Water Economics and Policy, Vol. 3, No. 3 (2016) 1650043 (22 pages)

DOI: 10.1142/S2382624X16500430

Decentralized Wastewater Systems in Bengaluru, India: Success or Failure?

Pradeep Kuttuva[*,†,‡], Sharachchandra Lele[†] and Gara Villalba Mendez[*]

[*]*Institut de Ciència i Tecnologia Ambientals (ICTA)*
Universitat Autònoma de Barcelona, Barcelona

[†]*Ashoka Trust for Research in Ecology and the Environment (ATREE), Bengaluru*
[‡]*pradeep.kuttuva@gmail.com*

Received 6 April 2016
Revised 22 June 2016
Accepted 22 November 2016
Published 2 February 2017

Decentralized wastewater treatment and reuse (DWTRU) using small-scale on-site sewage treatment plants (STPs) is an attractive solution addressing the problems of water pollution and scarcity, especially in rapidly urbanizing cities in developing countries, where centralized infrastructure for wastewater treatment is inadequate. But decentralized systems face several challenges (economic feasibility, public acceptance) that need to be better understood. The city of Bengaluru in India provides an excellent opportunity to evaluate such systems. In 2004, in an effort to curb the alarming levels of pollution in its water bodies due to untreated sewage disposal, the environmental regulatory agency mandated apartment complexes above a certain size to install STPs and reuse 100% of their wastewater, resulting in the installation of more than 2200 on-site STPs till date. This study attempts to analyze the factors influencing the extent of treatment and reuse in such systems, through structured surveys of residential associations, STP experts and government officials. The results are analyzed using a framework that integrates the technology adoption literature with the monitoring and enforcement literature. The study indicates that, while no apartment complex is able to reuse 100% of its treated water, there exists significant variation across apartment complexes in the level of treatment and reuse (from partial to poor) due to a complex mix of economies of scale, the price of fresh water, the level of enforcement and awareness, and technological choices made under information asymmetry. Only apartments dependent on expensive tanker water supply had clear economic incentives to comply with the order. Yet many large complexes that depended on low-priced utility or borewell supply were partially compliant, owing partly to lower (although positive) costs, higher level of formal enforcement and perhaps greater environmental awareness. On the other hand, the high treatment cost pushed smaller complexes to curtail the operation of their STPs (and the lower levels of enforcement further worsened this), resulting in inadequate treated water quality and consequently low reuse levels.

The study recommends relaxing the infeasible 100% reuse criterion, and raising the threshold size above which DWTRU should be mandated so as to reduce the cost burden and increase enforceability. Subsidies towards capital costs and enabling resale of treated water will enable wider adoption. DWTRU is an apparently attractive solution that however, requires judicious policy-making and implementation to succeed.

Keywords: Decentralized wastewater systems; urban wastewater recycling; wastewater treatment and reuse; zero liquid discharge; sewage treatment plant; Bengaluru.

1. Introduction

Rapidly urbanizing centers around the world face multiple challenges in their water and wastewater management. In many developing country cities, water supply has not been able to keep up with a rapidly increasing demand principally because a majority of the readily-available sources have already been exploited (Padowski and Gorelick 2014; McDonald *et al.* 2014). Further, many also lack adequate wastewater treatment infrastructure and consequently discharge a large portion of their wastewater directly into surface water-bodies impacting the health of downstream users and the environment (Ujang and Buckley 2002; Corcoran 2010). In this context, waste water treatment and its reuse within the city is an attractive solution that can simultaneously address both the above problems (Garcia and Pargament 2014; Jamwal *et al.* 2014).

Water reuse for irrigation has a history of over five thousand years (Angelakis and Gikas 2014). In many developing countries, unplanned reuse of untreated wastewater for agriculture is also common (Devi 2009; Amerasingle *et al.* 2013). Planned reuse of treated wastewater has also been happening at a significant scale since three decades, especially in water-scarce regions of the world. But a majority of these cases have centralized wastewater treatment systems whose treated water output is (re)used by downstream farmers, not on-site (Lazarova *et al.* 2013). This is not surprising, because centralized wastewater treatment has been the norm thus far.

Several studies have, however, shown that decentralized treatment (even without reuse) has economic and environmental benefits compared to centralized ones (Naik 2014; Ho and Anda 2004). Others have argued that the entire system, including reuse, needs to be decentralized as centralized systems are ‘a non-optimal solution’ (Michel *et al.* 2013). Several cities and countries have begun to make certain kinds and levels of decentralized wastewater treatment and reuse (DWTRU) mandatory, including in Japan, Australia, European Union and China, albeit largely focusing on greywater, not all wastewater (Gaulke 2006; Mankad and Tapsuwan 2011; Domènech and Saurí 2010; Zhang and Tan 2010).

Given the predominance of cases with centralized treatment as the source of treated water for reuse, studies of the costs, risks and challenges involved in such reuse have naturally focused on such projects (Urkiaga *et al.* 2008; Angelakis and Gikas 2014). But DWTRU also faces challenges. First, if only graywater is treated locally, then a centralized treatment system for black water is still required, which may be absent in many developing country towns. Second, high operation and management costs can compromise successful adoption of DWTRU systems (Liang and Van Dijk 2008; Domènech and Saurí 2010). In fact, even centralized water reuse projects have been found to be economically viable only if external environmental benefits are included in the feasibility analysis (Hernández *et al.* 2006; Molinos-Senante *et al.* 2011), especially because freshwater itself is heavily subsidized (Molinos-Senante *et al.* 2012). In such a scenario, DWTRU systems could be further disadvantaged due to the loss of economies of scale. These systems also require greater engagement by local communities (Domènech and Saurí 2010), including the financing of them, thereby adversely affecting their public acceptance.

Thus, several aspects of DWTRU systems need closer examination. Can all domestic wastewater, including gray and blackwater be treated and reused on-site? What factors affect the economics of treatment and reuse in DWTRU systems? What role do economic and also technical and social factors play in the adoption and level of decentralized reuse? What is the role of regulatory and other policies in influencing the adoption of on-site reuse?

The city of Bengaluru (aka Bangalore), the capital of the state of Karnataka in southern India, is a rare case where 100% wastewater treatment and on-site reuse (zero-liquid discharge (ZLD)) has been officially required for apartment complexes above a certain size since 2004 (Evans *et al.* 2014). Consequently, at least 2,200 residential and commercial complexes have installed or are installing DWTRU systems within their premises, as per data provided by the Karnataka State Pollution Control Board (KSPCB). While a KSPCB report claimed that most were working ‘quite well’ (KSPCB 2012), there have also been claims that over 80% of these small sewage treatment plants (STPs) in the city are not adhering to the official standards (Kodavasal 2015; Lalitha 2015). The city thus offers an excellent opportunity to study DWTRU and link theory with empirical data on the concept of DWTRU. Since many cities in India and around the world face similar constraints in their water and wastewater situation, learnings gleaned from Bengaluru could potentially benefit many of them.

