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## Review Article

# Water Reuse (WR): The Ultimate and Vital Solution for Water Supply Issues

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**Abstract:** Nowadays the humankind is urgently invited to make available for potable use satisfactory quantities of good quality water to its increasing population. There is a big effort by the water treatment specialists to analyze the solutions the humankind has at its disposition to respond to these risks. The contribution of water reuse (WR) would be great in the humankind's water tomorrow. This review aims to discuss the growing WR technology as a future solution for water supply issues. WR is broadly applied by industries to decrease the consumption of clean water. WR process should employ treated wastewater mixed with surface water at a certain proportion depending on the degree of purity of the treated water and assuring the dilution effect. WR should not employ at any case only wastewater, for safeguard reasons and psychological effects. WR should be obviously more sophisticated than both water treatment and wastewater treatment since pathogens contamination and chemicals presence can be there most elevated. Since pharmaceutical products and cosmetics substances at trace levels are found in tap water, should we assist to a new formulation of water treatment technology? This will be feasible if water treatment/wastewater treatment/WR would be merged in a super and highly standardized water/wastewater treatment technology, as a future trend.

**Keywords:** Water Scarcity, Water Reuse (WR), Drinking Water, Human health, Water/Wastewater Treatment, Environmental Principles

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## 1. Introduction

As the humanity starts this century, the humankind arrives at seeking carefully and thoroughly for new solutions for water reserve and controlling [1-14]. Since water treatment specialists' front toward water supplying confrontations among increasing population and global warming, water reuse (WR), or the using of greatly purified wastewater for drinking and/or non-potable water objectives, is becoming a vital solution [15-22]. Several specialists have applied low-priced WR installations, as bringing water to golf fields and playgrounds or supplying commercial cooling water in regions nearby the wastewater treatment manufactory [23]. Practically, these specialists are now acquainted with the benefits of WR, e.g. high reliability and shortage of water resistance of the water provision [24]. On the other hand, enlarged utilization of recovered water usually constitutes

bigger financial, technical, and institutional problems than usual sources and some consumers are worried concerning the safety of using recycled water for domestic usages. These issues have restricted the application of WR through the World [8, 9, 25-30].

The social, economic, and environmental effects of previous water resources development and unavoidable prospects of water scarcity, which becomes the "new normal" (needing WR), are driving the shift to a new paradigm in water resources management [31, 32]. New methods now include the principles of sustainability, environmental ethics, and public participation in project development. With several communities moving toward the limits of their available water supplies, water reclamation and reuse have become an interesting solution for conserving and extending available

water supply by potentially (1) substituting reclaimed water for implementations that do not need high-quality potable water, (2) increasing water sources and giving an alternative source of supply to assist in satisfying both present and future water requirements, (3) safeguarding aquatic ecosystems by reducing the diversion of freshwater, decreasing the quantity of nutrients and other toxic pollutants entering waterways, (4) reducing the need for water monitoring structures such as dams and reservoirs, and (5) complying with environmental regulations by better managing water consumption and wastewater discharges.

This paper is a review on the WR significance, fundamentals, and future trends.

## 2. Road Map for the WR Mission

A National Research Council Committee, convened by the Water Science and Technology Board (USA), performed a large study of the capacity for WR and reclamation of urban wastewater to enlarge and improve the available water supply solutions [9, 33-38]. The Committee was asked to list the main issues and questions encountered in the WR field (Table 1).

*Table 1. Road Map for the WR Mission [9].*

Task	Definition
1. Contributing to the water supplies	What are the big profits of enlarged WR and reclamation? How much municipal wastewater effluent is generated, what about its quality, and where is it released? What is the convenience of treated wastewaters for different usages, comprising potable water, non-potable urban uses, irrigation, industrial processes, groundwater recharge, and environmental restoration? What is the actual form of the technology in wastewater treatment and production of reclaimed water?
2. Assessing the state of technology	How do obtainable treatment techniques compare in terms of process efficiency, cost, energy use, and environmental effects? What are the actual technology issues and restrictions? What are the infrastructure needs of WR for different objectives?
3. Assessing risks	What are the human health hazards of using recycled water for different objectives, comprising indirect drinking reuse? What are the hazards of using recycled water for environmental objectives? How efficient are control systems?
4. Costs	How do the costs and benefits of water reclamation and reuse generally compare with other supply alternatives, such as seawater desalination and nontechnical options such as water conservation or market transfers of water?
5. Barriers to implementation	What implementation challenges (e.g., public acceptance, regulatory, financial, institutional, water rights) limit the applicability of WR to help meet the nation's water needs and what, if appropriate, are means to overcome these challenges?
6. Research needs	What research is required to progress the safe, reliable, and cost-effective reuse of municipal wastewater where traditional sources of water are inadequate? What are appropriate roles for governmental and nongovernmental entities?

