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MASTERPLAN FOR RIVERBANK FILTRATION IN INDIA

TO MITIGATE CLIMATE CHANGE EFFECTS AND GROUNDWATER OVER EXPLOITATION

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ABSTRACT

The water sector in India is highly dynamic and spatially heterogeneous such that there is a complex interlinkage with the other resources of energy, land and the climate. With climate change exerting additional pressures and uncertainties on these interlinkages, the consequent unprecedented levels of resource depletion have catalyzed increasing scarcity and conflicts across the country, necessitating urgent research and policy interventions. Bank/ riverbank filtration (BF/RBF), which is an element of managed aquifer recharge (MAR), is a proven and sustainable natural water treatment technology, where surface water is infiltrated to an aquifer through river or lake banks resulting in water quality improvements. MAR, including BF, is recognized as an increasingly important water management strategy in areas faced with changing climate, rising intensity of climate extremes or overexploitation of groundwater resources, in order to maintain, enhance and secure stressed groundwater systems and to protect and improve water quality.

Despite these advantages, RBF is intentionally used only at some places in India resulting in a low portion (<0.1 %) of drinking water produced thereof. On the other hand, there is a large potential to secure at least 5 % of India's drinking water supply by RBF. This can be achieved by the preparation of a science-based masterplan for RBF water supply, which is one of the aims of an Indo-German RBF network project funded by the Federal Ministry of Education and Research of Germany from July 2020 to June 2023. The project consortium comprising 7 German and 8 Indian partners will collaborate to expand the R&D activities of the Indo-German Competence Centre for Riverbank Filtration that was established by the National Institute of Hydrology Roorkee and the University of Applied Sciences Dresden in 2011. The masterplan will be based on the R&D activities to develop RBF demonstration sites in Haridwar, Agra, North East India and Goa and a constructed wetland demonstration site in Varanasi. Thereby the diverse hydro-climatic and geological conditions are incorporated.

The development of the masterplan includes scientific procedures based upon results from research and interlinked with relevant policy. Hydrogeological, water quality and numerical groundwater flow modelling investigations will be highlighted for a few selected RBF sites along with information, education and communication measures used to develop the concept for the masterplan. Measures to implement the masterplan and associated scientific investigations to explore potential RBF sites will be highlighted based on some of the demonstration sites such as in Haridwar.

Experiences from some of these demonstration sites have shown that to implement a RBF masterplan on the ground, the division of RBF-competency within India must be absolutely clear because the water supply practitioners need robust scientific results from R&D/ academic institutes and competent consulting and engineering firms in the private sector to provide planning and construction services. More over a clear and specific policy on RBF and a body to oversee and monitor the progress of the RBF masterplan in India is advantageous.

Keywords: drinking water security, riverbank filtration, managed aquifer recharge, sustainability

1 INTRODUCTION

Bank/ riverbank filtration (BF/RBF) is used as a natural means of primary and pre-treatment by water utilities throughout the world, especially in Europe and North America. In Europe, 150 years of experience exist in the operation and maintenance of large bank filtration schemes. At many sites, RBF schemes have been successfully operated for several decades.The most important sites are situated along the rivers Danube, Rhine, Elbe, and the lakes in the Berlin city area. A large variety of schemes have been designed and operated according to site-specific conditions. Groundwater (GW) derived from infiltrating river water provides about 50 % of drinking water supplies in Hungary and 55 % in the Slovak Republic (Sprenger et al., 2017). RBF in Germany provides about 8 % of total drinking water supplies. The city of Duesseldorf, situated on the River Rhine, is entirely supplied with drinking water from RBF. In the Rhine basin, more than 20 million inhabitants receive drinking water which is directly or indirectly derived from river water, mostly via bank filtration. The water supply for the city of Berlin depends mainly on lake bank filtration. In the city of Dresden public water supply on an average relies up to approximately 32 % on bank filtrate and 66 % on surface water (SW) from reservoirs.Although in Europe new RBF site developments are rare due to decreasing water demand, there is a renaissance of RBF technology in the USA, South Korea, Egypt, Thailand, China and other countries (e.g. Ghodeif et al., 2016; Hu et al., 2016; Shamsuddin et al., 2014).

The highly dynamic and spatially heterogeneous water sector in India is a complex interlinkage of energy, water and land resources, whereby climate change is resulting in uncertainties in these interlinkages such that unprecedented levels of resource depletion are necessitating urgent research and policy interventions (Madhusoodhanan et al., 2016). Managed aquifer recharge (MAR), including BF, is recognized as an increasingly important water management strategy in areas faced with changing climate, rising intensity of climate extremes or overexploitation of groundwater resources, in order to maintain, enhance and secure stressed groundwater systems and to protect and improve water quality (Dillon et al., 2019).In India, RBF has large potential and serves as an ecosystem service for human health because it effectively removes contaminants, especially pathogens and turbidity from water for drinking (Sandhu et al., 2011). Investigations on existing RBF-based drinking water schemes in different parts of Indiahave demonstrated that in addition to pathogens and turbidity, dissolved organic carbon and organic micropollutants are removed and improvements of inorganic water quality occur (Dash et al., 2014; Ghosh et al., 2015; Glorian et al., 2018;Gupta et al., 2015; Sandhu et al., 2019). From a sustainability point of view, RBF systems make better sense than full-scale treatment plants using SW, since the energy and resource use in RBF will be lower and little to no chemical residues will be produced. RBF systems will require less energy to operate and to deliver a unit amount of water than conventional SW treatment systems. The ecological impact of SW depletion using RBF is low compared to full-scale SW treatment plants because a portion of pumped water is GW.

