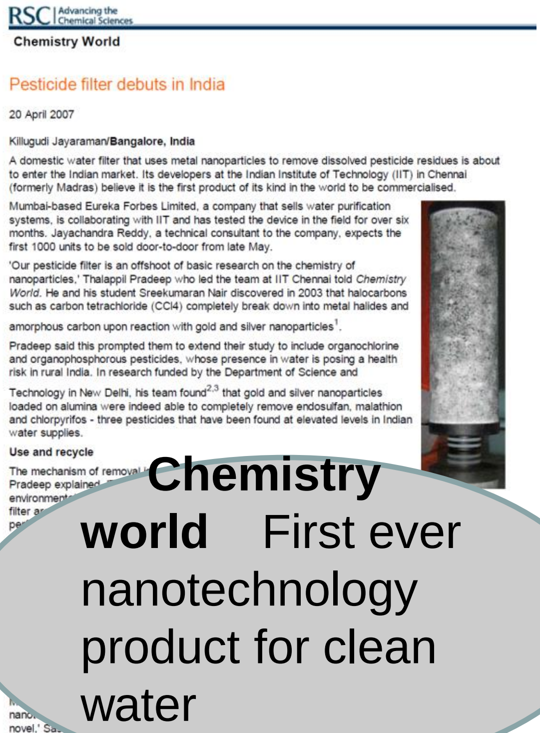
A.S. Nair, R.T. Tom, V.R. Rajeev Kumar, C. Subramaniam, T. Pradeep, Cosmos 3, (2007) 103

Indian patent 2006
PCT 2011 – US, Europe, Asia

June 2007

(L) Silver nanoparticles coated on activated alumina (R) Photograph of a pesticide filter device using supported nanoparticles (WQA certified)

World's first nanochemistry-based water purifier



RSC | Advancing the Chemical Sciences

Chemistry World

Pesticide filter debuts in India

20 April 2007

Killugudi Jayaraman/**Bangalore, India**

A domestic water filter that uses metal nanoparticles to remove dissolved pesticide residues is about to enter the Indian market. Its developers at the Indian Institute of Technology (IIT) in Chennai (formerly Madras) believe it is the first product of its kind in the world to be commercialised.

Mumbai-based Eureka Forbes Limited, a company that sells water purification systems, is collaborating with IIT and has tested the device in the field for over six months. Jayachandra Reddy, a technical consultant to the company, expects the first 1000 units to be sold door-to-door from late May.

'Our pesticide filter is an offshoot of basic research on the chemistry of nanoparticles,' Thalappil Pradeep who led the team at IIT Chennai told *Chemistry World*. He and his student Sreekumaran Nair discovered in 2003 that halocarbons such as carbon tetrachloride (CCl4) completely break down into metal halides and amorphous carbon upon reaction with gold and silver nanoparticles[1].

Pradeep said this prompted them to extend their study to include organochlorine and organophosphorous pesticides, whose presence in water is posing a health risk in rural India. In research funded by the Department of Science and Technology in New Delhi, his team found[2,3] that gold and silver nanoparticles loaded on alumina were indeed able to completely remove endosulfan, malathion and chlorpyrifos - three pesticides that have been found at elevated levels in Indian water supplies.

Use and recycle

The mechanism of removal ...

Chemistry world First ever nanotechnology product for clean water

A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

1. Patents: A method of preparing purified water from water containing pesticides, **Indian patent 200767**
2. Extraction of malatheon and chlorpiryhphos from drinking water by nanoparticles , **US 7,968,493** A method for decontaminating water containing pesticides, **EP 17,15,947**

Product is marketed now by a Eureka Forbes Ltd.

Several new technologies are now available

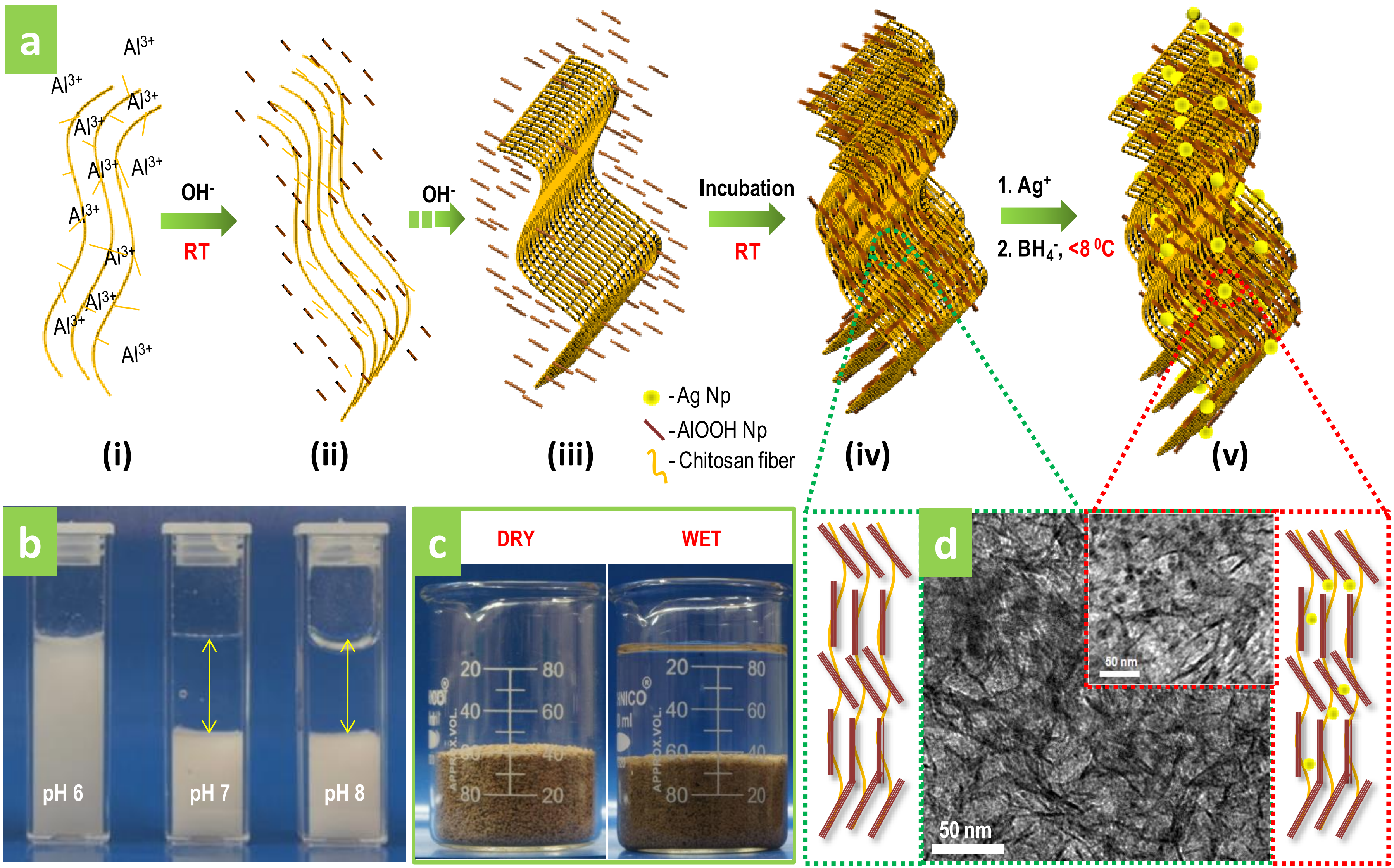
Affordable materials for water purification - Bioinspired

Water positive

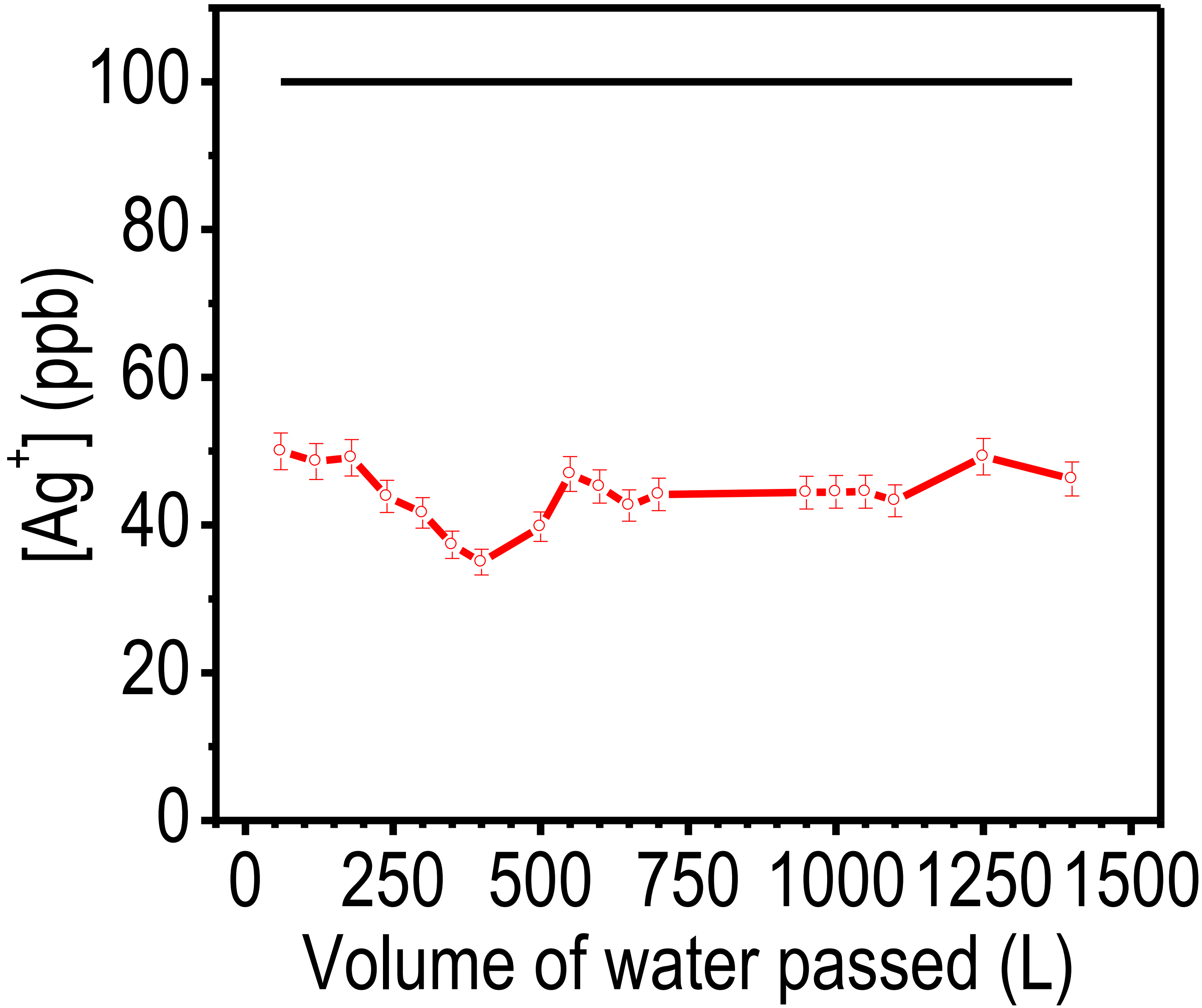
Water-based, room temperature, water stable

