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Potable Reuse of Reclaimed Wastewater: Challenges for Sustainable Water Management

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EXECUTIVE SUMMARY

Australia, being the driest continent in the world, experiences its worst drought currently. The cities located around the coastal areas look for desalination of seawater for potable supplies whereas inland cities explore the possibilities of wastewater reclamation as a last resort for indirect potable supply. The concept of reclaimed wastewater to be considered as a resource for indirectly augmenting the potable supplies has been a subject of debate. Wastewaters can introduce microbial and chemical contaminants into the environment. Even though the existing wastewater treatment plants can successfully remove the conventional contaminants such as organics and nutrients, they are less effective in removing the emerging contaminants such as pharmaceutical and personal care products, endocrine disrupting chemicals and new emerging microbial contaminants. Surface water partly fed with the effluents is widely used as water resource for drinking water and therefore the occurrence of trace organics in surface water is of concern. They are not causing any immediate threat to the humans when exposed since they are present in very low concentrations; however, we need to take precautionary measures to remove the presence of them from potable supplies to minimize the risk of unpredictable long-term effects. Planned indirect potable reuse aims to remove these contaminants in the tertiary treated effluent using advanced treatment technologies with multiple barriers before discharging them into the water bodies to augment the drinking water supply downstream or of their own. Advanced drinking water treatments could also be used to enhance the treatment. This paper discusses how waste treatment and source control will have to be equally managed for successful sustainable water resources management system of potable reuse of reclaimed wastewater.

INTRODUCTION

Population growth accompanied by higher standard of living and ongoing drought conditions caused by changing climatic patterns tend to make water availability as a key national issue not only at present but for the decades to come. The ever-increasing demand for fresh water supplies can inevitably lead to greater incidences of already prevailing unplanned indirect potable reuse practices and implementation of new planned indirect potable reuse situations. This can reduce the spatial and temporal distances between wastewater treatments and drinking water facilities, with the potential of newly emerging trace organic contaminants such as endocrine disrupting and pharmaceutical and personal care products leaking into the potable water supplies (Jones et al. 2005). But, the innovation of state-of-the-art technologies with multiple barriers would remove the trace organic contaminants that may be present in the tertiary treated effluent, and render this suitable for potable reuse. This has been reflected in that many utilities around the world have either been planning or already implementing the advanced reuse. This paper will discuss some of the challenges these potable reuse facilities will have to encounter and how they can be overcome to ensure the sustainability of these water resources.

TYPES OF WASTEWATER RECLAMATION AND REUSES

When discussing wastewater reclamation and reuse of treated municipal wastewater for potable uses, we need to be aware of the distinctions between direct and indirect potable reuses and planned and unplanned ones.

Unplanned Indirect Potable Reuse (UIPR)

Unplanned indirect potable use occurs when a water supply is abstracted for potable purposes from a natural source (surface or groundwater) that is fed in part by the discharge/disposal of treated or non-treated wastewater effluent. The subsequent potable use of the wastewater was not an intentional part of the effluent disposal plan and therefore, the wastewater discharged is not treated to a much higher degree as it is with the planned indirect potable reuse. This type of indirect potable reuse occurs whenever an upstream water user discharges wastewater into a water source that serves as a water supply for a downstream user (Figure 1). (National Research Council 1998, NEWater 2002)

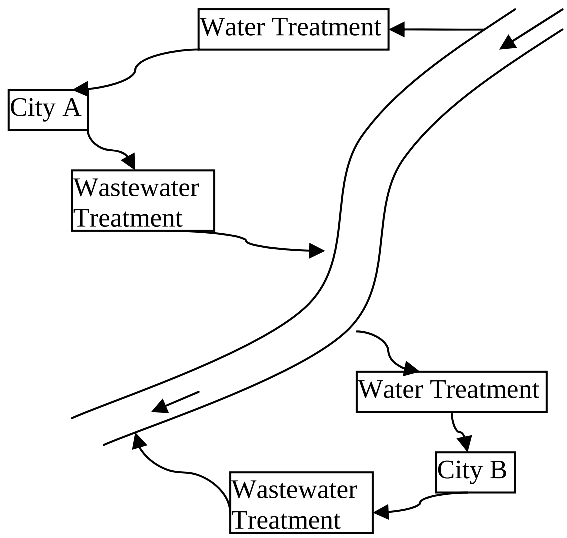

Figure 1: Unplanned Indirect Potable Reuse

Planned Indirect Potable Reuse (PIPR)