Despite the advantages of being a sustainable natural process, an element of integrated water resources management, conjunctive surface and groundwater use and a component of managed aquifer recharge(Grischek and Ray, 2009; Grischek et al., 2011), RBF is intentionally used only at some places in India resulting in a low portion of drinking water produced (<0.1% of total domestic water production; Sandhu et al., 2019). Moreover, only a few new drinking water schemes have been constructed to consciously take advantage of water quality improvements in the North Indian state of Uttarakhand since 2010 (Ronghang et al., 2019).

To take advantage of the benefits of RBF on a larger scale in India, it needs to be propagated in an organised manner. Therefore, it is necessary to reach out to the Indian water sector about RBF in a more consistent and wide-ranging way. Efforts towards this goal are being made since April 2014, when a strategy was developed at a workshop in April 2014 (HTWD and NIH, 2014). Subsequently the strategy evolved into a conceptual masterplancontainingscientific, policy, implementation and training aspects (Grischek et al., 2016). The conceptual masterplan evolved further with results and recommendations in conclusion to EU-India, German and Indian R&D projects (SaphPani, 2015; NIRWINDU, 2015–2018;Pey Jal Suraksha, 2016–2019) and discussions with water supply engineers and scientists during four training courses on RBF in India from 2016 to 2018 (NIH 2017; Uniyal et al., 2019). This strategy is holistically presented in this paper.

2 NEED FOR A SCIENCE-BASED MASTERPLAN FOR RBF

As of 2014, around 60% of the urban population in India or nearly 226 million persons (~19% of the total population; Census of India, 2011) were dependent on direct SW withdrawals and subsequent conventional treatment to meet their potable water requirements (Ghosh, 2014). However, the raw SW has been found on numerous occasions to contain pathogens, whose elimination by conventional treatment methods cannot be guaranteed especially for highly polluted surface waters and in monsoon, except by using cost- and maintenance-intensive membrane filtration and multi-step disinfection technologies. High levels of pollution in SW especially during low flow periods and high turbidity in monsoon, frequently interrupt the production of drinking water by conventional treatment plants.

A compilation of system design and capacity of 24 known small to large urban and rural RBF systems in different hydro-climatic conditions across India has indicated a total production capacity of all of these systems summed together to be around 384,000–410,000 m^3/day of water (Fig. 1).