We present the results of a study of DWTRU systems in Bengaluru in an attempt to understand the factors that have influenced the performance of DWTRU systems in Bengaluru. Using data from a detailed survey of a purposively chosen sample of apartment complexes, we construct cost curves and look at the possible influence of cost and other factors on the level of compliance with the ZLD regulation. We begin with an introduction to the case study area (Section 2). A conceptual framework for defining compliance and possible factors affecting it is presented in Section 3, followed by a summary of the methods followed for primary data collection and analysis (Section 4). The results are presented in Section 5, in which we find that the level of compliance varies but never reaches the 'zero-discharge' or 100% reuse standard, and a combination of cost and enforcement make large apartment complexes more compliant than the smaller ones. The broader conclusions and policy implications of the study are presented in the final section.

2. DWTRU in Bengaluru

Bengaluru city, with a population of 8.5 million in 2011 spread over $\sim$ 800 sq. km, is the fifth largest metropolis in India. Mehta *et al.* (2013) term the city "*a poster child of the problems confronting urban India*", which is especially true as regards to its water and wastewater management. The city's local surface water sources having dried up, the Bengaluru Water Supply and Sewerage Board (BWSSB) is pumping $\sim 1,250$ million litres per day (MLD) of water from the river Cauvery, which is located 100 km away and 300 m downhill. In addition, groundwater contributes an estimated 600 MLD, especially in the newly urbanized periphery of the city (DMG 2011). With withdrawals from the Cauvery river amounting to the entire allocation of Cauvery water for domestic water use in Karnataka as per the Cauvery Water Disputes Tribunal (Reddy 2013), and with groundwater levels dropping rapidly in the peripheral regions (CGWB 2012), the city is facing significant water shortages (Rao 2013).

The management of wastewater in the city presents an equally dismal picture. The total waste water generated in the city is estimated to be about 1,100 MLD, but the installed centralized treatment capacity is only 721 MLD (Vishwanath 2014). Moreover, a large fraction (40%) of the installed capacity is unutilized due to a lack of sufficient underground drainage networks and failures within the plants (Jamwal *et al.* 2015). Consequently over 60% of Bengaluru's sewage water is let out untreated into streams and lakes, resulting in widespread pollution including excessive foaming and even mass fish kills (CSE 2012; Nath 2015; Aravind 2016).

In this backdrop of water scarcity and inadequate water treatment, the Karnataka State Pollution Control Board (KSPCB) issued a ZLD order in 2004. It mandates that buildings with either more than 50 residential units or a built-up area of more than 5,000 m^2 in unsewered areas must install on-site STPs and reuse

100% of the treated water.[1] By all accounts, this is a stringent treatment-and-reuse requirement. For instance, in Tokyo and Fukuoka cities in Japan, only graywater is required to be treated, it is reused only for flushing, and the size threshold is larger (Kimura *et al.* 2007). This stringent order has led to the setting up of DWTRU systems in at least 2,000 buildings in the city by 2014, with a total treatment capacity estimated to be around 110 MLD (Evans *et al.* 2014) or 10% of the total wastewater generated in the city — probably the highest level of DWTRU amongst all Indian cities (Vishwanath 2014). The vast majority of these treat their wastewater to tertiary levels and about 70% employ Activated Sludge Process (ASP) for secondary treatment, as per a survey done by Centre for Dewats Dissemination, Bengaluru. The treated water is typically reused for landscaping, car washing and (if dual piping has been implemented) for flushing of toilets.

3. Conceptual Framework

3.1. *Compliance versus voluntary technology adoption*

Even though most of the examples of DWTRU have emerged in the context of regulations imposed by governments, the literature tends to see the problem in terms of the conventional literature on (voluntary) technology adoption, rather on enforcement and compliance. In the case of Bengaluru, the existence of DWTRU is clearly the result of the ZLD order. But preliminary investigation indicated that the order is fairly strongly enforced only at the first stage, i.e., the construction of STPs at the time of the construction of the apartment complex.[2] Subsequent monitoring of the quality of treated water and the extent of reuse is poor. Of the $\sim 2,200$ decentralized STPs listed in the KSPCB database, although $\sim 1,600$ are listed as 'to be constructed', several of the latter were found to be operational in our field visits without a formal 'consent for operation'. Moreover, as we show below, a large fraction of STPs did not face inspector visits and inspections. Thus, the degree of actual treatment and reuse through the DWTRU system would depend as much on 'technology adoption factors' as on 'monitoring and enforcement factors'.

[1] The order also applies to larger buildings (built-up area $> 20,000\,\mathrm{m}^2$) in areas that already have a sewerage network. There is no clarity as to what happens when the originally unsewered area becomes sewered.

[2] Obtaining 'consent for establishment' for an STP is now a part of the process of obtaining building permits.

3.2. *Characterising the level of compliance or adoption*

The literature on adoption of DWTRU in particular and technology adoption in general tends to characterize outcomes in binary terms: adoption or non-adoption. In our study, however, since the activity involves both treatment and reuse, adoption or compliance could be at varying levels. We characterized outcomes into four levels:

- STP installed but not operated = 'zero compliance'
- STP operated inconsistently, water quality report[3] not shared, and reuse $<$ 20% = 'poor compliance'
- STP operated regularly, water quality report meets standards, and reuse 20–70% = 'partial compliance'
- STP operated regularly, water quality report meets standards, and reuse 100% = 'full compliance'.

3.3. *Factors influencing adoption and compliance*

Studying on-site graywater reuse systems in Barcelona, Domènech and Saurí (2010) identify five factors influencing adoption: viz., cost, perceived health risk, technological choice and complexity, environmental awareness and external context (e.g., water scarcity). Cost itself has been shown to depend on scale of operation, technological choice and price of fresh water supplies (Friedler and Hadari 2006). However, as perceptions about health risk could vary widely across individual users within the apartment complex, it was not possible to characterize perception for the apartment complex as a whole. We decided to focus on the influence of cost, technology, environmental awareness and also monitoring-and-enforcement pressure (since, as explained earlier) this is not a case of purely voluntary adoption. Cost in turn was modeled in relation to the number of units in the apartment complex and the price of fresh water. We attempted to explain compliance levels in a multi-variate framework; however, our small sample size and collinearity between some of the above factors forced us to discuss some of the influences in a qualitative manner, using our discussions and observations from the RWAs.

