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# Addressing water stress through wastewater reuse: Complexities and challenges in Bangalore, India

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## Abstract:

Wastewater reuse is an important adaptation option for mitigating water stress in rapidly growing urban centres. But, wastewater reuse is easier said than done, particularly in developing countries. The task becomes even more challenging when one takes a basin-level perspective. We illustrate these challenges by studying the Vrishabhavathy River in Bangalore, India, which carries almost half of the city's wastewater. First, we find that the sewage treatment plant (STP) located on this river does not function efficiently and no positive impact of effluent discharge on river water quality was observed. Second, while the Sewerage Board has implemented conventional centralized sewage treatment and proposed its expansion and even larger scale projects, decentralized wastewater treatment, advocated by many civil society groups, may be more cost effective. Options at all scales, however, face several institutional challenges in implementation. Third, while untreated wastewater is a health hazard for downstream farmers using this water for irrigation, substantial wastewater recycling upstream would have a negative impact on their livelihoods by reducing the quantity of water available for irrigation. In addition, as the Vrishabhavathy is a tributary of the inter-state river Cauvery, reduced flows might impact on inter-state water sharing commitments complicating matters further. Realizing the potential of wastewater reuse in Bangalore will thus require techno-institutional integration and thinking at a basin scale.#

## Keywords:

Wastewater reuse and recycling, Treatment plant efficiency, Decentralized wastewater treatment, Downstream impacts

## 1. Introduction

Urban centres are expanding rapidly, particularly in developing countries like India that are witnessing rapid economic growth. As a result, there is the dual challenge of meeting the growing water demand from domestic, and industrial sectors, and of safely disposing/treating of the wastewater. Cities are reaching deeper into the hinterland or across river basins, and depleting their groundwater resources to meet their water needs, while the discharge of untreated effluents into water bodies rises in spite of increasing investments in wastewater treatment. In this context, wastewater treatment and reuse (WWRU) is often seen as a win-win proposition, as it increases net water availability, reduces dependence on other river basins and/or increases the groundwater buffer, while reducing negative health impacts on downstream water users and aquatic life.

While the idea of WWRU is tempting, several challenges remain. The health risks with wastewater reuse for downstream agriculture have been pointed out at length (Drechsel et al. 2009). But the idea of recycling water upstream for reuse in the city itself poses further challenges. What are these challenges and how does 'basin-level' thinking affect our understanding of WWRU? We explore these questions using preliminary findings from studies conducted in and around Bangalore city in southern India as part of the research project 'Adapting to Climate Change in Urbanizing Watersheds' (http://www.atree.org/project-ACCUWa) being supported by Canada's International Development Research Centre, complemented by research supported by the Tata Social Welfare Trust and the Department of Science and Technology. We begin by describing how wastewater is generated in Bangalore and currently reused downstream. Three challenges with WWRU are then discussed using data from our study of wastewater treatment, an analysis of ongoing debates regarding the scale of treatment, and our ongoing study of the downstream use and impacts of polluted water. We illustrate and argue that upstream WWRU may not be as straightforward and clear-cut an option as city planners tend to assume. Potential impacts downstream and the techno-institutional context in which it is applied need to be addressed in using WWRU as a strategy to reduce water stress.

### 2. Bangalore's wastewater and the Vrishabhavathy River basin

Bangalore is a mega-city in southern India with burgeoning light industrial and service sectors. The population of the city has doubled in the last decade (from 4.2 million in 2001 to 8.4 million in 2011). Although part of this increase has come from expanding Bangalore's boundaries to include neighbouring villages and towns, the attraction of jobs in this booming economy has been the key driver of in-migration. Previously water demand of Bangalore city was met from the sources within the basin. TG Halli and Hesaraghatta reservoirs used to supply 135 million litres per day (MLD) of drinking water to Bangalore city (Kumar 2009). The consequent growth in water demand as result of population growth has been met by increasing water imports from the Cauvery River and by increasing ground water extraction. This has however increased conflict with water users along the Cauvery River (Shiva Kumar 2012) and depleted groundwater resources on the fringes of the city (DMG 2011).

The city's wastewater treatment systems have not kept pace with the growth in water use. While imported water increased from 453 MLD in 1991 to 1360 MLD in 2013, the installed capacity of wastewater treatment plants (WWTPs) only increased from 420 MLD (primary treatment level) to 721 MLD (secondary treatment level) in the same period. The total wastewater generated in the city is estimated to be 1100 MLD (Vishwanath 2014) although no reliable estimates are available. The city has 14 centralized sewage treatment plants (STPs) managed by the Bangalore Water Supply and Sewerage Board (BWSSB) and 612 decentralized STPs managed by private owners. At present centralized and decentralized STPs are operating at 63.5% and 75% of their designed capacities, respectively (Times of India 2014). While the lack of an underground drainage (UGD) system means that the treatment capacity of centralized STPs is under-utilised, the decentralized STPs are overdesigned to meet the future wastewater inputs.

The fate of wastewater discharged from Bangalore city is presented in Figure1. Out of the total treated effluent from centralized STPs, only 4 MLD is reused by industries for non-potable purposes (Smitha 2006). The rest of the treated effluent, along with the untreated sewage, is discharged into open storm drains. There is no official data available on the reuse of effluent from private STPs. The net result is that an estimated 64% of Bangalore's untreated wastewater enters into its two river systems.

