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Review Article

Water Reuse (WR): Dares, Restrictions, and Trends

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Abstract: Drinking water is beginning to be a rare resource in several regions and both uses of water and wastewater outlet are of main environmental and economic significance in several nations. This work discusses dares, restrictions, and trends for water reuse (WR). WR so far constitutes a vital water supply in several regions. Reuse is largely expanding in the US, Australia, Europe, and different countries. Its potential is largely unexploited; nevertheless, because of some handicaps, comprising a deficiency of policy from governments and the public's opposition to resolved indirect potable reuse. WR must not be considered as just the remedy and reuse of wastewater effluents. On the contrary, a larger concept, comprising the reclamation and reuse of brackish groundwater, usage of stormwater and agriculture return flows, and desalination of the oceans, must be adopted. Despite the acquired advances in WR technologies and applications, great efforts remain to be accomplished to generalize WR implementations throughout the world. More attention should be accorded to the public acceptance of WR in terms of drinking water usage via ensuring highly treated wastewater especially in terms of bacteriological qualities. WR development would decrease the desalination tendency that is largely viewed until now as an ultimatum solution for water shortage knowing that it is relatively less expensive.

Keywords: Water Reuse (WR), Wastewater Treatment, Potable Water, Operation and Maintenance (O&M), Nanofiltration (NF), Reverse Osmosis (RO)

1. Introduction

The notion of water is a perpetual resource with an infinite renewable capacity fits in the past [1, 2]. Water reuse (WR) is progressively viewed as a vital mean for a valuable decrease in water supply necessities and economies in linked costs [3-6]. Many water scarcities and arid times are the major moving compulsions beyond WR for several nations; while others have been pushed by the augmenting ecological restrictions and the reality that water quality discharge regulations are more and more rigorous [7]. Besides, WR applications have begun to be more practically suitable thanks to the expansion of more enhanced refinement methods [8]. The application of true reuse for industrial objectives relies mainly on financial motivations [9, 10]. Since water costs escalate, there will approach a period when present or improving techniques will render water reprocessing and reuse an applicable profit-oriented exercise [11-13]. For several nations, despite that, agricultural irrigation even now prevails the leading reuse employment for industrial wastewater [14-16].

For example, water is largely employed in the food industry [17]. In such an industry, water recycling and reuse applications occur at present to supply cooling water, wash water or paradoxically process water, particularly after reconditioning; however, additional WR implementations are restricted if compared to the capacity [18]. The capacity for recycling and reuse in the food industry has been shown in several studies [19]. As an illustration, an investigation performed in the Netherlands established that a conclusive capacity for recycling and water cycle lock occurs in the food industry; and following the food sector it appeared easy to diminish the employment of water by 20-50% [9].

A planned procedure to WR has to be founded on a methodical examination and the concept that water users should not employ more water of a more elevated standard than rigorously required [5, 20]. The declaration may appear pretentious; however, it is certainly that suitable quality and quantity, as well as point-of-use accessibility, require to be equilibrated. In the food industry, reuse has been restricted for several years because of rigid regulations. Now, it happens that present guidelines and regulations concerning the usage and reuse of water in this industry accept the usage of various water qualities than that of drinking water [21-24]. This allows tolerance; however, it needs simultaneously an elevated level of multidisciplinary understanding and useful documentation from industry and regulatory authorities. Unhappily, investigation and maturation have been comparatively retarded in this field because of the apprehension of diminishing sanitary qualities. At the same time, such indecision may be comprehensible seeing that health hazards linked with reuse are hard to evaluate, the dares require being confronted to averting subsequent issues [9].

The motivations for enhancing water performance in the industry may be almost categorized into three kinds: economic, environmental and technological [25]. At the same time, the handicaps as well comprise factors relating to safety, legislation, perception, collaboration, and communication [26].

This work discusses dares, restrictions, and trends for WR.