Green

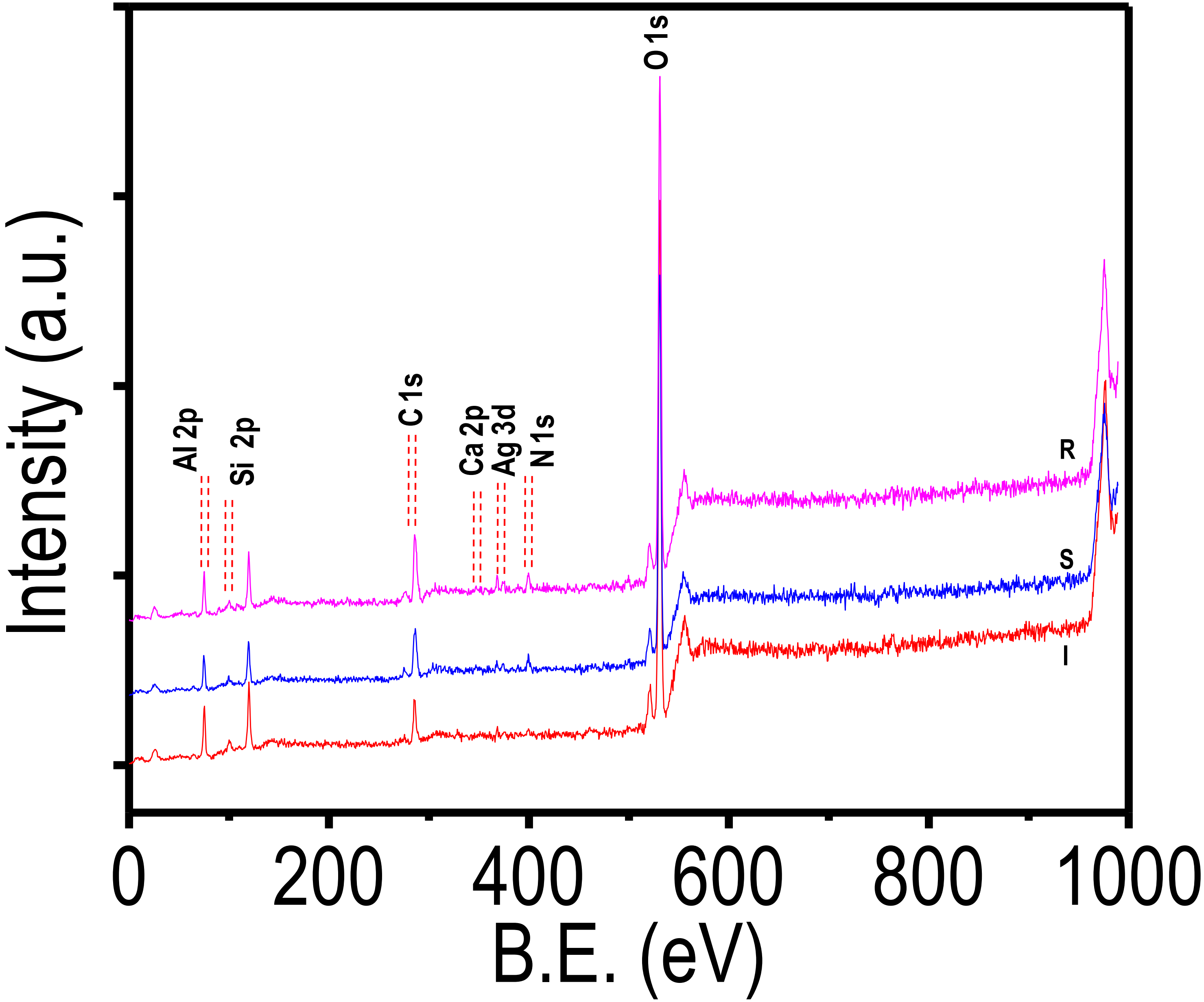
M. U. Sankar et al, PNAS 2013



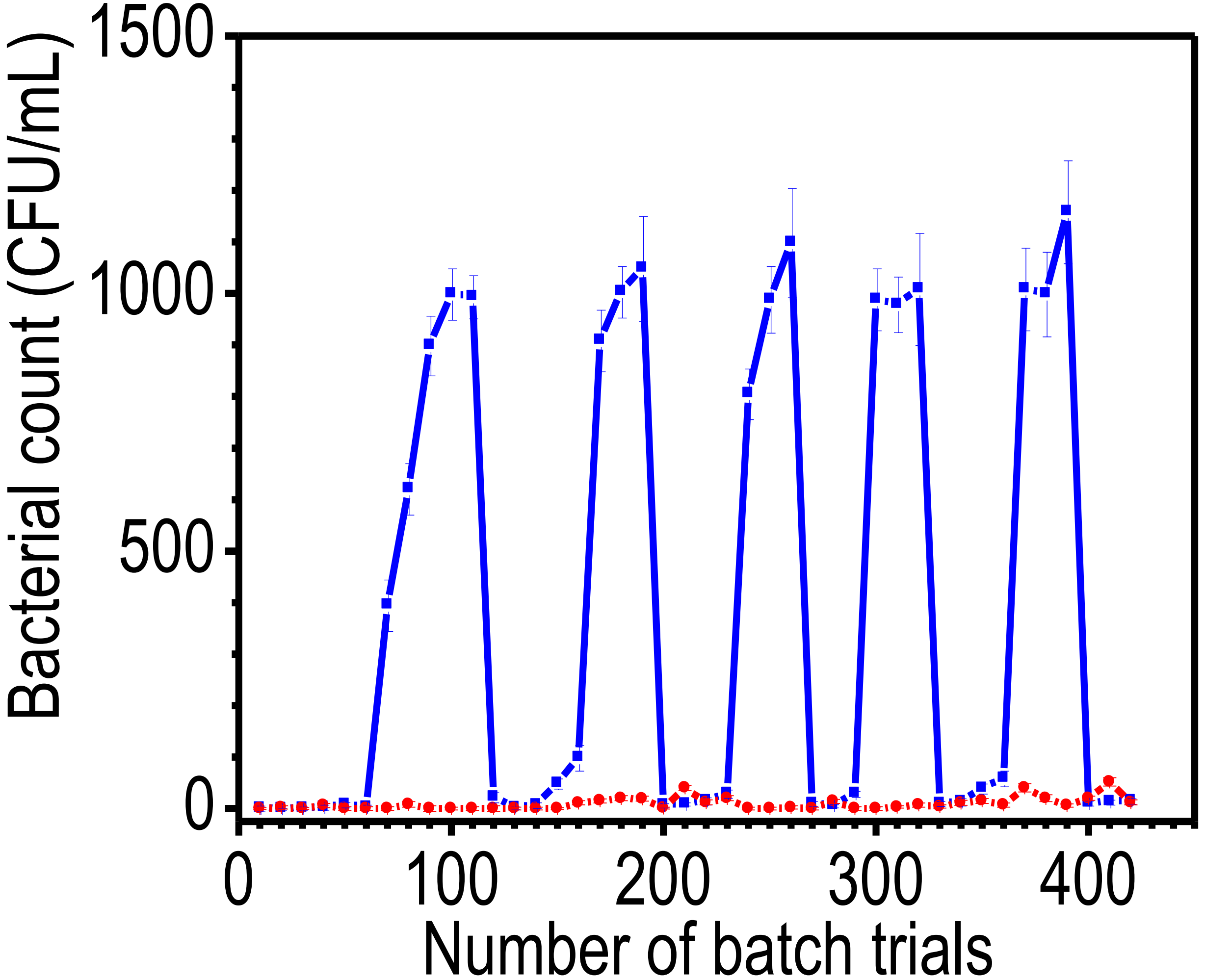
a
Al3+
OH-
RT
OH-
Incubation
RT
1. Ag+
2. BH4-, <8 0C
- Ag Np
- AlOOH Np
- Chitosan fiber
(i)
(ii)
(iii)
(iv)
(v)
b
pH 6
pH 7
pH 8
c
DRY
WET
d
50 nm
50 nm

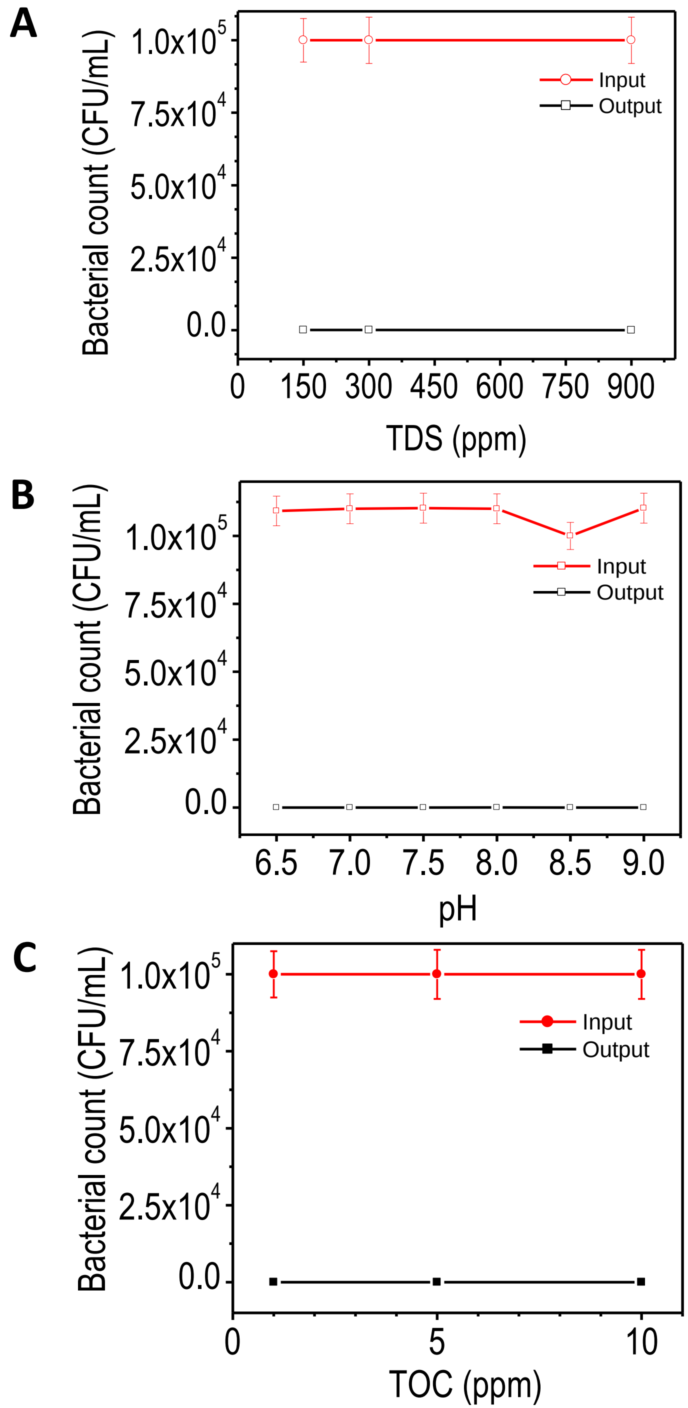


[Ag+] (ppb)
0
20
40
60
80
100
0
250
500
750
1000
1250
1500
Volume of water passed (L)



O 1s
Al 2p
Si 2p
C 1s
Ca 2p
Ag 3d
N 1s
R
S
I
Intensity (a.u.)
0
200
400
600
800
1000
B.E. (eV)


1500
1000
500
0
Bacterial count (CFU/mL)
0
100
200
300
400
Number of batch trials