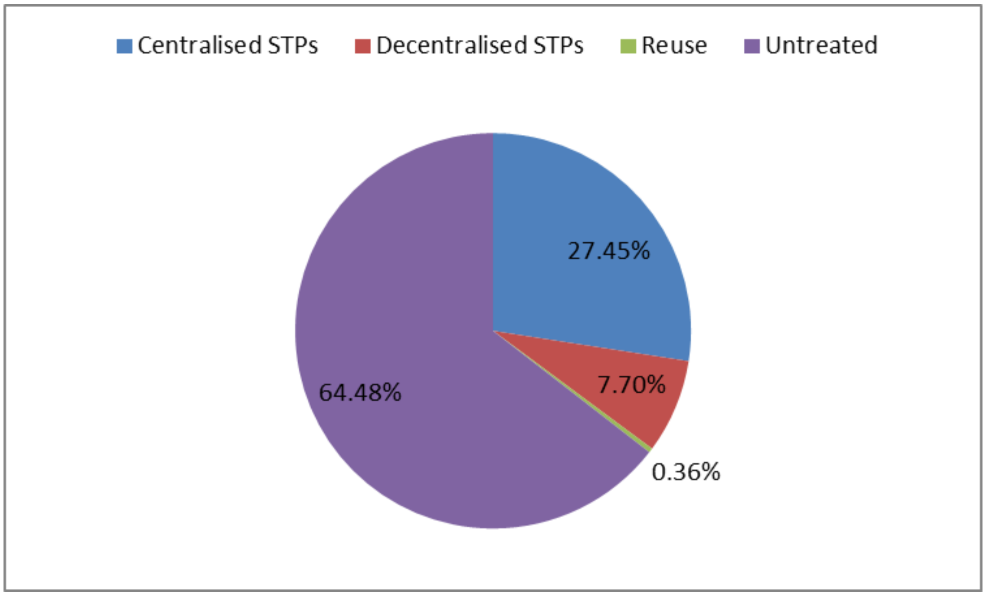


**Figure 1: Wastewater and its disposal in Bangalore (CII 2014)**

The city straddles two river basins: the Arkavathy-Vrishabhavathy basin on the west and the Pinakini basin to the east. Bangalore's wastewater enters the Vrishabhavathy and the Pinakini in almost equal quantities. Our study focuses on the Vrishabhavathy River, which originates in Bangalore and joins the Arkavathy about 50km downstream, and has a total catchment of 560 sq. km. An irrigation reservoir, called the Byramangala Dam, has been constructed across the Vrishabhavathy and farmers around the Byramangala reservoir irrigate their crops with the highly polluted but also nutrient-rich river water.

## 3. Challenges to wastewater reuse/recycling in Bangalore

Given the increasing demand for water, and the fact that Bangalore is at the limit of what it can legally withdraw from the Cauvery River, several analysts argue that the reuse and recycling of wastewater in Bangalore needs to be seriously considered (Hegde and Chandra 2012; CII 2014). The questions we explore here are whether this is already happening and to what extent, and what challenges would be faced by any attempt to expand WWRU in Bangalore, with a special focus on what insights are provided by basin-scale and integrative thinking. Based on our ongoing research in the region we have identified three major challenges, which we shall discuss below.

