Unexpected great journey with amazing people

BRICS4Water: Development of membrane-based methods to improve the recovery of pure water and valuable products from the waste

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STI FRAMEWORK PROGRAM

TIPS RAS

From blank page to successful application with "full house" in 3 months: Mission ~~im~~possible

Starting point (September 2017):

- No prior collaboration together with team members before BRICS call.
- Professional networking (visiting scientist in NL, attending int. conferences, council member of EMS).
- Project management (8+ years as Deputy director responsible for international affairs at TIPS RAS, FP7 projects).
- Great local team
- …and good luck :)

Story line:

- First contact Tao He (China) came from colleague Alberto Figoli (EMS) by visiting him in Italy in September 2017.
- Other contacts with potential collaborators were established by surfing membrane-related papers in Scopus and WoS.
- Recruiting future team mates by: i) giving interesting project concept, ii) finding strong sides of each partner that add complimentarily to consortium by avoiding internal competition.
- Deadline extension made possible to gather Big Five on board.

Project description

Title

Development of membrane-based methods to improve the recovery of pure water and valuable products from the waste

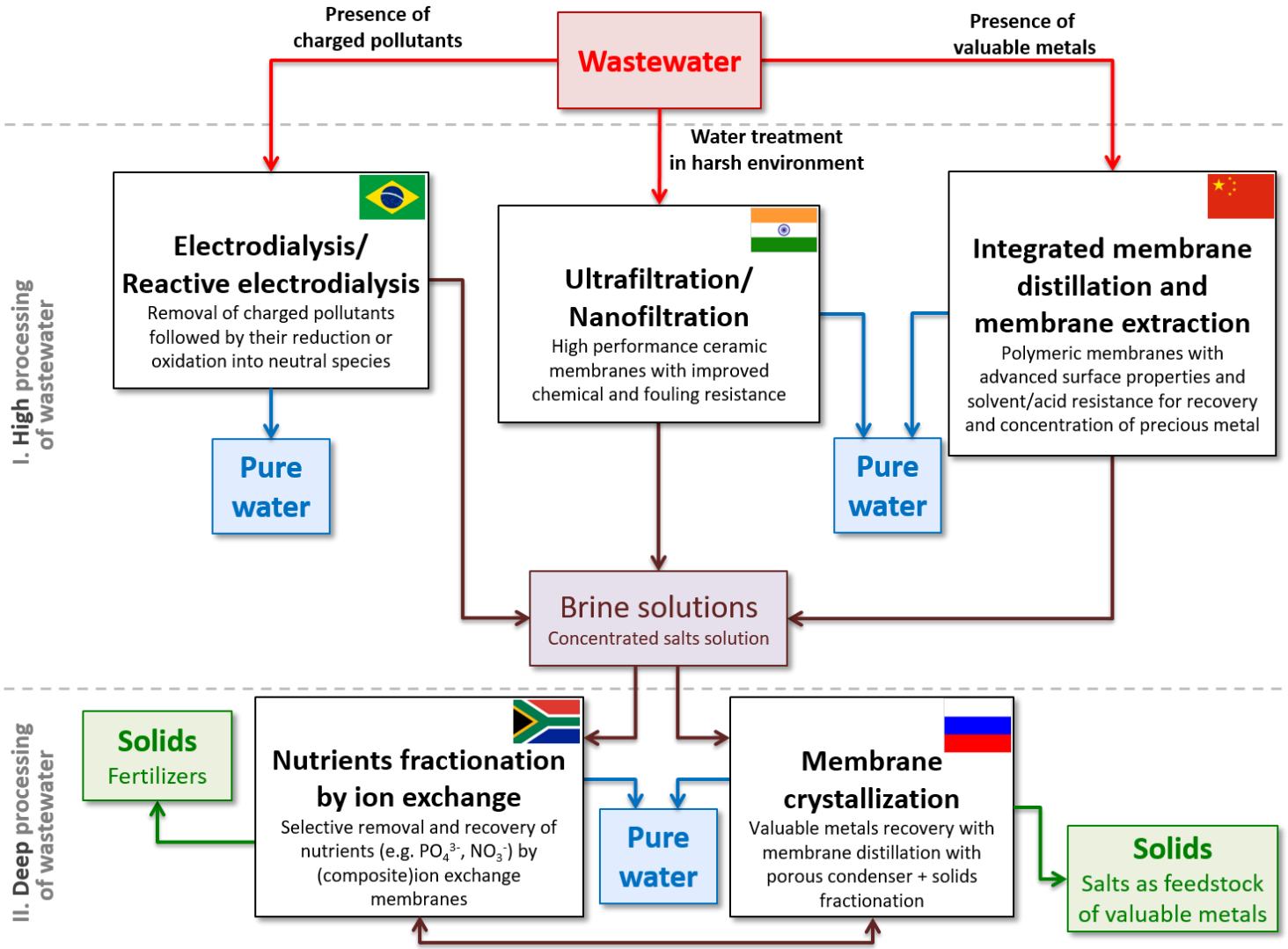
Acronym

From waste to resource

Goal

Develop membrane-based processes that can significantly reduce the energy consumption and the cost or to be operated independently for: effective operation in the remote areas to produce the clean water and recovery of organic and inorganic components together with clean water from the polluted water