4. Methodology

4.1. *Data collection*

Field work for this research was carried out in Bengaluru from April to June 2015. We obtained a partial list of existing DWTRU systems from the Centre for Dewats

[3]Independently testing the quality of treated water was not possible; we depended on the testing carried out by the RWA itself, usually using an outside agency.

Dissemination in Bengaluru, and added to this list using a snowball method. We then adopted a purposive sampling approach, adding samples in ways that we got some variation along three key attributes: treatment capacity/scale, treatment technology, and primary water source. Only residential complexes (as against commercial ones) were selected for the sake of uniformity. The Residents' Welfare Associations (RWAs) that manage the DWTRU system were then approached for a detailed interview. However, of 49 buildings visited, the majority (32) refused to be part of the survey, apparently due to a fear of repercussions from KSPCB, in spite of our assurances of confidentiality. We ended up with a total sample of 17 RWAs.[4] Of these, one RWA was in at 'zero compliance' as described above, and so was dropped from further analysis.

Information about each DWTRU system was collected through a detailed questionnaire[5] which included five types of questions: (1) technical details of the design, design issues, operation and maintenance issues; (2) cost and type of water source, operation and maintenance costs of the STP, and capital costs; (3) volumes of water reused; (4) extent of compliance with water quality standards (by asking for their latest report) and extent of enforcement pressure from KSPCB in terms of inspector visits and show causes notices received, and (5) an assessment of environmental awareness through questions on efforts at solid waste management and rainwater harvesting. In addition, extensive field notes were taken to record relevant additional information regarding the DWTRU process. A visual inspection of the STP and the treated water was always carried out, to validate the data provided. In addition, open-ended discussions were also carried out with the RWA officials to understand their perspectives and concerns.

Semi-structured interviews were also conducted with a number of other actors, including STP experts, STP operation and maintenance agencies, KSPCB officials and members of active citizen groups.[6] The main aim of these interviews was to understand the key institutional factors affecting STPs. Additional information was obtained from KSPCB documents collected from their offices and various other sources.

[4]The effort spent in locating the buildings, meeting with RWA office-bearers, and obtaining data from those who were willing took about a week per building.

[5]The questionnaire is part of the Supplementary Information of the paper and also given at http://www.atree.org/sites/default/files/Questionnaire_RWAs.pdf.

[6]The set of questions explored in these interviews are given at http://www.atree.org/sites/default/files/Interview_Guide_STP_Experts.pdf

4.2. *Estimating the cost of water treatment and savings from water reuse*

Conventionally, the cost of water treatment should include the amortized capital cost and the Operating & Maintenance (O&M) costs of the STPs. However, our enquiries revealed that for the RWAs, the capital cost of the STP was a sunk cost paid by the builder of the apartment complex — the RWAs neither knew the quantum nor was their decision to operate the STP dependent upon that cost, since (as explained above) the builder had to install the STP in order to get a building permit. We therefore focused only on O&M costs.[7]

The *gross* monthly O&M cost of water treatment incurred by the RWA would be given by:

$$C_t = C_E + C_P + C_M,$$

where C_E is the cost of electricity, C_P is the cost of personnel to run the plant, and C_M is other costs including the cost of chemicals and of sludge disposal. One would expect C_E and C_M to be positively related to the amount of wastewater treated and therefore with the number of units in the apartment complex (N). But one would also expect some economies of scale overall, since C_P is relatively fixed: for a wide range of sizes of STPs, the personnel required to operate are the same (typically: three persons working in shifts around the clock).[8] Therefore, the cost *per apartment unit*[9] c_t would be expected to be a declining function of scale or N. Following Hernandez-Sancho and Sala-Garrido (2008) and also Friedler and Hadari (2006), we fitted a simple power law expression:

$$c_t = aN^b$$

to the reported data.[10]

However, we noticed that there was a certain amount of endogeneity to the cost values being reported: when RWAs saw high costs, they reduced their level of

[7] In theory, the RWAs should be charging their members some amount towards depreciation, as the STP would have to be replaced/refurbished after say 10 years. However, none of the RWAs were levying any depreciation charges.

[8] The cost of supervision was typically internalized by the RWA through its office-bearers.

[9] The choice of this reference unit was to have direct policy relevance, because the ZLD order mandates DWTRU systems if the residential complex exceeds 50 apartment units. To estimate the consumption per capita, one may assume five inhabitants per apartment unit and an individual water use of 135 L per day (CPHEEO guidelines:http://cpheeo.nic.in/status_watersupply.pdf).

[10] As Rodriguez-Garcia *et al.* (2011) point out, size is not the only factor influencing costs in STPs; among other things, the quality of treated water produced would be an important variable as well. We have addressed this approximately, by keeping the 'poorly compliant' (where quality of water was poor) cases out of the cost-curve estimation.

compliance, such as switching off STP operations for several hours a day, skimping on chemicals, etc. and thereby reducing their costs. We therefore estimated the curve only using data from 10 RWAs that had a similar level of (partial) compliance. We further corroborated this curve by deriving an engineering cost curve using typical specifications of an STP that uses activated sludge technology, 24 h operation and average personnel costs.

The reuse of water led to a reduction in the money spent on equivalent volumes purchasing fresh water. But RWAs sometimes used multiple sources. In such cases, we valued the savings from water reuse at the highest price amongst the sources of water used by the RWA, as that would be the source to be cutback when any treated water becomes available. (It was assumed that reuse did not create a Jevon's paradox situation where RWAs then splurged on treated water.) Net cost was then defined as the total cost minus the savings from reused water.

5. Results

We shall first present the descriptive statistics for the outcome variable, and then for the independent variables. After this, we model the basic cost structure so as to identify the relationship between scale or size (number of apartments), the source (and hence price of fresh water), and the net costs of them for the dependent variable. We then examine possible collinearity between independent variables before exploring the influence of the independent variables on the outcome.

5.1. *The level of compliance/adoption*

The number of apartments at different levels of compliance is shown in Table 1. None of the apartments was 'fully compliant', i.e., able to properly treat and reuse 100% of the water (and this in spite of our best efforts to purposively locate such apartments).