2. Dares and Restrictions to Water Reuse (WR) in the Industry

Casani et al. [9] discussed the situation, comprising motivations and handicaps, beside the dares that can appear when applying WR procedures in the food industry with a special center of attention on the microbial details. Besides, Casani et al. [9] defined some procedures for reuse in food manufacturing factories. For these researchers, the word ''reuse'' alludes to the recovery of water from a processing stage and its next employment in a food manufacturing process, ''recycling'' makes reference to reuse within the identical food manufacturing process, and ''reconditioning'' deals with the treatment of water intended for reuse [27-29].

Casani et al. [9] concluded that the present legislation admits the employment of substitutional standards if the product safety and the safety of the working conditions are not menaced. Developing and applying Hazard Analysis Critical Control Point plans for WR, if feasible in collaboration with regulatory authorities, must guarantee control of safety dangers. Preparation of guidelines focusing on WR, research, and development on pertinent details and collaboration between academia, food processors and regulatory agencies are needed for simplifying the procedure of application of WR executions in the food industry [30]. Ambulant attestation setups can be useful when assessing the techno-economic applicability of water treatment techniques [31] for a specific industrial effluent as well as for enhancing the organized interchange of information from case studies.

Integrating WR substructure into a present water supply system is a difficult sociotechnical procedure [32]. For a dual reticulation program, infrastructure designs influence adoption, since the development of infrastructure locates when a household may adopt and become active in communicating about WR [33]. Kandiah et al. [34] presented a coupled framework to capture the dynamics between consumer adoption and infrastructure development. An agent-based modeling procedure is employed to simulate opinion dynamics within a risk public's framework, which is founded on the social amplification of risk and captures modifications in perceptions concerning the hazards and advantages of WR. The model is implemented to simulate and project the adoption of WR for the Town of Cary, North Carolina, employing data concerning new water reclamation accounts and plans for infrastructure expansion. The efficiency of the agent-based model is confronted with a cellular automata model for simulating historic data. Alternative infrastructure expansion schedules are simulated using the agent-based model to evaluate potable water savings and utilization of reclaimed water capacity, based on adoption projections. The framework gives a socio-technical method to assess development plans for infrastructure systems that depend on the adoption of infrastructure-dependent techniques.

Chen et al. [35], who focused on the centralized WR system with multiple applications in urban areas, showing the lessons from China's experience, presented a similar study. Chen et al. [35] work may be useful to water authorities and practitioners for long-term urban water management in other rapidly developing cities and regions that have encountered identical water-related problems. Chang et al. [36] assessed the energy consumptions and related greenhouse gas emissions in operation phases of urban WR systems in Korea (Figure 1).

Recently, Mukherjee and Jensen [37] studied the interaction among regulation, public acceptance, and technology adoption for potable reuse. They used a Process Tracing procedure to inspect two-nation examples, the US and Australia; both of which possess expertise in the infallible espousal of drinking reuse as well as instances of public resistance and abandonment of particular projects. The examples propose that local, collaborative, transparent risk-based regulation participates in augmented approval of reuse among the public and government officials and supports take-up of the technology.

3. Ambient Iron-mediated Aeration (IMA) for Water Reuse (WR)

For WR, Deng et al. [38] assessed the practical probability of iron-mediated aeration (IMA), an original, greatly cheap, holistic, oxidizing co-precipitation method working at ambient temperature, atmospheric pressure, and neutral pH. In the IMA technology, dissolved oxygen (O_2) [39] was constantly activated via zero-valent iron (Fe^0) [40] to form reactive oxygen species (ROS) at usual pH, temperature, and pressure. At the same time, iron sludge was produced as a consequence of iron corrosion. Bench-scale trials were performed to investigate the performance of IMA for handling secondary effluent, natural surface water, and simulated polluted water. The next elimination performances were attained: 82.2% glyoxylic acid, ~100% formaldehyde as an oxidation product of glyoxylic acid, 94% of Ca^{2+} and associated alkalinity, 44% of chemical oxygen demand (COD), 26% of electrical conductivity, 98% of di-n-butyl phthalate, 80% of 17β-estradiol, 45% of total nitrogen, 96% of total phosphorus, 99.8% of total Cr, >90% of total Ni, 99% of color, 3.2 log removal of total coliform, and 2.4 log removal of *E. coli*. Elimination was linked mainly to chemical oxidation, precipitation, co-precipitation, coagulation [41-45], adsorption, and air stripping at the same time taking place throughout the IMA process. Deng et al. [38] concluded that IMA is an encouraging treatment technique for WR.

