Key issues for decentralization in municipal wastewater treatment

Diana Paola Bernal, Inès Restrepo

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Diana Paola BERNAL* and Inés RESTREPO**

*CinaraInstitute, Universidad del Valle. Calle 13 No. 100-00 Bldg 341, Cali, Colombia
(E-mail: diana.p.bernal@correounivalle.edu.co ; dpaola22@hotmail.com)
**CinaraInstitute, Universidad del Valle. Calle 13 No. 100-00 Bldg 341, Cali, Colombia
(E-mail: inesrestrepo@corrreounivalle.edu.co; inrestre@hotmail.com)

Abstract

The pressure on water resources caused by accelerated urbanization, the inadequate management and disposal of wastewater and the implementation of sophisticated treatment systems which sometimes with low efficiency and coverage are some of the problems to be solved with alternative and innovative strategies that be in harmony with the recent trends on water management. One of these strategies is the decentralisation in wastewater treatment. In this article, it is proposed an overview of the state of the art and a review of successful cases worldwide, to identify technological, social, economic and environmental issues to be considered for implementation of decentralisation in treatment of municipal wastewater in Colombia. These aspects are a first step in building the conceptual model for the selection of decentralised - centralised treatment schemes.

Keywords

Decentralisation; wastewater management; municipal wastewater; developing countries; urban areas.

INTRODUCTION

The pressure on water resources as a result of city development has a negative effect on water systems. The expected population growth between 2000 and 2025 will concentrate in urban areas, where by 2025 about 80% of the population will be living in developing countries in Africa, Asia, or Latin America (United Nations, 2007). Thus, the growth dynamics of urban population should be considered one of the major issues of urban water pollution (Marsalek *et al.*, 2001) and is related to the lack of public access to sanitation (2.6 billion people do not have access to improved sanitation facilities). In the period 1990–2008, approximately 1.3 billion people gained access to improved sanitation, and 64% of them live in urban areas. However urban areas, though better served than rural counterparts, are struggling to keep up with the growth of the urban population (WHO and UNICEF, 2010).

At the present time, environmental protection and sustainable management of natural resources are in the foreground of economic and technological activities worldwide (Verstraete, 2009). The tendency in development must be aimed at achieving a self-sustainable urban water cycle, which is not only a closed-loop cycle in terms of water flows, but also minimises energy requirements and waste volumes discharged to the environment. Likewise, the plans, programs and projects must be subject to an environmental impact evaluation for the purpose of identifying potential alternatives for prevention, mitigation, and compensation, as well as of reforming the economic structure to direct towards a decision-making process in which environmental consequences are considered (Wang, 2009).

The traditional water planning approach includes a relentless increase of future demands that exceed the sources of supply, considering that the projections of population, the per capita water demand, the agricultural production, and the levels of economic productivity are calculated upward (Gleick, 2000, Marsalek et al., 2006). The conventional approach allows the use of drinking water for irrigation, toilet flushing, and draining, even when these uses do not require high quality standards. Wastewater treatment is a commonly spread practice in developing countries where a high percentage of the population (90%) is connected to centralised treatment systems (Metcalf and Eddy Inc., 2003). Decentralised systems, however, are becoming of special interest because of the possibility of reducing treatment costs in the long term and reusing wastewater (Daigger, 2009).

In urban water management there is a need for a change to improve the sustainability of the systems. This new approach should include the integration of social, economic, and environmental aspects with practices such as rainwater management, water conservation, wastewater reuse, rational energy management (incorporating the use of alternative sources), nutrient recovery, and sorting at source. This approach can be applied to centralised and decentralised schemes or even a combination of both (Daigger, 2009).

Decentralised wastewater management as an option for urban areas

Decentralised treatment is defined by the fact that raw wastewater is treated next to the source (Wilderer and Schreff, 2000 cited by Libralato *et al.*, 2011), this approach is becoming an viable alternative for wastewater management, minimizing the environmental impacts and facilitating the resources recovery (Nhapi, 2004).