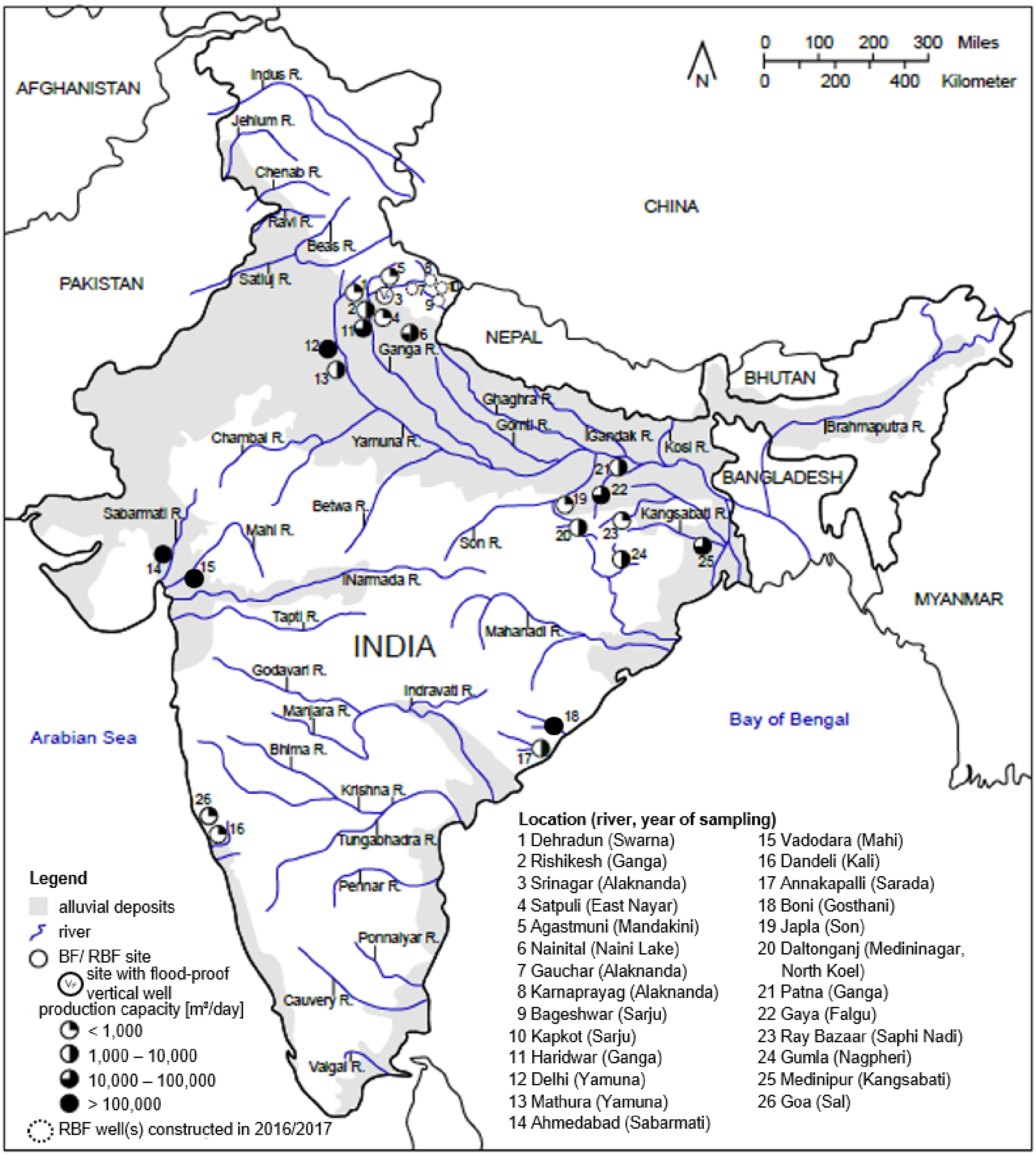

Fig. 1 Existing and potential RBF sites in India (Sandhu et al., 2019)

Considering the many existing but undocumented and unexplored RBF systems in India and taking into account the advantages of using RBF, there is a need to further explore the potential of bank filtration in India. In this context and by taking an example of a nation-wide strategy for the implementation of RBF in south-east Asia (Archwichai et al., 2011;Pholkern et al., 2015), there is not only scope for a scientifically based ranking system for assessment of RBF systems in India, but also the need for its organized further development by considering certain policy and implementation aspects.

3 MASTER PLAN FOR RBF WATER SUPPLY IN INDIA

3.1 SCIENTIFIC AND TECHNICAL ASPECTS

The development of a master plan must include scientific procedures to systematically select, investigate and evaluate potential RBF sites (Fig. 2). The need for these procedures has often come to light through interactions with Indian water supply organizations and is considered one of the most important components of the master plan. These procedures should include hydrogeological and water quality investigations and also recommendations for the management and maintenance of RBF systems.

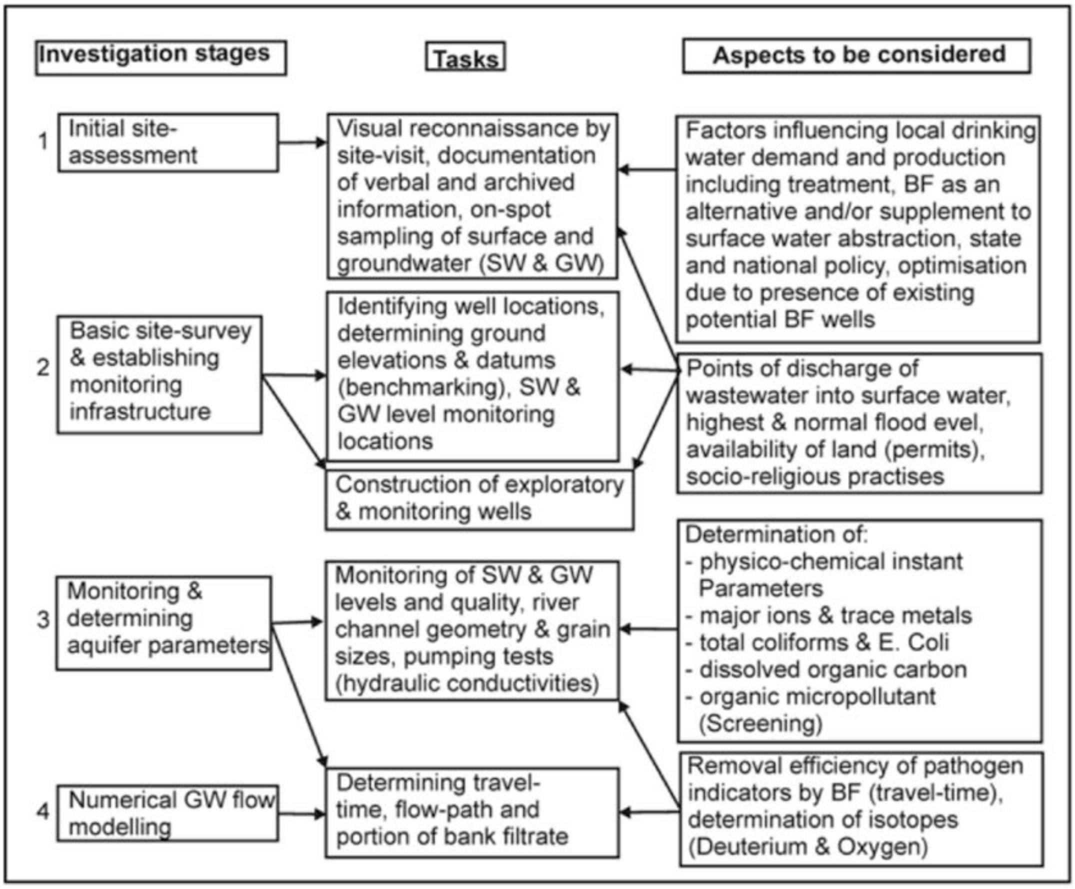

Fig. 2 Methodology to investigate a potential RBF site (Sandhu, 2015)