Planned indirect potable reuse involves intentional augmentation of natural water supply source such as river, lake, reservoir or underground aquifer for subsequent abstraction, treatment and distribution of water for drinking purposes. As shown in Figure 2, the wastewater discharged will be subjected to very high degree of treatment with multiple barriers to remove the contaminants before disposal into the natural water supply sources. With planned or unplanned indirect potable reuse, the storage provided between treatment and consumption allows time for mixing, dilution and natural physical, chemical, biological processes to purify the water. (National Research Council 1998, NEWater 2002)

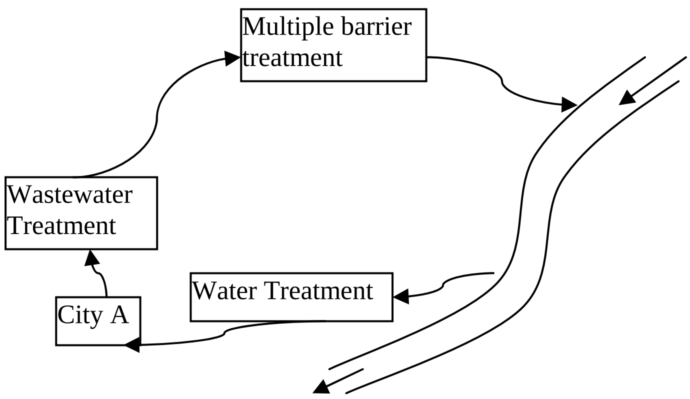

Figure 2: Planned Indirect Potable Reuse

Direct Potable Reuse (DPR)

Direct potable reuse refers to the introduction of highly treated wastewater with extensive processing beyond usual wastewater treatment directly into a water distribution system without intervening storage (Figure 3). Direct use of reclaimed wastewater for potable reuse without the added protection by storage in the environment is not considered as a viable option in Australia. (National Research Council 1998, NEWater 2002).

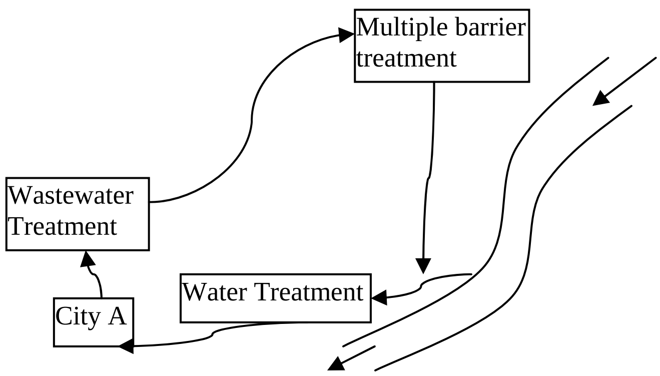

Figure 3: Direct Potable Reuse

COMPARISON OF DIRECT AND INDIRECT POTABLE REUSE

In the case of planned or unplanned indirect potable reuse, the contaminants that survived the treatments are further subjected to dilution, mixing and natural treatment prior to abstraction into drinking water facility. On the other hand, DPR demands extensive treatment of the wastewater prior to reintroduction directly into the drinking water facility; therefore, certain contaminants if not removed by the processes, have the tendency to concentrate over time when repeatedly recycled. The only documented case of an operational DPR is in Namibia, in Southern Africa since 1968 (National Research Council 1998). Since this is not widely practiced, the following discussions will not focus on DPR.

Planned indirect potable reuse cannot be considered as a separate one from unplanned one, as in both cases, a proportion of the wastewater after treatment is reused by the community. However, the degree of treatment given to the wastewater is higher for planned ones since there is an obvious intention to reuse the wastewater. Besides, in PIPR, reclaimed wastewater is mostly discharged upstream so that the same community is responsible to clean up the waste and benefit from reuse, whereas in the case of UIPR, wastewater effluent is discharged downstream for drinking water diversion so that the downstream communities clean up the water that contain upstream discharge of wastewater.

Many large communities unintentionally and unknowingly have been practicing UIPR. National research council concluded that “In US alone, more than two dozen water utilities in Philadelphia, Cincinnati and New Orleans, which draw water from the Delaware, Ohio and Mississippi rivers, serving populations from 25,000 to 2 million people, draw from rivers in which the total wastewater discharge accounts for more than 50% of stream flow during low flow conditions”. In Australia, for example, Canberra wastewater is discharged into Molonglo River and thereby into Murrumbidgee River, and the residents on the Murrumbidgee River below the Molonglo River draw this water for potable purposes.

