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Integration of urban water services

Yi Zhou[a,b], K. Vairavamoorthy[a,b*], M.A.M. Mansoor[c]

[a]*Department of Urban Water and Sanitation, UNESCO-IHE Institute for Water Education, Westvest 7, Delft, The Netherlands*
email: z.yi@bham.ac.uk
[b]*Department of Civil Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK*
Tel. +44 (0) 121 414 5147; Fax +44 (0) 121 414 3675; email: k.vairavamoorthy@bham.ac.uk
[c]*Water and Waste Water Group, Halcrow Group Ltd., Bristol BS1 6DG, UK*
email: mansoorm@halcrow.com

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Abstract

An important aspect of urban water systems is the interactions that take place between different components of the system (e.g. foul water from leaky sewers entering into a drinking water distribution network). It is widely recognised that it is important to consider these interactions in order to maintain effective, efficient and safe water and sanitation services. Hence, an integrated approach to urban water management (IUWM) is necessary.

This paper begins by presenting a case study in India that highlights the important interactions that takes place between different components of the urban water system. The case study highlights the need to recognise these interactions in order to provide safe and sustainable urban water services. The paper then presents ongoing research on development of integrated urban water modelling tool that allows an integrated approach to urban water services. By applying an IUWM approach it is possible to satisfy the water and sanitation needs of a community at the lowest cost to society whilst minimising environmental and social impacts.

Keywords: Global change pressure; Urban water management; IRA-WDS; SWITCH; City water

1. Introduction

It is widely accepted that one of the major challenges of the 21st century is to provide safe drinking water and basic sanitation for all. Presently, more than 1 billion people lack access to improved water sources, and over 2.6 billion people lack access to basic sanitation – nearly all of these people live in developing countries [1,2].

Unsafe water and poor sanitation is a major cause of disease in the world. Every year, unsafe water coupled, with a lack of basic sanitation, kills at least 1.6 million children under the age of five years [3]. Waterborne diseases also inflict significant economic burden through the loss of productivity in the workforce and through increasing national health care costs.

* Corresponding author.

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Consequently, over a billion people are locked in a cycle of poverty and disease [2].

Providing adequate water supply and sanitation, particularly in urban areas, is a challenging task for governments throughout the world. This task is made even more difficult because of the predicted dramatic global changes such as: climate change, predicted to cause significant changes in precipitation patterns and their variability affecting the availability of water; population growth, urbanization, industrial activities, leading to a dramatic increase in water consumption and wastewater discharge; the technological and financial challenges of maintaining and upgrading the infrastructure assets to deliver water to all sectors while maintaining the quality of water distributed to users.

The current models of urban water systems, and their corresponding infrastructure, originate from the 19th century and are questionable from the perspective of cost effectiveness, performance and sustainability. It is generally recognised that there is a need for change in the way we manage urban water. This paper describes the challenges facing cities of the future in relation to urban water supply and sanitation and suggests a way forward.

2. Existing situations

2.1. Urban water supply

It has been reported that in 2002 about 1.1 billion people were using water from unimproved sources, with two thirds of them from Asia. The problem of water scarcity in urban areas is of particular concern. For example, it is estimated that by 2050, half of India's population living in urban areas will face acute water problems [2].

Since the water quantity available for supply generally is not sufficient to meet the demands of the population, water conservation measures are employed. One of the most common methods of controlling water demand is the use of intermittent supplies, usually by necessity rather than design. This is where the water is physically cut-off for most of the day and hence limiting the consumers' ability to collect the water. The Asian Development Bank [4–6], reported that, in 2001, 10 out of the 18 cities studied in Asia, supplied water for less than 24 h a day.

Intermittent supply leads to many problems including, severe supply pressure losses and great inequities in the distribution of water. For example it has been reported that in several cities in India the per capita water consumption ranges from 16 to 300 L/day depending on the locality and the economic conditions of the people [7]. Another serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system [8].

2.2. Sanitation

Only 59% of the world's population had access to any type of improved sanitation facility in 2004 – in other words, 4 out of 10 people around the world have no access to improved sanitation. These people are obliged to use unsanitary facilities, with a serious risk of exposure to hygiene-related diseases.