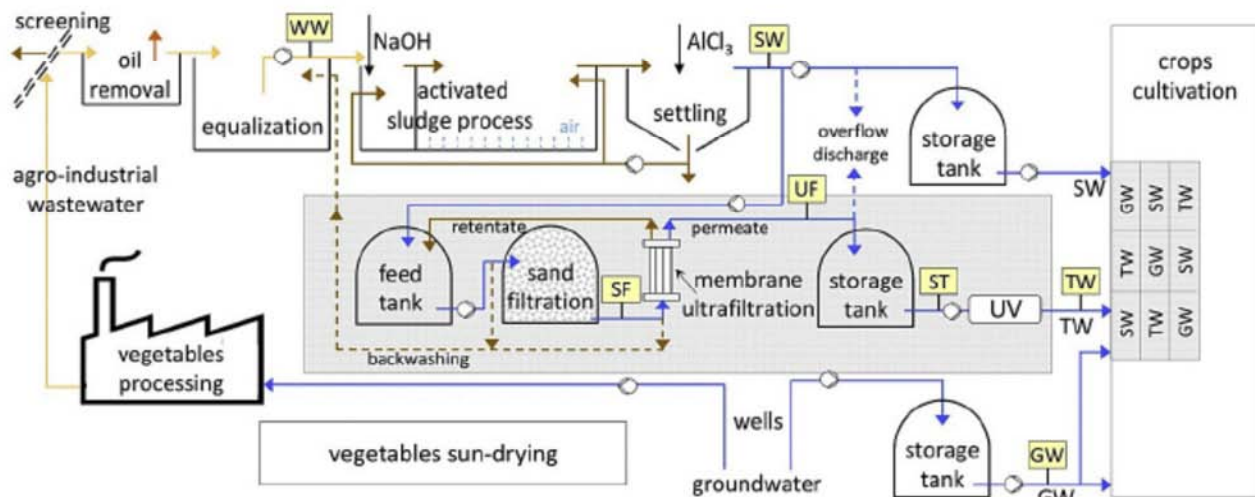
### 2.1. Background and Capability for WR

Municipal WR gives the capability to importantly augment the global at hand water reservoirs [9, 39]. As an example, in USA, 45 million cubic meters per day of municipal wastewater effluent are discharged to an ocean or estuary out of the 121 million cubic meters per day discharged nationally. Recycling these littoral releases would immediately increase at hand water reservoirs (identical to 6 percent of the evaluated global US water usage or 27 percent of public stock). When repaired water is employed for non-consumptive usages, the water stock gain of WR may be surprisingly bigger if the water may once more be apprehended and recycled. Central wastewater releases can as well be accessible for WR, even if large-scale recycling possesses the capacity to impact the water stock of downstream users and ecosystems in water-limited surroundings. WR unaccompanied cannot treat all of the country's water stock defiance, and the future

participations of WR will change by area. Even so, WR can provide important not yet exploited water provisions, especially in regions confronting water scarcities [33, 40].

As an illustration, in USA, WR is a usual operation. Several manners are accessible for recycling sewage liquids to give water for industry, irrigation (see Figure 1) [41, 42], and drinking provision, included in additional usages, even if restricted evaluations of WR propose that it considers for a low portion (<1 percent) of US WR. Water repair for non-drinking usages is well set up, with methodology conceptions and remediation techniques that are usually adopted by societies, specialist, and regulatory authorities [9, 33].

The usage of repaired water to increase drinking water provisions possesses crucial capacity for assisting to satisfy coming requirements; however, arranged drinking WR at best considers a low portion of the volume of water presently being recycled [9, 33, 43].