Comprehensive hydrogeological investigations are necessary to characterize the SW-GW interaction, determine the quantity of bank filtrate that can be abstracted and its travel time. Critical aspects thereby are the parametrization of the aquifer thickness, hydraulic conductivity, riverbed clogging and geochemical investigations of the riverbed sediment and its effect on the quality of bank filtrate. To guarantee the sustainability of RBF systems, it is necessary to routinely monitor water quality for pathogens, major ions and relevant inorganic parameters. The dissolved organic carbon and organic micropollutant concentrations should be monitored occasionally even though RBF serves as an effective barrier in removing them and lowers the risk of the potential formation of carcinogenic disinfection byproducts. In areas affected by nitrate, ammonium, iron, manganese, arsenic and fluoride, RBF should be applied with caution and only after feasibility or risk-assessment studies confirm that their concentrations would not exceed the limits in the Indian

Standard for Drinking Water (IS 10500, 2012) or appropriate post-treatment steps are implemented.

The identification of existing wells that are likely to be abstracting bank filtrate, drilling of exploratory wells and geophysical investigations are useful to characterize some of the hydrogeological conditions at a RBF site. During the operation of RBF wells, their abstraction rates and drawdowns should be routinely monitored.

3.2 POLICY AND PLANNING

The results of investigations conducted on RBF as part of various projects from 2005 to 2014 have demonstrated that it can potentially improve the drinking water supply in India (HTWD and NIH, 2014). If RBF is feasible at a potential site(section 3.1), then a detailed project report (DPR) for the full-scale development of the RBF site should be prepared. The DPR has to include the design, methodology of implementation and funding possibilities that are essential for developing the potential site into a full-scale RBF system.

For the effective propagation of RBF in the various states in India, the Central Government should issue a directive to state governments. The directive should emphasize the consideration and eventual application of RBF as an alternative and/or supplement to existing or planned direct SW abstraction systems. Such a directive will not only serve as an official “permission” from the Centre to the state governments, but also clear the path for state governments to seek subsequent technical and financial assistance to develop RBF from third parties, e.g. R&D organizations, universities, private and public sector enterprises and monetary institutions. As a positive example, the Department of Drinking Water of the Government of Uttarakhand, issued a government order (GO) in March 2006 wherein specific technologies for drinking water supply such as RBF and the use of indigenous “Koop” wells should be encouraged by water supply organizations working in Uttarakhand. This GO in turn simplified the participation of the Uttarakhand state water supply organization Uttarakhand Jal Sansthan (UJS) in national and international R&D, demonstration, capacity enhancement and research marketing projects on RBF and lead to the unhindered creation of a dedicated “RBF Cell” within UJS.

In the above context the following aspects are relevant for policy recommendations on RBF in India (SaphPani, 2015):

- RBF should be further developed and applied in India wherever there is a clearly-defined need for it and it is technically feasible, e.g. where suitable hydrogeological conditions exist and in combination with appropriate post-treatment systems.
- RBF projects could be financed within infrastructure development programmes of the Government of India like the National Rural Drinking Water Programme, Urban Development Programme and City Development Plans (CDP). Various other schemes such as the “Jawaharlal Nehru National Urban Renewal Mission (JNNURM)”, the Asian Development Bank’s current “North Eastern Region Capital Cities Development Investment Programme” and the World Bank’s “National Ganga River Basin Project” can also be considered.
- The technical (scientific) and socio-economic feasibility and benefits of using RBF for urban and decentralised water supply schemes should be investigated for locations (covered by above programmes) having suitable hydrogeological conditions and should be compared to existing (or planned) drinking water production plants using SW directly as source water.
- Safety issues should be highlighted by preparing a fact-sheet on related advantages of RBF, such as a high buffering capacity to cope with extreme events, accidental spills and terrorism.

3.3 IMPLEMENTATION

The implementation of the master plan for RBF requires an effective and proactive information, education and communication campaign, for which pivotal steps include:

- the establishment of first contacts with key officials at the higher administrative level and to transmit compact factsheets focusing on the holistic benefits of RBF with the aim to sensitize them,
- consolidate contacts with other interested (in the use of RBF) parties and conduct regional workshops tailored to their interests and to the needs of local water supply organizations that will help to solve site-specific RBF issues in a focused manner and to build engineering and management capacity,
- form core groups of interested administrators, state-level water supply practitioners and researchers and prepare adapted factsheets focusing on detailed science and technology aspects of RBF and associated service providers,
- organize regional meetings to bring together interested practitioners with suitable and interested enterprises (especially small-medium enterprises) and consulting firms that can provide services in planning, design, implementation and monitoring aspects of RBF systems. Like this both parties can benefit from the knowledge and develop longer-term collaborations with each other. This will also significantly enhance their competencies and improve their competitiveness.

The implementation of the master plan can be achieved through the formation of core groups possessing relevant science and engineering capabilities, interested researchers and state-level water supply practitioners by preparing adapted versions of the factsheets focusing on how RBF works and who can provide the associated services. Finally, the interested water supply organizations have to be linked with suitable and interested service providers (small-medium enterprises, consulting & well construction firms) through regional meetings. In this context, a database of industrial firms, including small and medium enterprises having the required skills, should be made and published via internet.