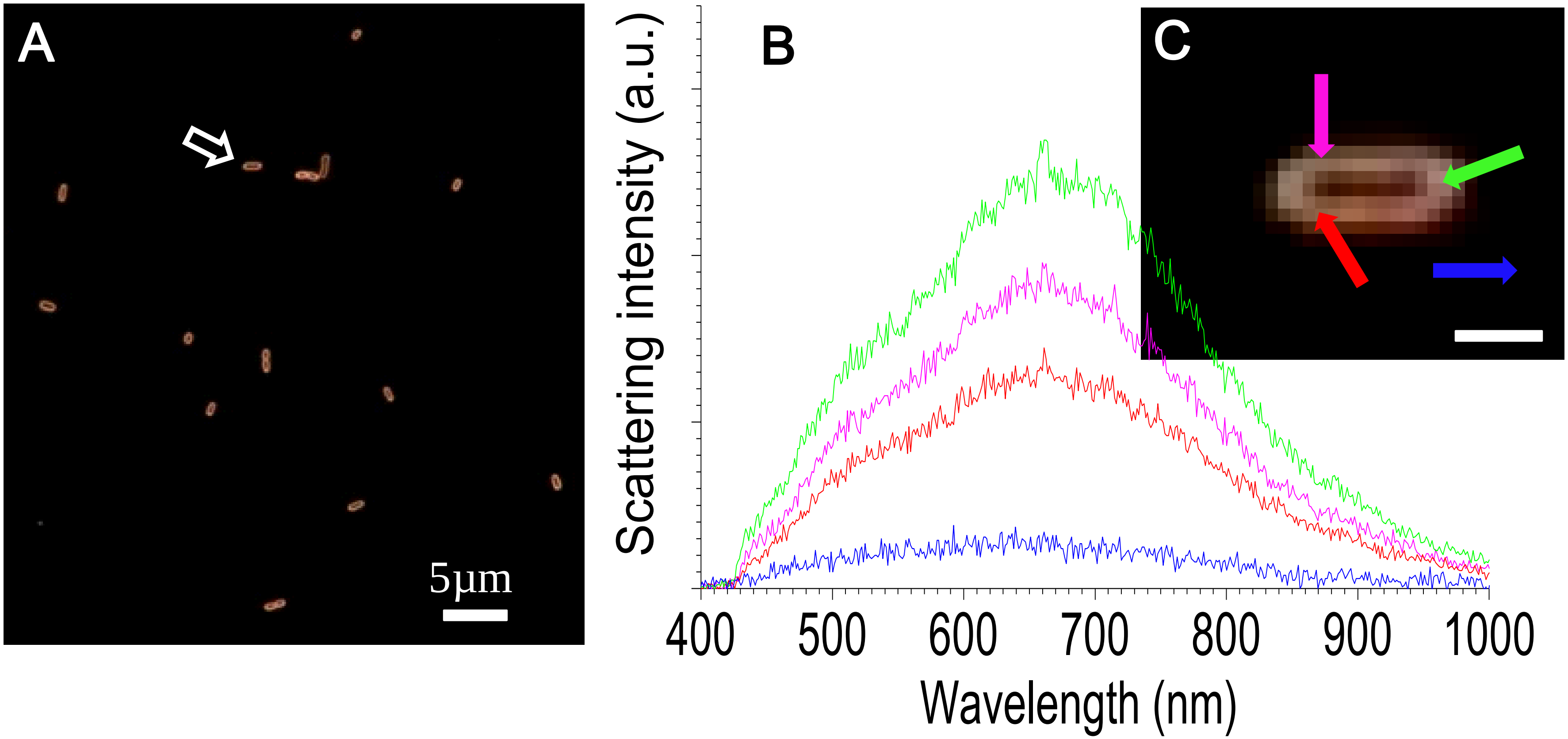
TDS

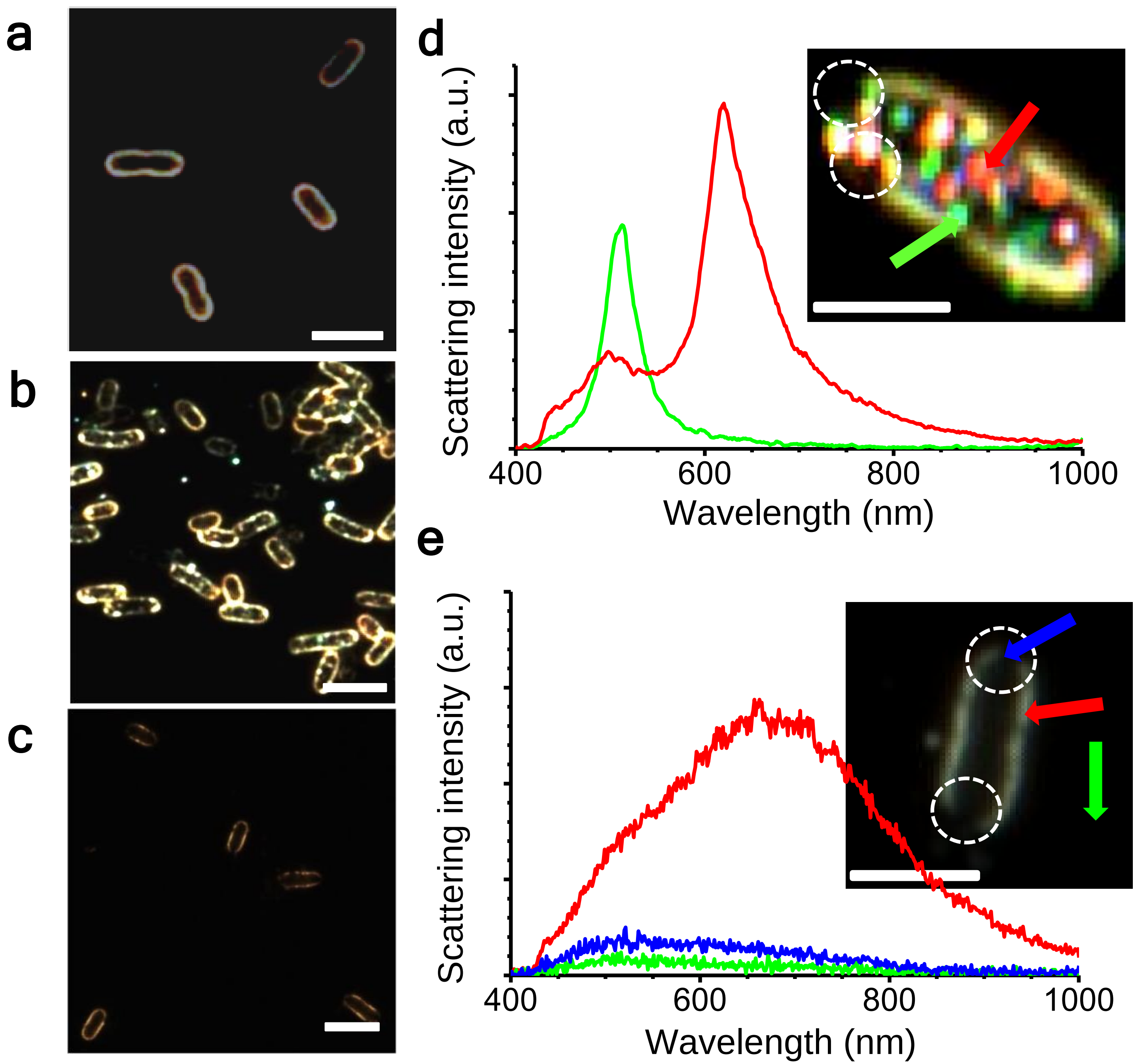
pH

Real water experiments

TOC – Humic acid

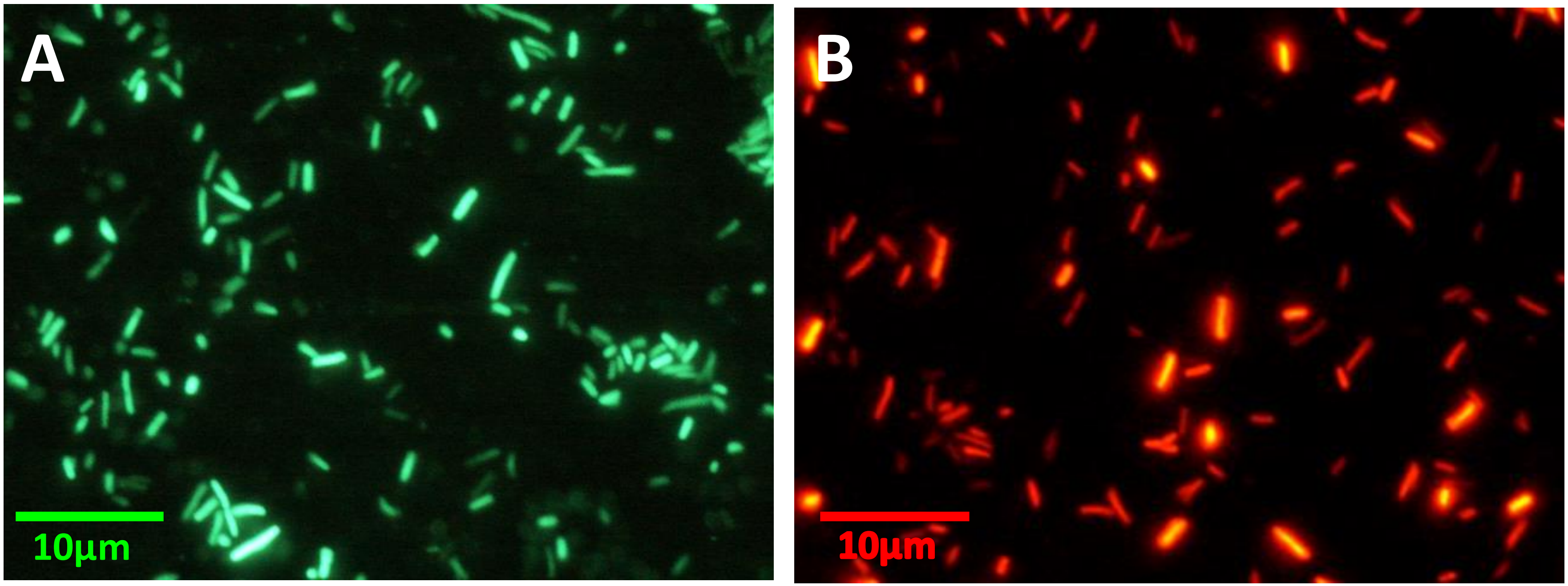
Nanotoxicity?

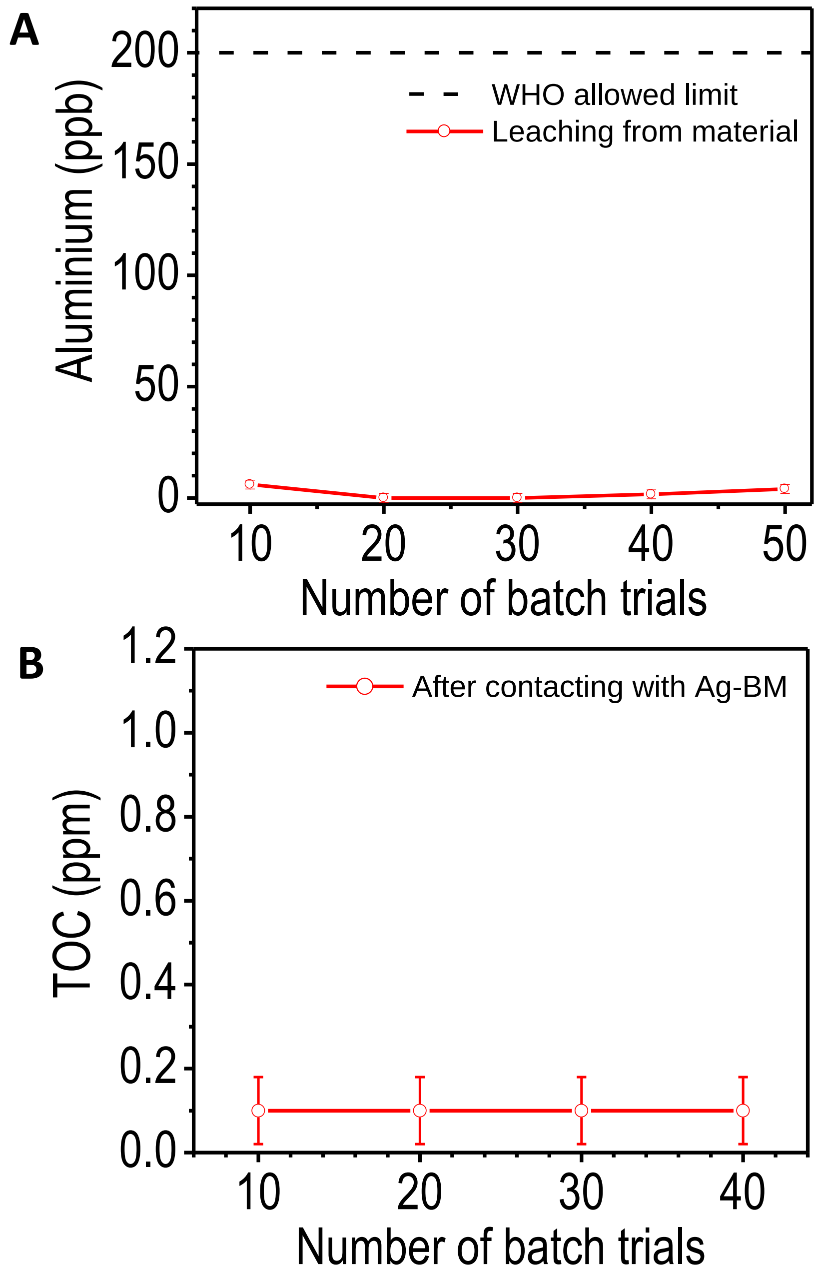




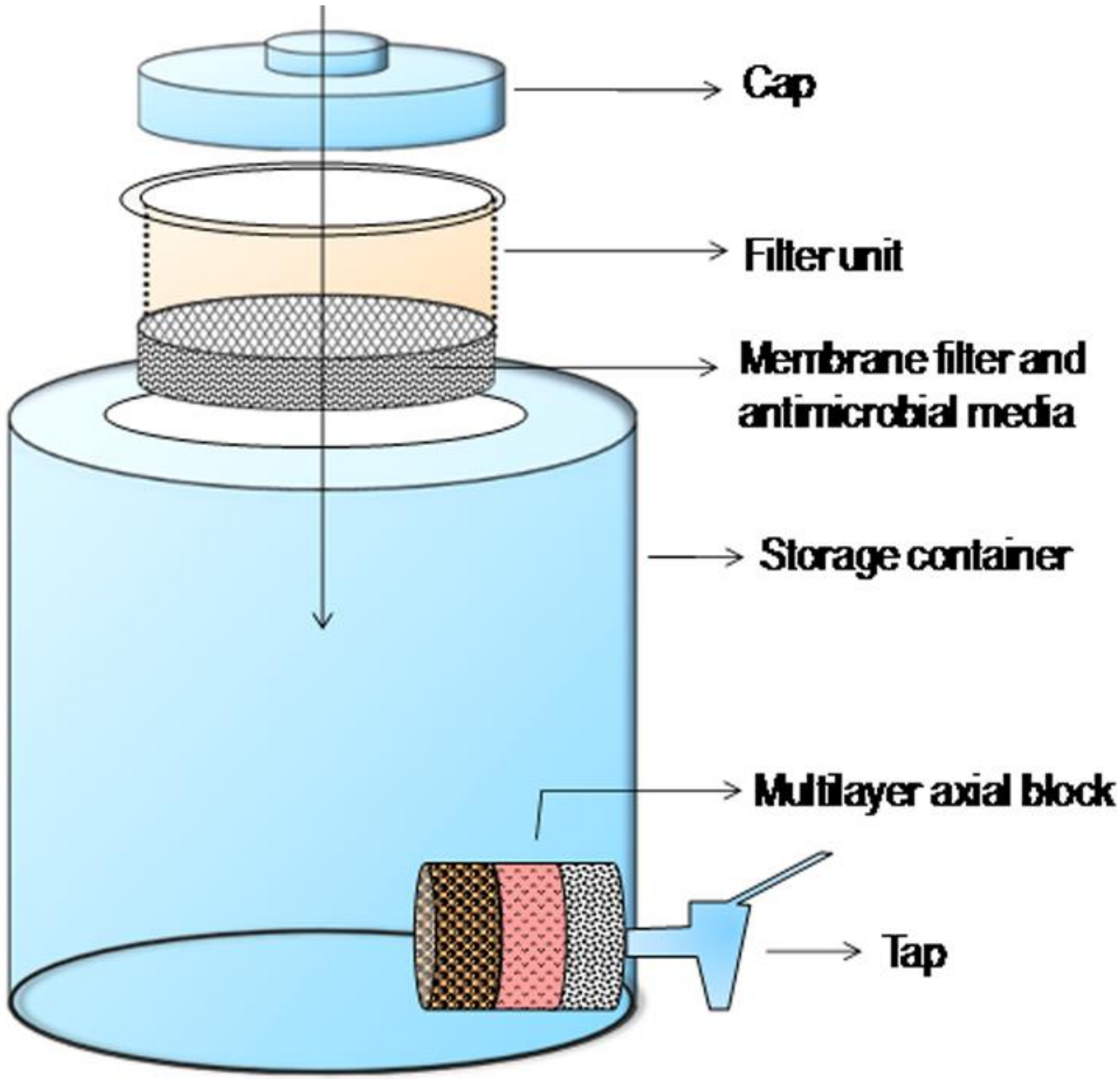
a
b
c
d
e
Scattering intensity (a.u.)
Wavelength (nm)
400
600
800
1000
Scattering intensity (a.u.)
Wavelength (nm)
400
600
800
1000