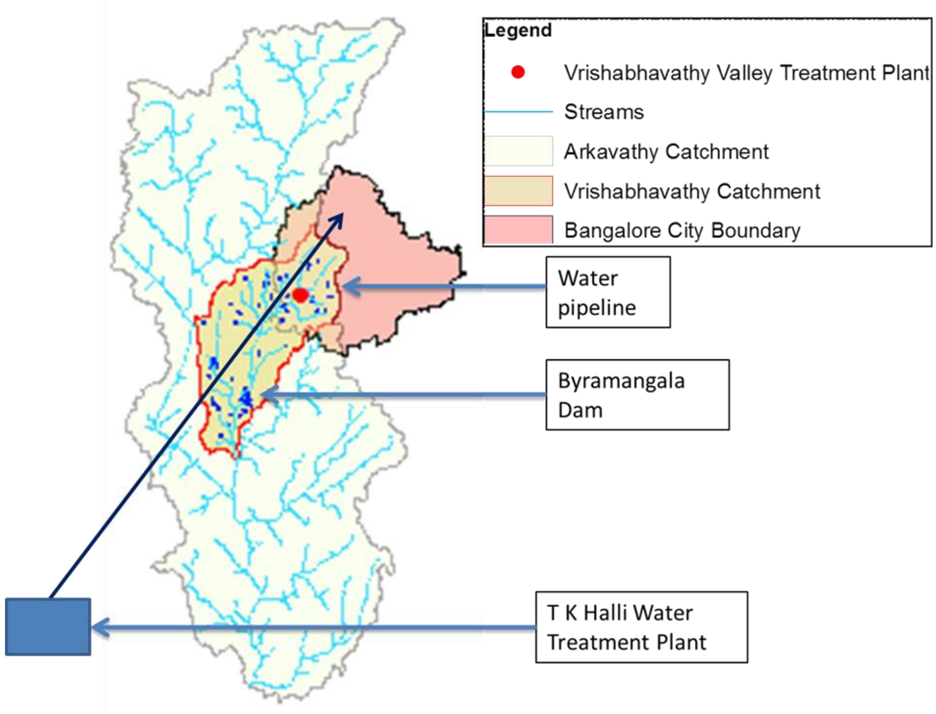


**Figure 2. Bangalore and the Vrishabhavathy River sub-basin**

## 3.1. Efficiency and efficacy of waste water treatment plants[1]

The first requirement for WWRU is that the WWTPs function efficiently and efficaciously. The removal efficiency of a wastewater treatment system is defined as the percent reduction in pollutant concentration that occurs during the treatment process (Jamwal et al. 2009). WWTPs can be inefficient for many reasons, with a prominent one being that secondary wastewater treatment employs a biological process and therefore requires optimal influent biochemical oxygen demand (BOD) to support biomass growth in aerobic reactor for WWTP to function (Daniel et al. 2002; Jamwal et al. 2009). However, the efficacy of WWTPs may be defined as whether they eventually achieve the goal of producing clean water, and whether the water of the rivers that emerge from cities meets environmental standards (CPCB 2014).Our study of one of the largest WWTPs in Bangalore, viz. the Vrishabhavathy Valley Treatment Plant (VVTP) points to many limitations on this front.

VVTP is located on the bank of the Vrishabhavathy River at a point 14 km from its origin. The catchment at this point is 78 sq. km. and the estimated river flow is 500 MLD. The upstream catchment of VVTP contains both domestic and industrial water users (EMPRI 2008). VVTP is designed to treat 180 MLD of sewage. It employs primary, secondary and tertiary water treatment technologies: 120 MLD capacity up to

[1]This section draws upon detailed findings presented in Jamwal et al. 2014.

secondary level and 60 MLD up to tertiary levels. However, due to the lack of an UGD system in many parts of its catchment, the VVTP receives only 26 MLD via the sewerage network, and so it takes in another 104 MLD directly from the Vrishabhavathy River (Figure 3). Ironically, while Bangalore faces water stress, 3 MLD of the tertiary-treated water is sold to industry, with the rest released back to the Vrishabhavathy. A schematic diagram of wastewater treatment and reuse at VVTP is presented in Figure 4.

**Figure 3. Wastewater diversion to VVTP from the Vrishabhavathy River**

To evaluate the process efficiency, water samples were collected at the inlet (VVTP-1) and exit (VVTP-2) of VVTP. The efficacy of VVTP on river water quality was investigated using a combination of water quality testing and mass balance modelling to estimate pollutant concentration (Jamwal et al. 2014). River samples were collected upstream (VRH-5) and downstream (VRH-6) of VVTP. The volume of river flow was estimated, so as to enable a mass balance. River water quality at VRH-6 was also estimated using a simple mass balance model. The observed and estimated river water quality was compared to understand the causes of the observed patterns. The water samples were analysed for physical, chemical and biological parameters. The levels of various contaminants were estimated following the American Public Health Association (APHA 2005).

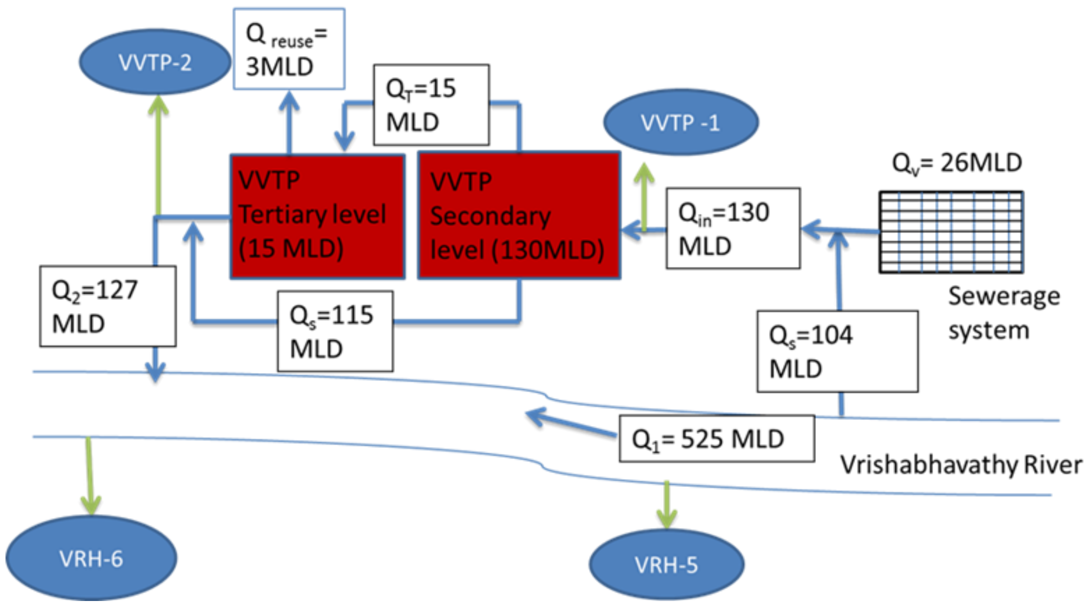


**Figure 4. Schematic diagram of the study site indicating water flow and sampling points**

**Vrishabhavathy Valley Treatment Plant efficiency**

A comparison of effluent water quality with the discharge standards is presented in Figure 5. The data shows that the 5 day BOD ($BOD_5$) removal efficiency of VVTP is very low and the effluent does not meet the discharge standards for $BOD_5$ and fecal coliforms (FC) (CPCB). The total suspended solids (TSS), $BOD_5$ and chemical oxygen demand (COD) removal efficiency of VVTP was 82 %, 77% and 47%, respectively. The low $BOD_5$ removal efficiency could be attributed to the low $BOD_5$/COD ratio in influent samples. The quality of influent does not meet the $BOD_5$ design criteria thereby impacting the overall efficiency of VVTP. Average $BOD_5$/COD ratio in influent water at VVTP-1 was less than 0.2, which suggests that the biological treatment process is not appropriate for non-biodegradable wastewater.