3.4 DEVELOPMENT OF RBF DEMONSTRATION SITES – HARIDWAR EXAMPLE

For greater visibility of RBF and improved technology transfer, at least one RBF demonstration site should be developed in the state where it can be applied. In 2005 the RBF well number 18 (well 18) on Pant Dweep island was equipped with two monitoring wells (Fig. 3). Wide-ranging civil engineering works, including intensive well-cleaning and construction of a sanitary seal and a boundary wall to create a well-head protection zone, were conducted. Detailed hydrogeological and water quality investigations commenced same year on well 18. The results of the investigations are on display at the well. A steady transfer of technology on different aspects of RBF-based water production to Uttarakhand Jal Sansthan (UJS; Uttarakhand State Water Supply Organisation) has also been achieved. During regular training courses, workshops and conferences conducted on RBF in nearby Roorkee and Dehradun, excursions have been organized to well 18 nearly every year since 2006. These excursions have enabled scientists, water resources engineers and managers, students and policy and decision makers to acquaint themselves with RBF.A major milestone as a result of these activities was the formal recognition as a RBF demonstration site by the UNESCO IAH Managed Aquifer Recharge Network in 2009.

Fig. 3a RBF well 18 at demonstration site

Fig. 3b Monitoring wells at well 18

One of the crucial issues in India for year-round safe drinking water from RBF schemes is to achieve a robust and sustainable disinfection (Sharma et al., 2016). A solution successfully tested at the RBF demonstration well 18was the coupling of inline-electrolysis pilot-plants (to well 18) for stand-alone decentralized disinfection of water with a capacity to disinfect ~20 m³/day running on photovoltaic energy and manufactured by AUTARCON GmbH (Fig. 4a& b; Otter et al., 2019; AquaNES, 2016–2019) and a medium-capacity plant to disinfect around 1,600 m³/day manufactured by Hydrosystemtechnik GmbH in research cooperation with the DVGW Water Technology Centre in Dresden (Fig. 4c), HTW Dresden and UJS (NIRWINDU, 2015–2018). Water quality monitoring results from both plants over 12 months operation show that no total coliforms and E. coli were present in the produced (disinfected) drinking water. Therefore both systems are potential solutions to achieve continuous and robust disinfection.

Fig. 4a–c Small- (left & center) and medium-scale (right) inline-electrolysis pilot plants at well 18 (Photos 4a & b: P. Otter, AUTARCON, 2016; 4c: Hydrosys / TZWD, 2016)

A major aim of the recently commenced project "Expansion of the Indo-German Competence Centre for Riverbank Filtration – CCRBF" (07/2020 – 06/2023) is the further development of the RBF demonstration site in Haridwar and the new development of three RBF demonstration sites in Agra, North-East India and Goa and the development of a new constructed wetland demonstration site in Varanasi (Fig. 5). The CCRBF project consortium comprises seven German and eight Indian partners (Tab. 1). They will collaborate to expand the R&D activities of the Indo-German Competence Centre for Riverbank Filtration that was established by the National Institute of Hydrology Roorkee and the University of Applied Sciences Dresden in 2011 (Fig. 6). The masterplan will be based on the R&D activities that will accompany the development of these demonstration sites. Thereby the diverse hydro-climatic and geological conditions are incorporated.