Decentralised systems can offer a profitable long-term option to guarantee the accomplishment of public health and water quality objectives (EPA, 1997). These systems, however, involve changes in the way in which planning and decisions are made with regard to the management of water resources, as well as infrastructure, operational, and maintenance changes. Additionally, considering climate change, environmental degradation, and increasing concerns about security further exacerbates the pressures on urban water systems (Jackson et al., 2001cited by Milman and Short, 2008). A decentralised infrastructure offers benefits because it spreads the risks of drought and extreme events and so it is often more climate resilient (Howard and Bartram, 2010).

To complement the above, the concept of decentralisation provides greater flexibility in choosing and locating the types of facilities for treating urban water. A distributed system is also inherently more reliable and less susceptible to failure and outside intervention than a centralised system (Andoh, 2002, Daigger and Crawford, 2007, Panebianco and Pahl-Wostl, 2006, Gikas and Tchobanoglous, 2009, Nelson, 2008).

Decentralisation also emphasises a more holistic approach that considers the benefits of reducing the amount of waste at source and the option of recycling or reuse at the site. Besides, decentralised systems keep the collection component of a wastewater management system as minimal as possible and focus primarily on the necessary treatment and disposal of wastewater. The fee collection costs can be reduced down to more than 60% of the total budget for wastewater management in a centralised system, particularly in small communities with low population densities (Massoud *et al.*, 2009).

Considering the variety of sustainable factors, such as social, cultural, environmental, and technical factors, which must be taken into account in order to implement a wastewater treatment system, the financial aspect is often the most decisive factor in developing countries. This is the reason for which decentralised systems are being considered increasingly as a viable alternative because they are less intensive in terms of resource requirements and more ecologically sustainable (Tchobanoglous *et al.*, 2003).

However, in the majority of countries, there is a lack of suitable institutional arrangements for managing decentralised systems and a lack of a suitable policy framework that encourages a decentralised approach. Without technical assistance and other capacity-building measures, problems of institutional capacity that existed under a centralised operation are simply passed on to the new structures (Parkinson and Tayler, 2003). Similarly, there is limited information on how sustainability applies to the general field of wastewater infrastructure, including both centralised and decentralised treatment approaches (Danyluk, 2008). Table 1 shows the drivers and constraints of decentralisation of wastewater treatment

Table 1 Drivers and constraints for decentralisation

Drivers	Constraints
▪ Water crises and other new societal demands on the infrastructure – Droughts and water supply shortages – Water quality and habitat degradation – Climate change and resilience – Aging infrastructure costs - repairs and expansion – Alternatives to sprawl development (promoted by sewers and large-lot septic systems) – Quality of life in urban and rural communities□ pervasive grey infrastructure ▪ Population growth ▪ Water scarcity ▪ Resource constraints ▪ Available technology ▪ Increased demand ▪ New ideas and design concepts□ natural, social, economic systems ▪ Niche innovations by advocates and entrepreneurs	▪ Government policies and regulations founded on centralised infrastructure ▪ Market failures, with fragmentation and little information ▪ Distorted rates of water ▪ Fragmentation of the water and sanitation agencies ▪ Civil society based on the conventional ▪ Minimum investment in research ▪ Lack of local models that combine technology, management, financing and customer acceptance ▪ Segregation of actors (entrepreneurs, professionals, and academics) in three different areas: supply, storm water and wastewater ▪ Lack of acceptance public ▪ Lack of economic evaluations procedures ▪ Stove-pipe professional thinking ▪ Institutional constrains ▪ Existing practices

Source: (Daigger, 2009, Nelson, 2008)

The drivers listed in Table 1 show that many of the environmental problems associated with municipal wastewater could be mitigated and controlled through the implementation of decentralised schemes. However, the main constraint is the lack of knowledge by professionals and institutions in the water sector where training is given to provide conventional solutions with an "end-of-the-pipe" approach. There are constraints on the part of the government agencies that establish the guidelines for plans, policies, and regulations in relation with urban planning and urban water management. Additionally, current centralised schemes do not enable communities to access and acquire technical solutions.