Rivers have the natural assimilative capacity to clean up the wastes discharged into them; however, their limits have been exhausted during last decade or so due to increased loading discharged containing synthetic chemicals. This is evident from the occurrence and prevalence of newly emerging contaminants in the surface water bodies mainly through sewage effluent disposal. These chemicals have either the natural resistance for degradation resulting in their persistence in the surface water, or are continuously released into the environment, which offset their biodegradation. The concern of these contaminants present in the drinking water would be higher where UIPR is practiced since no advanced treatment is rendered to remove these contaminants from the sewage facilities. This is further aggravated as the population growth resulting from urbanization demands additional plants to be constructed resulting in shorter distance (and therefore less time available for natural treatment) between the effluent disposal from sewage treatment and raw water intake for potable supplies.

Considering the fact emerging innovative technologies are available to remove these contaminants, PIPR could be a promising solution for sustainable water resources management. Several utilities around the world have already upgraded or are planning to upgrade their wastewater treatment facilities with state-of-the-art technologies. There are a number of successful PIPR in operation in US, in California, Virginia and Texas that provide safe drinking water, some of them, for over 25 years (Law 2003, National Research Council 1998). NEWater from Singapore has commissioned its plant as recently as 2000 (NEWater 2002).

POTENTIAL CONCERNS OF POTABLE REUSE OF WASTEWATER

Sewage contains a number of contaminants that can pose environmental threat when humans are exposed to, and therefore require advanced treatment to remove the contaminants of concern before the wastewater can be used for potable reuse. While the existing advanced sewage treatment plants can successfully mineralize conventional organic contaminants and nutrients discharged into them, they are not designed to treat the newly emerging trace organic contaminants.

Emerging chemical contaminants

Newly emerging trace organic contaminants can include endocrine disrupting chemicals, pharmaceutical and personal care products that are released into the sewer through households, trade wastes and hospital wastes. These chemical contaminants are found to be having low elimination rates in the treatment processes and have been subsequently detected in trace amounts in the effluents, surface waters, in river water intakes and, in some cases, in drinking water as well. They persist in the environment due to their inability to biodegrade naturally coupled with the continued release (Jones et al. 2005). In order to gain greater understanding of the occurrence of pharmaceuticals, hormones, and other organic wastewater contaminants in water resources, the U. S. Geological survey conducted a nationwide survey to measure concentrations of 95 organic wastewater contaminants in water samples from a network of 139 streams across 30 states during 1999-2000 (Kolpin et al. 2002). They concluded that 82 out of 95 were detected at least once during this study. Further, 75% of streams contained two or more contaminants, 54% had greater than five, while 34% had more than 10 and 13% tested positive for more than 20 targeted contaminants. The researchers expressed caution in interpreting and extrapolating the results because the sampling sites were located downstream of intense urbanization and livestock production, where these contaminants are inevitable to exist. The measured concentrations were generally low and rarely exceeded drinking water guidelines, even though many compounds do not yet have such guidelines established (Kolpin et al. 2002).

In addition to the presence of pharmaceuticals and personal care products, the disinfectants used can introduce disinfection by-products that may be causing adverse effects. Disinfectants are powerful oxidants, in addition to inactivating the waterborne pathogens; oxidize the natural organic matter as well as bromide present in the source water and inevitably form disinfection-by products (DBP) in the drinking water facility. Although more than 500 DBPs have been reported including trihalomethanes, haloacetic acids, total organic halides (Richardson 2003), only a small number have been addressed in either quantitative occurrence or health effect studies. The DBPs that have been quantified in drinking water are generally present in at sub- µg/L (ppb) or low-to-mid- µg/l levels. These DBPS in the drinking water will be recycled to the waste treatment facility, which might survive in the effluent and subsequently in the surface water. In addition, researchers are yet to identify the DBP potential of a wastewater effluent comprising several organic contaminants that survive the biological processes. When orange county water district conducted extensive monitoring program in the reclaimed water, they found trihalomethanes at concentrations substantially lower than the drinking water standards (National Research Council 1998).

The emerging organic contaminants in the surface water, mainly through the sewage treatment plants, have the potential to contaminate the potable water supply. There are very few studies on the occurrence of pharmaceuticals in point-of-use drinking waters (Jones et al. 2005). Based on those limited studies, human pharmaceuticals have been occasionally detected in drinking water with concentrations generally being in parts per trillion (ng/L^{-1}). Several studies conducted demonstrate that the levels of drugs found in the drinking water are unable to induce any acute effects in humans since they are far below the recommended therapeutic dosages. But the presence of them in the surface water is of concern, as no one knows the synergistic (the combined effect of the mixture of chemicals is greater than if they were present alone) antagonistic (the effect of one being reduced by the other due to interference), combined (the combined effect of mixture is equal to the addition of individual ones) long term effects of chronic exposure of these low-dosage drugs.