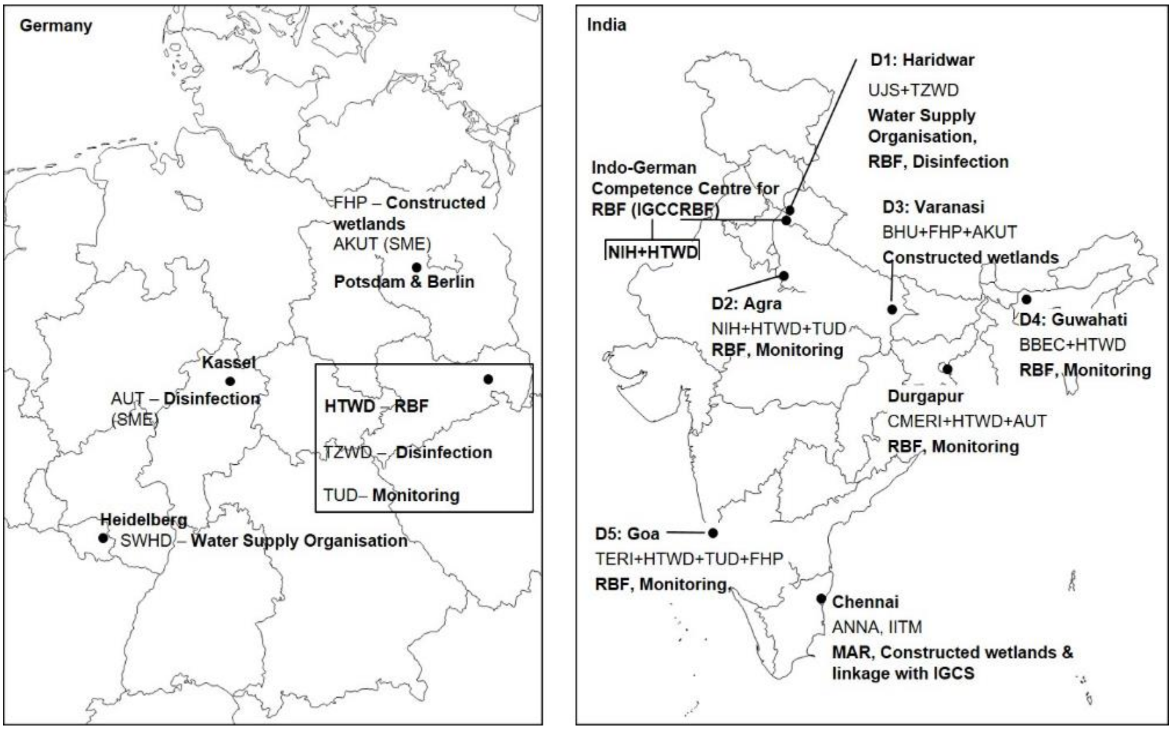

Fig. 5 Location of Indo-German CCRBF project consortium partners, five demonstration and two case-study sites in India (D1–D5) and thematic focus of partners (bold letters)

Tab. 1 CCRBF project consortium partners

Germany	**India**
University of Applied Sciences Dresden (HTWD): Project principal investigator and coordinator [R&D & IHE]	National Institute of Hydrology, Roorkee (NIH) [R&D]: project co-coordinator
DVGWWater Technology Center, Dresden branch (TZWD) [R&D]	Uttarakhand Jal Sansthan, Uttarakhand (UJS) [utility]
Institute for Water Chemistry, TechnischeUniversität Dresden (TUD) [R&D]	Banaras Hindu University, Institute of Environment and Sustainable Development, Varansi (BHU) [R&D & IHE]
University of Applied Sciences Potsdam (FHP) [R&D & IHE]	Bineswar Brahma Engineering College, Kokrajhar, Assam (BBEC) [R&D & IHE]
AKUT Umweltschutz Ingenieure Burkard und Partner mbB, Berlin (AKUT) [SME]	The Energy & Resources Institute, Southern Regional Centre, Goa (TERI) [R&D]
AUTARCON GmbH, Kassel (AUT) [SME]	Anna University, Department of Geology, Chennai (ANNA) [R&D & IHE]
Stadtwerke Heidelberg / Waterworks Heidelberg (SWHD) [utility]	Council of Scientific and Industrial Research – Central Mechanical Engineering Research Institute, Durgapur, West Bengal(CMERI) [R&D]
Abbreviations IHE: institute of higher education R&D: research & development SME: small-medium enterprise	Indian Institute of Technology Madras (IITM)/ Indo-German Centre for Sustainability at IITM [R&D & IHE]

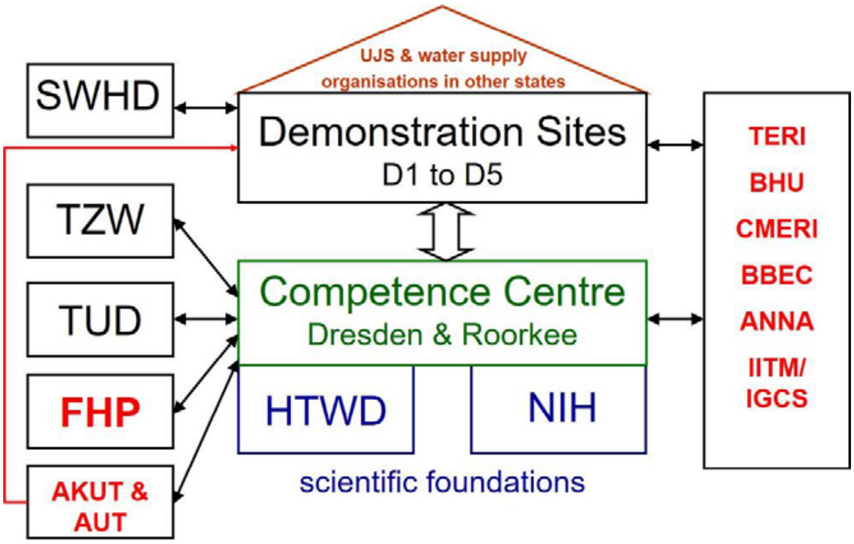

Fig. 6 CCRBF project structure (2020 –2023)

3.5 CAPACITY DEVELOPMENT AND TRAINING

The implementation of the masterplan to achieve the 5 % RBF water supply target will be difficult to realize unless trained human resources, especially from water supply organizations, and specialized industries to undertake RBF-related activities are available.In this context and regarding the implementation aspects, the CCRBF has attained technical experience in the implementation of RBF projects mainly in Uttarakhand. The Indian CCRBF project consortium partnersarewell positioned to propagate RBF scientifically at a national level. Thus the CCRBF are presently in a good position to technically assist other state governments to implement RBF across India. But to be able to effectively assist other states, it is first necessary to strengthen their own capacity.