Live/dead staining experiments





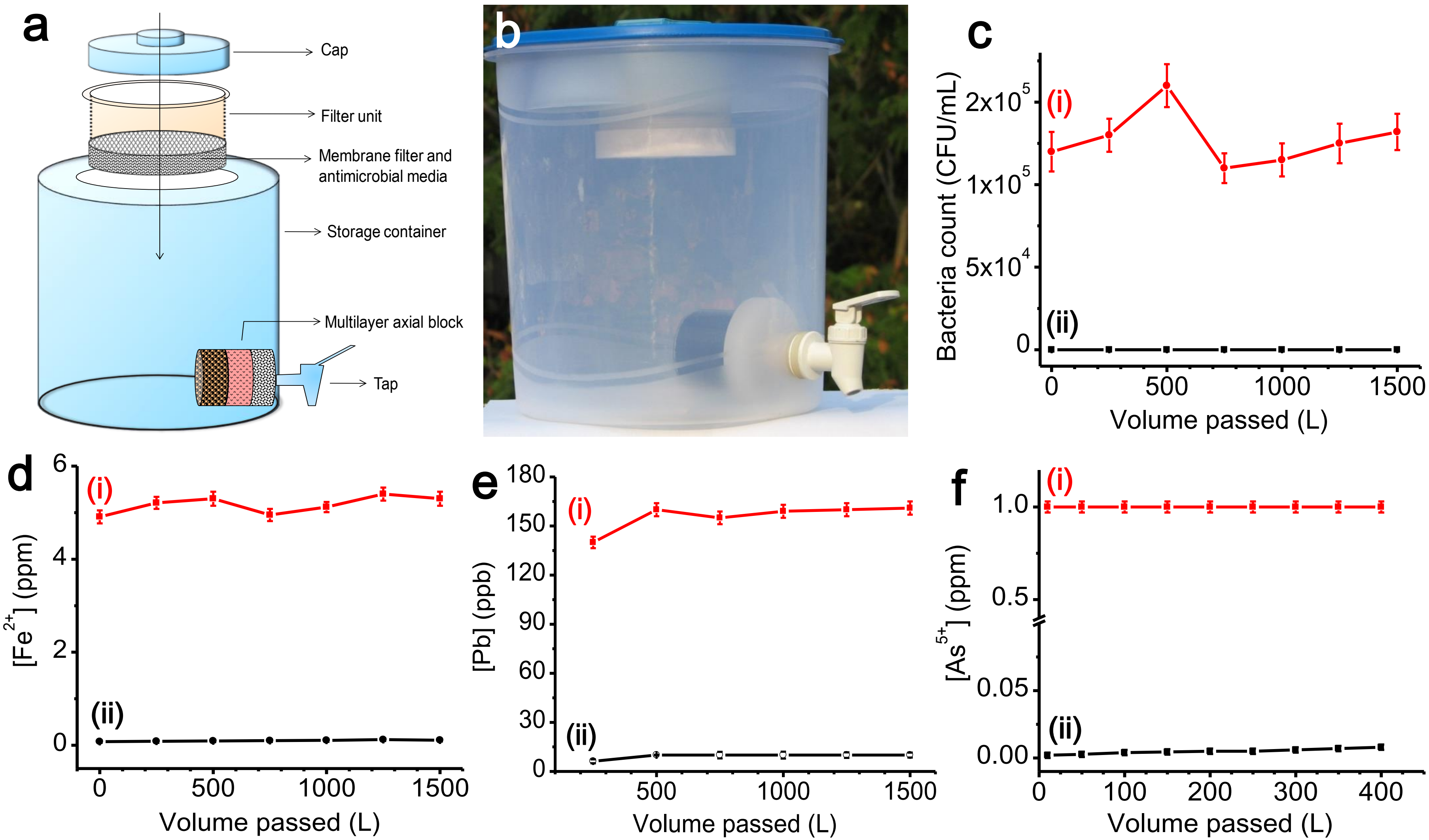
Leaching experiments



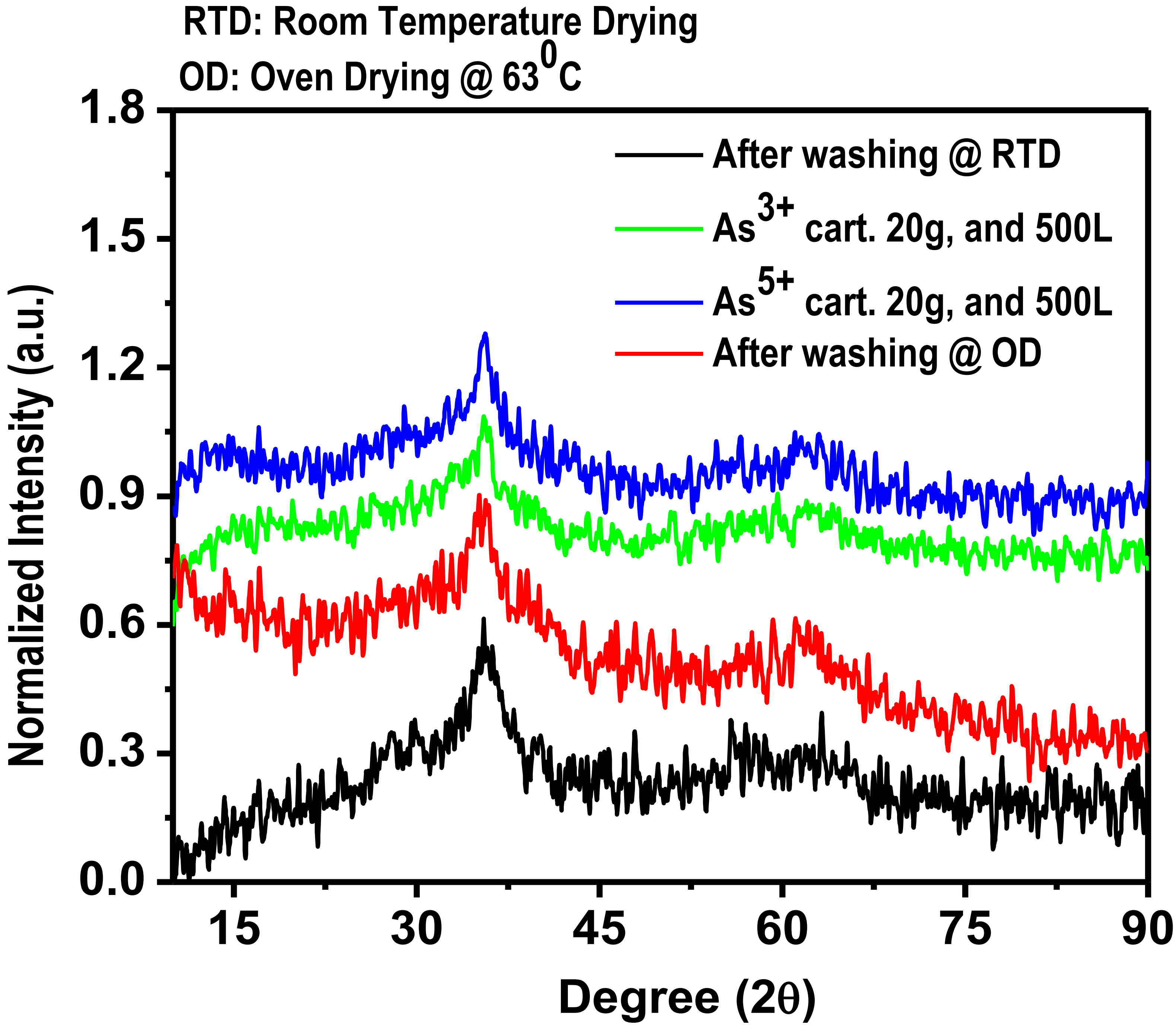
Cap
Filter unit
Membrane filter and antimicrobial media
Storage container
Multilayer axial block
Tap

Physicochemical characteristics of influent natural drinking water
(Note: All parameters are expressed in mg L^{-1}, except for pH and conductivity)
ND-not detected
Natural drinking water (without treatment so that there is a residual bacterial count in it) was used for testing to ensure that that the material functions in the field.

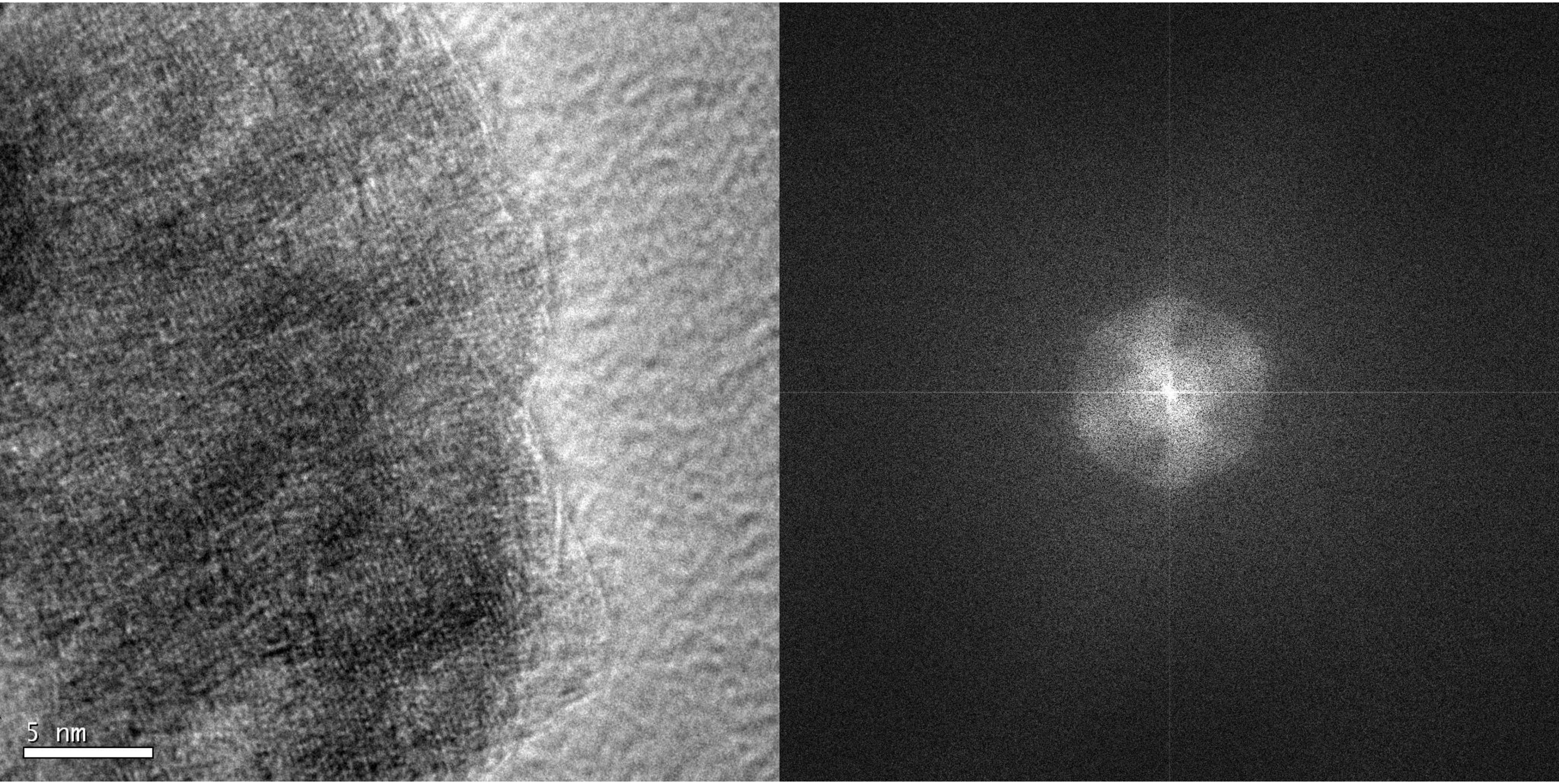
Parameters	Value
Total coliforms (CFU/mL)	1-2 x 10^3
p H @25° C	7.8
Conductivity (µS/cm)	640.000
Fluoride	0.573
Chloride	86.340
Nitrate	1.837
Sulphate	32.410
Silicate	15.870
Lithium	ND
Sodium	53.740
Ammonium	ND
Potassium	2.330
Magnesium	14.340
Calcium	28.720