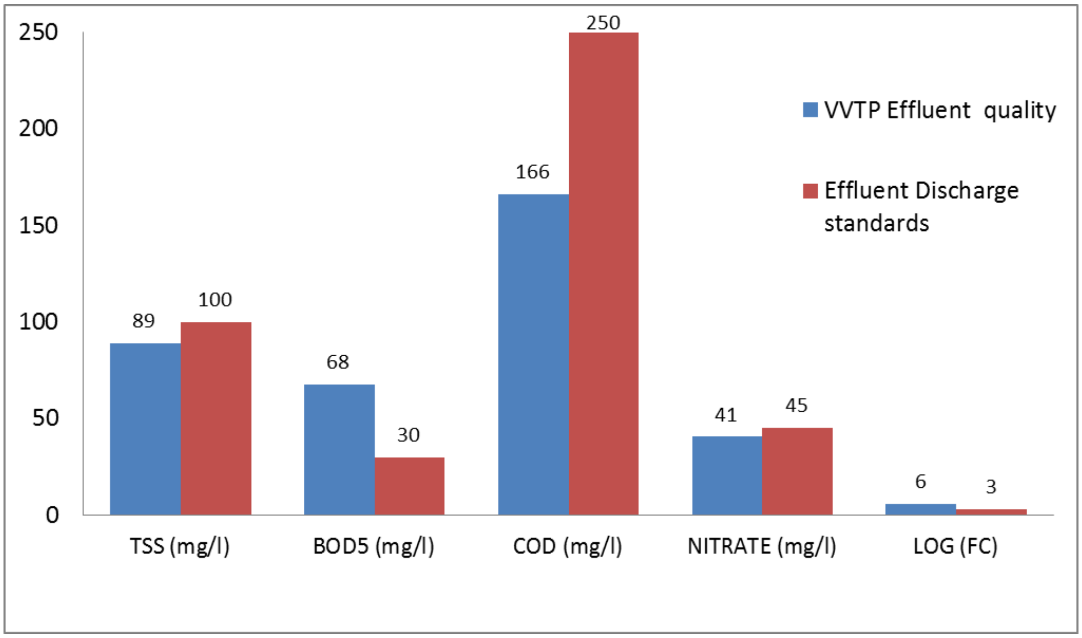


**Figure 5. Comparison of VVTP effluent water quality with CPCB effluent discharge standards**

**Efficacy of Vrishabhavathy Valley Treatment Plant at the river scale**

To evaluate the impact of VVTP on overall river water quality, the average levels of various physical, chemical and biological parameters at the upstream (VRH-5) and downstream (VRH-6) sites were compared statistically. Interestingly, except for COD, no significant difference was observed in the mean levels of TSS, $BOD_5$, Nitrates, FC and fecal streptococcus (FS) levels at VRH-5 and VRH-6 ($p<0.05$). Given that the VVTP itself is achieving some reductions in $BOD_5$ levels, we hypothesized that the overall lack of improvement might be due to the re-suspension of organic sediments. To confirm this, we compared the proportion of dissolved and suspended COD at VRH-5 and VRH-6, and found that the fraction of suspended COD was higher at the downstream site. The effluent discharge from VVTP increases the river's flow velocity, which causes particles to re-suspend and contribute to $BOD_5$ load. Similar studies conducted by various researchers on river water quality found that the re-suspension of particulates into the water column is one of the major causes of pollution during high-flow periods (Azzellino et al. 2006; Passerat et al. 2011).

Thus, an inadequate UGD network forces VVTP to try to treat a part of the Vrishabhavathy River flow. Our study indicates that this diversion may be negatively affecting the treatment efficiency of VVTP as seventy to eighty percent of the total organic matter in the influent water is non-biodegradable. The WWTPs are designed to treat the biodegradable waste; therefore, to improve the efficiency of VVTP either the biological parameters needs to be modified or chemical treatment process needs to be employed. Secondly, this lifting and subsequent discharge of water back into the river causes re-suspension of particles in river due to increased flow velocity and turbulence, thereby further reducing the overall impact of the treatment plant on the river's water quality. Thirdly, the problem will not be solved by improving the UGD network alone, because the under-utilization of WWTP capacity is across the board (CSE 2012a) and is also caused by poor operations, poor electricity supply, clogging of existing UGD networks, among other issues (Jamwal and Mittal 2010).

### 3.2. Scale and social organization of urban WWRU[2]

The response of BWSSB has been at two scales. At the conventional scale, it has invested heavily in building more STPs, with contracts for 11 new STPs already issued (BWSSB 2014). At a bigger scale, BWSSB has proposed two major projects for the in-stream treatment and reuse of wastewater by transporting large volumes of treated wastewater into the drying Arkavathy river. One project involves diversion from the Vrishabhavathy to their reservoir on the western edge of the city (CSE 2012a), and another involves an even bigger diversion from the treatment plant on the east to the upstream origin of the Arkavathy (Nataraj 2013). On the other hand, several analysts have proposed more neighbourhood-scale treatment and reuse, with lakes acting as water storage structures (CSE 2012b). Finally, WWRU is already being enforced at a micro-scale due to certain regulations imposed by the Karnataka State Pollution Control Board (KSPCB) on apartment complexes. Under these regulations, apartment complexes of more than 50 apartments are required to install STPs and recycle and reuse all their effluents under a zero-liquid-discharge order by the KSPCB (CII 2014). However, there is a need to seriously examine how different WWRU options fare in terms of technically feasibility, economic viability and social practicality. Moreover, the debate has focused primarily on the technical aspects, whereas the challenges on the socio-economic and institutional side need more attention (Harsha 2012). A preliminary characterization of the different scales at which WWRU can be carried out is given in Table 1.