Some 2.6 billion people, half of the developing world, live without improved sanitation (compared to 2% of the developed world). In sub-Saharan Africa the coverage is a mere 36%, and in China and India there are nearly 1.5 billion people without access to improved sanitation services [3]. In order to meet the Millennium Development Goal sanitation target, 1.6 billion more people need to gain access to improved sanitation over the coming decade. Unfortunately, it is unlikely that this target will be met (it will full short by approximately 600 million).

In developing countries, rapid population growth and urbanization is creating an added demand for housing and infrastructure, including sanitation services. Providing sanitation services especially for the urban poor who are living outside the designated residential areas like illegal settlements or slums is more challenging. The World Bank estimates that almost 26% of the global urban population, over 400 million people, lack access to the simplest latrines [3].

Moreover, the drainage, sewerage and solid waste collection services in these urban areas are not adequate. The systems are poorly planned, designed and operated or poorly maintained. Most of the wastes from these urban areas, are dumped and discharged directly to the open environment (street gutters, open streams or drainage canals), and this creates unpleasant living conditions, public health risks and environmental damage [9].

3. Future challenges

Cities all over the world are facing a range of dynamic regional and global pressures [10–12]. Due to these pressures, providing safe water supply, basic sanitation and maintaining the environment is likely to be more difficult in the future.

Three of the major pressures are:

- *Climate change*: predicted to cause significant changes in precipitation and temperature patterns, affecting the availability of water and quality.
- *Population growth and urbanization*: leading to a dramatic increase in water consumption, while the discharge of insufficiently treated wastewater increases costs for downstream users and has detrimental effects on the aquatic systems.
- *Ageing and deteriorating water related infrastructure*: there is a technological and financial challenge to maintain and upgrade infrastructure in such a way that quality water can continue to be delivered to all sectors and wastewater can be adequately collected and treated.

Currently, providing safe water supply and basic sanitation services across the globe is a major challenge. With increasing global change pressures coupled with existing un-sustainability factors and risks inherent to conventional urban water management, cities of the future will experience difficulties in efficiently managing scarcer and less reliable water resources. Realising the shortcoming of conventional urban water system, there are calls for a paradigm shift in the way we manage urban water [13,14]. This paradigm shift should be based on several key concepts of urban water management. This paper focuses on the importance of recognising the interactions between different components of the urban water system and how this can improve urban water management.

4. Integrated urban water management (IUWM)

Traditionally urban water systems, their planning, development and management, are based on the consideration of their isolated components as opposed to the complete holistic or integrated system. However, it is widely recognised that there are close interactions between the various components and that this cannot be ignored. The performance of one system is often influenced by another.

For example:

- Leakage from water distribution systems often impact groundwater and this may result in increase infiltration into sewers. This may result in dilution of wastewater and increase hydraulic loads in the sewers and ultimately to the wastewater treatment works. On the other hand sewers often leak and this may result in contamination of water supplies in the distribution networks.
- Implementation of various demand control measures may affect the quantity and quality of wastewater entering into sewers. Factors like hydraulic retention time of the wastewater in the sewers, natural aeration within the sewers, extent of the period of anaerobic conditions, etc. can have a direct impact on the change in qualitative characteristics of the wastewater during transport. This will affect the performance of the wastewater treatment plant.

It is widely recognised that it is important to consider these interactions in order to maintain an effective, efficient and safe service of water and sanitation [15]. An IUWM approach involves managing freshwater, wastewater, and storm water as links within the resource management structure, using an urban area as the unit of management. Urban areas are appropriate as units of management, as specific problems and needs faced by cities may transcend the physical and scientific boundary embodied by more traditional units of management of catchments and watersheds. Hence, this unit of management offers a relevant framework for decision making.

Recently there have been significant researches in the area of IUWM, particularly in the development of integrated urban water modelling tools, for example:

- Urban Volume and Quality (UVQ) – a daily urban water and contaminant balance model, which represents water and contaminant flows through the existing urban water, wastewater and storm water systems, from source to discharge point [16].