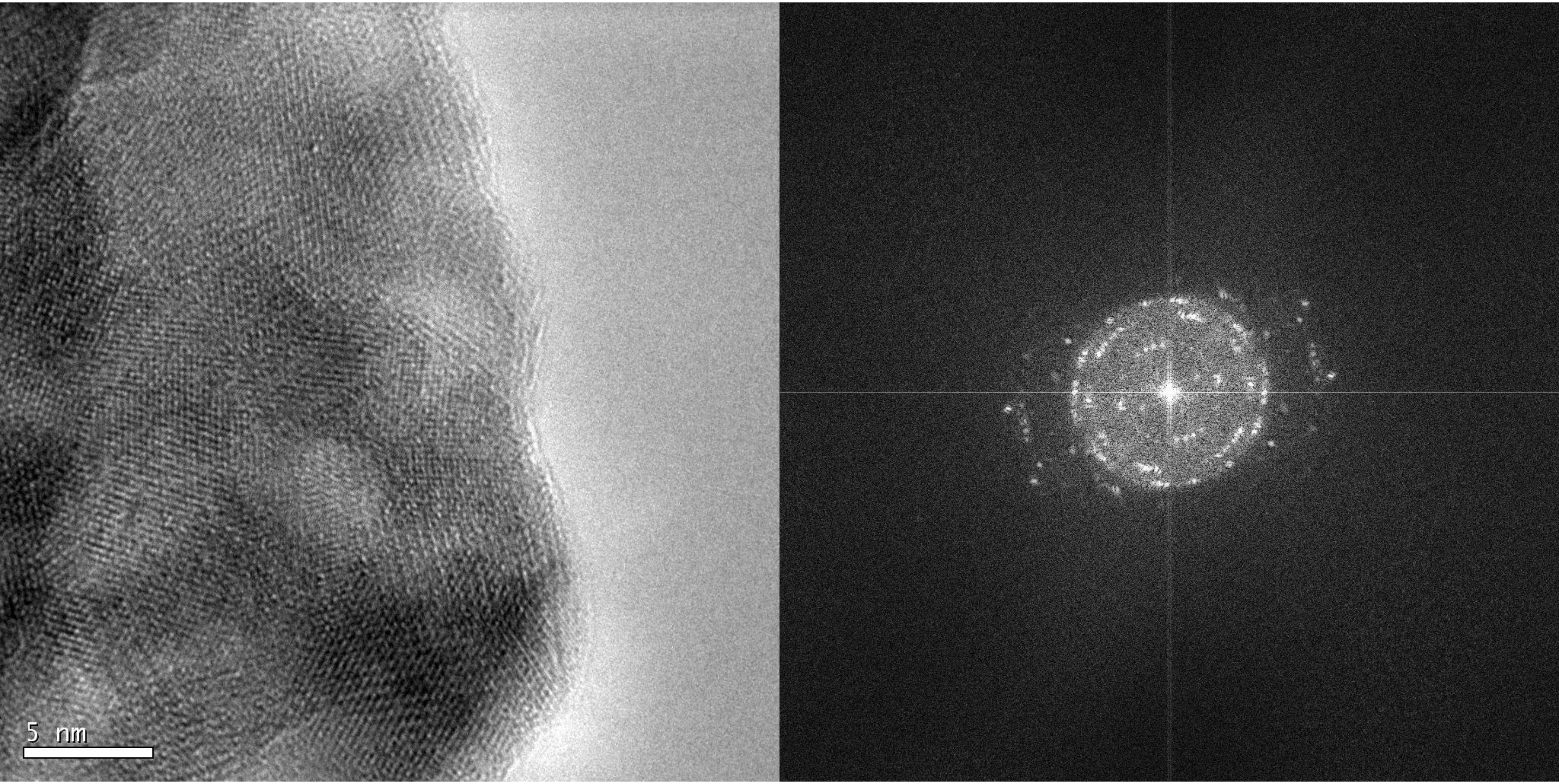
a
Cap
Filter unit
Membrane filter and antimicrobial media
Storage container
Multilayer axial block
Tap
b
c
Bacteria count (CFU/mL)
(i)
(ii)
0
5x10^4
1x10^5
2x10^5
0
500
1000
1500
Volume passed (L)
d
$[Fe^{2+}]$ (ppm)
(i)
(ii)
0
2
4
6
0
500
1000
1500
Volume passed (L)
e
[Pb] (ppb)
(i)
(ii)
0
30
60
90
120
150
180
500
1000
1500
Volume passed (L)
f
$[As^{5+}]$ (ppm)
(i)
(ii)
0.00
0.05
0.5
1.0
0
100
200
300
400
Volume passed (L)


RTD: Room Temperature Drying
OD: Oven Drying @ 63 0C
After washing @ RTD
As3+ cart. 20g, and 500L
As5+ cart. 20g, and 500L
After washing @ OD
Normalized Intensity (a.u.)
Degree (2θ)
1.8
1.5
1.2
0.9
0.6
0.3
0.0
15
30
45
60
75
90

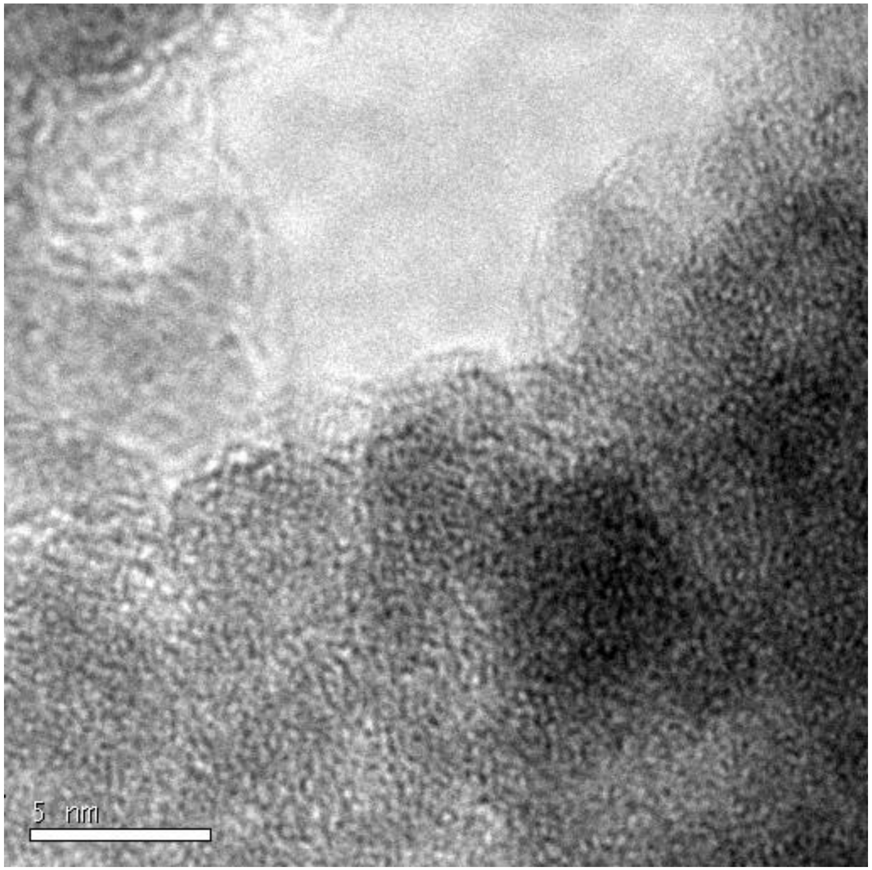
Metastable phase

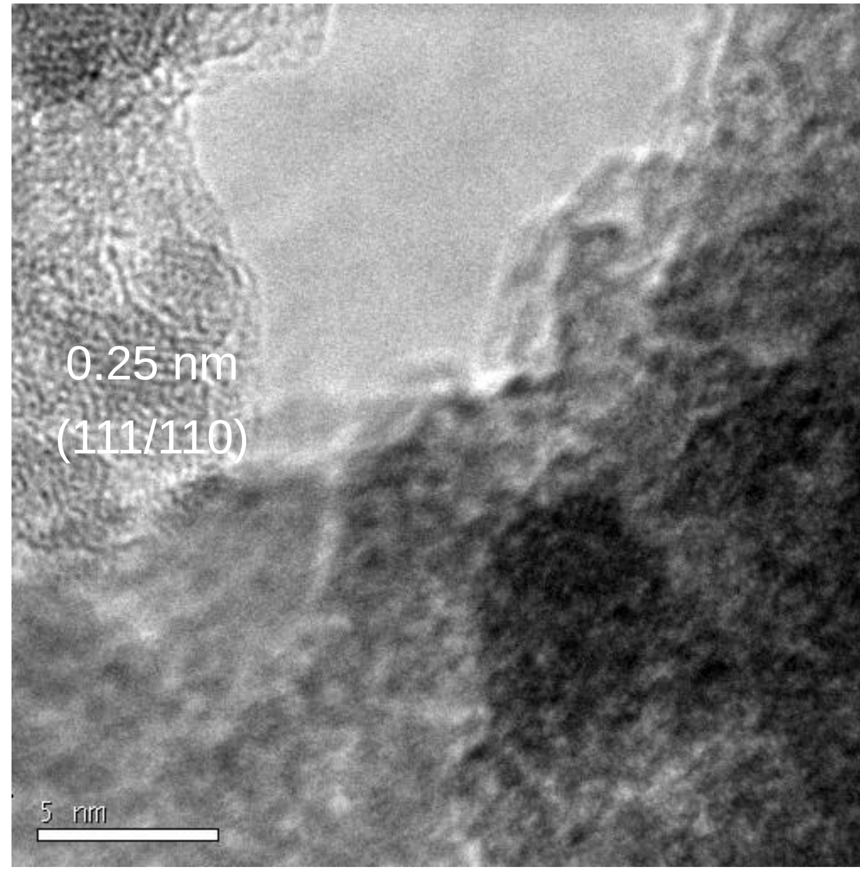


Time dependent TEM


5 nm

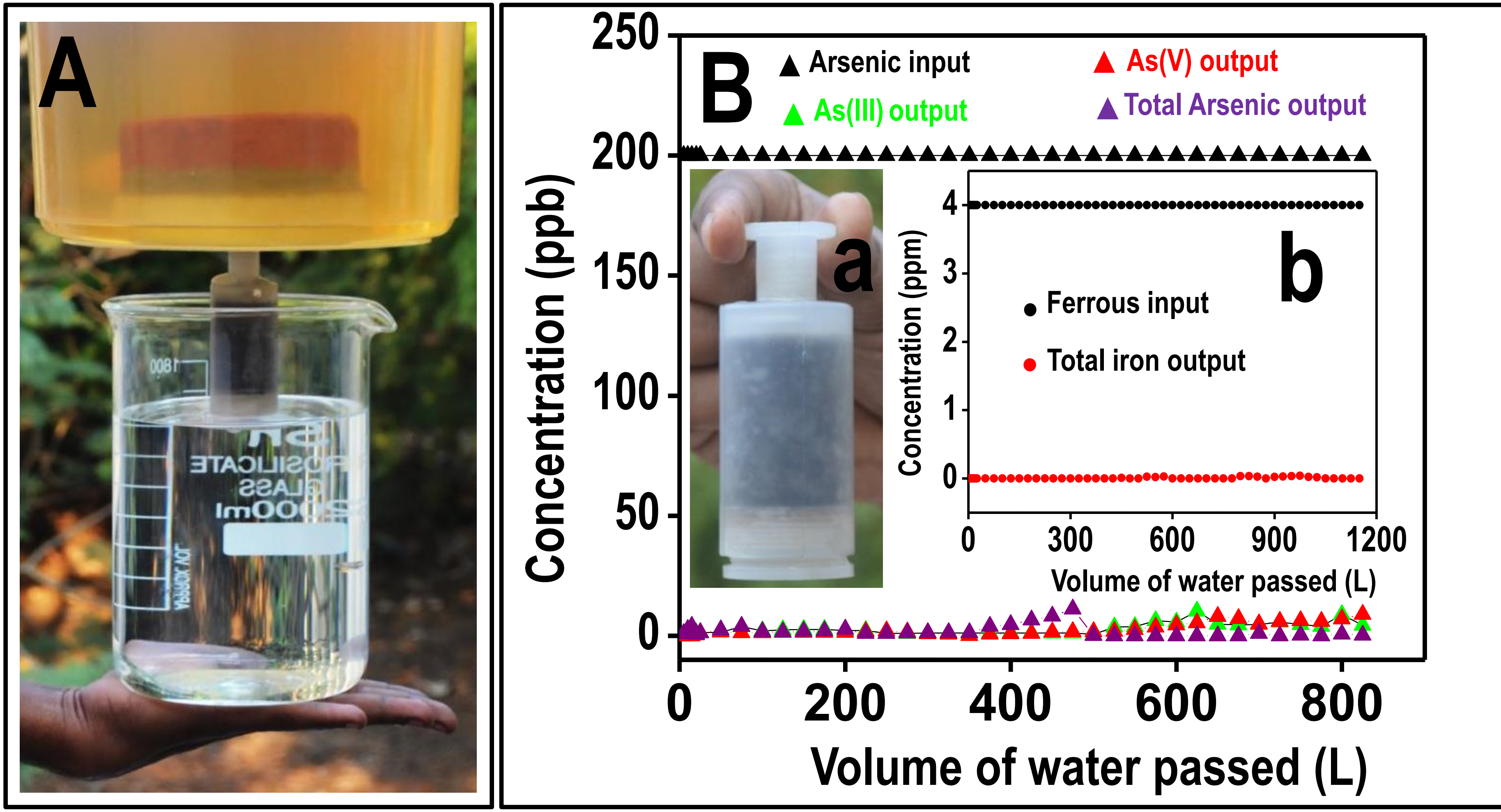
HRTEM images of As(V) adsorbed (or reacted) material [image from the same area at different depth of focus]