The decentralised wastewater management is aimed at the development of systems more financially affordable, more socially responsible, and more environmentally benign than conventional centralised systems, bridging the gap between onsite systems and conventional centralised systems (Nhapi, 2004, Burkhard et al., 2000).

Environmental problems in urban areas are a consequence of the number of people producing waste in high concentrations. In this sense, a centralised approach to managing wastewater is the best option from the standpoint of per-capita costs of treatment. However, when there are high population densities in peri-urban areas located at great distances from centralised systems, this economy of scale disappears, leading centralised systems to require large investments (Chung et al., 2008, Fane et al., 2002).

The implementation of a decentralised system calls for a different kind of planning where the feasibility, design, and implementation activities should be carried out by independent sectors within the urban area, taking into account specific contexts and providing solutions that meet their individual needs. This is done also considering the existing heterogeneity in a urban centre, where the social, environmental, geographic, economic, and technological conditions may vary widely (Liang and van Dijk, 2008). Decentralisation has the advantages not only of being easily adaptable to local conditions in urban areas, but also of extending its capacity in line with population growth. Besides, this approach facilitates reusing water and recovering by-products in the form of nutrients, sludge, and energy. Table 2 shows a comparison between centralised and decentralised approaches.

Table 2 Comparison between centralised and decentralised schemes

Parameter	Centralised	Decentralised
Collecting system	Large diameters, long distances	Small diameters, short distances
Requirements space	Large area in one place	Small areas in many places
Operation and maintenance	Full time technical staff requirements	Less demanding, can be monitored remotely
Uniformity of water	Many types of water	More uniform water
Dilution grade	Less control over the stormwater, more dilution	More control over the stormwater, more concentrate
Risk	Risk on a larger scale	Risk distributed
Water transfer	Increase the needs for water transfer	Water is used and reused in the same area
Social control	Social control is lost	More social control
Ease of expansion	High costs, more complexity to implementation	Low cost, less complexity to implementation
Potential to reuse	All water is concentrated in one point	Water can be reused locally

Source: Adapted by CODESAB (2011)

Experiences of decentralisation

The decentralisation for wastewater management present different levels from individual solutions, clusters and individual buildings to semi-centralised or satellite treatment systems that could be also integrated within the existing centralised system even if only for solid sludge processing (Libralato et al., 2011). Additionally, Orth(2007) classify the decentralisation in 3 categories: *i*) simple sanitation systems, whose purpose to assure minimum hygienic standards for the population, with water pollution control being of minor significance. *ii*) Small-scale mechanical-biological treatment plant that are designed to limit water pollution, beside to assuring a high standard of hygiene; iii) Recycling systems which priority is the environmental protection while simultaneously maintaining a high standard of hygiene, a common principle is separation of the different sewage or material streams (urine, faeces, grey water, and stormwater).

The extreme level of decentralisation corresponds to individual solutions, being this option one of the most commonly reported in literature, mainly at locations with low population density and scattered. Furthermore this kind of alternative is also used in peri-urban areas. In the United States around 60 million people use some form of onsite wastewater treatment, and about 20 million of them use the conventional septic tank system (Bradley et al., 2002). Another example of an individual solution is the use of dry toilets with the recovery of nutrients which are used in approximately 700,000 households in China (Larsen et al, 2009 cited by Libralato et al., 2011). In Turkey, almost 28% of the municipalities are served by septic tanks (Engin and Demir, 2006 cited by Massoud et al., 2009). In New Haven, Adelaide, South Australia, there are onsite treatment facilities for wastewater generated by 65 households on a two-hectare site (Mitchell, 2004).

Successful cases of decentralisation are documented in Japan, where about 2,500 decentralised systems are associated with large blocks of buildings that treat and reuse their own wastewater. In general, there are clusters of residential buildings, hospitals, schools or institutional centres (Yamagata et al., 2002). Likewise, both the Solaire residential complex in New York and the Metropolitan Government facilities in Tokyo have a collection and treatment system in place for reusing wastewater for a toilet-flushing and cooling system (Gikas and Tchobanoglous, 2009).