- City Water System – Sustainable Water Management Improves Tomorrow's Cities Health (CWS-SWITCH) – a decision support system (DSS) for IUWM being developed as part of the SWITCH project [17].
- IRA-WDS– this model assesses the contaminant intrusion risk in intermittent water supply systems [15,18].

In the next section, the paper presents a case study application of IRA-WDS in South India. This application highlights the important interactions that takes place between different components of the urban water system and shows how by modelling these systems one can aim to provide safe and sustainable urban water services.

5. Integrated risk assessment

5.1. Intermittent water supplies

In most developing countries, water supplies are intermittent due to the prevailing water scarcity as a result of depletion of existing water sources. Intermittent systems are systems where there are no supplies for long periods of time. A serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of supply interruptions due to negligible or zero pressures in the system.

Water distribution pipes often lie below the foul water bodies, leaky sewers, open drains and ditches from which the contaminants seep into the surrounding soil and move towards the water pipes. Contaminants enter the deteriorated pipes and pollute the water in the distribution system. Therefore, contamination risk is high where the integrity of the distribution system is compromised, coupled with the movement of contaminated water from various foul water bodies, sewers, drains, etc. Fig. 1 shows the process of contaminant intrusion into the distribution system.

Hence, there is a need to develop control measures to minimize the risks associated with pollution of drinking water, and improve management of water quality in urban drinking water distribution systems. By identifying the relative risks associated with contaminant intrusion into water distribution system, it may be possible for decision makers to prioritise their operational maintenance strategy in order to achieve maximum benefits from their investments in terms of improvements to water quality.

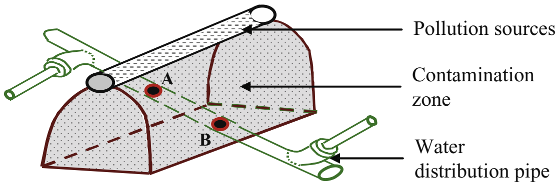

Fig. 1. Illustration of contaminant intrusion into WDS.

5.2. IRA-WDS

Integrated Risk Assessment–Water Distribution System (IRA-WDS) is a GIS based spatial decision support system (SDSS) to assist the authorities in improving water quality. It predicts the risks associated with contaminated water entering the water distribution system from surrounding foul water bodies, sewers, drains and ditches. The IRA-WDS model consists of following three main components:

- Contaminant ingress model – generates contaminant zones by simulating the movement of contaminated water from foul water bodies, sewers, drains etc. through typical soils and towards drinking water supply pipes. The contaminant ingress model is divided into two components. One of them is contaminant zone model that predicts the zone or envelope of contamination emanating from a pollution source and the section of the water distribution pipes in the contaminant zone. Another one is contaminant seepage model that simulate the variables concentration of the contaminant within the contaminant zone and predicts the contaminant loading along the section of pipes in the contaminant zone (SPCZ). By considering if the route of a drinking water supply pipe intersects with the contaminant zone, it maybe possible to estimate the potential contaminant load entering water supply pipes from the pollution sources.
- Pipe condition assessment model – considers each pipe in a water distribution system and estimates their relative condition. The condition of each pipe is assessed by means of numerous indicators related to physical (e.g. pipe diameter, length),

environmental (e.g. soil corrosively, ground water condition) and operational (e.g. number of valves, breakage history) aspects of water distribution system. Finally, these indicators are combined to give a single measure of the relative condition of each pipe.

- Risk assessment model – utilizes the outputs from the contaminant ingress model and pipe condition assessment model and combines these outputs by using appropriate weightings to generate risk scores. For example, the combination of hazard agent from the contaminant ingress model and the vulnerability of the water pipe from pipe condition assessment model produce the risk index for contaminant intrusion into the water distribution system. A conventional multiple criteria evaluation, and the weighted linear combination, can be employed to calculate the risk index. The outputs from the model are relative risk maps showing the relative risk of contaminant intrusion into the entire water distribution system.

The risk maps generated by IRA-WDS will enable decision makers/engineers to: identify sections of distribution system that are most vulnerable to contaminant intrusion; prioritise operational maintenance strategy to have maximum impacts in terms of improving water quality; investigate potential improvements in water quality to changes to operational maintenance (by simulating the models for various scenarios); strategically plan future rehabilitation programmes that have maximum returns in terms of water quality for their investments.