## 2.2. Water Characteristics and Wastewater Repair Applied Science

A series of treatment choices, comprising engineered and managed natural treatment manners, exists to mitigate microbial and chemical pollutants in reclaimed water, facilitating a multitude of process combinations that may be designed to meet specific water quality objectives. Advanced treatment processes are as well able of addressing current water quality problems related to drinking recycling implicating emerging pathogens [44] or trace organic chemicals. Advances in membrane filtration have made membrane-based techniques [54] specifically interesting for WR applications. Nevertheless, restricted cost-effective concentrate disposal alternatives hinder the application of membrane technologies for WR in inland

Natural systems are used in most drinking WR systems to give an environmental buffer. Nevertheless, it cannot be established that such “natural” barriers give any public health safeguard that is not as well accessible by other engineered techniques (e.g., advanced treatment processes, reservoir storage) [9, 39, 55].

Recycling methods must be conceived with treatment trains that comprise reliability and robustness. Redundancy fortifies the reliability of pollutant elimination, specifically crucial for pollutants with acute effects, while robustness uses mixtures of techniques that address a large range of pollutants. Recycling methods conceived for applications with possible human contact must comprise redundant barriers for pathogens [44] that produce waterborne diseases. Drinking reuse methods must use diverse manners that may work as barriers for several kinds of chemicals, taking into account the large variety of physiochemical characteristics of chemical pollutants [9, 47].

## 2.4. Appreciating the Hazards

Health hazards stay hard to completely describe and measure by means of epidemiological or toxicological surveys;

however, well-confirmed principles and processes exist for evaluating the hazards of diverse WR uses. Complete protection is a worthy objective of society; nevertheless, in the estimation of protection, certain level of hazard should be regarded sustainable. To estimate these hazards, the principles of risk recognition, exposure assessment, dose-response assessment, and hazard characterization can be employed. Risk assessment screening manners enable estimates of potential human health effects for circumstances where dose-response data are lacking. In spite of the fact that risk assessment will be a crucial input in decision making, it only constitutes one of several such inputs, and risk management decisions comprise a range of additional factors, like cost, equitability, social, legal and regulatory factors, and qualitative public preferences [9, 47].

### **2.5. Evaluating the Hazards of Drinking Recycling in Context**

It is convenient to compare the hazard of water produced by drinking reuse projects with the hazard linked with the water supplies that are currently in usage [39]. Researchers [9] have presented the results of an original comparative analysis of potential health hazards of drinking recycling in the context of the hazards of a classical potable water supply derived from surface water that receives a small percentage of treated wastewater. These researchers [9] compared the evaluated hazards of a common potable water source usually perceived as safe against the evaluated hazards of two other drinking recycling scenarios. They proposed that the hazard from 24 selected chemical pollutants in the two drinking recycling scenarios does not overpass the hazard in common existing water supplies. The findings are useful in giving perspective on the relative significance of diverse groups of chemical products in potable water.

As an illustration, disinfection by-products (DBPs) [50, 56-58], in particular nitrosodimethylamine (NDMA), and perfluorinated chemicals deserve particular consideration in WR projects since they constitute a more dangerous human health hazard than do pharmaceuticals and personal care products. Regardless of uncertainties inherent in the analysis, these findings show that following proper diligence and using designed advanced treatment trains and/or natural engineered treatment, drinking reuse systems may give safeguard from trace organic pollutants comparable to what the public experiences in several potable water supplies today [9].

Concerning the pathogens [44, 59, 60], despite the fact that there is a big level of uncertainty, researchers [9] proposed that the hazard from drinking recycling does not seem to be any higher, and may be orders of magnitude lower, than currently experienced in at least some current (and approved) potable water treatment systems. State-of-the-art water treatment trains for drinking reuse must be convenient to treat the worries of microbial pollution if finished water is protected from recontamination during storage and transport and if multiple barriers and quality assurance strategies are in place to ensure reliability of the treatment processes [9].