The combination of onsite treatment and semi-centralised alternatives is the case of Surabaya, Indonesia where wastewater management has been divided into smaller sub-districts (RukunTetangga RT, the lowest level of an organised community) with the two following options for treatment: a communal toilet for a part of population in the RT who does not have their own/private WC (water closet) with source separation (yellow, brown, and grey water) and decentralised domestic wastewater treatment for the rest of the population in the RT who have their own WC with treatment and storage of faeces and urine in every household and grey water carried to the decentralised treatment unit (Prihandrijanti et al., 2008).

Another approach is the connection into decentralised systems with a centralised collection system. The largest satellite plant is the Tillman WWTP in Los Angeles which has a capacity of approximately 80 Mgal/day. The excess of flow and solids from the Tillman WWTP are discharged to the collection system feeding the Hyperion WWTP. In another example, the Los Angeles County Sanitation District maintains seven satellite plants to facilitate water reuse projects throughout the county. Similarly, the Serrano development in CA was made possible with a satellite water reuse system for irrigation water (Leverenz and Tchobanoglous, 2009). Other experiences of decentralisation of wastewater treatment are summarised in Table 3 below.

Table 3 Experiences of decentralisation for wastewater treatment

Location	Description
Serrano, El Dorado County, CA, UnitedStates	Yard and community landscape irrigation with reclaimed wastewater from decentralised system. During the summer period the reclaimed water supply must be augmented (Gikas and Tchobanoglous, 2009)
Rouse Hill, Nueva Gales del Sur, Australia	Reclaimed water from decentralised system used for a variety of non-potable uses (Mitchell, 2004)
St. Petersburg, Florida, Estados Unidos	Landscape irrigation from four decentralised water reclamation plants (Gikas and Tchobanoglous, 2009)
Upland Hills Country Club Golf Course, Upland, CA. United States	One of the earliest satellite systems involving sewer mining and treatment for golf course irrigation. System has been in operation for 25 years (Ripley, 2006 cited byGikas and Tchobanoglous, 2009)
LowerJordanRift Valley, Jordan	Development of a strategic plan to include decentralised and semi-centralised systems for rural and urban areas in the water master plan of Jordan 2009 2022 (van Afferden *et al.*, 2010).
Venice, Italy	4,493 decentralised systems distribute in 119 islands (MAV, 2007 citado por Libralato et al., 2011)
Muscat, Oman	12 wastewater treatment systems serve to 30% of population; the remaining 70% is served by individual septic tanks. The wastes generated are sent to municipal treatment plant. There are 137 private treatment plans (Bakir, 2001)
Gweru, Redcliff, Mupandawana, Nemanwa, Zimbabue	Analysis and development of an alternative strategy of decentralised wastewater management in Zimbabwe. The conceptual plan was developed taking into account capital and operational cost, wastewater generation patterns and quality, and urban agriculture (Nhapi, 2004)
Beijing, China	Around 1,000 decentralised wastewater recycling systems have been constructed and are operational in Beijing. According with the regulations, all institutes, schools and hotels of which a construction area larger than 30,000 m^2 have their own water recycling system (Liang and van Dijk, 2008)
New York, United States	Decentralised wastewater collection and treatment incorporating 14 wastewater treatment plants (Daigger and Crawford, 2007)

IDENTIFYING THE KEY ISSUES FOR DECENTRALISATION

Based on a review of the state of the art and documented experiences, the key issues to the implementation of decentralised systems in urban areas were identified and classified, particularly in the context of developing countries. A review of 14 different studies provided the basis for establishing commonalities between them with regard to various issues, which were classified into the six following categories: planning, demographic, technological, economic, environmental, and social issues. These issues and their respective authors are summarised in Table 4.

The key aspects to the implementation of a decentralised system were identified in each category based on the largest number of commonalities between the authors. Nevertheless, there were some issues in each category that were more relevant than others (where more than 50% of authors agreed) which can make a difference in implementing decentralised schemes in the context of urban areas in developing countries. These issues are shown in Figure 1.