Emerging microbial contaminants

Microbial pathogens such as bacteria, viruses, and protozoas of enteric origin can be present in the wastewater and have the potential to cause waterborne diseases upon consumption of fecal contaminated water. Most of the conventional water borne diseases such as typhoid and cholera etc have been eradicated by means of efficient disinfection systems and they are no more prevalent in developed nations (Richardson 2003). However, new water borne diseases are emerging. Certain protozoan cysts and oocysts such as Giardia and Cryptosporidum have been found to be causing adverse health effects due to their ability to survive the conventional treatment systems and their resistance to chemical disinfection. High concentrations of Cryptosporidum and Giardia were repeatedly observed in both raw and treated water in Sydney during three events during 1998, although no increase in water borne diseases was detected (John 2004). Though the source of these protozoa has been difficult to trace (that could be from infected livestock that can contaminate the surface water), the possibility of sewage contamination cannot be overlooked. This recognition, as well as concerns over disinfection by-products when chemical disinfection is used as a means of inactivating the pathogens, has led to research on and use of alternative disinfection strategies that are continuously evolving.

CHALLENGES FOR SUSTAINABLE WATER MANAGEMENT

Researchers continue to study the fate, transport and occurrence of newly emerging contaminants in the environment. Humans may be exposed via potable reuse. There has been no proof that very low concentrations of pharmaceuticals can have any adverse health effects. Nevertheless, water utilities need to take precautionary measures to eliminate or reduce the presence of wastewater signature contaminants from the drinking water to minimize the risk of unpredictable long term effects. The obvious solutions would be

- To upgrade existing tertiary wastewater treatment facilities to advanced treatment facilities employing multiple barrier techniques aiming at removing trace organic contaminants (PIPR)
- To upgrade existing conventional water treatment facilities to include advanced water treatment facilities to remove any trace contaminants present
- To include both in the water resources network

Since the effluent disposal via sewage treatment plants is a point source contamination of emerging chemicals, it would be appropriate to have multiple barrier treatments prior to discharge. We would like to think that this would completely eliminate the risk of newly emerging contaminants entering the potable supplies. But these contaminants could still enter the stream as non-point source contamination at any place after the effluent disposal but prior to abstraction by the potable supplies as described below.

While sewage effluents form a source for these contaminants in the rivers, industrial or other sources cannot be excluded. The veterinary pharmaceuticals and additives will also have the potential to enter the water resources during the treatment and disposal of wastes. Antibiotics is said to be one of the main additives found in the feed for the livestock and is added to enhance their growth. When the manure of these livestock is fed as fertilizers for agricultural purposes, the antibiotics and pharmaceuticals present in the manure along with pesticides used in the agriculture form the non-point diffuse source of contamination for the water bodies. When the sewage sludge is used as soil improvers, they have the potential to introduce the trace human Pharmaceuticals and Personal care Products into the surface water during irrigation (Pedersen et al. 2005). Since they cause non-point source pollution, they are difficult to control at the point of origination.

Therefore, the raw water intake can still contain the traces of these contaminants that have to be dealt with in the drinking water treatment facilities. In order to ensure that the drinking water is free from emerging organics, the advanced treatment facilities may therefore have to be installed either at the points of effluent disposal from the wastewater treatment or intake of drinking water treatments. Implementing both would be an ideal solution though ambitious and expensive. Currently, most of the water treatment facilities are still conventional (coagulation, flocculation, sedimentation, filtration and disinfection) and so less effective in removing the emerging contaminants while wastewater utilities have been upgrading the plants to remove as many contaminants possible.

Treatment processes

During the last decade, several researchers have been concentrating on evaluating the effectiveness of different treatment processes in removing the newly emerging organic contaminants like EDCs, PPCA (pharmacologically active components (PhACs) and personal care products (PCAs). The summary of treatment methodologies and their effectiveness as reviewed by (Snyder et al. 2003) indicates that the reverse osmosis is excellent in removing all types of contaminants followed by ultrafiltration. Membrane technology has been widely used for surface water and wastewater reclamation showing an exponential growth (Law 2003). The most recent example comes from NEWater from Singapore, where secondary treatment is followed by membrane filtration, reverse osmosis, UV disinfection followed by stability control and chlorination. They have produced reclaimed water of a better quality than the local water supply or drinking water. Reverse osmosis is an excellent membrane technology that can remove the emerging chemical and microbial contaminants to provide clear filtrate. However, membrane processes are physical processes that do not alter the chemical nature of the constituents. While the filtrate is free from the contaminants depending on the membrane nominal pore size, the rejected waste stream will have very high concentrations of them. So long as the contaminants remain in the water media, they have the potential to contaminate the receiving water bodies since complete closure of water cycles is an essential part of sustainable water resources management. Therefore, concentrate stream deserves effective treatment prior to disposal or reuse. Currently, the concentrate stream is either disposed to the coastal sea (if the treatment plants are located closer to sea) or directed back to the inlet of the wastewater treatment plants. Evaporation basin is an option; however, site has to be selected on relatively impermeable soil to avoid groundwater contamination by salt infiltration, while research needs to be done whether the recovered salt could be safely used for any commercial purposes (John 2004).