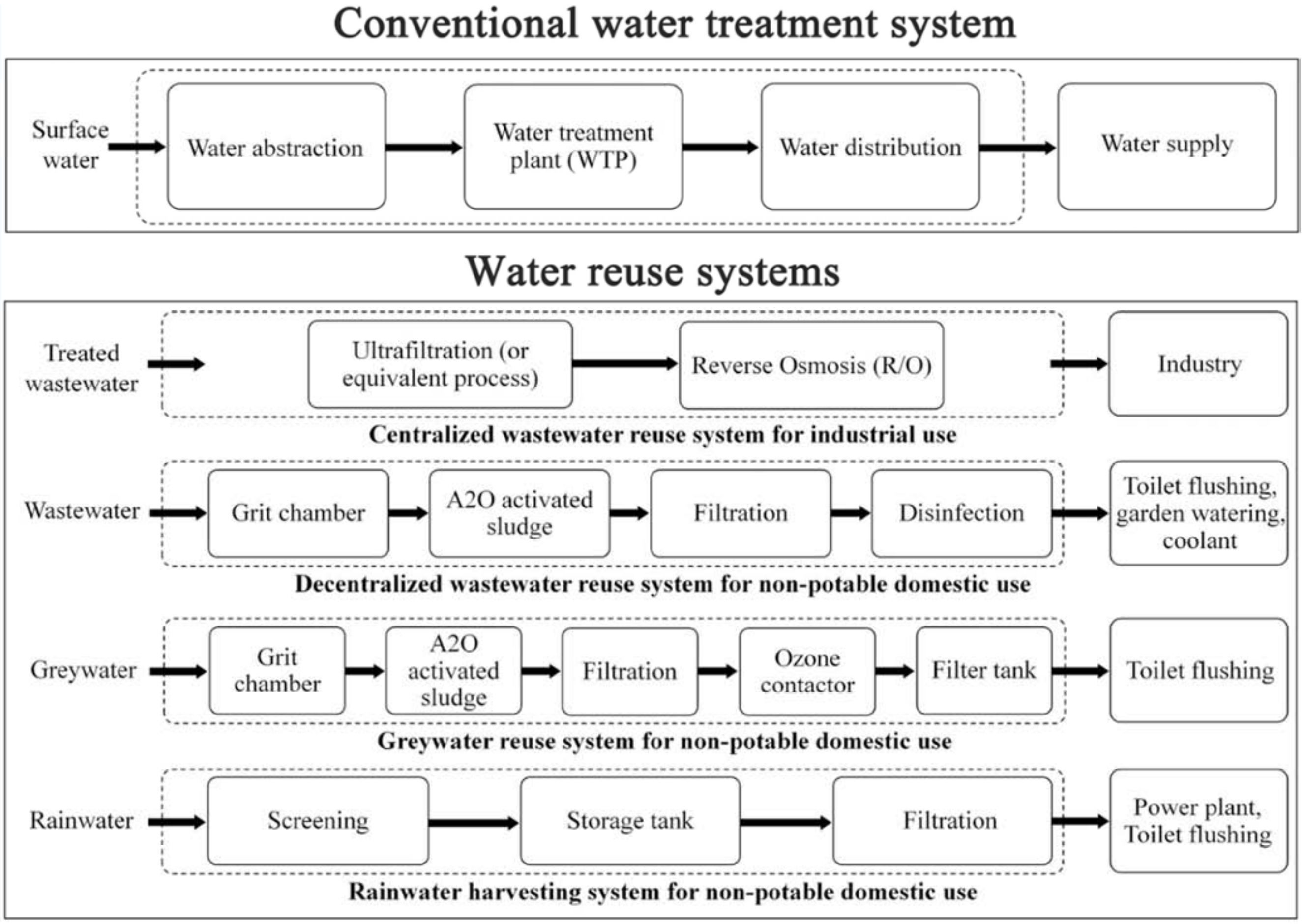

Figure 1. *System boundaries of the conventional water treatment system and different types of WR systems examined [36].*

4. Antibiotic Resistance Genes (ARGs) Behavior and Removal

To decrease the probable impacts on human health, which are linked to the employment of treated wastewater in agriculture, antibiotic resistance genes (ARGs) are needed to be cautiously observed in WR methods and their diffusion must be blocked via the expansion of performant treatment techniques. Luprano et al. [46] evaluated ARGs decrease performances of a fresh technological treatment method for agricultural reuse of urban wastewaters. They suggested an advanced biological treatment (Sequencing Batch Biofilter Granular