Table 4: Overview of the key issues for decentralisation

Issue	Authors
Planning	
Urban area planning	2,4,5,7,8,10
Geographical distribution and land uses	1,3,4,5,7
Strengthening of master plans and urban development plans	1,2,6,7,8,10,12,14
Strengthening of legislation	1,2,6,8,10,12,14
Strengthening of institutions	6,10,12,14
Administrative and political reforms	6,8,14
Demographic	
Size	1,2,3,4,8,9,10
Distribution of population	1,2,3,4,5,7, 9,13
Density	1,2,4,9,13
Growth rate	1,2,3,4,10
Technological	
Sewer system existence	1,2,3,5,6,13
Sewer system coverage	3,5,10,13
Wastewater treatment existence	1,2,3,13,14
Wastewater treatment coverage	3,5,10
Non-conventional technologies	1,2,9,10,13,14
Technologies combination	1,2,3,13,14
Water demand	2,3,4,8,14
Wastewater production	2,3,8
Wastewater composition	2,4,5,6
Efficiency	2,3,4,5,6,7,13,14
Reliability	2,3,4,5,6,7,13
Reclamation and reuse of wastewater	1,2,3,6,7,8,9,10,11,12,13,14
Combination of centralised and decentralised schemes	1,2,3,6,7,9,10,13,14
Compliance with quality standards	2,4,5,6,7,13,14
Economic	
Collecting and conveyance cost	1,2,3,4,5,6,7,8,9,13,14
Treatment cost	1,2,3,4,5,6,7,8,9,11,14
Construction cost	3,5,8,11
Maintenance and operation cost	2,3,5,7,8,11
Materials cost	1,5,8
Environmental cost	8,11,12,14
Environmental	

Environmental protection	3,4,6,8,9,11,13
Resources consumption	7,8
Environmental benefits	4,8,11,12,14
Social	
Acceptance	4,7,8,11,12
Social awareness on the environment	6,8,11,12,14
Environmental education	6,11,12
Health Impact	6,7,8,9,13
Water culture	11,12,14

Source: 1. Prihandrijanti*et al.*, (2008) 2. van Afferden et al., (2010) 3. Libralato et al., (2011) 4. Gikas and Tchobanoglous(2009) 5. Chung et al., (2008) 6. Massoud et al., (2009) 7. Daigger and Crawford (2007) 8. Liang and van Dijk(2008) 9. Naphi(2004) 10. Daigger(2009) 11. Mankad and Tapsuwan(2010) 12. Parkinson and Tyler (2003) 13. Bakir(2001) 14. Panebianco and Pahl-Wostl(2006)