6. Application of IRA-WDS

6.1. Case study

This study was undertaken as part of a major DFID research project. The study site chosen was a single zone in Guntur City, Andhra Pradesh, India. As in most parts of the country, intermittent water supply is prevalent in this area. Water is supplied through pipe networks for about 1 h/day. The zone studied has a population of about 60,000 and area of 4 km^2. Data for the study area was collected over a period of 12 months from June 2002 with the assistance of the local authorities.

The drinking water supplies in this area are prone to contamination due to various pollution sources, which exist in this zone. At several locations, underground sewer pipes run close, parallel and above the water distribution pipes. Frequent leaks are reported in the sewer network due to blockages. Sewer pipes only cover a small part of this zone. Most sewage is directly discharged into open drains and canals. The general condition of these open drains was that there was significant seepage because of the poor condition of lining. Thus, a considerable amount of contaminant seepage occurs from these open drains and since the open drains are at ground level, seepage from these drains reaches water distribution pipes. Stagnated water is also present in natural depressions.

It has been reported that in this system, there has been frequent occurrence of contamination by mixing of sewage with the drinking water in the distribution system. Since, the majority of the population depends on public water supply; any contamination in the network affects large number of people. Therefore, the authorities responsible for managing this system were keen to understand the risks on the water supply associated with the hazards described above, and to develop a maintenance strategy that would provide maximum improvements to water quality with their limited investments.

6.2. Application of IRA-WDS to case study area

The application of IRA-WDS to this case study required the construction of several databases. Four thematic maps were constructed related to: water distribution network; sewer network; canals/open drains network; and surface water bodies. The three models of IRA-WDS (contaminant ingress, pipe condition assessment and risk assessment model) extract the necessary information from the corresponding databases of each theme in order to run the simulations. The outputs of each model are returned back to the geodatabase where the corresponding output themes are generated. In this study, three output themes are generated namely: the SPCZ theme generated from ingress mode; pipe condition theme generated from the pipe condition assessment model; and risk assessment theme generated from risk assessment model.

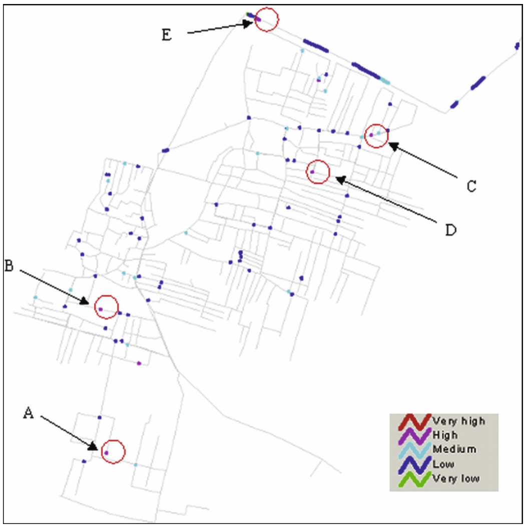

Fig. 2. Risk map for Guntur case study area.

6.3. Contaminant intrusion risk maps

The risk map generated for Guntur case study area is shown in Fig. 2. This figure indicates that most of water pipes are in medium and low risk. However, there are a small number of pipes (in red) with very high and high risk of contamination. The main factors contributing to this are the open drains in areas where there are many pipe joints and connections (high hazard with high vulnerability). Also, high risk is observed in areas where there are foul water bodies coupled with poor condition pipes (high hazard with medium vulnerability). From the risk map shown in Fig. 2, several recommendations were made to the authorities to reduce the risk of contaminant intrusion. Areas in very high to high risk (e.g. the northeast risk areas A and southwest risk area B); require immediate actions for risk mitigation. The recommended actions for the very high and high risk areas include: replace/rehabilitate AC pipes which are found to be in bad condition and very high susceptibility to contaminate intrusion (area A); undertake a leakage detection and repair programme in areas with many joints and connections (area B); inspect open drains and reline where necessary (area C); dewater and fill foul water bodies in the north east (area E).