### **2.6. Ecological Applications of WR**

Presently, few studies have documented the environmental hazards linked with the purposeful usage of reclaimed water for ecological improvement. WR for the purpose of ecological enhancement is a relatively new and promising area of research; however, few projects have been completed. As environmental enhancement projects with reclaimed water increase in number and scope, the amount of research conducted concerning the ecological hazard must as well augment, so that the potential benefits and any issues linked with the recycling use may be identified [9, 47].

### **2.7. Costs**

Financial costs of WR are largely changing since they are dependent on site-specific factors. Financial costs are affected by size, location, incoming water quality, expectations and/or regulatory needs for product water quality, treatment train, method of concentrate disposal, extent of transmission lines and pumping requirements, timing and storage requirements, costs of energy, subsidies, and the complexity of the permitting and approval process. Capital costs in particular are site specific and can vary markedly from one community to another. Data on reuse costs are limited in the published literature [9,39,61].

## **3. WR for a “Closed Water Cycle” Method**

As seen above, the recycling of wastewater is a fundamental factor in a closed water cycle approach, in which wastewater is treated and then reutilized. This manner is both obligatory for the development of dry areas and indispensable for the sustainability of industrialized countries in terms of environmental effects and resource protection. In spite of the fact that there are several exemplary examples of WR projects in the World, there is still much to be performed, particularly in terms of incentives and economic viability. Prisciandaro et al. [15] presented thermodynamic and engineering elements in order to develop an economic incentive to promote WR and to adopt the closed water cycle approach. They also presented a techno-economic analysis of the civil wastewater depuration and reverse osmosis treatment of the secondary effluent, by using the typical approach of the chemical engineering (Figure 2). They calculated the cost of the treated water in relation to the fundamental parameters of the plant together with an “energy based” incentive, evaluated through the efficiency of the state-of-the-art desalination process. This last may make a reuse project economically feasible on the basis of rigorous thermodynamic considerations. They estimated the validity of the proposed method through the analysis of three wastewater treatment and reuse projects at different scale. Their findings illustrate how it is easy to achieve positive earnings before interests and taxes for plant productivity above the 200 m<sup>3</sup>/day, by comprising the proposed incentive in the business plan of the integrated plant

of Water Treatment and Reuse [15].