Reactor, SBBGR) pursued by sand filtration and two various disinfection [47] final steps: ultraviolet light (UV) radiation and peracetic acid treatments (Figure 2). Their findings proved that SBBGR technology is encouraging for diminishing ARGs, attaining steady elimination efficiency extending from 1.0±0.4 to 2.8±0.7 log units, which is analogous to or more important than that mentioned for traditional activated sludge treatments.

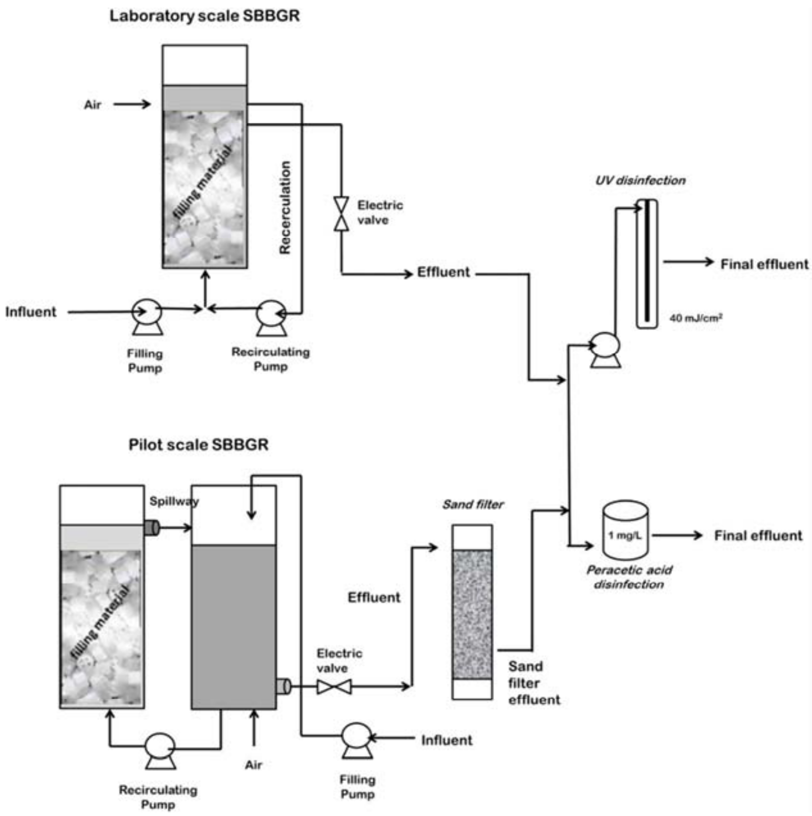

Figure 2. *Schematic chart of the SBBGR (laboratory and pilot plant), followed by tertiary treatments [46].*

In this context, Lu et al. [48] presented an excllent research on the fate of ARGs in reclaimed WR system with integrated membrane process (IMP) (Figure 3).