As we can, none of the RWAs were fully compliant with the ZLD order, because they found it impossible to consumptively use 100% of the treated water and not

Table 1. Distribution of RWAs by Level of Compliance

Level of Compliance	Compliance with Installation	Compliance with Water Standards	Extent of Reuse	Number of Apartments Sampled
Full compliance	STP installed	Yes	100%	0
Partial compliance	STP installed	Yes	20–70%	10
Poor compliance	STP installed	Mixed	0–20%	6

let any water out. Ten of the residential complexes were partially complaint with the order, reusing up to 20–70% of the treated water. Six did not appear comply with the water quality standards prescribed by the KSPCB,[11] and their level of reuse was also low.[12]

5.2. *The independent variables*

The range of values obtained in the sample for the independent variables is given in Table 2.

We see that there is a large range in the size of the apartment complexes, from 35 units (actually below the threshold set by the ZLD order) all the way to 450 units. There is also significant variation in the source of fresh water and the corresponding price: own borewell water is very cheap, whereas those who have neither own borewells nor water supply from the utility pay a hefty price for water purchased from tankers. And these are not outliers — a large number of the new and large apartment complexes are coming up in the peripheral parts of Bengaluru where there is no city supply and where groundwater levels have dropped alarmingly in recent years.

In terms of technological choices, activated sludge was the most common process as indicated earlier. The adoption of dual piping (so as to use treated water for toilet flushing) varied significantly (and in some cases, dual piping was installed but fresh water was used anyway). But we also found that the design of the STPs was not always adequate: 8 out of 16 reported that the STPs were under-designed for the sewage being generated, and several of these eight also reported other flaws.

There was also significant variation parameters representing monitoring and enforcement and environmental awareness.

5.3. *The basic cost structure of DWTRU*

The per unit treatment cost (c_t) is plotted in Figure 1 against scale (N), including:

- The actual values for only the partially compliant cases,
- the power law curve fitted these data points (red line), and

[11]All of the six refused to share water quality data, and visual observations of the water and the plant showed that treatment was incomplete.

[12]As mentioned earlier, we also encountered one RWA that had not bothered to even install an STP, and we suspect there are several others in that category, but we did not put in further efforts to locate such RWAs, focusing our analysis instead on the question of post-installation level of compliance with treatment and reuse norms.

Table 2. Descriptive Statistics of Independent Variables

Category	Variable	Range of Values and Central Tendency
Scale	Number of apartment units	35–850 (Median = 150)
	Number of water users	175–4250 (Median = 750)
	Treatment capacity (kilo litres per day: kLD)	30–450 (Median = 100)
Technological factors	Treatment Technology	Activated Sludge Process = 13 Sequencing Batch Reactor = 2 Rotating Biological Contactor = 1
	Reuse technology	Dual plumbing (flushing with treated water) = 10

	Design limitations	under capacity = 5;
		under capacity & missing tanks = 2;
		under capacity & wrong technology = 1

O & M costs	Total cost of electricity (Rs/month)	8,000–150,000 (average = 45,500)
	Total cost of personnel (Rs/month)	8,000–80,000 (average = 34,300)
	Other O&M costs, incl. chemicals (Rs/month)	0–25,000 (average = 8,000)
Fresh water savings	Fresh water source	Borewells (8); Tanker (2); Borewell+Tanker (3); Borewell+Piped supply (3)
	Price of fresh water (Rs/kL)	5–80 (Average = 29)
Net cost	O&M minus savings (Rs/unit/month)	+680 to −380
Monitoring & Enforcement	Random checks by pollution control board	Yes (10); No (6)
	Notices received	Yes (9); No (7)
Environmental Awareness	Environmental responsibility	Yes (12); No (4)
	Operational waste segregation	Yes (8); No (8)
	Rainwater harvesting	Yes (13); No (3)

Note: Rs = Indian Rupee; 1 Euro is approximately 75 Rs at the time of the study.

- the engineering cost curve based on normal operation and average reported values (black line and points).

The fitted power law curve has a fairly high *r*-square value (0.74) and statistically significant coefficients ($p < 0.05$), and the engineering cost curve matches the fitted curve well. The curves thus indicate a clear decline in per unit treatment cost with scale, or alternatively a sharp rise in per unit costs when N falls below 150 units. This is mainly due to the fact that the personnel cost is largely

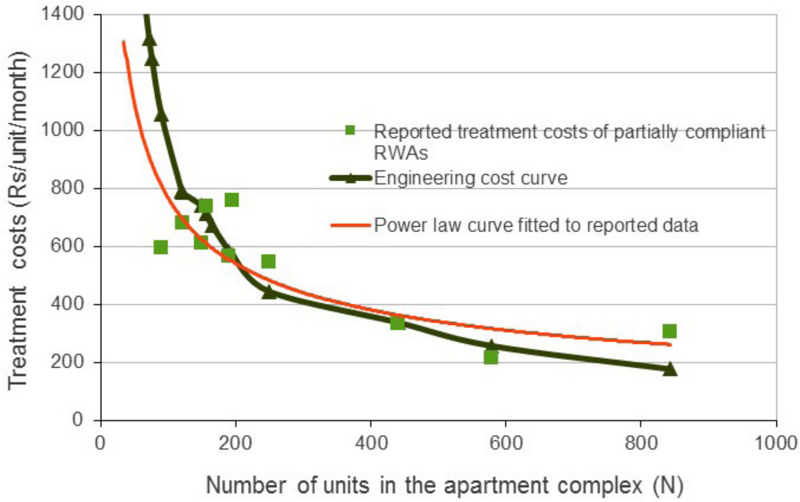

Figure 1. Variation of Treatment Cost with Scale

independent of the size of the STP, as it requires the hiring of 3–4 staff to operate on a 24×7 basis.