Research project framework: From waste to resource



CSIR-Central Glass and Ceramic Research Institute

Ultrafiltration/Nanofiltration

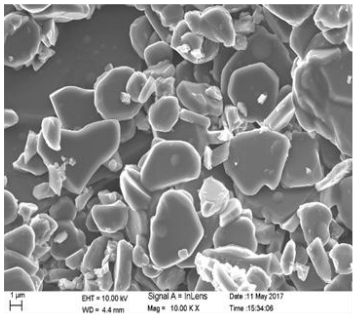
The project leader of research group from India – Principal Scientist **Sourja Ghosh** in Membrane and Separation Technology Division of CSIR-Central Glass and Ceramics Research Institute, Kolkata, India and Associate Professor of Academy of Scientific & Innovative Research (ACSIR).

High performance ceramic membranes with improved chemical and fouling resistance

Alumina (Al_2O_3) + Clay + Binder + Additives + Dispersant

Mixed and extruded | Sintered

Clay alumina support tube of length 150 mm (ID mm and OD 10 mm)



FESEM image. Porosity – 47 %; Bulk density – 1.93 %

Results at the moment

- Ceramic UF membrane was prepared with titania coating on clay-alumina based support with clean water flux of about 180 $lm^{-2}h^{-1}$ at 1 bar transmembrane pressure
- Hydrophobic surface modification was done at both outer and inner side of the ceramic tube
- Contact angle was obtained up to 139° which may be enhanced further by process optimization which is under progress

Federal University of Rio Grande do Sul
Electrodialysis/Reactive electrodialysis

The project leader of research group from Brazil – Full Professor **Andrea Moura Bernardes** in Post-Graduation Program in Mining, Metallurgical and Materials Engineering, department of the Fedral Univeristy of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil.

Removal of charged pollutants followed by their reduction or oxidation into neutral species

Municipal wastewater → great potential

- Abundance of volume, although they contain relatively low concentrations of phosphate
- Liquid phase: simpler and economically feasible[1]

Precipitation/cristallyzation (one of the most studied and promising technique to recover phosphorus)

- Limited by the phosphorus concentration ≥ 0.100 g L^{-1}

↓

Municipal wastewater: 0.004 to 0.040 g L^{-1} of phosphorus[2]

↓

Pre-concentration by Electrodialysis

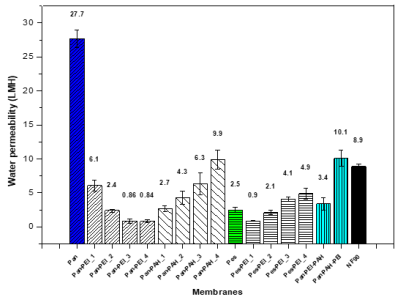
Results at the moment

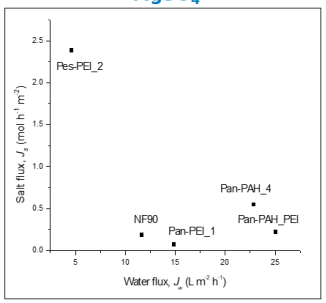
- A two-stage electrodialysis setup to phosphorus recover from a low phosphate-containing municipal wastewater may be suggested. The first stage consists in the use of underlimiting current density conditions to obtain a phosphate concentrated solution. A concentration of $H_xPO_4^{3-x}$ ≥ 0.120 g $^{L-}$1 is reached in the concentrated reservoir. The second step is based on the use of overlimiting current density conditions, allowing the separation of phosphate from the coexisting anions, such as sulfate, in a municipal wastewater.

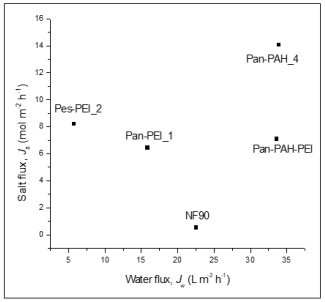
University of South Africa
Nutrients fractionation by ion exchange

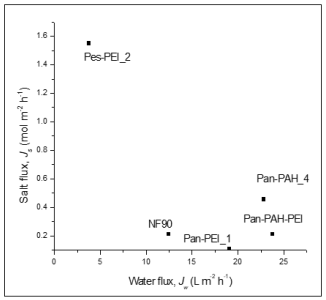
The project leader of research group from South Africa – Associate Professor **Lueta-Ann de Kock** in Institute for Nanotechnology and Water Sustainability, University of South Africa (UNISA), Johannesburg, South Africa.