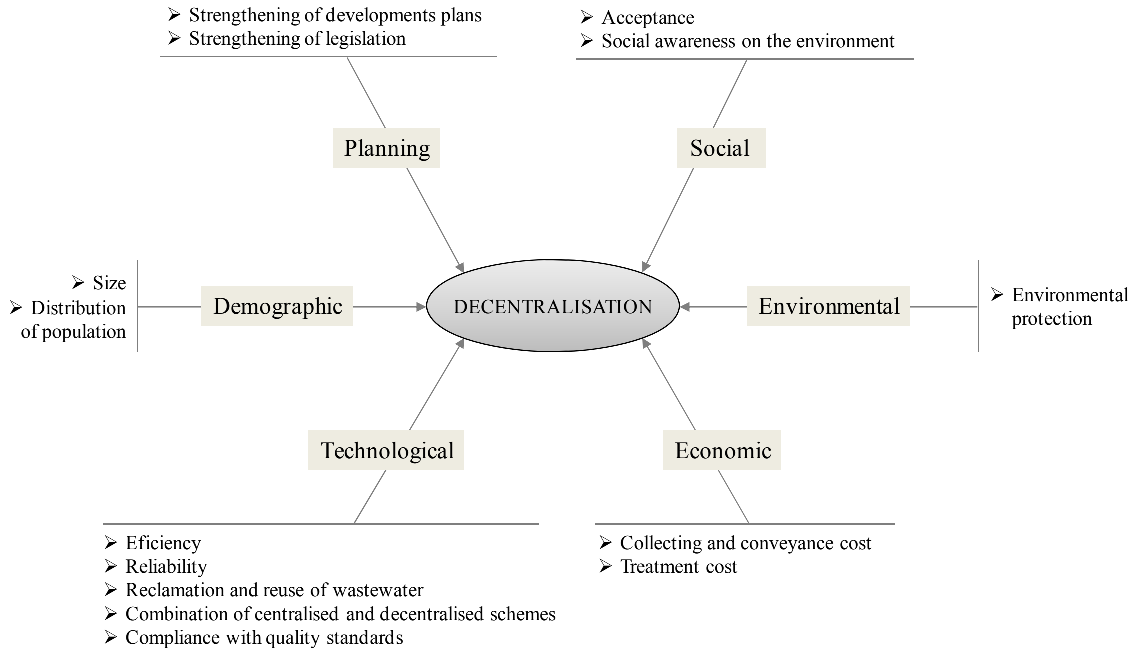

Figure 1: The most relevant key issues of decentralisation

RESULTS AND DISCUSSION

Planning category

Six key issues were identified in this category, namely, urban area planning; geographical distribution and land uses; strengthening of master plans and urban development plans; strengthening of regulations; strengthening of institutions; and administrative and political reforms. All these key issues are related to the form of planning for water management in a city, where a centralised approach prevails with conventional end-of-the-pipe solutions with results that have not yet shown the expected efficiency regarding pollution control.

In this sense, in order to implement decentralised treatment schemes mainly in cities in developing countries, it is necessary to integrate urban planning with water resource planning based on geographical and spatial distribution and land uses, so it can be defined the level of decentralisation and evaluate the potential of reuse in each sector. However, to achieve this, it is essential to make some reforms to the legal, political, and administrative framework of urban planning and water resource management, promoting decentralisation as an innovative solution to the pollution problems, improving wastewater treatment coverage, and meeting quality standards that ensure public health and environmental protection.

The importance of reforming the political, legal, and administrative framework as well as of strengthening the capacity of institutions involved in the water and sanitation sectors in relation to the issue of decentralisation can become a critical instrument to ensure sustainability of these alternatives and their articulation with already operating centralised schemes.

Demographic category

Aspects such as size, distribution, density, and growth rate of population are critical to the development of any project for urban water management; but for decentralisation, distribution and population size are especially important considering that these issues are the basis of good planning respect to the number of decentralised systems and the level of decentralisation to provide.

Technological category

Most authors agree that efficiency, reliability, and compliance with quality standards are key issues under a decentralised scheme because of the need for a strict control of the technology to meet removal efficiencies required by the regulations, especially when they are small decentralised schemes operating in isolation from the central treatment system.

On the other hand, the common characteristic of all the described decentralised options is the "zero-discharge" and the "closing-the-loop" approach aimed at recycling treated effluent for agricultural or municipal reuse (Zhang and Tan, 2010); In this sense, the selected technology must be capable of providing water quality according to the subsequent use of the effluent, and the infrastructure installed in a decentralised scheme should facilitate reuse.

Lastly, another important technological issue is related with the possibility of combining centralised and decentralised schemes, taking into account that this would facilitate the implementation of decentralised treatment systems within existing centralised systems. As the case of satellite treatment plants that could be also integrated within the existing centralised system even if only for solid sludge processing (Libralato et al., 2011). Apart of the obvious utility for water reuse, the satellite treatment systems may also be used to reduce wastewater flows to the centralised facilities, or as means to eliminate or reduce discharges to impacted receiving water bodies (Gikas and Tchobanoglous, 2009).

Economic category

In centralised systems, it is well recognized that most of the financial costs are related to the construction and maintenance of the sewage collection system. Conversely, most of the decentralisation costs are related to the treatment unit (Hong et al., 2005 cited by Libralato et al., 2011). An economic analysis should be performed of each particular project to assess the costs associated with environmental and social benefits (externalities) associated with the technological scheme.