[2] This section is based on preliminary analysis of the literature, interviews and secondary data.

**Table 1. Socio-technical characteristics of WWRU options at different scales**

| Scale | Method | Implementer | Regulator | User | Challenge |
|---|---|---|---|---|---|
| 100+ MLD | Large-scale transport and in-stream treatment | BWSSB | KSPCB | Industry, urban consumers | Technical feasibility poor/unclear |
| 20-100 MLD | Large-scale treatment + local sale/ delivery | BWSSB | KSPCB | Industry | No disincentives to industry using groundwater |
| 1-5 MLD (neighbourhood scale) | Treat and discharge in lakes | BWSSB | KSPCB | Lakeside residents (as environmental amenity users) | Environmental amenities goal differs from reuse goal |
| | Treat and supply / sale | BWSSB | KSPCB | Industrial/ parks, institutions | No links established with users, no disincentive to users using groundwater instead of treated water |
| <1 MLD (apartment complex scale) | Treat and reuse on their own | Large apartment complexes | KSPCB | Only complex itself | Too much treated water for apartments to reuse; poor regulation |

In the case of the macro-scale proposals involving transport and in-stream treatment, the hydrological assumptions need much more scrutiny (Lele 2013). For instance, one of these proposals involves taking 200 MLD of treated water from the eastern counterpart of the VVTP (K&C valley treatment plant) and pumping it 60km north and more than a 100m uphill to the origin of the Arkavathy River and expect 135 MLD to eventually reach the TG Halli reservoir downstream. The flaw is that the fraction of water that would reach downstream reservoirs in such a scheme would be much smaller than the claimed 135 MLD because of the presence of more than 10 major irrigation tanks that are currently mostly dry and will therefore block and evaporate or infiltrate most of the water that is introduced upstream. Moreover, the complete drying up of the shallow aquifer in the upper Arkavathy catchment (Lele et al. 2013) means that increased infiltration will not lead to increased base flow for many years to come. Secondly, the costs of pumping water 100m uphill over 60km distance, after the investment in its treatment, will increase the price of water tremendously, when, as we show below, even treated water available at STPs is not getting sold today.

The STP-level recycling concept, which is where BWSSB has already begun investing, and where it proposes to generate more than 300 MLD of treated water across 11 STPs (Kumar 2009), faces challenges of transportation to the user and consequent costs. Currently, at the VVTP, 15 MLD of water receives tertiary treatment, and is offered for sale at Rs.15 /kL at the plant or Rs.25/kL if it has to be piped to the user (Kumar 2009). This shows that transporting the treated water is almost as expensive as treating it. Currently, only 3 MLD is being sold (as per data gathered by our team). There has been greater success in selling treated water at the Yelahanka treatment plant (Kumar 2009), but that is because of proximity to certain industrial clusters and the airport. When BWSSB adds 300 MLD or more of tertiary treatment capacity, it is not clear that it will have buyers, unless industries are stopped from pumping water from borewells or purchasing borewell water from tanker operators.

The cost of delivering treated water has prompted interest in more decentralized forms of recycling, which are outlined in rows 3 and 4 of Table 1. The neighbourhood-level STP would still be operated by BWSSB and although costs of delivery might reduce, it would a) still required a UGD network to bring the sewage to the plant, b) some means of transporting the treated water back to users, and c) a set of users willing to use the treated water. Creating a ‘market’ will again require significant social engineering, such as requiring all public parks and institutions to use treated water only for their gardens.

Another complicating factor is that the demand for neighbourhood-scale STPs is largely coming from an environmentalist lobby that is concerned about raw sewage being let into lakes, thereby polluting the lakes and killing aquatic life and injuring bird life, apart from affecting the quality of life for residents adjacent to the lakes (D’Souza and Nagendra 2011). Lake ‘rejuvenation’ would then require the treated water to be retained in the lake as an environmental amenity. While important in itself, this environmental use would then not make any water available for domestic, irrigation or industrial use.

The even more decentralized option, viz., of treating at the multi-dwelling scale, is actually being implemented in Bangalore, but in a way that may be doomed to fail. KSPCB has imposed the zero-discharge rule without considering whether apartments complexes can actually reuse all the treated water they generate, even if they have invested in dual piping (for using grey water to flush toilets). Moreover, KSPCB, being a state-level agency with responsibility for monitoring all forms of pollution, simply does not (and cannot) have the capacity to actually monitor and enforce this rule at the level of individual apartment complexes. Not surprisingly, field observations by our team and others (CII 2014) indicate low compliance. The few compliant ones complain that they cannot use all the treated water. This again points to the need for making it mandatory for certain categories of users (such as public parks) to only use treated water, which requires coordination between KSPCB and the Bangalore Development Authority or the municipal corporation. Here, singling out large apartment complexes and making them ineligible for sewerage service from BWSSB, KSPCB has inadvertently removed BWSSB from the picture, where in fact BWSSB would have an incentive to mediate between producers and users, so as to reduce its own sewage treatment burden. The advantage of highly decentralized treatment plants, viz., that they do not have depend upon a large network of sewerage pipes being in place, is important in a place like Bangalore where the pace of growth is far higher than the rate at which BWSSB can create such networks. But again, it requires coordination amongst the different agencies involved.