The net cost to the residents, however, depends not just on the treatment cost, but also on savings possible due to treated water reuse. In Figure 2, we have overlaid on the fitted treatment cost curve the savings obtained for different sources of fresh water, assuming 50% reuse. We see that apartment complexes that pay a low price for fresh water by sourcing it either from their own borewells (Rs. 10/kL) or from the water utility (Rs. 22/kL) always face a positive net cost, regardless of

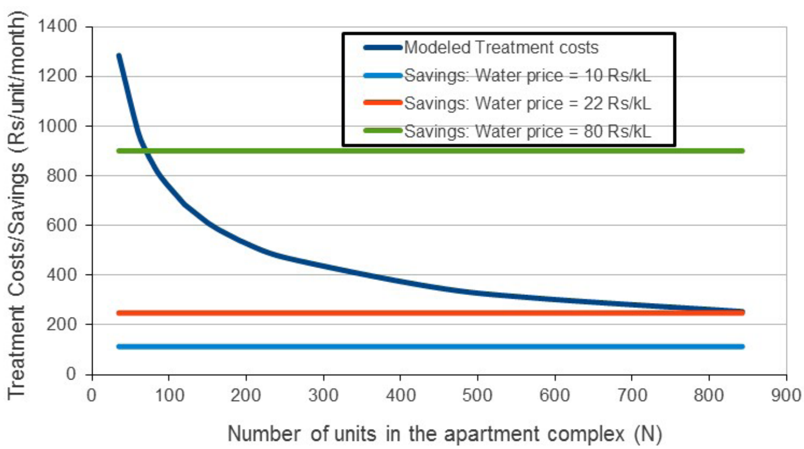

Figure 2. (Colour online) Comparison Between Treatment Cost and Savings from Reuse

their size. Even apartment complexes that use much more expensive tanker water will face positive net cost if their size is below 80 units; a negative net cost (positive benefit) is incurred only above this size. Note that the net cost curve derived from Figure 2 would also be negatively correlated with size.

However, the actual values of net cost do not show a very clear relationship with the number of units (see Figure 3). The random variation in price of fresh water and the deviation from engineering cost estimates due to under-operation of the poorly compliant STPs blurs the relationship (red points in Figure 3). This implies that in future analysis of the influence of economic factors, it would be prudent to treat net cost and size or price of fresh water and scale (number of units or capacity of STP) as independent variables. In subsequent analysis, we chose number of units as the measure of scale because it is more easily understood and the ZLD order is also generally applied using the number of units.

5.4. *Collinearity between independent variables*

Before testing for the influence of the independent variables on the level of compliance, we checked for collinearity between the independent variables: net cost or scale (because they are closely related), enforcement and environmental awareness. Our discussions with the RWAs and the KSPCB suggested that enforcement by KSPCB officers may be targeting the bigger apartment complexes. The Spearman's rank correlation coefficient between size and our

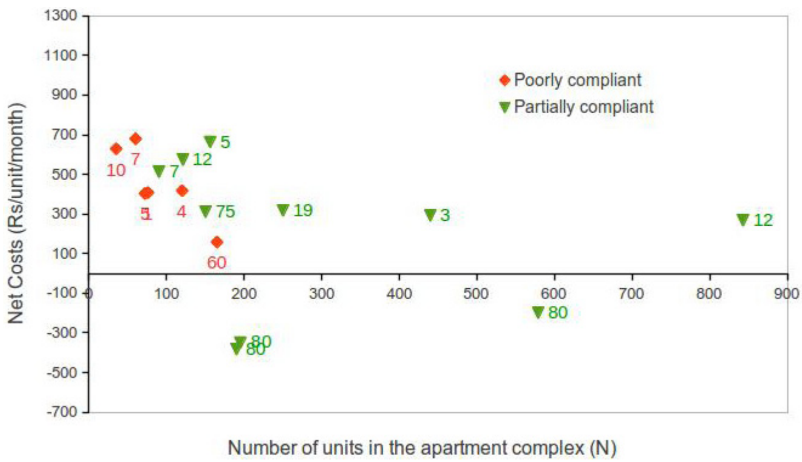

Figure 3. (Color online) Reported Net Cost Variation with Size of Apartment Complex (Data Points are Tagged with Price of Fresh Water in Rs/Kl)

Table 3. Relationship between Size of Apartment Complex and Enforcement by KSPCB

Size of Apartment Complex (N)	Index of Enforcement	
	0	1 or 2
Small (< 150)	5	2
Large ($>= 150$)	1	8

index of enforcement[13] was 0.7 ($p < 0.01$). This can also be seen in the 2×2 matrix in Table 3: a majority of the larger apartments reported inspection visits and notices for non-compliance, while a majority of the smaller apartments reported neither. Comparing size separately with whether KSPCB officers visited or not, and with whether notices regarding were received or not yielded identical results.

We also found a somewhat surprising correlation between measures of environmental awareness and the size of the apartment complex. The Spearman's rank correlation coefficient between our index of environmental awareness[14] and size was 0.78 ($p < 0.01$). Although we could not build a social profile of the inhabitants or office-bearers of the RWAs, we did notice that there was a correlation between the size of apartment complexes and socioeconomic class that could explain this correlation. The larger complexes tended to be inhabited by people from professional classes — typically the information technology sector, which has been the booming sector in Bengaluru. Members of this class are known to be more environmentally aware, as witnessed in other environmental campaigns in Bengaluru around lake conservation and tree-felling.

Given this collinearity between size and the variables representing enforcement and environmental awareness, we do not include the latter variables in the statistical analysis linking independent variables to compliance in the next section. We discuss the possible role that these variables might play along with technological parameters in Section 5.5.

5.5. *Influence of economic factors on compliance*

As explained earlier, price of fresh water and number of units were considered as two independent economic variables that might explain compliance of the sampled DWTRU systems.

[13]Giving one point each for positive responses on the two measures of enforcement: inspection visits and notices.
[14]Giving one point each for positive responses on our two measures of environmental awareness.

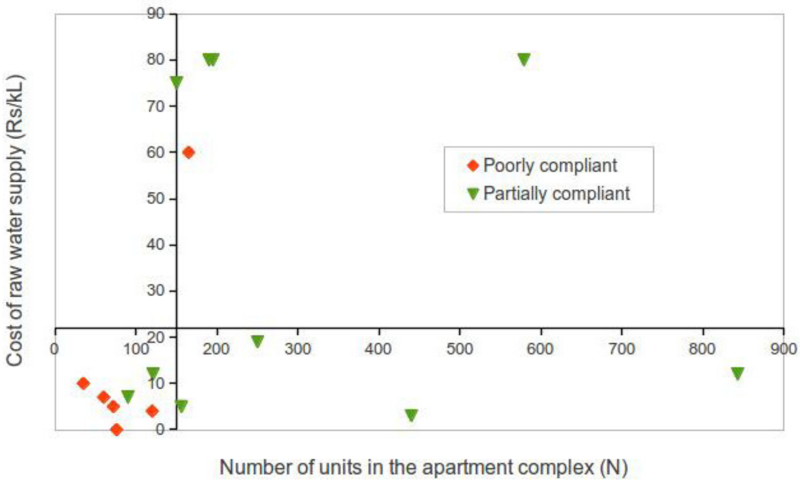

Figure 4. Influence of Size and Fresh Water Price on Level of Compliance

The level of compliance is plotted against these two variables in Figure 4, and is also summarized in simplified form in Table 4. As expected, almost all (5 out of 6) poorly compliant RWAs are clustered at the left bottom of the graph or left top of the table: i.e., small size (hence high treatment cost) and low price of fresh water (hence low gains from reuse). The one poorly compliant RWA with high price of water actually reported that its poor compliance was the result of design flaws — an aspect we discuss later.