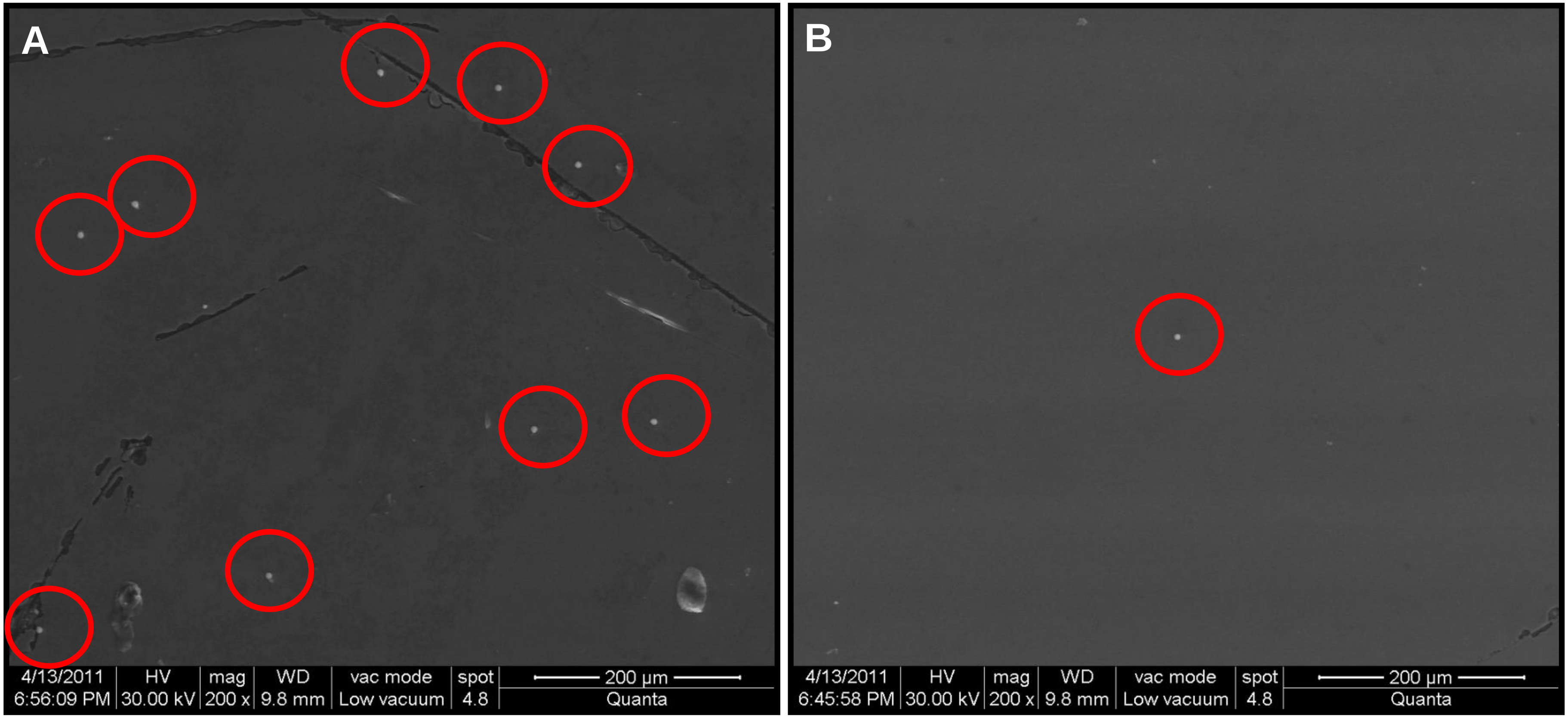
Goethite: α **–FeOOH (0.25 nm)**
PCPDF No. **81-0464 (Orthorhombic)**
a = 4.604, b = 9.959 , c = 3.023
α = β = , ƴ=

Ferrihydrite: 0.22 nm, 0.25 nm
PCPDF No. **29-0712 (Hexagonal)**
a = 5.08, b = , c = 9.4
α = β = , ƴ=



A simple set-up which has been used for arsenic testing study: arsenic containing water is turned into arsenic free clean drinking water using a simple cartridge having the arsenic adsorbent (A), and a cartridge having about 20 g of the adsorbent (a). Arsenic experiment which was conducted using a 60 g cartridge, under natural water conditions (B), and the ferrous experiment which was conducted with combination of arsenic experiment (b).

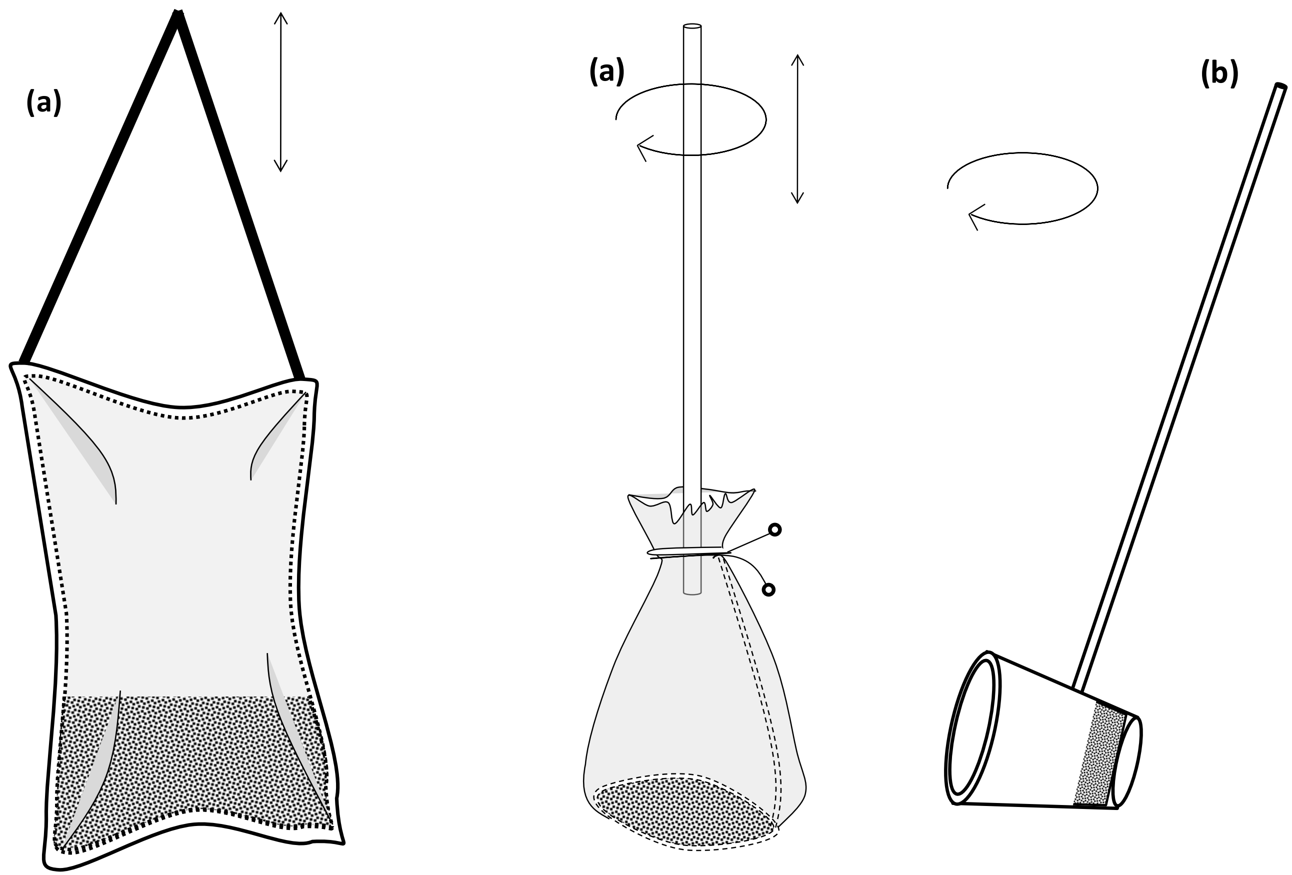
Cyst removal



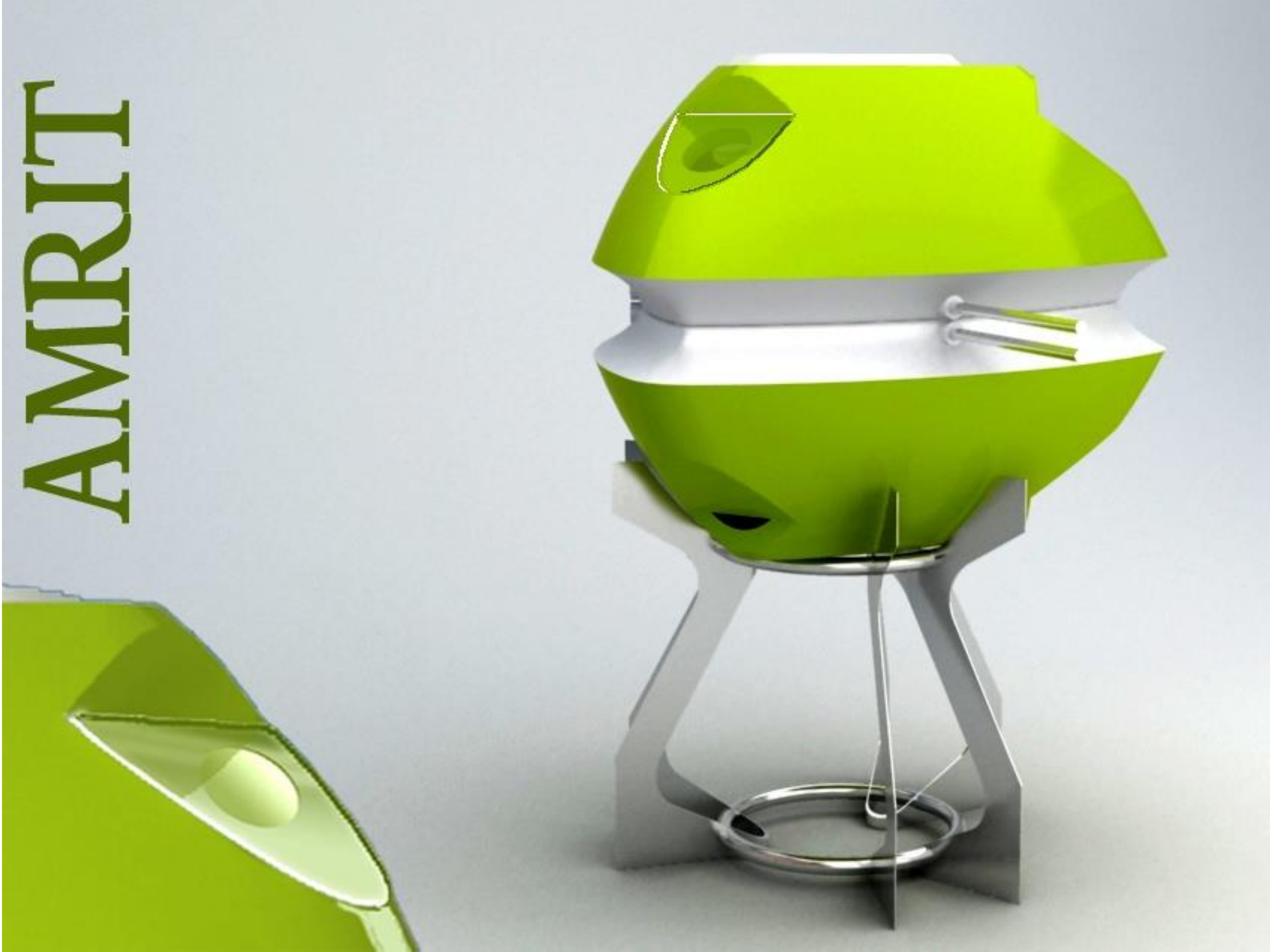
Performance summary

		NSF norms	NSF Standard	InnoNano's Product
Functional Parameters	Sand & Sediment	Turbidity: 11 NTU to <0.5 NT	NSF/ANSI 53	√
	Chlorine	2 ppm to <0.5 ppm	NSF/ANSI 42	√
	Bacteria	105 CFU/ml to absent	NSF/ANSI 55	√
	Virus	103 PFU/ml to absent	NSF/ANSI 55	√
	Cyst	50000/ml to <2/ml	NSF/ANSI 53	√
	Pesticides	Chloroform: 300 ppb to <15	NSF/ANSI 53	√
	Iron	2 ppm to <0.2 ppm		√
	Lead	150 ppb to 10 ppb	NSF/ANSI 53	√
	Arsenic	300 ppb to 10 ppb	NSF/ANSI 53	√
	Mercury	6 ppb to 2 ppb	NSF/ANSI 53	√
	TDS	Not applicable		X
	Nitrate	Not applicable		X