The treatment for concentrate disposal in the rejected stream from membrane treatment should aim at either mineralizing the contaminants or removing them from water media. Since biological processes are ineffective in mineralizing the pharmaceutical and personal care products, the other treatment methodologies such as physical and chemical treatments need to be explored. The advanced oxidation processes using ozone and hydrogen peroxide can mineralize some of the contaminants of concern even though ozone could produce some disinfection by products. The activated carbon could be excellent in removing moderately hydrophobic compounds such as hormones and non-polar contaminants. The powdered form of activated carbon can be even more effective, removing every possible pharmaceutical and personal care product if properly used as cited in a research report (Sinclair Knight Merz 2003).

Source control

Reuse initiatives will also have to focus their attention on source control aiming at minimization of chemical usage in the catchment. Varieties of chemicals are produced in the market every day and they find their way into the sewer by household, commercial and industrial discharge. While trade and industrial wastes are regulated, the wastes from households are not. When the potable water is used for everyday household activities, large quantities of detergents, cleansing agents, personal care and pharmaceutical products find their way into the environment. While pharmaceutical drugs are essential for well-being, a survey conducted in the USA reveals that the vast majority of the people disposed of unneeded medications via municipal sewage facilities as cited in (Khan and Ongerth 2004).

Historically, potential detergent contamination of the environment followed when soap-based detergents were changed to synthetic ones using varieties of chemicals. Some of the detergent metabolites are hard to biodegrade. These household products also introduce salinity into the wastewater as most of them have high sodium content in them. Salinity input into the wastewater treatment plant could be greatly reduced by switching onto products that have low sodium content (Patterson 1997). Sodium in the laundry detergents is mainly used as fillers, which does not serve any purpose for washing. In the west, the industries produce compact and tablet size detergents eliminating unnecessary ingredients. Household cleansers contain several chemicals, the formulations of which are rarely revealed by the manufacturers. The consumers only know the active ingredients, and even the common names of the active ingredients mostly do not indicate the chemical nature of the compound (e.g., 2,4,5-T) (Khan and Ongerth 2004). The study on the chemical characterization of the substances in the households revealed there were 900 different substances found to be potentially present in the greywater from the product information available in the list of common household and personal care products, among which 200 of them were identified as organic compounds that are foreign to microorganisms (Eriksson et al. 2003).

Successful potable reuse of reclaimed wastewater depends on efficient source control, whereby pollutant sources need to be identified and controlled. We need to conduct a comprehensive inventory of the chemical input into the catchment, evaluate their biodegradability and toxicity, and suggest alternative products that are environmental friendly. They need to be encouraged to engage in cleaner production. For example, significant reduction of salt input into the sewer could be achieved by eliminating the usage of bulk agents in the production of detergents. Policies on mandatory labeling and life cycle assessment for the newly introduced products should be implemented on the manufacturers so that all the chemicals used in the formulation are revealed and evaluated for their environmental effects.

The community needs to be educated by well-informed professionals on the selection of environmentally friendly products and safe disposal of leftover or unused or outdated pharmaceutical drugs, personal care products and other household chemicals so that they do not contaminate the soil and waterways.

CONCLUSIONS

Increase in population and climatic change have caused scarcity of fresh and clean water resources. This has inevitably resulted in higher incidences of potable reuse of reclaimed wastewater. The occurrence and prevalence of newly emerging contaminants in the surface water mainly as a point source from sewage effluent disposal and as non-point sources from agricultural and live-stock practices have caused concerns regarding the potable reuse. In order to eliminate / reduce the contamination from the sewage facilities, wastewater utilities can employ innovative technologies with multiple barriers for the biologically treated tertiary effluent. At the same time, conventional drinking water treatment facilities could also be upgraded with advanced treatment processes to further polish the surface water that might have been tainted with the contaminants. Since the combined method would prove to be costly, prevention such as source control and reduction has to be attempted simultaneously with remediation. This paper discussed how waste treatment and source control have to be equally managed for sustainable management of available water resources.

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