### 3.2.1 Downstream implications of wastewater and its upstream recycling3

Currently, villages downstream of the Byramangala reservoir on the Vrishabhavathy are affected both positively and negatively by Bangalore’s wastewater flowing in this river. On the one hand, wastewater provides a very significant and nutrient-rich source of irrigation water. The Vrishabhavathy has become a perennial river, in stark contrast to the other streams in the larger Arkavathy river basin where water bodies have dried up, probably due to massive amounts of groundwater extraction(Lele et al. 2013).Wastewater is used for irrigation directly from the stream or through irrigation canals in the command area of Byramangala reservoir.

As part of an ongoing study on the implications of Bangalore's urban expansion for adjoining villages, we looked at how livelihoods have changed in the Vrishabhavathy sub-basin upstream and downstream of the Byramangala reservoir. It was found from census data that, in the sub-basin as a whole, the period of 1991-2011 saw substantial reduction in the proportion of the working population engaged in agriculture, as people have shifted to non-agricultural and city-based jobs. However, villages adjacent to the river and in the command area of the Byramangala reservoir presented a contrasting picture, with livelihoods still centred around agriculture. Our field research during 2013 explored the reasons behind this, covering three villages along the Vrishabhavathy river, two in the Byramangala command and one upstream. The methods used included participatory rural appraisal (PRA) techniques, questionnaire survey and water quality analysis. PRA aimed at gauging community level perceptions on change, especially in agriculture and non-agricultural employment, water quantity and quality and in crops cultivated over the past two decades. Questionnaire survey examined these issues in detail at the household level using a random sample of households selected from each village. Ground and surface water samples were collected from the villages and results were shared with the community members in an effort to inform and sensitize the people.

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[3] This section is based on data gathered under a complementary research project titled 'Rural-urban conundrum: political economy of social and environmental transformation in agrarian landscapes' supported by the Tata Social Welfare Trust.

We found that the availability of wastewater has retained local people in agriculture, which they found profitable in spite of the non-agricultural job opportunities that Bangalore and two industrial areas close by brought forth. As data from our study show (Table 2), 86.5% of the total cultivated area belonging to the survey respondents is irrigated, mostly through water from the stream and the canals. This is a phenomenally high fraction of irrigation in a sub-basin that is otherwise dominated by rain-fed agriculture. Alongside, and interestingly, the portfolio of crops grown in the region has undergone considerable change over the same period. While in the past, staple crops including millet and rice were cultivated along with vegetables, the deterioration in water quality has prompted the farmers to shift to high-value crops such as baby corn, aimed at the urban consumers and mulberry. While millet is still grown, dairying has come up as a new source of income and fodder is being grown for dairying.

**Table 2. Irrigated and rain-fed area along the Vrishabhavathi River (2012-13)**

| | |
|---|---|
| No. of households in the sample | 83 |
| No. of cultivator households | 62 |
| Cultivated area (in acres) | 110.31 |
| Irrigated area (in acres, % of total cultivated area in brackets) | 95.43 (86.5) |
| Rain-fed area (in acres, % of total cultivated area in brackets) | 14.88 (13.5) |

**Source**: Field research, 2013

On the other hand, wastewater use in agriculture has affected public health in the region, especially that of farmers and agricultural workers who are in contact with polluted water on a day-to-day basis (Madhukar and Srikantaswamy 2013). Aquatic life in the stream has also been badly impacted. Studies in the region have established heavy metal contamination in Byramangala reservoir (Jan et al. 2008) and the stream, which has possibly entered into the food chain (for more references, see Lele et al, 2013: 29). Farmers have reported skin infections and ailments during our field work. Although the impact of heavy metals on the health of the farmers and the consumers of farm produce has not been conclusively established, the health risks of using wastewater that is far below the quality standards set for irrigation water are obvious.

Given this double-edged nature of wastewater use in agriculture, one can anticipate that attempts to substantially increase upstream wastewater treatment and use will also have mixed implications. Treating all the effluents of Bangalore will improve river water quality thereby benefitting aquatic life and reduce health risk to the downstream population and consumers of their agricultural produce. Recycling and reusing of treated effluent by urban consumers upstream will affect downstream farmers in two ways. First, it will substantially reduce level of domestic wastewater in River and second, the reduced domestic flows will reduce dilution of industrial effluents as a result the levels of heavy metals and other contaminants in river water will increase. Therefore, farmers will likely see significant reductions in their agricultural profits as well as health status. This is particularly because the quantity of effluent discharge is relatively even across seasons making the river flow during summer months and therefore recycling will significantly reduce summer flows, and might eliminate at least one crop. It is not clear how farmers might respond to this decline. On the one hand, they could argue that they have customary rights on the wastewater of Bangalore. On the other hand, they could take the view that they were incidental beneficiaries of a phenomenon that had to be controlled eventually. More detailed studies of the quantum and timing of the decline will be required to anticipate the exact impacts and likely responses.