Implementing methods




AMRIT
DRINKING WATER
ARSENIC & METAL REMOVAL BY INDIAN TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY MADRAS


AMRIT

Imagining how new adsorbents are changing the dynamics at ground level

Existing unit for iron and arsenic removal – 20 m^3/h

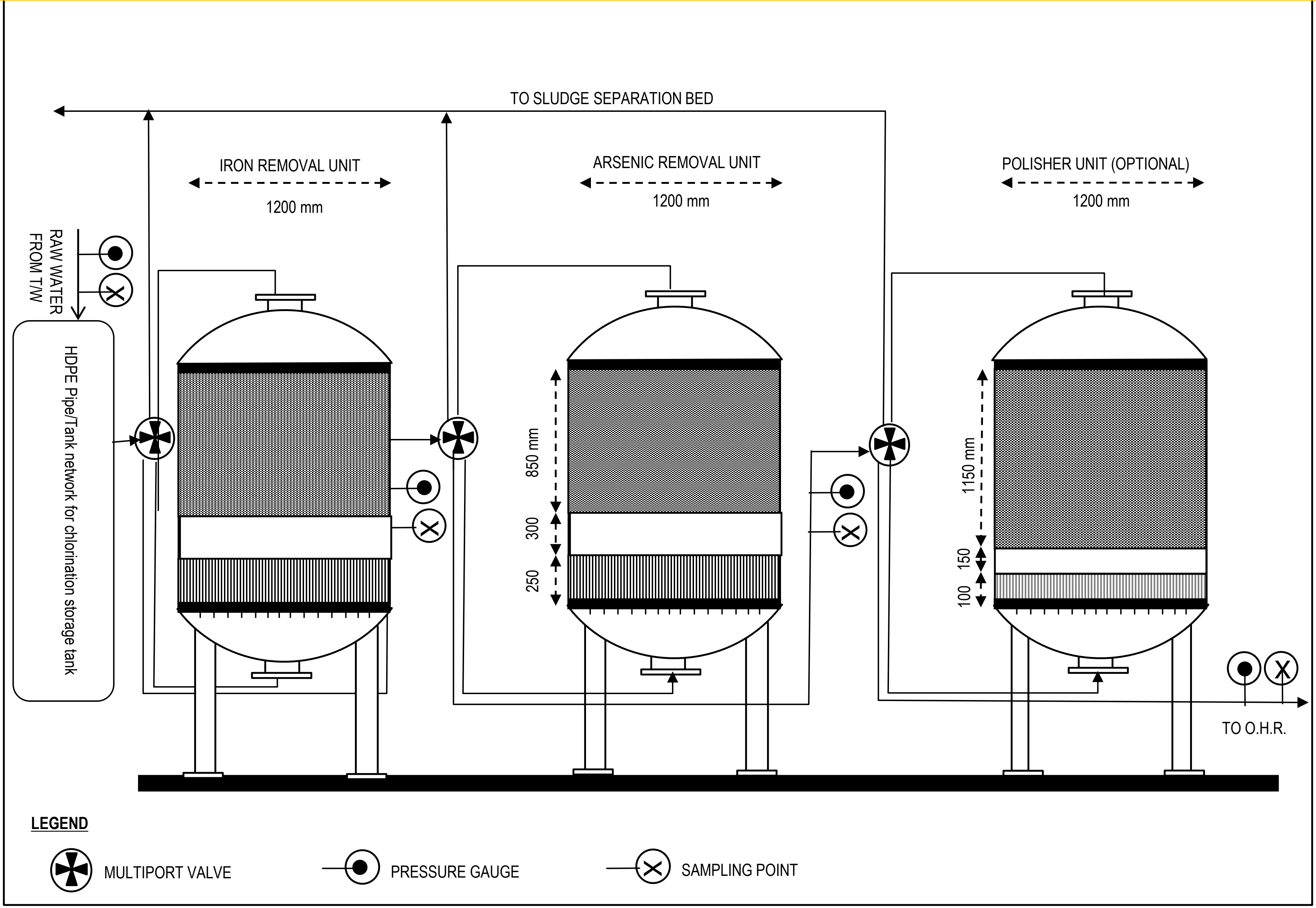
Uses activated alumina and iron oxide (old generation of adsorbents)

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

Understanding the design of IARP based on Nanotechnology



From laboratory to implementation - Our product portfolio

DOMESTIC UNIT
20 L/DAY

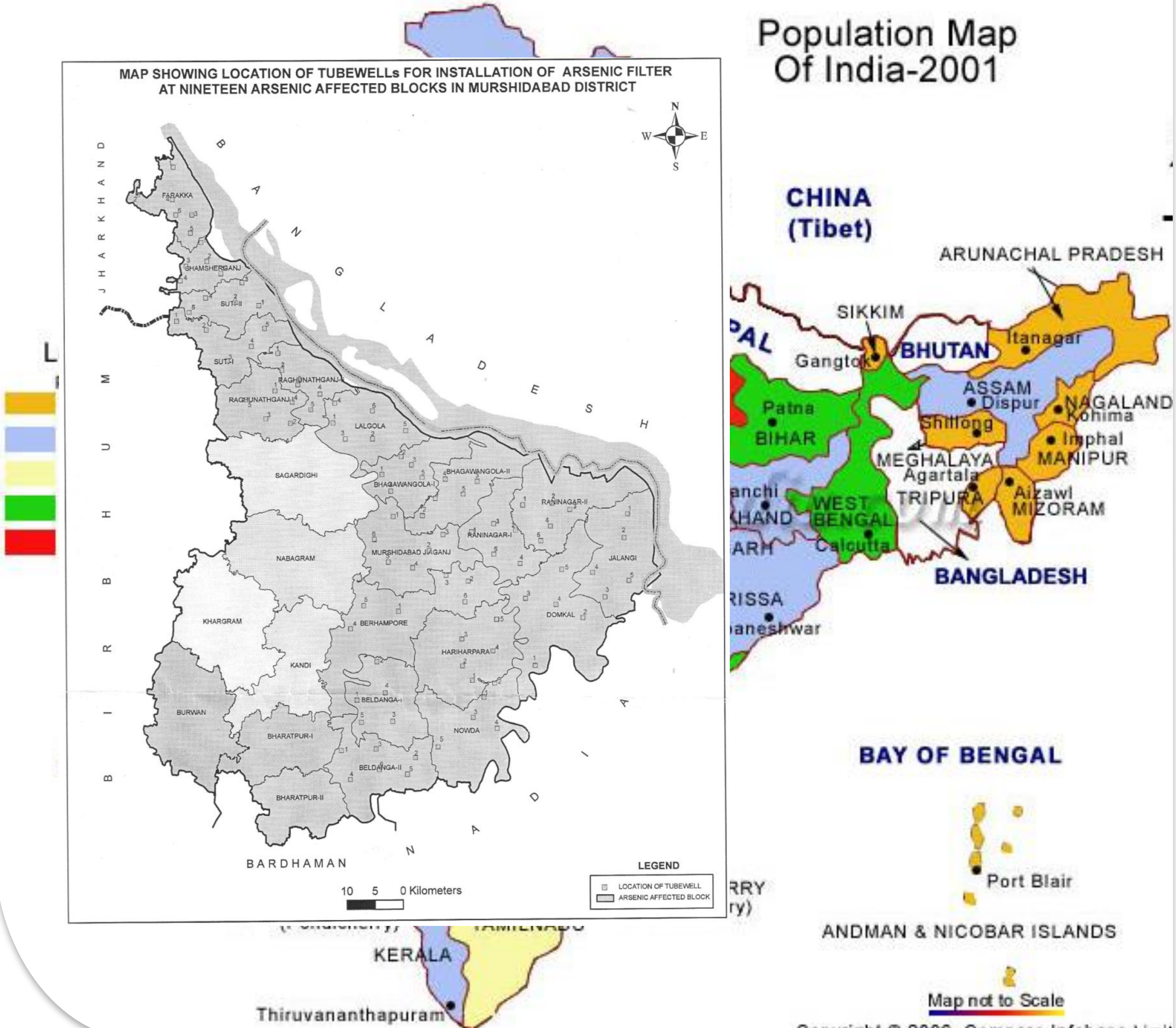
HANDPUMP ATTACHED UNIT
1000 L/DAY

LARGE COMMUNITY UNIT
5000 L/DAY

SMALL COMMUNITY UNIT
2000 L/DAY

Small community unit: iron concentration of 7.2 ppm at flow rate of 1000 L/h

MULTI-VILLAGE WATERSUPPLY SCHEME
100,000 L/DAY


Population Map
Of India-2001
CHINA
(Tibet)
ARUNACHAL PRADESH
SIKKIM
Gangtok
BHUTAN
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Patna
BIHAR
Shillong
Imphal
MEGHALAYA
MANIPUR
Agartala
TRIPURA
Aizawl
MIZORAM
WEST
BENGAL
Calcutta
BANGLADESH
BAY OF BENGAL
Port Blair
ANDMAN & NICOBAR ISLANDS
KERALA
Thiruvananthapuram
Map not to Scale
Copyright © 2006, Compare Infobase Limit
MAP SHOWING LOCATION OF TUBEWELLs FOR INSTALLATION OF ARSENIC FILTER
AT NINETEEN ARSENIC AFFECTED BLOCKS IN MURSHIDABAD DISTRICT
N
W
E
S
JHARKHAND
BANGLADESH
BIRBHUM
BARDHAMAN
NADIA
FARAKKA
SHAMSHERGANJ
SUTI-II
SUTI-I
RAGHUNATHGANJ-II
RAGHUNATHGANJ-I
LALGOLA
SAGARDIGHI
BHAGAWANGOLA-I
BHAGAWANGOLA-II
RANINAGAR-II
RANINAGAR-I
MURSHIDABAD JIAGANJ
NABAGRAM
JALANGI
KHARGRAM
BERHAMPORE
DOMKAL
HARIHARPARA
KANDI
BELDANGA-I
BURWAN
BHARATPUR-I
NOWDA
BELDANGA-II
BHARATPUR-II
LEGEND
LOCATION OF TUBEWELL
ARSENIC AFFECTED BLOCK
10 5 0 Kilometers

A glimpse of performance data for installations in Murshidabad

S.No	Sample Name	Input arsenic (ppb)	Output arsenic (ppb)	Number of days running
1.	Topidanga Jumma Masjid, Bhagwangola-II	31.0	0	30 days
2.	Bhandahara Jumma Masjid, Bhagwangola-II	20.7	0.4	30 days
3.	Horirampur Jumma Masjid, Bhagwangola-II	37.0	0	45 days
4.	Dihipara Jumma Masjid, Bhagwangola-II	4.8	1.8	30 days
5.	Bahadurpur High School, Bhagwangola-I	9.4	0.2	30 days
6.	Charlabangola Higher Sec School, Bhagwangola-I	28.2	0.1	245 days
7.	Mahisasthali Girls' High School, Bhagwangola-I	0	0	30 days
8.	Orahar Girls' High School, Bhagwangola-I	0.5	0	10 days
9.	Rabindratola BN Pandey High School, Bhagwangola-I	84.3	0	245 days
10.	Karbalajamam Masjid, Berhampore	6.8	0	150 days
11.	PHED office, Berhampore	32	0	10 days
12.	Nabipur Bazar Jumma Masjid, Raninagar-II	1.3	0	60 days
13.	Rukunpur Jumma Masjid, Hariharpara	25.6	2.2	60 days
14.	Klyanpur Jumma Masjid, Domkal	64.7	0	200 days
15.	Benadaha Mondalpara Hanafi Jamat, Beldanga-I	9.04	0	180 days
16.	Maniknagar Jumma Masjid, Domkal	1.0	0	60 days
17.	South Hariharpura Jumma Masjid, Hariharpara	5.5	0.0	60 days
18.	Lochan Mati Danga Para Jumma Masjid, Hariharpara	14.6	0	150 days
19.	Paschim Malipara Jumma Masjid, Raninagar – II	3.3	0.1	90 days
20.	Khalilabad Jumma Masjid, Hariharpara	179.0	0	270 days
21.	Bhatu Komnagar Masjid, Raninagar –II	67.9	0.2	360 days