However, when we carried out a logistic regression on compliance as the dependent variable and size and price of fresh water as the independent variables, we did not get any significant results $(0.1 < p < 0.2)$, although a regression on size alone does give a significant result $(p < 0.10)$. Clearly, with a small sample size, and the absence of samples in the 'high fresh water price-and-small size' category, the statistical results are not as clear as one would have expected. Additionally, the presence of several large apartments that are partially compliant in spite of paying

Table 4. Influence of Size and Fresh Water Price on Compliance

Cross Tabulation	Price of Fresh Water	
Size of Apartment Complex	Low (<22 Rs/kL)	High (>= 22 Rs/kL)
Small ($N < 150$)	Partially compliant STPs = 2 out 7	Nil
Large ($N >= 150$)	Partially compliant STPs = 4 out of 4	Partially compliant STPs = 4 out of 5

low prices for fresh water further complicates the scenario. Given that these apartments clearly lack an economic incentive, the influence of non-economic factors in their partial compliance cannot be discounted.

5.6. *Possible influence of other factors on outcomes*

Economic factors alone do not seem to be sufficient to explain the level of compliance observed in the sample. However, the small sample size (a result of the reluctance of RWAs to share information for fear of repercussions) and the observed collinearity between scale and non-economic variables has significantly constrained our ability to discuss the role of the latter factors. Nevertheless, our qualitative observations suggest that these factors may also play a role.

First, enforcement certainly has a role to play. Respondents from the partially compliant STPs did identify enforcement as one of the primary drivers for operating their STP. And conversely, poorly compliant RWAs did mention that they were not generally monitored. At the extreme, if there were no ZLD order and if it were not at least partially enforced in the form of requiring installation of STPs to get building permits, most apartment complexes would not install them voluntarily, given the positive net costs of DWTRU for those using cheap sources of fresh water. Moreover, if the cost of replacing the STP equipment after their functional life of about 10–15 years were factored in by the RWAs, the cost of water treatment would be even higher, and voluntary treatment even less likely.

Second, environmental awareness was clearly displayed by some of the partially compliant RWAs. These respondents were aware of the water crises facing the city and the direct environmental benefits of DWTRU in terms of pollution reduction and freshwater savings. As the president of one RWA put it: “In spite of the high economic costs of running the STP, we feel relieved at the end of the day that we are not adding to pollution of the lakes of Bengaluru”. The implementation of other environment friendly technologies like organic waste segregation units and rain water harvesting systems within the residential complex further indicate a level of awareness in these RWAs.

Third, while the above two are factors supporting compliance, discussions with the poorly compliant RWAs also revealed a factor that works against compliance, viz., information asymmetries between builders and apartment buyers. While the RWAs are held liable by the KSPCB for failures in the STP, they have very little role in technological and design choices that are made by the builder of the apartment complex. The builder not only chooses the type of treatment technology (activated sludge, rotating biological contactor, or sequencing batch reactors), but also its actual implementation (such as tank sizes) and the technology of reuse (such as dual plumbing). He can cut corners and construct under-capacity STPs or use cheap technologies or designs. The buyers were unaware of these choices; sewage treatment arrangements were never discussed when individual households purchased the apartments, nor was this information provided in any brochures. Design faults led to the failure of the STP in at least one case. Several RWAs also complained about inadequate capacities or tank sizes (see Table 2),[15] and cited that as a cause of poor treated water quality. RWAs also felt that the builders focused on just the capital cost, rather than the life cycle costs, and hence rejected technologies with lower operating costs.

6. Summary and Policy Implications

Our study of a sample of DWTRU systems in Bengaluru indicates that significant variation in the extent of compliance with the requirement of tertiary treatment and 100% reuse in large apartment complexes. While the technical impossibility of 100% reuse meant that even the highest level of compliance violated the order, the reasons for the observed range of partial and poor compliance levels are a complex mix of economies of scale, the price of fresh water, the level of enforcement and awareness, and technological choices made under information asymmetry. The study highlights that only apartment complexes dependent on purchased tanker water (and hence paying a high price for their fresh water) have a clear economic incentive to adopt DWTRU.[16] These were generally partially compliant. For the rest, the STPs remain a financial burden. Yet the larger of these apartment complexes with positive net costs ($N >= 150$) were partially compliant with the regulation, partly owing to heightened environmental awareness, partly to more stringent formal enforcement from the KSPCB and partly to lower O&M costs (due to economies of scale). On the other hand, the high treatment cost for the smaller complexes ($N < 150$) motivated (and the lower levels of enforcement enabled) several of them to not operate their STPs 24×7, resulting in inadequate treated water quality and lower reusability and hence reuse levels.

The study has several limitations, including a small sample size and a dependence largely on self-reporting of water quality or reuse levels. Nevertheless, the study is useful not only because it is perhaps the first from the Indian subcontinent,

[15]One of the authors also personally observed this when his residential layout was flooded by sludge dumped by a neighboring apartment complex, and subsequent investigations showed a disconnect between the builder and the RWA.

[16]Even this assumes that the capital cost is a sunk cost. Alternatively, one could say that the capital cost might be similar to the one-time 'betterment' charges that they would have to pay to the water utility to get a sewerage connection.

but also because it goes beyond the standard technology adoption literature to present a framework that combines adoption and enforcement perspectives.

The findings of this study also have several policy implications. First, in spite of the small sample size, it is clear that 100% reuses is simply not feasible. Even the most well-meaning RWAs were unable to meet this norm. And engineering calculations easily corroborate the theoretical impossibility of 100% reuse. The CPHEEO[17] norm of 135 L of water supply per capita per day includes 25% for flushing use. Assuming four persons in a household and that flushing is done using treated water, and another 20% is lost to evaporation in drinking, cooking, wiping, etc., the RWA is still stuck with 320 L of treated water per flat that has to be reused in landscaping, car washing and other uses. Typical garden space in Indian apartment complexes never exceeds 25% of the floor space (much less for high rises). Consumptive water use in such gardens cannot exceed 4 L per sqm. per day, and at least three months of the year this comes from rainfall. Consequently, RWAs can at best use about 200 L per flat for this and other purposes, which amounts to only 50% of the fresh water used. The 'ZLD' requirement is unrealistic,[18] unfair and only leads to a culture of evasion and lack of faith in the law. A 50% reuse requirement would be much more realistic. In Bengaluru in particular, monitored discharge of the remaining treated water into neighborhood lakes could be a win–win solution, since today the lakes are anyway receiving clandestine releases of much poorer quality.