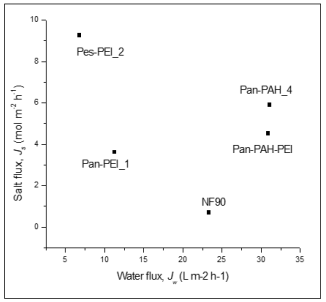
Preparation and characterization of charged nanofiltration membranes











- Permeability was reduced due to bilayer deposition
- Modified polyacrylonitrile substrates produced high performing membranes
- Salt rejection followed this order $Mg^{2+}>Ca^{2+}>Na^{+}\geq K^{+}$
- Rejection was a function of electrostatic and acid-base forces

Results at the moment

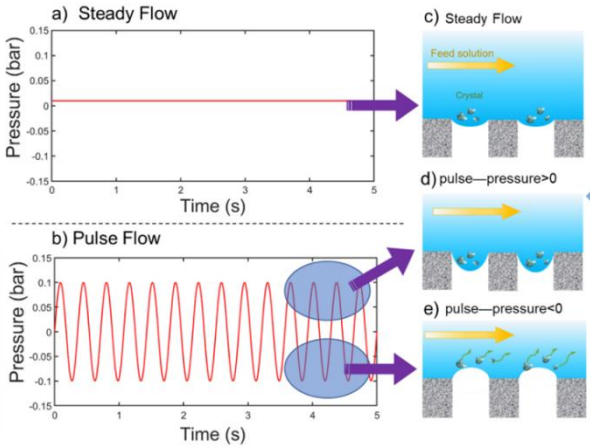
- The ultrathin polyelectrolyte films resulted in favorable interactions between the membrane and water molecules which increased the polar component of the membrane surface free energy, thus improving its hydrophilicity.
- The layer-by-layer assembly technique (of Polyelectrolytes) enabled the preparation of membranes that could be easily tailored towards effective removal of cationic species in water.

Shanghai Advanced Research Institute

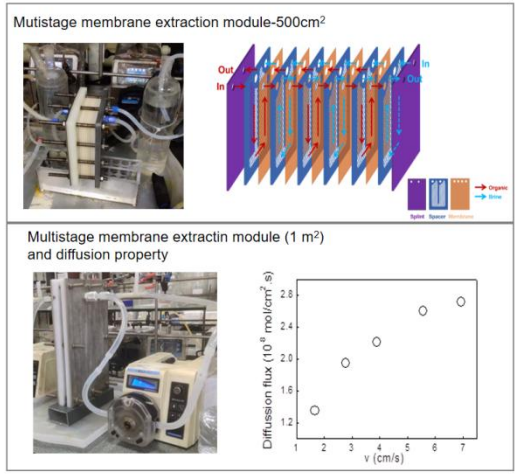
Integrated membrane distillation and membrane extraction

The project leader of research group from China – director and professor **Tao He** in Membrane Materials and Separation Technology at SARI, Chinese Academy of Sciences, Shanghai, China.

Polymeric membranes with advanced surface properties and solvent/acid resistance for recovery and concentration of precious metal



Discovery of slippery as the key factor for scaling and fouling resistance of superhydrophobic membrane



Scale-up of membrane extraction module to 1 m2

Results at the moment

- We developed the new theory of slippery surface for scaling and fouling resistance in membrane distillation.
- MicroMolding phase separation (μPS) was utilized to prepare pillared hydrophobic membranes. Porous micropillars PVDF surface appeared superhydrophobic
- We discovered the difference of chemical and physical modification of membrane surface to make superhydrophobic membranes to be wetting state difference.
- Acid and solvent resistant poly (ether ether ketone) (PEEK) membrane was prepared for lithium stripping
- Membrane extraction module was scaled-up

A.V.Topchiev Institute of Petrochemical Synthesis
Russian Academy of Sciences

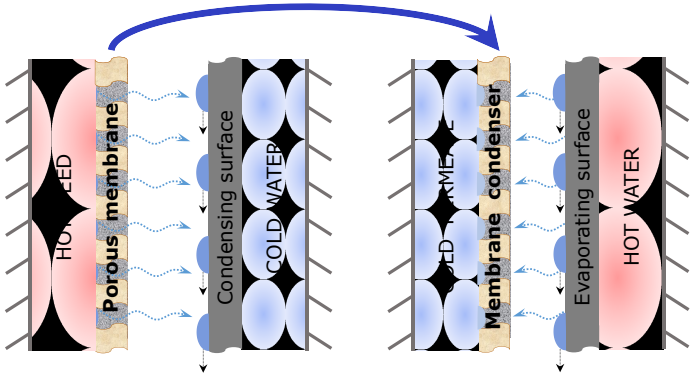
Membrane crystallization

The project leader of research group from Russian Federation – Deputy Director **Alexey Volkov** in Polymeric membranes laboratory of A.V.Topchiev Institute of Petrochemical Synthesis Russian Academy of Sciences, Moscow, Russian Federation.