One of the major benefits of using IRA-WDS is that it is possible for the decision makers to gauge the impacts of the above recommendations on the risk index. This can be achieved by simply modifying the database appropriately and rerunning the model. However, as there may be several other objectives related to an investment strategy for the water distribution system, these should also be considered. For example, it would be prudent to combine the outputs of this model with a hydraulic model to establish the most significant pipes in terms of both the risk of contaminant intrusion, and also improving the hydraulic carrying capacity of the system.

7. SWITCH approach

SWITCH is a research project that aims to develop scientific, technological and socio-economic solutions for the sustainable and effective management of water in the city of the future – 2050. SWITCH aims to develop innovations in several key areas including interventions over the entire urban water cycle. The SWITCH programme will develop tools to analyse the interactions across the urban water cycle for a range of management and technological solutions. It will enable optimal urban water systems to be developed, driven by sustainability criteria, while recognising uncertainties associated with global change pressures.

The tool being developed within SWITCH is called the *City Water* [17]. The first draft of the information sharing platform will become available in 2008. It is anticipated that City Water will provide a greater understanding of different components of the water system in a city and their interactions. It will help evaluate the future potential impacts of global change pressures on the urban water cycle and identify appropriate technical options to address these pressures.

City Water has a number of component tools and models:

- *City Water Vision* – an interactive tool to assist stakeholders in exploring urban water issues and scenarios. It consists of several online questionnaires to help stakeholders identify and define urban water problems in their city.
- *City Water Balance* – A scoping model to show decision makers possible improved solutions for their urban water system. It will have the capability to take into account future global change pressures and explore various alternative water management

strategies (e.g. direct grey water irrigation, stormwater re-use, wastewater recycling, etc.).
- *City Water Drain* – assesses the performance of the existing urban drainage systems, their impacts on the receiving water, and how this performance would be affected by different strategic options and scenarios including climate change and increasing urban population.
- *City Water Futures* – models the urban water system as a collection of autonomous decision-making entities called agents. The models simulate the simultaneous operations of the multiple agents in an attempt to re-create and predict the actions of complex strategies.
- *City Water Strategy* – a performance assessment tool coupled with a solution explorer and optimiser to develop strategies to cope with environmental, demographic and societal changes. It will develop sets of technical and non-technical options and find the optimal solution through multi-criteria analysis.
- *City Water System* – displays the urban water system through schematics of the components (e.g. treatment plants, energy resources, standards and policies, etc.) and their interrelations (e.g. influences between components, water/pollutant/energy fluxes, monetary or data flows). It will provide stakeholders in cities with an information system about their water system.
- *City Water Economics* – A model to explore the potential economic implications of future strategies on urban water management by analysing scenarios for cost recovery and economic drivers for change (financing, pricing and subsidies). Cost allocation and pricing schemes can be formulated for the entire range of water services provided.

8. Conclusions

There is an urgent need for planned action to manage water resources effectively. The problems in urban areas of developing countries are of particular concern as still large sections of the community are living without safe water supply and basic sanitation services. Providing adequate urban water and basic sanitation is likely to become more challenging in the near future due to several global change pressures. To address the challenge of urban water management for the future, there is a need for a paradigm shift. The paradigm shift should include interventions over the entire urban water cycle, recognising interactions between the various components of the urban water system.

This paper presents a new modelling tool IRA-WDS that recognises the interaction between water supply and wastewater systems. The tool simulates the movement of contaminants from foul water sources into water distribution systems. The model has been specifically developed for intermittent systems where contaminant intrusion has been widely reported. The tool generates risk maps where risk is defined as a combination of hazard (considered as pollution sources around water distribution pipe that will potentially contaminate water distribution pipe), and vulnerability (condition of water distribution pipes). The developed modelling tool has been applied to a water distribution network in South India and identified sections of the water supply system that are most at risk and this enables engineers to prioritise maintenance for risk mitigation.

Finally the paper also introduces a new modelling tool being developed as part of the SWITCH project. The tool, City Water, will provide a greater understanding of different components of the water system in a city and their interactions. It will help evaluate the impacts of global change pressures, and identify appropriate technical options to address these pressures.

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