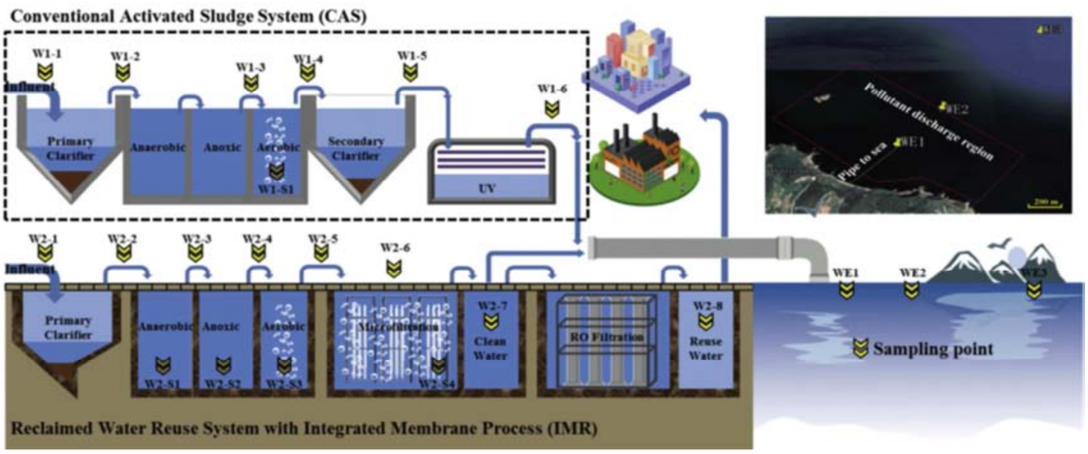

Figure 3. *Schematic diagram of the reclaimed WR system with integrated membrane process (IMR) and conventional activated sludge system (CAS) in wastewater treatment plants. Upper-right corner, the map of seawater sampling locations [48].*

5. Membrane Bioreactor (MBR) Technology

Membrane bioreactor technology (MBR), incorporation of the activated sludge process with micro- and ultrafiltration, is largely considered as a performant means for industrial water treatment [49] and WR thanks to its elevated treated water quality and low footprint. Thanks to their hardiness and flexibility, submerged MBR setups are more and more favored. Hoinkis et al. [50] discussed two case studies for industrial implementation in a commercial laundry and in a textile factory. A large-scale inserted WR method founded on the MBR+RO technique (capacity 200 m^3/d) has been conceived and constructed in a laundry conducting to a reuse ratio of about 80% of the total wastewater. The method was in full operation and has been run economically for five years without any defeat. A small-scale MBR (capacity up to 0.4 m^3/d) has been with a large success experimented in a Chinese textile factory. Despite an elevated concentration of low biodegradable chemicals in the wastewater, the COD removal rate attained about 90%. Nevertheless, the MBR permeate quality was not as elevated as in the laundry because of the remaining colored dyestuff that necessitates a supplementary treatment stage like nanofiltration (NF) [51, 52] or reverse osmosis (RO) [53-55] indispensable to augment the ratio of reused water.

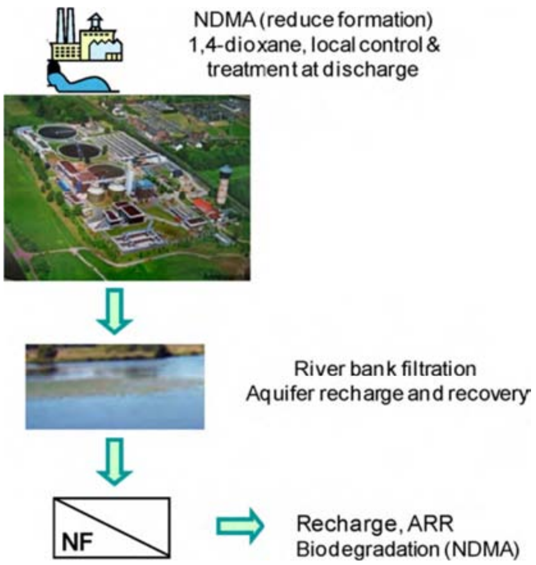

Figure 4. *Reduction of organic pollutants with ARR-NF (modified multiple barrier method) [51].*