Some of the externalities related to decentralised water systems include avoiding the effects of water restrictions on lifestyle, private green space and property value; reducing nutrient flow into the environment from reduced treated wastewater discharge; and reducing potable water demand which can help delay the need for additional potable water sources in the future (Mankad and Tapsuwan, 2010)

Likewise, while decentralisation is economically feasible, it is necessary to have a plan for funding the system to ensure its sustainability over time. The implementation of decentralised systems may reduce the cost of investment required for wastewater management, save water resources and capital investments, but they have the risk of not continue operating in the long term because the financial problems, taking into account that the majority of local government agencies and departments lack the resources to invest in new infrastructure and rely on grants from higher levels of government to finance improvements in service provision (Angelakis et al., 2003, Parkinson and Tayler, 2003).

Environmental category

Environmental protection is the ultimate goal of a treatment system. For the context of decentralisation there is a special connotation, considering that significant pollution problems by the discharges of wastewater without treatment or deficient treatment associated to centralised systems. In contrast, in decentralised scheme the flows at any point would remain small, implying less environmental damage from any mishap. System construction would also result in less environmental disturbances as the smaller collection pipes would be installed at shallow depths and could be more flexibly routed (Nhapi, 2004)

Social category

Social repercussions of small wastewater treatment systems and of decentralisation processes in general, are frequently underestimated compared to the economic and environmental ones. Actually, the general feeling is that centralisation has no reason to be substituted by decentralisation where it is already in force (Ho and Anda, 2004 cited by Libralato et al., 2011). Centralised systems are already accepted by the general public, while the success of a decentralised system depends on many aspects of the acceptance of the population served and the surrounding population where the system is located. This acceptance is accompanied by environmental awareness which is also linked with information access, environmental education, and water culture.

The public acceptance for the use of decentralised water or non-potable uses is compelling. Acceptance is strongly driven by environmental concerns and social responsibility to reduce household demand; however, beliefs about appropriate applications for alternative water seem to also be influenced by cognitive perceptions related to water quality. Social research has provided clear evidence that the public□s acceptance of alternative water is based on measurable concerns that are heavily influenced by perceptions of risk and health-related concerns (Mankad and Tapsuwan, 2010).

CONCLUSIONS

Environmental pollution, water scarcity, population growth, innovation, and technological developments are drivers that encourage rethinking the current approach to urban water management. In this sense, decentralisation encourages us to think of urban water management in a holistic way, integrating all sectors, drinking water, wastewater, and stormwater to get the most benefit out of them, thereby reducing costs, improving environmental management, expanding service coverage, and considering social and environmental benefits that are not visible with the current perspective.

The above mentioned should be accompanied by a reform of policies and guidelines that govern urban development plans and water management plans in cities in developing countries. The incorporation of decentralisation as a viable option for wastewater management in urban areas and the regulation of reusing practices such as defining quality criteria are necessary actions to articulate the conceptual framework with the actions that occur in reality.

Based on a review of the state of the art and experiences with decentralisation, it can be concluded that the social, financial, and environmental benefits of decentralisation become critical factors when considering this kind of scheme in urban water management plans, mainly in peri-urban areas where wastewater collection and/or treatment is not available. In addition to the benefits, the key issues of each one of the identified economic, social, and environmental categories should be discussed. These include, among others, the cost of collecting and treating wastewater, acceptance and social awareness, and environmental protection, all of which must be considered in implementing decentralisation in urban areas in developing countries.

According to the context of each case, the level of decentralisation may be a critical issue to achieving sustainability of a wastewater management system. In many cases, a semi-centralised scheme can be a feasible option to introduce decentralisation in an urban area in a developing country, considering that the planning policies and the regulatory framework do not have many components that facilitate a different kind of management other than the traditional "end-of-the-pipe" solutions and with use of conventional technologies in centralised systems.

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