At a larger basin-level scale, further complications are likely to arise due to the fact that the Arkavathy River itself is a tributary of the Cauvery, which is an inter-state river in which water sharing has been a matter of major dispute. After two decades of deliberation and controversy, the Cauvery Water Disputes Tribunal (CWDT) decided in 2007 (CWDT 2007), to put a cap on the amount of water that can be lifted from the Cauvery by each state for domestic and industrial use. This decision was put into effect only in 2012 and Bangalore has already reached this limit (Reddy 2013). The CWDT has also assumed that 80% of water lifted from the Cauvery will come back as return flow. If, however, WWRU proceeds at a significant scale in Bangalore, the quantity of water returning to the Cauvery after use in Bangalore will drop, possibly below this limit.[4] This could create significant difficulties for Bangalore in meeting its obligations under the CWDT.

## 4. Concluding remarks

Cities have typically depended upon imported water, but as basins close and claims on water increase, they will have to redirect attention towards options such as WWRU. WWRU can take two forms: reuse of wastewater downstream versus recycling of wastewater in the city itself. This case study of Bangalore illustrates the complexities involved in either form, and the particular challenges involved in using WWRU to reduce water stress faced by the city itself through increased recycling and reuse within the city. The conclusions of this study may be summarised as follows:

[4] Indeed, it is not even clear that 80% of the water lifted from the Cauvery and pumped to Bangalore is returning to the Cauvery. It is quite likely that half of the return flows are ending up in the Pinakini, which does not meet the Cauvery. As of now, the CWDT is not monitoring return flows. But this may change in the future.

- Any form of WWRU must meet stringent health standards to avoid new forms of environmental and human health problems. The first and foremost challenge that developing country cities might face is simply having effective (efficient and efficacious) treatment. One of the major obstacles seems to be the absence of and poor functioning of sewerage networks.

- Water agencies have a tendency to look for technological solutions and to treat WWRU as one such. They also tend to prefer large projects. But effective WWRU within a city requires significant attention to the links between producers and users, and significant coordination across agencies and individual actors. It also requires modifications to building guidelines and planning of neighbourhoods. It is thus not a project to be implemented by the water agency alone.

- A basin-scale perspective also brings to the fore possible complications for upstream reuse in the form of impacts on the interests of pre-existing downstream users and commitments that may have been made on inter-state rivers.

Academically speaking, this study highlights the need for more attention to understanding the hydrological links between upstream recycling and downstream use, and the implications of introducing environmental flow or storage requirements. In addition, the socio-technical reconfigurations that may be required to actually make WWRU work constitute a fertile area for further research. Finally, as we saw, a basin approach is a useful perspective that highlights wider health, economic, and environmental implications of policy interventions such as WWRU.

## Acknowledgements

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## References:

APHA (2005) Standard Methods for Examination of Water and Wastewater.21st ed. APHA.

Azzellino, A., Salvetti, R., Vismara, R. & Bonomo, L. (2006) *Combined Use of the EPA-QUAL2E Simulation Model and Factor Analysis to Assess the Source Apportionment of Point and Non Point Loads of Nutrients to Surface Waters.* Science of the Total Environment *371* (1-3): 214–22

BWSSB (2014) Current Projects. http://bwssb.org/current-projects-3/ Accessed 13 May 2014.

CII (2014) *An Integrated Water Management Strategy for Bengaluru.* Bangalore: Chamber of Indian Industry (CII) Karnataka Chapter.

CPCB (2014) Water Quality Standards. http://cpcb.nic.in/index.php Accessed 13 May 2014.

CPCB. General Standards For Discharge of Environmental Pollutants Part-A Effluents. Central Pollution Control Board. http://cpcb.nic.in/GeneralStandards.pdf Accessed 13 May 2014.

CSE (2012a) The Water-Waste Portrait - Bangalore City. Centre for Science and Environment, New Delhi.

CSE (2012b) Excreta Matters. Citizens' Seventh Report on the State of India's Environment. New Delhi, India: Centre for Science and Environment.

CWDT (2007) The Report of the Cauvery Water Disputes Tribunal: Volumes I to V. New Delhi, India: Cauvery Water Disputes Tribunal, Ministry of Water Resources, Government of India. http://wrmin.nic.in/index3.asp?subsublinkid=376&langid=1&sslid=393 Accessed 13 May 2014.

D'Souza, R., & Nagendra, H. (2011) *Changes in Public Commons as a Consequence of Urbanization: The Agara Lake in Bangalore, India.* Environmental Management *47* (5): 840–50. doi:10.1007/s00267-011-9658-8

Daniel, M. H. B., Alexandra, A., Montebelo, M. C., Bernardes, J. Ometto, de Camargo, P. B., Krusche, A. V., Ballester, M. V. , Victoria R. L., & Martinelli, L. A. (2002) *Effects of Urban Sewage on Dissolved Oxygen, Dissolved Inorganic and Organic Carbon, and Electrical Conductivity of Small Streams along a Gradient of Urbanization in the Piracicaba River Basin.* Water, Air, and Soil Pollution *136* (1-4): 189–206.

DMG (2011) Groundwater Hydrology and Groundwater Quality in and around Bangalore City. Department of Mines and Geology, Government of Karnataka. Bangalore. http://www.indiawaterportal.org/articles/groundwater-hydrology-and-groundwater-quality-and-around-bangalore-city-department-mines Accessed 14 May 2014.

Drechsel, P., Scott, C. A., Raschid-Sally, L., Redwood, M. & Bahri, A. (2009) Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries. IWMI and Earthscan. London, UK and Sterling, Virginia.