Valuable metals recovery with film distillation with membrane condenser + solids fractionation

Novel thermo-gradient method for brine concentration

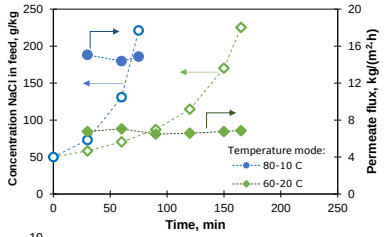
Change of membrane position: HOT→COLD

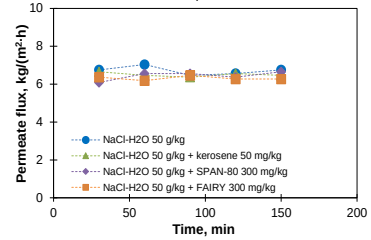


AIR GAP MEMBRANE DISTILLATION

FILM DISTILLATION + MEMBRANE CONDENSER

Conditions: C_{NaCl} = 50 g l^{-1}; T_{feed} = 60–80 °C; $T_{coolant}$ = 10–20 °C; l = 2 mm; V_{feed} = 500 ml





✓ **Scaling and fouling resistance**

✓ **Stable and high fluxes, regardless of additions**

Results at the moment

- A novel concept of film distillation equipped with the membrane condenser (FD-MC) was proposed and implemented for the concentration of brine salt solutions.
- FD-MC demonstrated higher water flux (14.7 kg/m²·h) and stable performance during the concentration of NaCl solution from 50 up to 230 g/l even in the presence of organic pollutants.
- A mathematical model of heat and mass transfer in FD-MC process was proposed and successfully verified (the energy consumption and thermal efficiency of FD-MC process were in the range of 2.7-3.2 MJ/kg and up to 97%, respectively).
- A technique has been developed for carrying out the process of membrane crystallization by combining the stage of concentrating brines using FD-MC and subsequent crystallization in order to increase the depth of processing of technogenically polluted waters.

Project website: BRICS4water

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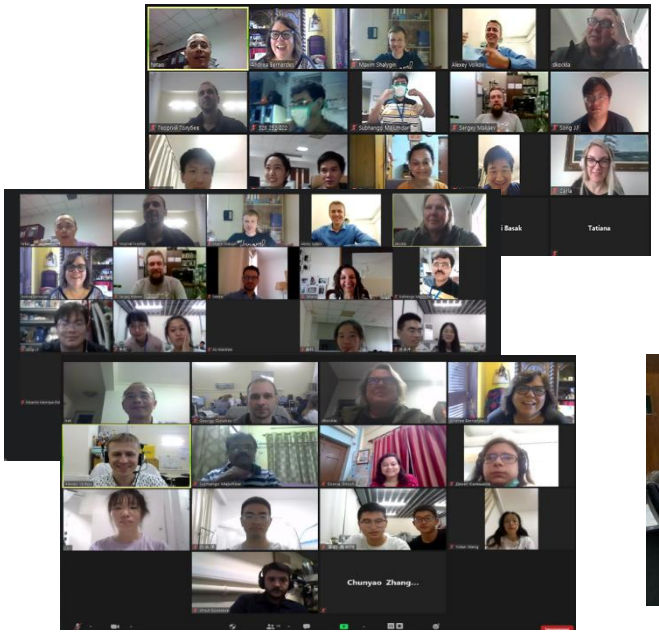
www.brics4water.org

Kick-off and progress meetings

Online meetings



Face-to-face meetings

Conferences

- 6th IWA Regional Membrane Technology Conference (Vadodara, Gujarat, India; 10-12 December 2018);
- International Symposium "Membranes for Waste2Resources-2019" (Shanghai, China; 1-2 June 2019);
- 12th conference of the Aseanian Membrane Society (Jeju, Korea; 2-5 July 2019);
- Membrane Conference of Visegrad Countries PERMEA 2019 (Budapest, Hungary; 26-29 August 2019);
- International Workshop "Membranes for Water Management and Waste to Resources with Special Focus on NextGen Membrane Technology" (Kolkata, India; 5-6 November 2019);
- 10th International Membrane Science & Technology Conference (IMSTEC2020) (Sydney, Australia; 2-6 February 2020);
- International Congress on Membranes & Membrane Processes 2020 (Online; 7-11December 2020);
- Scientific Russian-Indian webinar on the topic "Waste-to-Wealth Technologies" (Online; 10-11 March 2021)
- 5th International Conference on Desalination using Membrane Technology, Membrane Desalination 2021 (MEMDES2021) (Online; 14-17 November 2021)