In the same direction, and for WR implementations, "rigid" NF membranes (of polyamide) as an option to RO may be an efficient barrier against pharmaceuticals, pesticides, endocrine disruptors, and many organic pollutants [56-59]. The employment of RO in present WR plants is mentioned and reviewed, taking into account that rigid NF may be a more cost-effective and performant technique to pick out the issue of organic pollutants [60, 61]. It was deduced that rigid NF is a reasonable barrier for organic pollutants since its elimination efficiency is near that of RO, and thanks to decreased operation and maintenance (O&M) costs in the long-term project applications. The medium decrease of neutral compounds (comprising 1,4-dioxane) was around 82% and 85% for NF and RO, respectively, and the medium reduction of ionic compounds was around 97% and 99% for NF and RO, respectively. Furthermore, "soft" NF following aquifer recharge and recovery (ARR) may be an efficient block against micro-contaminants with reductions of more than 90% (Figure 4). If there is the existence of hard to reduce organic pollutants like NDMA and 1,4-dioxane; for 1,4-dioxane, source control or application of treatment methods in wastewater treatment facilities will be a choice. For NDMA, an appreciable procedure is to restrict its generation throughout wastewater treatment; however, it is obvious that biodegradation of NDMA may be attained throughout ARR [51].

Vajnhandl and Valh [62] discussed the status of WR in European textile sector in which MBR technology is well utilized. Recently, de Aquima [63] performed a research on WR as an alternative to reduce the environmental effect on the leather industry.

Di Trapani et al. [64] studied the treatment of citrus wastewater using MBRs following various combinations for WR. Especially, one MBR and one aerobic granular sludge MBR (AGS+MBR) bench-scale factories were run for 2 months. The working campaign was divided into two times. In Phase I, a traditional hollow fiber MBR was used for the treatment of the raw high strength wastewater, while in Phase II a configuration of in-series reactors (AGS+MBR) was employed for the treatment of the high strength citrus wastewater. Their findings established that both plant combinations reached extremely elevated COD elimination, with medium levels near to 99%. Respirometric batch experiments showed a significant high metabolic activity of the biomass in both plant combinations, with more important levels in the AGS+MBR. It was suggested that the MBR reactor was enriched in active biomass deriving from the erosion of the external granule layers in the upstream reactor. Concerning fouling tendency [65], more significant resistance to filtration was detected in the AGS+MBR factory, also known by more significant irremovable resistance augmentation confronted to the MBR factory, which might badly influence the membrane service life (Figure 5).