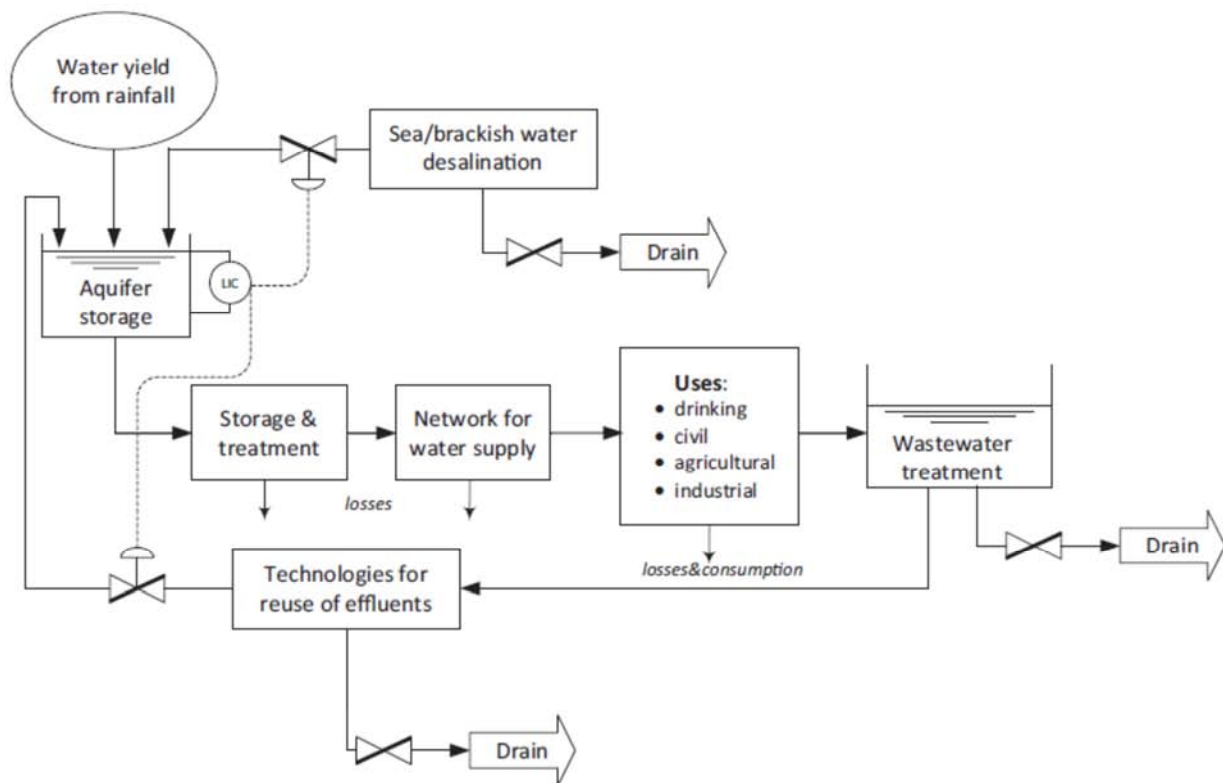


Figure 2. "Closed Water Cycle" Manner [15].

#### 4. Electron Beam Treatment for Drinking WR

Wang et al. [57] studied a manner for eliminating bromate and perfluorooctanoic acid (PFOA) from synthetic water conceived to simulate a treated wastewater intended for drinking WR. In the absence of oxygen, an exponential model was able to relate bromate concentration to absorbed dose. Nevertheless, a more complex model was required to show PFOA defluorination, so Wang et al. [57] developed a model that supposed generation of one partially defluorinated intermediate and employed this model to illustrate the link between free fluoride concentration and absorbed dose. They showed that nitrate negatively influenced the elimination of bromate and the dose constant was inversely proportional to the nitrate concentration as predicted by a simple model that supposes the presence of radical scavengers. In contrast, the presence of nitrate enhanced the decomposition of PFOA, probably due to production of oxidizing radicals or by other reactions of nitrate degradation products. Fulvic acid and alkalinity exerted negligible effects on bromate elimination. Fulvic acid inhibited the defluorination performance, perhaps because of the scavenging of oxidizing radicals such as the hydroxyl radical ( $\bullet\text{OH}$ ). They also observed that alkalinity accelerate PFOA defluorination, probably due to the generation and reactivity of the carbonate radical ( $\text{CO}_3^{\bullet-}$ ). As pH augmented from 5.0 to 7.3, the dose constant for bromate

removal augmented from  $0.45 \text{ kGy}^{-1}$  to  $0.69 \text{ kGy}^{-1}$ ; however, it scarcely varied when pH was further augmented to 9.0. In the presence of oxygen, both pollutants were decomposed less efficiently and illustrated more complex patterns of degradation. Finally, they concluded that pretreatment to remove dissolved oxygen would perhaps be required to apply electron beam in practice for degradation of bromate and PFOA [57].

#### 5. WR Methods: Energy Consumptions and Related Greenhouse Gas Emissions

As seen above, WR systems have been largely applied through the World as a solution to water shortage and freshwater pollution. Continuous disagreements concerning probably elevated energy cost and the absence of enough facts to boost advantages of WR are detaining more growth of application of WR methods. In order to elucidate the opacity concerning the energy demand and give an impartial differentiation between the WR alternatives and the conventional water supply system, Chang et al. [25] investigated energy consumptions and greenhouse gas emissions in operation phases of various WR facilities and the conventional water supply system in South Korea (Figure 3). The average total energy consumption and the greenhouse gas emission of the conventional process were estimated to be

0.511 kWh/m<sup>3</sup> and 0.43 kgCO<sub>2</sub>e/m<sup>3</sup>, respectively. Centralized WR systems had prohibitively elevated energy consumptions (1.224-1.914 kWh/m<sup>3</sup>) and greenhouse gas emissions (0.72-0.83 kgCO<sub>2</sub>e/m<sup>3</sup>). The decentralized WR systems, greywater reuse and rainwater harvesting systems, all employed for non-potable purposes, had comparable or more elevated energy demands than the conventional process (0.246-0.970 kWh/m<sup>3</sup> after adjustment), even if evaluated

greenhouse gas emissions from these processes were lower than the conventional process (0-0.33 kgCO<sub>2</sub>e/m<sup>3</sup> after adjustment). Taking into account the hidden environmental benefit (0.357 kWh/m<sup>3</sup>) from decrease of pollutant release, the energy demand of greywater reuse drops far below that of the conventional system, proposing that decentralized WR is the key to an energy-efficient water management with minimal impact on climate change [25].