EMPRI (2008) Environmental Database for Peenya Industrial Area Bangalore. Complementary Project Report. Bangalore.

Harsha, J. (2012) *River Diversion Schemes versus Waste Water Recycling for Bangalore City.* Current Science *103* (2): 144–46.

Hegde, G. V., & Subhash Chandra K.C. (2012) *Resource Availability for Water Supply to Bangalore City, Karnataka.* Current Science *102* (8): 1102–4.

Jamwal, P., & Mittal, A. K. (2010) *Reuse of Treated Sewage in Delhi City: Microbial Evaluation of STPs and Reuse Options.* Resources, Conservation and Recycling *54* (4): 211–21. doi:10.1016/j.resconrec.2009.08.002

Jamwal, P., Mittal, A. K. & Mouchel, J-M.(2009) *Efficiency Evaluation of Sewage Treatment Plants with Different Technologies in Delhi (India)*. Environmental Monitoring and Assessment *153* (1-4): 293–305.

Jamwal, P., Zuhail T. Md., Raje Urs, P., Srinivasan, V. & Lele, S. (2014) *Wastewater Treatment and Its Implications on Urban Streams in Bangalore: A Case Study.* Current Science (under review).

Jan, N., Nandini, N. , Jumbe, A. S. & Anupama. B.S. (2008) *Impact of Municipal and Industrial Pollution on Byramangala Lake, Bengaluru Rural District, India*. Taal 2007 : The 12th World Lake Conference, 1717–28.

Kumar, V. C. (2009) Presentation on Status of Water and Sanitation in Bangalore. Executive Engineer, BWSSB. Presentation at Indian Council for Research on International Economic Relations (ICRIER).http://www.icrier.org/pdf/bangalore_status.pdf Accessed 14 May 2014.

Kvarnström, E., Verhagen, J., Nilsson, M., Vishwanath, S., Ramachandran, S. & Singh, K. (2012) *The Business of the Honey-Suckers in Bengaluru (India): The Potentials and Limitations of Commercial Faecal Sludge Recycling.* Occasional Paper. The Hague, Netherlands: IRC International Water and Sanitation Centre.www.irc.nl/url/48092 Accessed 13 May 2014.

Lele, S. (2013) Arkavathy: Rejuvenation to Governance. Keynote presentation presented at the Public Consultation on Arkavathy Rejuvenation organized by AKNPS, July 2, Gandhi Bhavan, Bangalore.

Lele, S., Srinivasan, V., Jamwal, P., Thomas, B. K., Eswar, M., & Zuhail, T. Md. (2013) *Water Management in Arkavathy Basin: A Situation Analysis*. Environment & Development Discussion Paper 1.Bangalore: Ashoka Trust for Research in Ecology and the Environment. http://www.atree.org/sites/default/files/ARKAVATHY%20_web.pdf Accessed 13 May 2014

Madhukar, R., & Srikantaswamy S. (2013) *Impact of Industrial Effluents on the Water Quality of Vrishabavathi River and Byramangala Lake in Bidadi Industrial Area, Karnataka, India.* International Journal of Geology, Earth & Environmental Sciences *3* (2): 132–41.

Nataraj, P. (2013) BWSSB Plans to Recharge TG Halli Reservoir with Treated Water. Deccan Herald, June 26. http://www.deccanherald.com/content/341242/bwssb-plans-recharge-tg-halli.html Accessed 13 May 2014.

Passerat, J., Nouho Koffi Ouattara, Mouchel, J-M, Rocher, V. & Servais, P. (2011) *Impact of an Intense Combined Sewer Overflow Event on the Microbiological Water Quality of the Seine River.* Water Research *45* (2): 893–903. doi:10.1016/j.watres.2010.09.024

Reddy, Y. M. (2013) An Inconvenient Truth: Bangalore's Future Is in the Gutter, Daily News & Analysis, DNA, June 23. http://www.dnaindia.com/bangalore/report-an-inconvenient-truth-bangalores-future-is-in-the-gutter-1851841 Accessed 14 May 2014.

Shiva Kumar, M. T. (2012) Planning to Stop Water Supply to Bangalore: Farmers' Leader. The Hindu, September 21. http://www.thehindu.com/todays-paper/tp-national/tp-karnataka/planning-to-stop-water-supply-to-bangalore-farmers-leader/article3920740.ece Accessed 14 May 2014.

Smitha, K. C. (2006) *Urban Governance and Bangalore Water Supply & Sewerage Board (BWSSB).* Unpublished Paper, Institute of Social and Economic Change, Bangalore. http://www.isec.ac.in/Urban%20Governance.PDF Accessed 14 May 2014.

Times of India (2014) Treated Wastewater Goes down the Drain. The Times of India. http://timesofindia.indiatimes.com/city/bangalore/Treated-wastewater-goes-down-the-drain/articleshow/22530530.cms Accessed 7 April 2014.

Vishwanath, S. (2007) Water Bills Need to Say More. The Hindu, November 3, Bangalore edition. http://www.thehindu.com/thehindu/pp/2007/11/03/stories/2007110350030200.htm. Accessed 13 May 2014.

Vishwanath, S. (2014) How to Benefit from Waste-Water. The Hindu, March 15. http://www.thehindu.com/todays-paper/tp-features/tp-propertyplus/how-to-benefit-from-wastewater/article5786234.ece Accessed 14 May 2014.

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