Second, if the long-term policy of the water utility is to provide water supply to all residents of Bengaluru at anywhere near their current price of Rs 22/kL of bulk supply to domestic consumers, then DWTRU does not have net positive economic benefits (irrespective of scale) and its voluntary adoption will be low. The water utility needs to provide a more stable and consistent set of price signals towards reuse across all residents to avoid an unfair burden on those already paying hefty water prices. Permitting sale of treated water would be a way of tilting the economics in favor of wider adoption.

Third, the current ZLD policy imposed by KSPCB (the pollution control agency) also sends confusing signals about who is responsible for sewerage. If the utility is primarily responsible for providing sewerage to all citizens of Bengaluru, it then follows that RWAs that carry out sewage treatment should be given a subsidy by the utility, as is the case in Japan. Currently, not only is there no subsidy, but in fact the utility also charges RWAs for disposal of treated water.[19]

[17]Central Public Health and Environmental Engineering Organization (http://cpheeo.nic.in/).

[18]KSPCB is actually aware of this (KSPCB 2012, p. 7), but has not modified its order.

[19]Though officially the norm is zero discharge, the utility allows RWAs with STPs to connect to the sewerage system when it becomes available, provided they pay a sewerage charge!

Fourth, imposing any treatment-and-reuse requirement must be backed up with both realistic enforcement and reduction of information asymmetries. The recent news stories of only 50% of the decentralized STPs being in compliance with treatment norms (not to mention reuse norms) (Rao 2015) are reflective of the challenge of enforcing such an order: the monitoring and enforcement burden on KSPCB jumped from 14 centralized STPs in the city to an additional 2,200 decentralized ones! Our observations suggest that the regulator may be better off raising the threshold to around 150 units, i.e., only require and enforce the order for large complexes, especially since the smaller apartment complexes (N<150) also face much higher per unit O&M costs. In general, regulators may want to refrain from imposing DWTRU requirements on small complexes. Simultaneously, given that the builders and the residents will always be different in apartment complexes (as against independent houses), the regulator must bring about greater transparency in the design choices being made by the builder and its implications for the residents.[20]

In summary, water scarcity and rising water pollution burden appears to make DWTRU an attractive and perhaps necessary option, especially in developing countries where the sewerage infrastructure is lagging far behind urbanization rates. But its adoption will not be voluntary, as the bulk of the benefits are public, not private. Enabling widespread adoption will require a judicious combination of incentives, and clear, consistent and fair regulation.

Acknowledgments

We wish to thank the office-bearers and staff of the Resident Welfare Associations that opened their gates to us and shared their experience and information, and also officials of KSPCB and independent DWTRU experts for their cooperation and inputs. We are also grateful to Stanzin Tsephel and his colleagues at Centre for Dewats Dissemination Society, Bengaluru for sharing their preliminary survey data on DWTRU systems in Bengaluru with us, and to Priyanka Jamwal, Veena Srinivasan and Nakul Heble from ATREE for their suggestions and help. This work is part of the master thesis final project of Pradeep Kuttuva under the Joint European Masters program in Environmental Studies (JEMES-CiSu), for which funding was provided by the Erasmus Mundus Scholarship (Specific Grant Agreement No. 2013-1961/001-001-EMMC). Sharachchandra Lele's participation was supported by grants from IDRC Canada (Grant no. 107086-001) and the Royal Norwegian Embassy (Grant no. IND-3025 12/0050).

[20]A demand made by publicly by RWAs in Bengaluru a while ago (Navya 2011).

References

Amerasingle, P, RM Bhardwaj, C Scott, K Jella and F Marshall (2013). Urban wastewater and agricultural reuse challenges in India (Research Report No. RR 147), International Water Management Institute (IWMI), Hyderabad.

Angelakis, AN and P Gikas (2014). Water Reuse: Overview of Current Practices and Trends in the World with Emphasis in EU States. *Water Utility Journal*, 6, 67–78.

Aravind, I (2016). Bengaluru's Ulsoor Lake Turns into Fish Graveyard: Is Pollution Plaguing Water Bodies? *The Economic Times*. Mar 2016. Available at: http://economictimes.indiatimes.com/news/politics-and-nation/bengalurus-ulsoor-lake-turns-into-fish-graveyard-is-pollution-plaguing-water-bodies/articleshow/51473174.cms (accessed on 3 August 2016).

Corcoran, E (ed.) (2010). Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Program, UN-HABITAT, GRID-Arendal.

CGWB (2012). Ground Water Information booklet, Bangalore Urban District, Karnataka, Central Ground Water Board, Ministry of Water Resources, Government of India.

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

Devi, MG (2009). *A framework for determining and establishing the factors that affect wastewater treatment and recycling*. Ph.D. Thesis, Department of Resource Management and Geography. University of Melbourne.

DMG (2011). Groundwater hydrology and groundwater quality in and around Bangalore city. Bengaluru: Department of Mines and Geology, Government of Karnataka.

Domènech, L and D Saurí (2010). Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resources, Conservation and Recycling*, 55(1), 53–62.

Evans, AEV, S Verma and A Krishnamurthy (2014). Formal approaches to Waste water reuse in Bangalore, India. *37th WEDC Int. Conf.* Hanoi.

Friedler, E and M Hadari (2006). Economic feasibility of on-site greywater reuse in multi-storey buildings. *Desalination*, 190, 221–234.

Garcia, X and D Pargament (2014). Reusing wastewater to cope with water scarcity: Economic, social and environmental considerations for decision-making. *Resources, Conservation and Recycling*, 101, 154–166.

Gaulke, LS (2006). Johkasou: On-site wastewater treatment and reuses in Japan. *Proc. Institute of Civil Engineers — Water Management, 159WM2*, pp. 103–109.

Hernández, F, A Urkiaga, L De las Fuentes, B Bis, E Chiru, B Balazs and T Wintgens (2006). Feasibility Studies for Water Reuse Projects: An Economical Approach, *Desalination* 187(1), 253–261.

Hernandez-Sancho, F and R Sala-Garrido (2008). Cost Modelling in Waste Water Treatment Processes: An Empirical Analysis for Spain. In *Dangerous Pollutants (xenobiotics) in Urban Water Cycle*, P Hlavenik, O Bonacci, J Marsalek and I Mahrikova (eds.). Dordrecht: Springer.