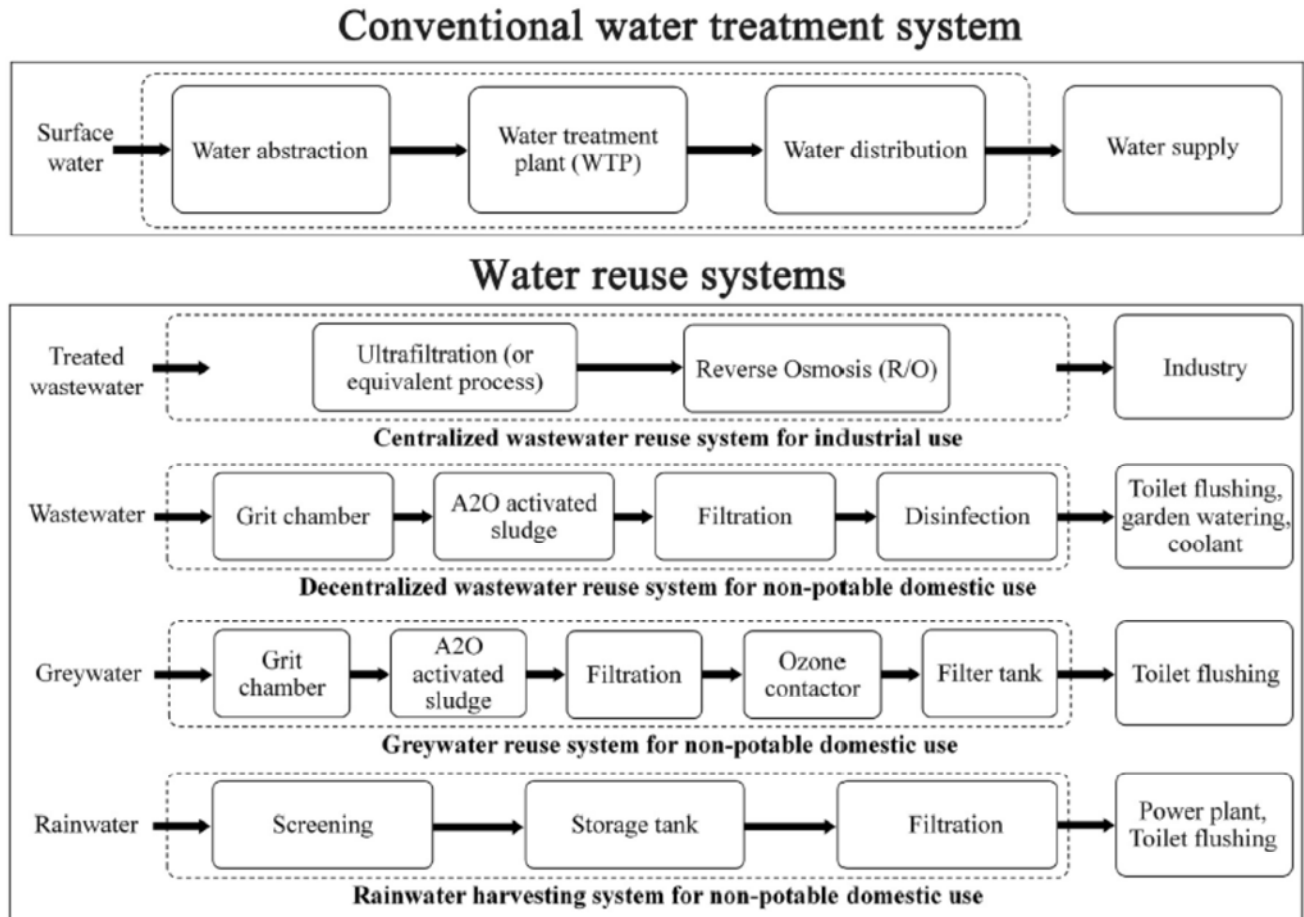


Figure 3. System Boundaries of the Conventional Water Treatment System and Different Types of WR Systems Examined in [25].