…

Publications within the framework of the BRICS project

38 articles were published and 1 RF patent was filed

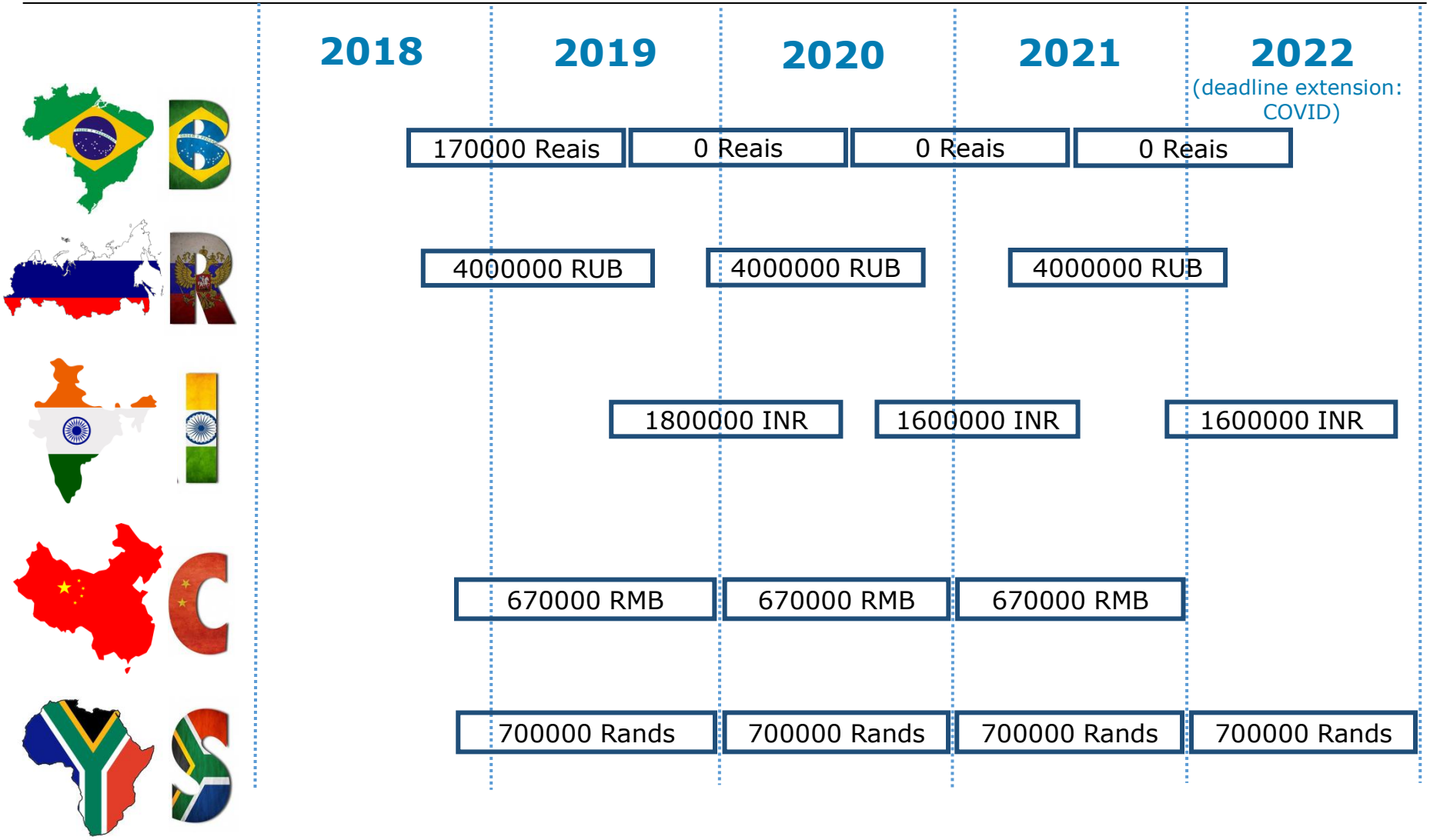
Scientific publications based on the results of the project in journals Q1:

1) Basak, S. Barma, S. Majumdar, S. Ghosh. Role of silane grafting in the development of a superhydrophobic clay-alumina composite membrane for separation of water in oil emulsion. Ceramics International. (2022) In press.
2) W. Zhai, H. Yu, H. Chen, L. Li, D. Li, Y. Zhang, T. He, Stable fouling resistance of polyethylene (PE) separator membrane via oxygen plasma plus zwitterion grafting, Separation and Purification Technology 293 (2022).
3) L. Liu, L. Charlton, Y. Song, T. Li, X. Li, H. Yin, T. He, Scaling resistance by fluoro-treatments: the importance of wetting states, Journal of Materials Chemistry A 10 (2022) 3058-3068.
4) Y. Liu, T. Horseman, Z. Wang, H.A. Arafat, H. Yin, S. Lin, T. He, Negative Pressure Membrane Distillation for Excellent Gypsum Scaling Resistance and Flux Enhancement, Environ Sci Technol 56(2) (2022) 1405-1412.
5) Y. Wang, H. Yu, X. Yang, L. Liu, S. Xu, H. He, Y. Zhang, T. He, Concentrating phosphoric acid by direct contact membrane distillation using a low-cost polyethylene separator, Desalination 530 (2022).
6) L. Liu, L. Charlton, Y. Song, T. Li, X. Li, H. Yin, T. He, Scaling resistance by fluoro-treatments: the importance of wetting states, Journal of Materials Chemistry A 10 (2022) 3058-3068.
7) L. Liu, H. He, Y. Wang, T. Tong, X.-M. Li, Y.-B. Zhang, T. He, Mitigation of gypsum and silica scaling in membrane distillation by pulse flow operation, Journal of Membrane Science 624 (2021) 119107.
8) G.Golubev, I.Eremeev, S.Makaev, M.Shalygin, V.Vasilevsky, T.He, E.Drioli, A.Volkov. Thin-film distillation coupled with membrane condenser for brine solutions concentration. Desalination, 503 (2021) 114956
9) L. Liu, Z. Xiao, Y. Liu, X. Li, H. Yin, A. Volkov, T. He. Understanding the fouling/scaling resistance of superhydrophobic/omniphobic membranes in membrane distillation. Desalination, 499 (2021) 114864 **32 citations** (Scopus)
10) E.H. Rotta, L.Marder, V.P. Herranz, A.M. Bernardes. Characterization of an anion-exchange membrane subjected to phosphate and sulfate separation by electrodialysis at overlimiting current density condition. Journal of Membrane Science, (2021) 119510
11) Venzke, C. D., Rizzana, D. U., Giacobbo, A., Rodrigues, M. A. S., He, T., & Bernardes, A. M. (2021). Membrane distillation treating a real petrochemical reverse osmosis concentrate: Influence of membrane characteristics on the process performance. Journal of Water Process Engineering, 39, 101722
12) Zhai, W., Wang, M., Song, J., Zhang, L., Li, X. M., & He, T. Fouling resistance of 3-[[3-(trimethoxysilane)-propyl] amino] propane-1-sulfonic acid zwitterion modified poly (vinylidene fluoride) membranes. Separation and Purification Technology, 239 (2020) 116589
13) Z.Xiao, H.Guo, H.He, Y.Liu, X.Li, Y.Zhang, H.Yin, A.V.Volkov, T.He. Unprecedented scaling/fouling resistance of omniphobic polyvinylidene fluoride membrane with silica nanoparticle coated micropillars in direct contact membrane distillation. Journal of Membrane Science, 599 (2020) 117819
14) Y. Liu, J. Wang, Z. Xiao, L. Liu, D. Li, X. Li, H. Yin, T. He, Anisotropic performance of a superhydrophobic polyvinyl difluoride membrane with corrugated pattern in direct contact membrane distillation, Desalination 481 (2020) 114363
15) Z. Xiao, R. Zheng, Y. Liu, H. He, X. Yuan, Y. Ji, D. Li, H. Yin, Y. Zhang, X.-M. Li, T. He, Slippery for scaling resistance in membrane distillation: a novel porous micropillared superhydrophobic surface, Water Research 155 (2019) 152-161 **108 citations** (Scopus)
And other….

RF Patent:
V.Vasilevsky, G.Golubev, И.Л.Борисов, I.Eremeev, A.Volkov. Distillation module for concentration and desalination of aqueous solution and method of concentrating and desalting aqueous solution using thereof. RU2737524C1 (2020)

Publications in media: RIA Novosti (https://crimea.ria.ru/20210212/Uchenye-nashli-novyy-sposob-ochistki-tekhnogennykh-vod-1119247017.html), Indicator (https://indicator.ru/chemistry-and-materials/razrabotan-sposob-pererabotki-gryaznoi-vody-10-02-2021.htm) and Scientific Russia (https://scientificrussia.ru/articles/uchenye-predlozhili-novyj-sposob-ochistki-tehnogennyh-vod).

Challenges with project timeline synchronization and money

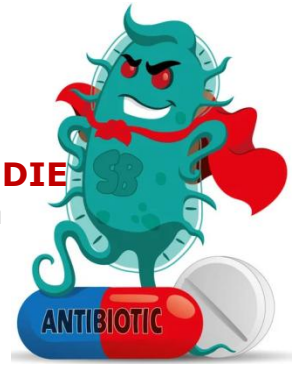


Prospects for further cooperation: continuing saving the world

Water contamination by antibiotics → **Emergence of antibiotic resistant bacteria**

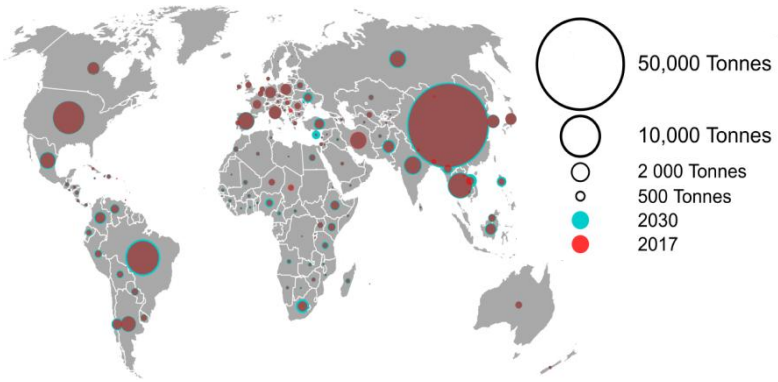
Prediction:

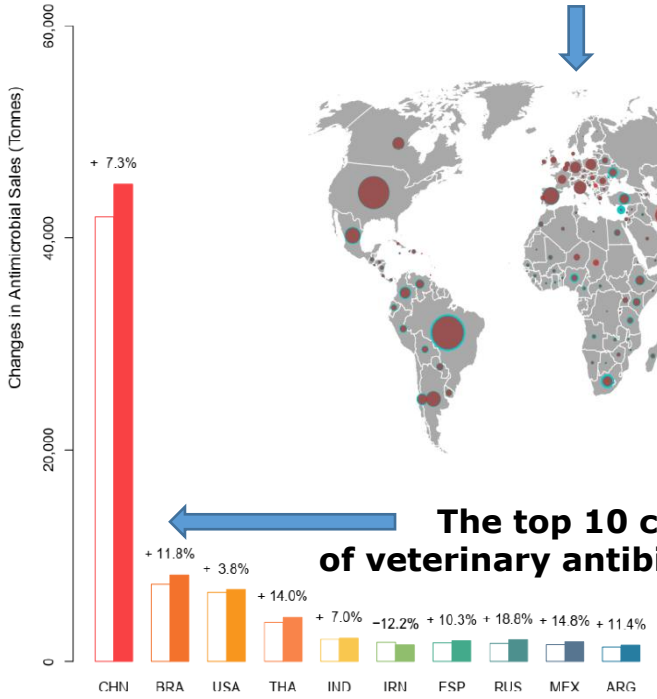
By 2050, about
10 MILLION PEOPLE A YEAR COULD DIE
from **antibiotic-resistant bacteria**



BRICS COUNTRIES are among the **TOP 10** countries in **antibiotic consumption**

World consumption of antibiotics





The top 10 consumers of veterinary antibiotics by country

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Project application description

Title

Monitoring and removal of antibiotics from wastewater by membrane separation

Acronym

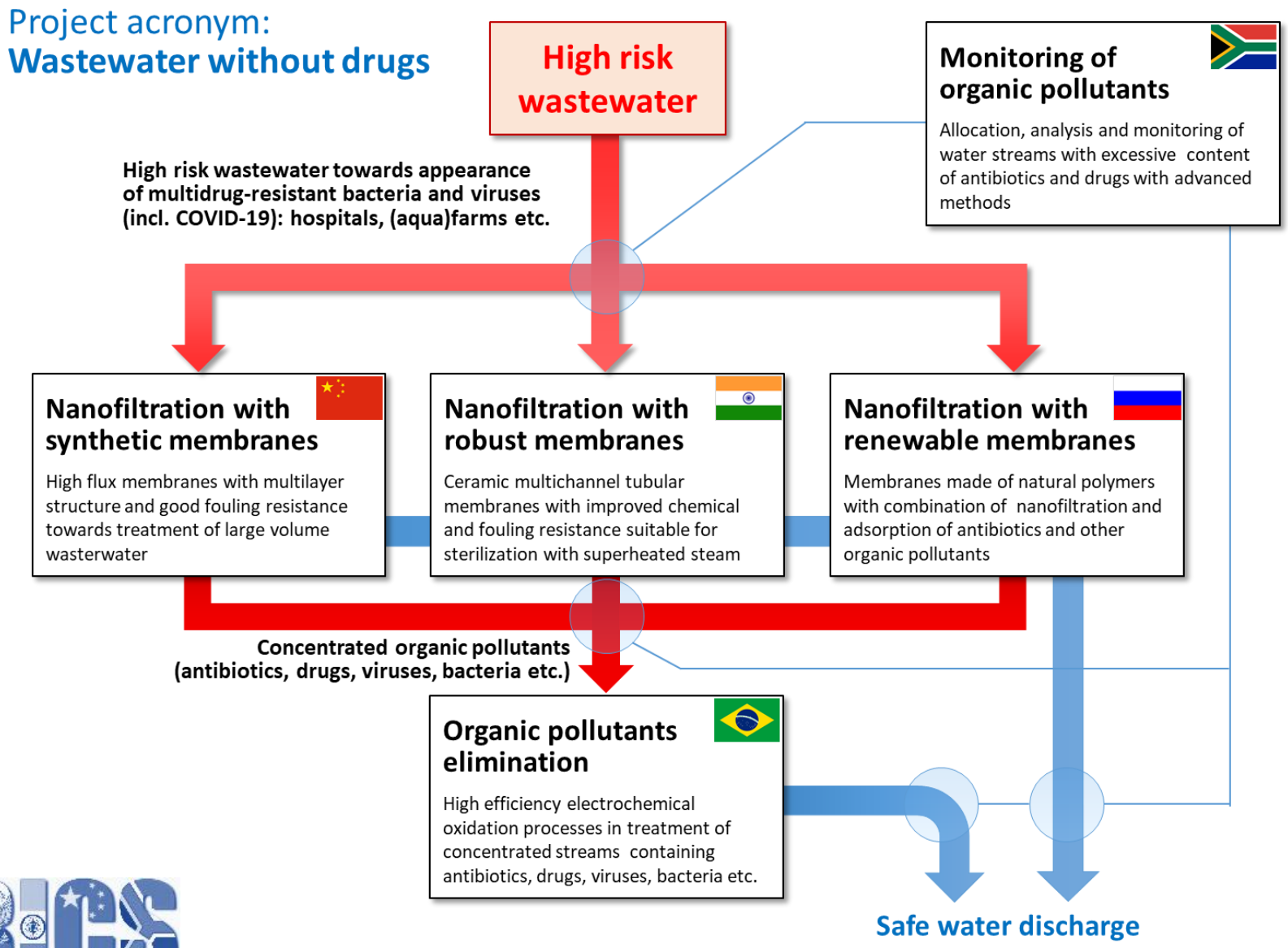
Drug-Free Wastewater

Goal

Detection, concentration and removal of antibiotics from water via a membrane-based hybrid process:

- identification of high-risk water sources by monitoring antibiotics and pathological microorganisms in municipal and surface waters;
- treatment of identified water sources by membrane separation for isolation of antibiotics and pathological microorganisms to concentrated solution by using nanofiltration membranes with different functionalities;
- electrochemical oxidation to eliminate these chemicals.