Ho, G and M Anda (2004). Centralised versus decentralised wastewater systems in an urban context: The sustainability dimension. *Second IWA Leading-Edge Conf. Sustainability.*

Jamwal, P, BK Thomas, S Lele and V Srinivasan (2014). Addressing water stress through wastewater reuse: Complexities and challenges in Bangalore, India. *Proc. Resilient Cities 2014 Congress, 5th Global Forum on Urban Resilience & Adaptation. Organized by ICLEI*, pp. 29–31. Bonn, Germany.

Jamwal, P, TM Zuhail, Praveen Rahe Urs, V Srinivasan and S Lele (2015). Contribution of sewage treatment to pollution abatement of urban streams. *Current Science*, 108(4), 677–685.

Kimura, K, D Mikami and N Funamizu (2007). Onsite wastewater reclamation and reuse in individual buildings in Japan. *6th IWA Specialist Conf. Wastewater Reclamation and Reuse for Sustainability*, October 9–12, 2007. Antwerp, Belgium.

Kodavasal, A (2015). Sewage Treatment plants — An assessment of various technologies prevalent in Bengaluru. Presented at Knowledge Seminar on Strategies for Wastewater management and sanitation, 19 June 2015, Bengaluru. Also available at: http://travailsofanenvironmentalengineer.blogspot.in/2015/10/wastewater-treatment-and-utilisation.html.

KSPCB (2012). A report of monitoring committee on performance of wastewater treatment plants in the apartments and other establishments in BBMP limits of Bangalore, Karnataka State Pollution Control Board, Bangalore.

Lalitha, S (2015). Board Finds Many Sewage Treatment Plants Faulty. *The New Indian Express*. November 2. Available at http://www.newindianexpress.com/cities/bengaluru/Board-Finds-Many-Sewage-Treatment-Plants-Faulty/2015/11/02/article3109586.ece (accessed on 3 August 2016).

Lazarova, V, T Asano, A Bahri and J Anderson (eds.) (2013). *Milestones on Water Reuse: The Best Success Stories*. London: IWA Publishing.

Liang, X and MP Van Dijk (2008). Economic and financial analysis of decentralized water recyclingsystems in Beijing. *3rd SWITCH Scientific Meeting,* held at Belo Horizonte, Brazil.

Mankad, A and S Tapsuwan (2011). Review of socio-economic drivers of community acceptance and adoption of decentralised systems, *Journal of Environmental Management*, 92(3), 380–391.

McDonald, RI, K Weber, J Padowski, M Flörke, C Schneider, PA Green, T Gleeson, S Eckman, B Lehner, D Balk *et al.* (2014). Water on an urban planet: Urbanization and the reach of urban water infrastructure. *Global Environmental Change*, 27, 96–105.

Mehta, V, E Kemp-Benedict, R Goswami, S Muddu and D Malghan (2013). Social ecology of domestic water use in Bangalore, *Economic and Political Weekly*, 48(15), 40–50.

Michel, L, L Vincent and C Catherine (2013). The Syracuse project-A global approach to the management of water uses in an urban ecosystem. Available at: http://thesyracuselab.com/wp-content/uploads/2013/06/Novatech_2013-Lafforgueal.pdf.

Molinos-Senante, M, F Hernández-Sancho and R Sala-Garrido (2011). Cost–benefit Analysis of Water-Reuse Projects for Environmental Purposes: A Case Study for

Spanish Wastewater Treatment Plants. *Journal of Environmental Management* 92(12), 3091–3097.

Molinos-Senante, M, F Hernandez-Sancho and R Sala-Garrido (2012). Tariffs and Cost Recovery in Water Reuse, *Water Resources Management*, 27, 1797–1808.

Naik, KS (2014). *Decentralized Wastewater Management Solutions for Improved Public Health Protection and Reclamation: Optimization and Application*. Ph.D. Thesis, UCLA: Civil Engineering.

Nath, S (2015). In pictures: Bellandur lake's fire and snow. *Citizen Matters*, 20 May 2015. Available at: http://bangalore.citizenmatters.in/articles/in-pictures-bellandur-snow (accessed on 27 August 2015).

Navya, KP (2011). Pollution watchdog to support apartments for better STPs. *Citizen Matters*. 21 Dec. Available at http://bangalore.citizenmatters.in/articles/print/3658-kspcb-to-support-apartments-for-better-stps (accessed on 27 August 2015).

Padowski, JC and SM Gorelick (2014). Global analysis of urban surface water supply vulnerability. *Environmental Research Letters*, 9(10), 104004.

Rao, R (2013). Solving Bangalore's Water Woes. *Business Standard*, April 29, 2013. http://www.business-standard.com/article/economy-policy/solving-bangalore-s-water-woes-113042900023_1.html (accessed on 3 August 2016).

Rao, MM (2015). Only 22 of City's Sewage Treatment Plants Follow Norms. *The Hindu*. November 3, 2015. http://www.thehindu.com/news/cities/bangalore/only-22-of-citys-sewage-treatment-plants-follow-norms/article7836465.ece (accessed on 3 August 2016).

Reddy, YM (2013). An Inconvenient Truth: Bangalore's Future Is in the Gutter. *DNA*. June 23, 2013. http://www.dnaindia.com/bangalore/report-an-inconvenient-truth-bangalores-future-is-in-the-gutter-1851841 (accessed on 3 August 2016).

Rodriguez-Garcia, G, M Molinos-Senante, A Hospido, F Hernández-Sancho, MT Moreira, and G Feijoo (2013). Environmental and Economic Profile of Six Typologies of Wastewater Treatment Plants. *Water Research*, 45(18), 5997–6010.

Ujang, Z and C Buckley, (2002). Water and wastewater in developing countries: Present reality and strategy for the future. *Water Science Technology*, 46(9), 1–9.

Urkiaga, A, L de las Fuentes, B Bis, E Chiru, B Balasz and F Hernández (2008). Development of Analysis Tools for Social, Economic and Ecological Effects of Water Reuse. *Desalination* 218(1), 81–91.

Vishwanath, S (2014). How to Benefit from Waste-Water. *The Hindu*, 16 Mar 2014. Available at: http://www.thehindu.com/todays-paper/tp-features/tp-propertyplus/how-to-benefit-from-wastewater/article5789870.ece (accessed on 27 August 2015).

Zhang, DQ and SK Tan (2010). Decentralized wastewater management and its application in an urban area of Beijing, *China. 4th Int. Conf. Bioinformatics and Biomedical Engineering*, 18–20 June Chengdu, China.