In response to the above, NIH with technical support from HTWD, Uttarakhand and some other Indian and German partners from the CCRBF project consortiumorganised four 5-day-long training courses on RBF between September 2016 and March 2018(NIH & UCOST, 2016–2018). The courses aimed to support the development of new RBF systems in different river basins covering all states of India. Consequently, they provided scientific and technological knowledge on wide-ranging and India-specific aspects of RBF to engineers from state government water resources and water supply departments, scientists and other stakeholders. Engineers who attended these courses suggested that as a policy, RBF should be considered as a supplementary source for rural water supply. Taking the example of the state of Gujarat where village-level water committees (“*panisamitis*”) manage their water sources, the committees would be prepared to use RBF if its application improves the quality of water supplied to them. Experience from Gujarat has shown that there is scope to evolve a business model for the application of RBF in rural areas, because there is a willingness to pay (tariffs) for high quality water supplied from schemes which are built by the government.

The further development of the “Master Plan for RBF in India” and especially its implementation could become a major long-term collaborative project of the Federal Ministry of Education and Research (BMBF) in Germany and the Ministry of Jal Shakti (formerly Ministry of Water Resources, River Development and Ganga Rejuvenation) and the Ministries of Science and Technology, Drinking Water and Sanitation, Rural Development and Urban Development in India under the umbrella of the Indo German Science and Technology Centre (IGSTC).

4 CONCLUSIONS

To implement a RBF master plan on the ground, the division of RBF-competency within India must be absolutely clear because the water supply practitioners need competent consulting firms in the private sector to provide planning and construction services. And the consulting firms need competent technical advisors at universities and research institutions to provide know-how and solve challenging problems encountered during the execution of work for RBF systems. The development of this competence must occur in parallel to, or shortly after, an IEC campaign, such that there is a corresponding supply for the demand that arises.

A concerted central and state government action would be required to support the vision of 5 % water supply based on RBF by the year 2030, including administration and funding. Based on long-term experiences from Europe, a focused investment on RBF-based drinking water projects, further enhancement of the scientific and technical expertise of the CCRBF project consortium and capacity development especially of water supply organizations, firms and other involved stakeholders is much needed to achieve the vision. Potential future research topics willaddress the inclusion of RBF for wastewater treatment similar to constructed wetlands, as will be demonstrated for the constructed wetland demonstration site in Varanasi (D3 in Fig. 5).

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REFERENCES

AquaNES (2016–2019) Demonstrating synergies in combined natural and engineered processes for water treatment systems. Available: http://www.aquanes-h20.eu.

Archwichai, L., Srisuk, K., Chusanatus, S., Pholkern, K., Munyou, S.,Saraphirom, P. (2011) Development of the Site Selection Criteria for Riverbank Filtration Project, Thailand. In: Proc. Int. Conf. GEOINDO 2011, KhonKaen, Thailand, 1 - 3 December 2011, 352-361.

Census of India (2011) Provisional Population Totals. Census of India, Office of The Registrar General and Census Commissioner, Ministry of Home Affairs, Government of India. Available: http://censusindia.gov.in/ 2011-prov-results/paper 2/data_files/india/Rural_ Urban_2011.pdf

Dash, R.R., Mehrotra, I., Kumar, P., Grischek, T. (2014) Study of water quality improvements at a riverbank filtration site along the upper course of the River Ganga, India. Desalination and Water Treatment 54(9), 2422-2431.

Dillon, P., Stuyfzand, P., Grischek, T., et al. (2019) Sixty years of global progress in managed aquifer recharge. Hydrogeol. J. 27,1-30.

Ghodeif, K., Grischek, T., Bartak, R., Wahaab, R.,Herlitzius, J. (2016) Potential of river bank filtration (RBF) in Egypt. Environ. Earth Sci. 75:671, doi: 10.1007/s12665-016-5454-3.

Ghosh, N.C. (2014) Future steps for bank filtration in India. Int. Conf. on Natural Treatment Systems for Safe and Sustainable Water Supply in India: Results from the “SaphPani Project”. 18-19 September 2014, New Delhi, India.

Ghosh, N.C., Khatania, S.K., Indwar, S.P., Sandhu, C.S.S., Jain, C.K., Mittal, S., Goel, R. (2015) Performance evaluation of riverbank filtration scheme. Current Science 109(2), 301-310.

Glorian, H., Börnick, H., Sandhu, C., Grischek, T. (2018) Water quality monitoring in Northern India for an evaluation of the efficiency of bank filtration sites. Water 10, 1804.

Grischek, T., Ray, C. (2009) Bank filtration as managed surface - groundwater interaction. Int. J. Water 5(2), 125-139.

Grischek, T., Schoenheinz, D.,Sandhu, C. (2011) Water Resources Management and Riverbank Filtration. In: Dobhal, R., Grischek, T., Uniyal, H.P., Uniyal, D.P.,Sandhu C. (eds.) Drinking Water – Source, Treatment and Distribution. Uttarakhand State Council for Science and Technology (UCOST), Dehradun, 1-7.

Grischek, T., Sandhu, C., Ghosh, N.C., Kimothi, P.C. (2016) A Conceptual Master Plan for RBF Water Supply in India – Science, Policy & Implementation Aspects. Proc. Indo-German Conference on Sustainability 2016, Indo-German Centre for Sustainability (IGCS, IIT Madras & RWTH Aachen), Chennai (Indien), 27.–28.02.2016, 118-123.