## 6. Centralized WR System with Multiple Applications in Urban Areas

Chen et al. [40] have established that the growth of WR in China has positive correlations to local water resource availability and gross domestic product (GDP) levels, and the WR rate in some megacities has already reached 35-60%. Centralized WR systems have largely acquired approval. Therefore, a centralized WR framework with three utilization patterns is proposed. Particularly, a multiple-utilization model that applies a hierarchical use structure is observed to be practicable for satisfying multiple water quality requirements. Additional patterns address environmental and cascading ways in maximizing the value of reclaimed water use. A case study in a Chinese megacity, Tianjin, is demonstrated where a large-scale centralized WR project with a multiple barrier

treatment approach and a hierarchical distribution and use structure has contributed to WR development in a safe, reliable and economical manner. Such study may be useful to water authorities and practitioners for long-term urban water management in other rapidly developing cities and regions that have encountered similar water-related issues [40].

## 7. Direct Drinking Recycling of Reclaimed Water

Direct drinking reuse alludes to the injection of greatly treated reclaimed water either directly into the drinking water supply distribution system downstream of a water treatment plant [62-70], or into the raw water supply immediately upstream of a water treatment plant (Table 2). Indirect potable reuse alludes to the planned incorporation of reclaimed water



into a raw water supply, such as in potable water storage reservoirs or a groundwater aquifer, resulting in mixing and

assimilation, thus providing an environmental buffer [31, 71-77].

**Table 2.** Fundamental Definitions Used in Direct Drinking Reuse [31].

Term	Description
Direct potable reuse	The introduction of highly treated reclaimed water either directly into the potable water supply distribution system downstream of a water treatment plant, or into the raw water supply immediately upstream of a water treatment plant. Introduction could either be into a service reservoir or directly into a water pipeline. The water used by consumers could be therefore diluted reclaimed water originating from municipal wastewater.
Indirect potable reuse	The planned incorporation of reclaimed water into a raw water supply, such as in potable water storage reservoirs or a groundwater aquifer, resulting in mixing and assimilation, thus providing an environmental buffer.
Integrated water resources planning	A process that promotes the coordinated development and management of water, land, and related resources to maximize the resultant economic and social welfare in an equitable and sustainable manner.

The fundamental distinction between indirect and direct potable reuse is that direct potable reuse does not comprise temporal or spatial separation such as natural (environmental) buffers between the reclaimed water introduction and its distribution to the end consumer [78-81]. In the extreme case, direct potable reuse consists of pipe-to-pipe blending of reclaimed water and potable water. Few direct potable reuse applications have been reported worldwide, although the extraction of water for potable purposes from rivers containing substantial quantities of wastewater effluent is fairly common (*de facto* potable reuse) [82-89]. There are no direct potable reuse applications in the US [31].

Asano et al. [31] mentioned three case studies to give a glimpse of different aspects of direct potable reuse: (1) a historical example (1956-57) in Chanute, Kansas, (2) a current international example in Windhoek, Namibia, and (3) a past direct potable reuse demonstration project in the US.

## 8. Logically Imposed Sequence: Water Treatment, Wastewater Treatment, and WR

In terms of environmental chemical reactions, water treatment, wastewater treatment and WR processes may be resumed as follows:

For water treatment:

$$\text{Surface Water} \rightarrow \text{Drinking Water} \quad (1)$$

For wastewater treatment:

$$\text{Wastewater} \rightarrow \text{Treated Water} \quad (2)$$

For WR:

$$\text{Treated Water} + \alpha \text{Surface Water} \rightarrow \text{Drinking Water} \quad (3)$$

Considering Eq. (3), WR process should employ Treated Water mixed with Surface Water at a certain proportion  $\alpha$ . This fraction  $\alpha$  depends on the degree of purity of the Treated Water assuring the dilution effect. These equations [(1)-(3)] imply that WR should not employ at any case only Wastewater, for safeguard reasons and psychological effects. Moreover, WR should be obviously more sophisticated than both Water Treatment (Eq. (1)) and Wastewater Treatment

(Eq. (2)) since pathogens contamination and chemicals presence can be there most elevated. The passage from Eq. (2) to Eq. (3) is called *Indirect Potable Reuse* [37].