Research project framework: Wastewater without drugs



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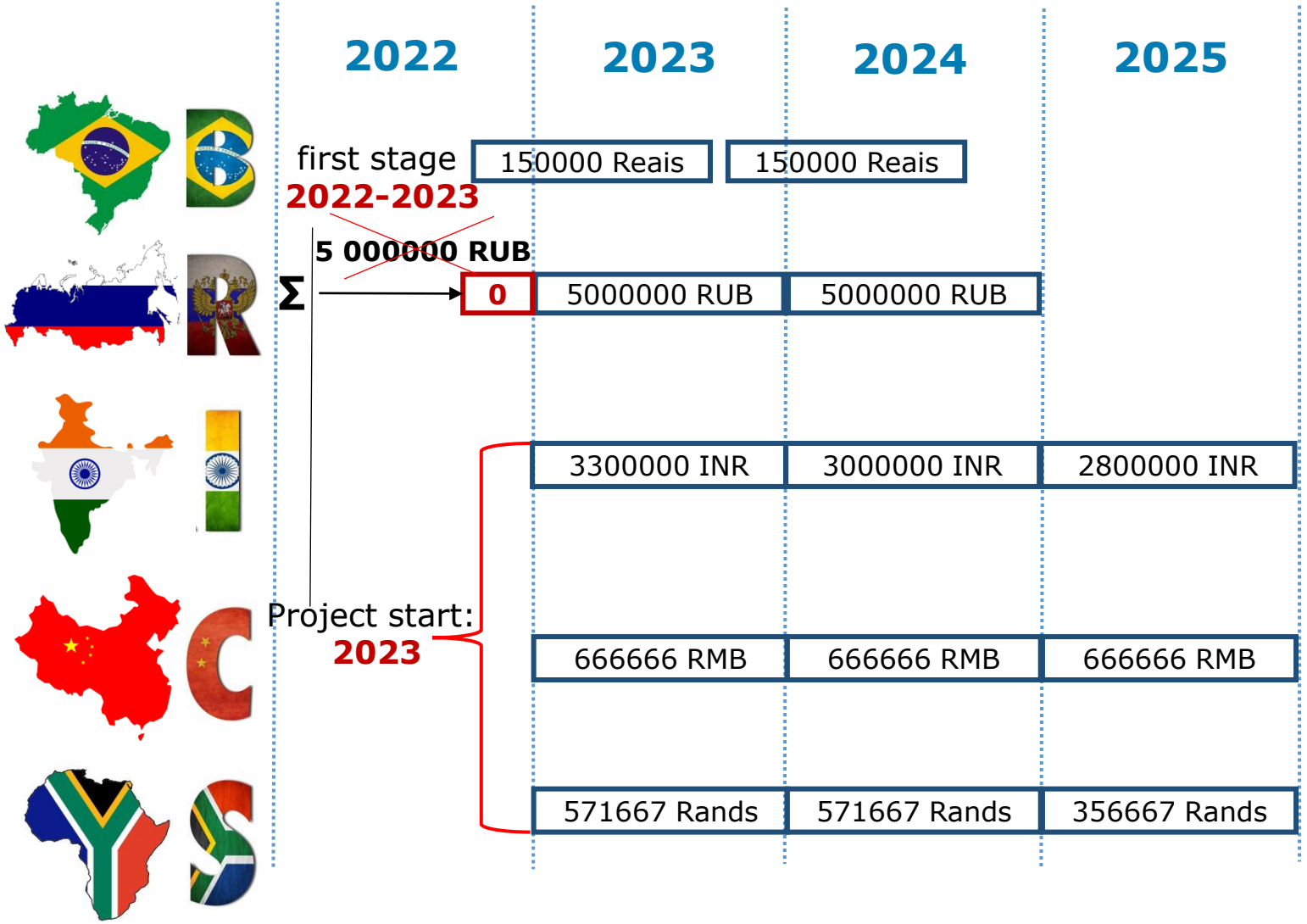
www.brics4water.org

Already challenges: again time and money



Thank you for attention!

BRICS4Water: Development of membrane-based methods to improve the recovery of pure water and valuable products from the waste

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RFBR RUSSIAN FOUNDATION FOR BASIC RESEARCH

NSFC

Department of Science & Technology
Ministry of Science & Technology
Government of India
सत्यमेव जयते

NRF National Research Foundation

CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

BRICS STI FRAMEWORK PROGRAM

TIPS RAS