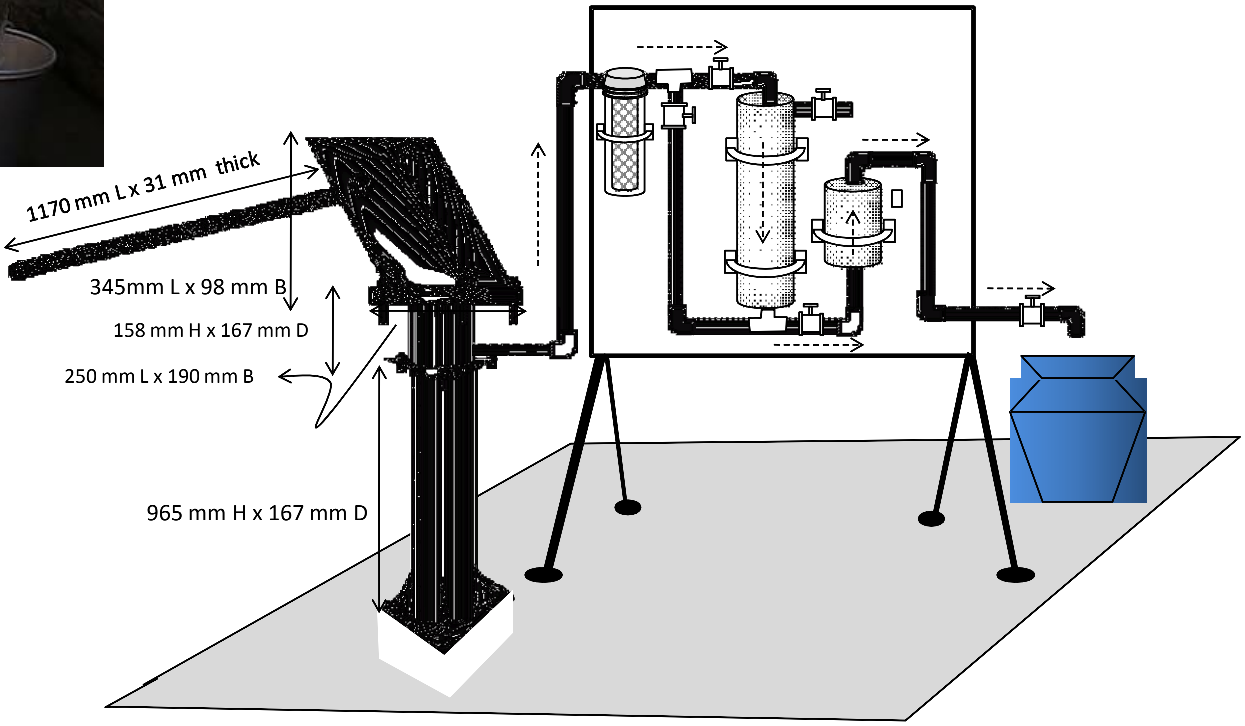
Performance data from Murshidabad (continued)

S. No.	Sample Name	Input arsenic (ppb)	Output arsenic (ppb)	Number of days running
23.	Babaltali Jumma Masjid, Raninagar – II	10.7	0	180 days
24.	Sargachhi Paschimpara Jumma Masjid, Beldanga – I	1.26	0.0	180 days
25.	Pratappur Jumma Masjid, Hariharpara	27.2	0.1	180 days
26.	Fakirabad Jumma Masjid, Domkal	24.7	0	180 days
27.	Shialmari Jumma Masjid, Raninagar – II	287.5	0.1	240 days
28.	Bhabta Ahelahadis Jumma Masjid, Beldanga	8.6	5.7	240 days

A glimpse of performance data for installations in Nadia

S. No.	Sample Name	Input arsenic (ppb)	Output arsenic (ppb)	Number of days running
1.	Dhapadia Junior Madrasah	46.5	2.2	30 days
2.	Khidirpur Shishu Shiksha Kendra	15.0	0	260 days
3.	Junior Madrasah	12.7	0	60 days
4.	Dhapana Board High School	15.0	0.6	45 days
5.	Birpur Primary School	20.0	0	90 days
6.	Bethuaduari JCM High School	4.6	0	45 days
7.	Jugnuthala Primary School	23.4	0	60 days
8.	Dahakula Primary High School	36.6	0	60 days
9.	Bargachi Primary School Nagadi	9.6	0	90 days
10.	Dahakula Primary School	22.7	0	60 days
11.	BJ Kumari Primary School	5.9	0	100 days
12.	Arijnagar Primary School	0.1	-	60 days
13	Patikpari Girls Primary School	9.6	0	60 days
14	Bawanipur Primary School Nagadi	0.5	0	60 days

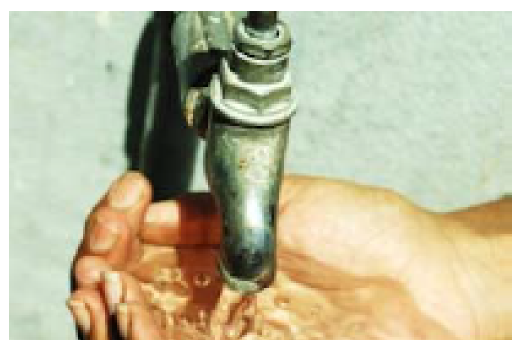
Understanding hand pump model based on Nanotechnology



Cheap Nanotech Filter Clears Hazardous Microbes and Chemicals from Drinking Water

A $16 device could provide a family of five with clean water for an entire year

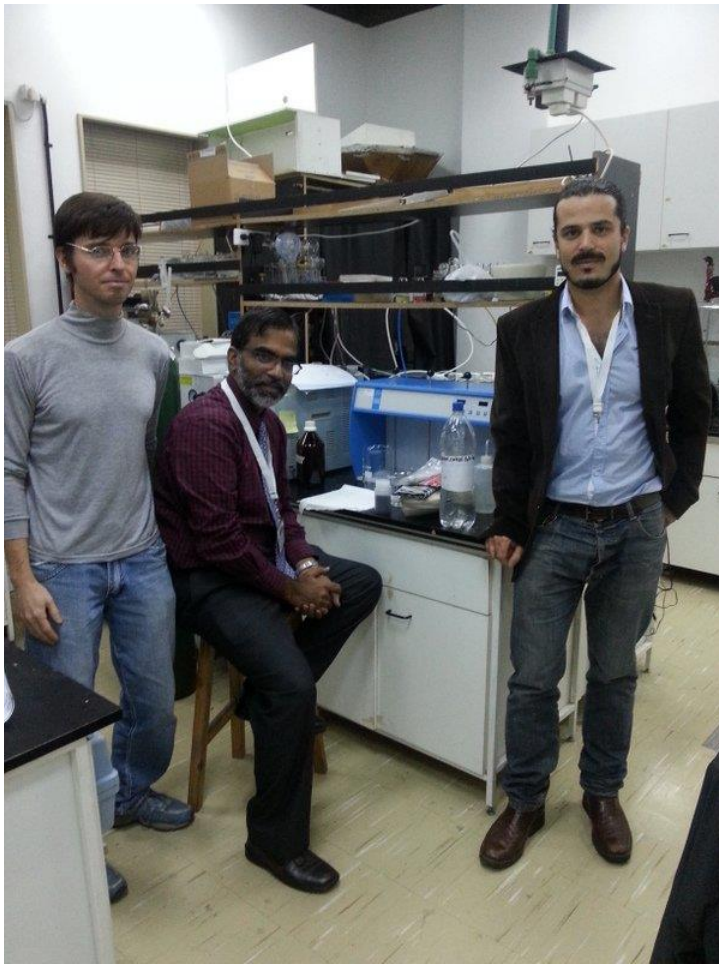
By Luciana Gravotta



About 780 million people—a tenth of the world's population—do not have access to clean drinking water. Water laced with contaminants such as bacteria, viruses, lead and arsenic claims millions of lives each year. But an inexpensive device that effectively clears such contaminants from

Work was featured in several journals

Nature Nanotechnology, July 2014 issue




Standard Colour Comparison Chart
Arsenic
μg/l (ppb)
10ppb(0.01 μg/l)
20ppb (0.02 μg/l)
50ppb (0.05 μg/l)
200ppb (0.2 μg/l)
400ppb (0.4 μg/l)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सिद्धिर्भवति कर्मजा


ADMINISTRATION

DST Nano Mission

Perspectives

The problem of water is poverty and associated issues of corruption and management.

It is important to have a basket of solutions at various price points and various water quality parameters.

Public participation and awareness are central to the success of any technology – curriculum - schools.

Water opens up too many issues for investigations at various levels – interdisciplinary research to be nurtured.

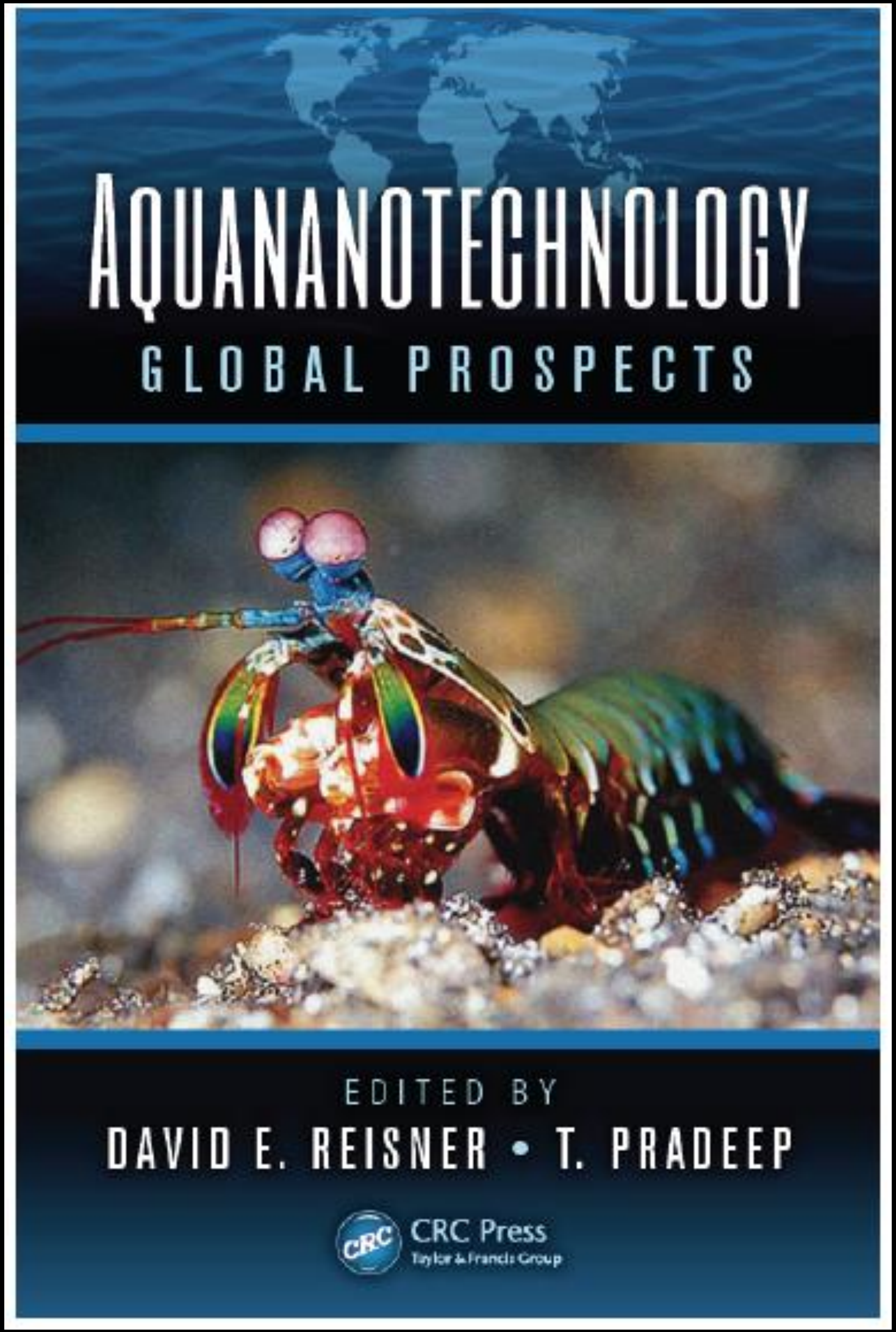
Affordable water censors are most essential to understand water quality, quantity and availability at point of use.

ITC enabled services in the water sector have to be developed.

Quality water can be delivered affordably, at point of use, with available technologies

Funding mechanisms for basic science institutions for perfecting technologies – technologies do not get developed in labs alone

New Book



Acknowledgements
DST, Nano Mission

Video