When Wastewater Treatment will be sufficiently developed, Eq. (2) may become:

$$\text{Wastewater} \rightarrow \text{Drinking Water} \quad (4)$$

Eq. (4) means that Treated Water is now Drinking Water and Wastewater Treatment becomes WR. This context is called *Direct Potable Reuse* [37].

There is an interesting environmental concept suggested in [37]. Instead of “waste” water term, researchers proposed the word “used” water (Figure 4). They explained this adoption by the fact that water on the globe is the same quantitatively since God Has Created Earth, and there is only its quality which varies with space and time depending on its usage types and water/waste(used)water treatment processes [2].

- It's **Used** water
- Used water has value!!
- Look at water not just as a liquid stream from the faucet, but as an embedded resource (virtual water) in every aspect of our lives.
- When it comes to used water, THE FUTURE IS NOW! Let's push to use it directly, cost-effectively, and safely.

**Figure 4.** “Used” Water Instead of “Waste” Water New Concept Suggestion [37].

On the other hand, there is a worrying fact about surface water (raw water) quality. Since pharmaceutical products and cosmetics substances at varying levels are found in surface water and more dangerously in tap water, the [37]’s new concept of used water may further find its justification. Consequently, should we assist to a new formulation of water treatment technology?

For water treatment/wastewater treatment/WR:

$$\text{Surface Water/Wastewater/Treated Water} \rightarrow \text{Drinking Water} \quad (5)$$



This will be feasible if water treatment/wastewater treatment/WR would be merged in a super and standardized water/wastewater treatment technology, as a future trend. As the best available technology (BAT) of water/wastewater treatment and seawater desalination, simulation of the open sky seawater distillation was previously suggested [2].

## 9. Conclusion

The main important points drawn from this review may be listed as:

WR gives opportunities to shift towards a more efficient and sustainable water supply system. Several infrastructural and technological arrangements exist, with the local governing constraints – comprising land availability, water markets, technological development, existing infrastructure, energy availability, public acceptability and freshwater availability – often determining which form of WR system is or should be implemented.

Public perception is commonly found to act as a crucial barrier to the application of WR schemes. Public objection may be partially attributed to the lack of empirical evidence from existing schemes demonstrating system success and safety to public health. The lack of information may restrict the development of further schemes which are unable to progress upon past experiences. In addition, widespread variety in WR arrangements and applications demonstrates the requirement for local constraints to be appropriately represented when considering the costs and benefits of a new scheme. This is particularly a complex issue when integrating this new form of infrastructure within the existing ones. Appropriate policies are also needed for the development of new decentralised WR technologies. Policy can trigger the creation of artificial niche markets which recognise the need to protect such emerging technologies and infrastructural arrangements from market forces. The establishment of appropriate water quality regulation could also encourage the emergence of WR technology and be subsequently slackened when systems have a proven track record and are publicly acceptable.

In a general manner, direct reuse of wastewater for drinking purposes is intelligibly restricted; however, indirect reuse for drinking purposes takes place constantly and on a worldwide basis. Indirect drinking reuse is more acceptable to the public than direct potable reuse as the water loses its identity as it moves through a river, lake, or aquifer. Indirect reuse, by virtue of the residence time in the water course, reservoir, or aquifer, often provides additional treatment and offers an opportunity for controlling the quality and taking adequate measures before the water is ready for distribution. In some instances, however, water quality may actually be degraded as it passes through the environment.

WR process should employ treated water mixed with surface water at a certain proportion. This fraction depends on the degree of purity of the treated water assuring the dilution effect. WR should not employ at any case only wastewater, for safeguard reasons and psychological effects.

Moreover, WR should be obviously more sophisticated than both water treatment and wastewater treatment since pathogens contamination and chemicals presence can be there most elevated.

There is a worrying fact about surface water quality. Since pharmaceutical products and cosmetics substances at varying levels are found in tap water, should we assist to a new formulation of water treatment technology? This will be feasible if water treatment/wastewater treatment/WR would be merged in a super and highly standardized water/wastewater treatment technology, as a future trend.

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