Gupta, A., Singh, H., Ahmed, F., Mehrotra, I., Kumar, P., Kumar, S., Grischek, T., Sandhu, C. (2015) Lake bank filtration in landslide debris: irregular hydrology with effective filtration. Sustain. Water Resour. Manag. 1(1), 15-26.

Hu, B., Teng, Y., Zhai, Y., Zuo, R., Li, J., Chen, H. (2016) Riverbank filtration in China: A review and perspective. J. Hydrol. 541, 914-927.

IS 10500 (2012) Drinking Water - Specification. Indian Standard (second revision), Bureau of Indian Standards, New Delhi, India.

Madhusoodhanan, C.G., Sreeja, K.G., Eldho, T.I. (2016) Climate change impact assessments on the water resources of India under extensive human interventions. Ambio 45, 725-741.

NIH& UCOST (2016–2018) Country-wide Capacity Building Program on Bank Filtration for Sustainable Drinking Water Supply. Ground Water Hydrology Division, National Institute of Hydrology Roorkee and Uttarakhand State Council for Science & Technology (09/2016–03/2018); fundedby Department of Science & Technology (DST), Ministry of Science & Technology, Government of India.

NIRWINDU (2015–2018) Safe and sustainable drinking water production in India by coupling natural and innovative techniques – NIRWINDU. Project funded by the German Federal Ministry of Education and Research (BMBF) CLIENT programme, grant agreement no. 02WCL1356. https://www.htw-dresden.de/nirwindu

Otter, P., Malakar, P., Sandhu, C., Grischek, T., Sharma, S.K., Kimothi, P.C., Nüske, G., Wagner, M., Goldmaier, A., Benz, F. (2019) Combination of river bank filtration and solar-driven electro-chlorination assuring safe drinking water supply for river bound communities in India. Water 11, 122.

PeyJal Suraksha (2016–2019) Project funded by Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India.

Pholkern, K., Srisuk, K., Grischek, T., Soares, M., Schäfer, S., Archwichai, L., Saraphirom, P., Pavelic, P.,Wirojanagud, W. (2015) Riverbed clogging experiments at potential river bank filtration sites along the Ping River, Chiang Mai, Thailand. Environ. Earth Sci. 73(12), 7699-7709.

Ronghang, M., Gupta, A., Mehrotra, I., Kumar, P., Patwal, P., Kumar, S., Grischek, T., Sandhu, C. (2019) Riverbank filtration: a case study of four sites in the hilly regions of Uttarakhand, India. Sustain. Water Resour. Manag. 5(2), 831-845.

Sandhu, C. (2015) A concept for the investigation of riverbank filtration sites for potable water supply in India. PhD thesis, TU Dresden, Faculty of Environmental Sciences, and University of Applied Sciences Dresden, Germany. http://nbn-resolving.de/urn:nbn:de:bsz:14-qucosa-208460.

Sandhu, C., Grischek, T., Kumar, P., Ray, C. (2011) Potential for riverbank filtration in India. Clean Technologies and Environmental Policy 13(2), 295-316.

Sandhu, C., Grischek, T., Börnick, H., Feller, J., Sharma, S.K. (2019) A water quality appraisal of some existing and potential riverbank filtration sites in India. Water 11, 215.

SaphPani (2015) Policy recommendations for bank filtration in India. In: Final report summary – SaphPani. CORDIS – Community Research and Development Information Service, European Commission. http://cordis.europa.eu/result/rcn/165667_en.html (accessed 28Sept 2020).

Shamsuddin, M.K.N., Sulaiman, W.N.A., Suratman, S., Zakaria, M.P.,Samuding, K. (2014) Groundwater and surface-water utilisation using a bank infiltration technique in Malaysia. Hydrogeol. J. 22, 543-564.

Sharma, S.K., Sandhu, C., Grischek, T., Gupta, A., Kumar, P., Mehrotra, I., Grützmacher, G., Sajilkumar, P.J., Lakshmanan, E., Ghosh, N.C. (2016) Pre- and Post-treatment of BF and MAR in India: Present and Future. In: Wintgens, T., Nättorp, A., Lakshmanan, E., Asolekar, S.R. (eds.) Natural water treatment systems for safe and sustainable water supply in the Indian context – SaphPani. IWA Publishing, London, UK, 2016, 191–206. ISBN13-9781780407104.

Sprenger, C., Hartog, N., Hernández, M., Vilanova, E., Grützmacher, G., Scheibler, F.,Hannappel, S. (2017) Inventory of managed aquifer recharge sites in Europe: historical development, current situation and perspectives. Hydrogeol. J. 25, 1909-1922.

HTWD and NIH (2014) Recommendations of the “Indo-German Workshop on Science-based Master Planning for Bank Filtration Water Supply in India”. University of Applied Sciences Dresden and National Institute of Hydrology Roorkee. 8-10 April 2014, Dresden, Germany.

Uniyal, D.P., Dobhal, R., Ghosh, N.C., Aswal, J.S. (2019) Awareness strategies on bank filtration in India. In: Dobhal, R., Uniyal, D.P., Ghosh, N.C., Grischek, T., Sandhu, C. (eds.) Guidelines on bank filtration for water supply in India. Uttarakhand State Council for Science & Technology (UCOST) and M/s Bishen Singh Mahendra Pal Singh, Dehradun, 115–126, ISBN: 978-8121109932.

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