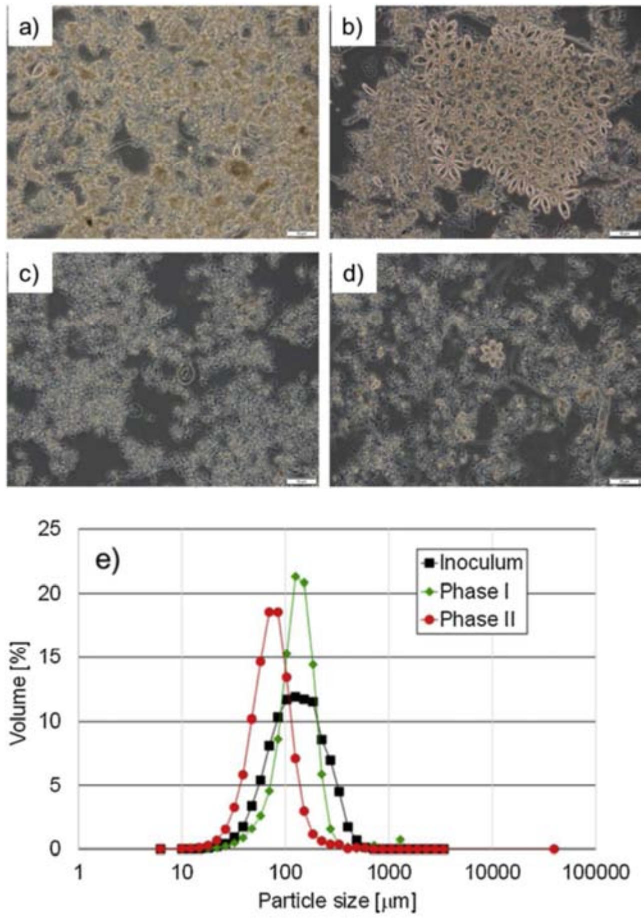

Figure 5. *Phase contrast observation of activated sludge floc (a) and example of opercularia colony (b) in Phase I; phase contrast micrographs of activated sludge flocs (c–d) in Phase II and particle size distribution (e) throughout experiments [64].*

6. Water Reuse (WR): An Economic Strategy

In general, the procedures employed to evaluate the prospect of WR plans are centered on internal costs. Hernández et al. [66] presented a procedure to estimate the prospect of a WR plan considering not just the internal effect, but as well the external effect (e.g., environmental and social) and the opportunity cost determined from the project. Internal benefit is determined by the difference between internal income and internal costs. Internal income is assessed via multiplying the selling price of reclaimed water and the volume obtained. Internal costs are made up of the sum of investment costs, operating costs, financial costs, and taxes. However, several of these parameters defined may be determined directly in terms of money, biophysical and social aspects demand the definition of units of measurement. To homogenize findings, an annual reference is suggested. A monetary value may be determined from the calculation of each impact. On the other hand, there are a series of externalities for which no explicit market exists. In such situations, economic valuation techniques are employed, founded on hypothetical scenarios or models detected in linked markets.

Usually, WR projects are frequently underestimated when confronted with various projects because of the lack of success to conveniently measure advantages of reuse like watershed safeguard, local economic expansion, and enhancement of public health [67]. Specialists who are assessing project choices frequently contrast exclusively the financial costs of different choices and do not assess either social costs or social advantages. Consequently, the real advantages and costs of many WR projects have never been appropriately estimated. If the non-monetizable advantages could be evaluated, the advantages of many WR projects would surpass the costs and, employing benefit/cost ratio as an assessment tool, would begin to be economically suitable [68].

Diverse studies have been directed which establish that reclaimed water costs resemble positively with those of substitutional sources. In recommending the implementation of a free-market procedure to the recycled water system development, specialists evaluated that the average cost to amend a recycled water customer site was \$2.14/m^3 of possible employment at that site [69]. The 2001 cost of potable water in San Diego was around \$0.52/m^3, and the recycled water rate was 90% of the potable water rate, or about \$0.47/m^3. At a 50% potable water rate, the city could regain its spending if the site employed for 10 years [68].

7. Water Reuse (WR) *vs.* Desalination

Côté et al. [70] confronted the cost of WR to the cost of seawater desalination. With a view to treating water of equivalent quality, an RO stage was introduced to the process flow diagrams shown in Figure 6. In this situation, RO [71] is required to eliminate dissolved organic carbon and residual nutrients like nitrate. For desalination, it was supposed that surface seawater (TDS of 35,000 mg/L) was pretreated via coagulation [72-74] and multi-media filtration before RO. The process flow diagrams are illustrated in Figure 7 and the parameters employed for the two techniques are confronted in Table 1.

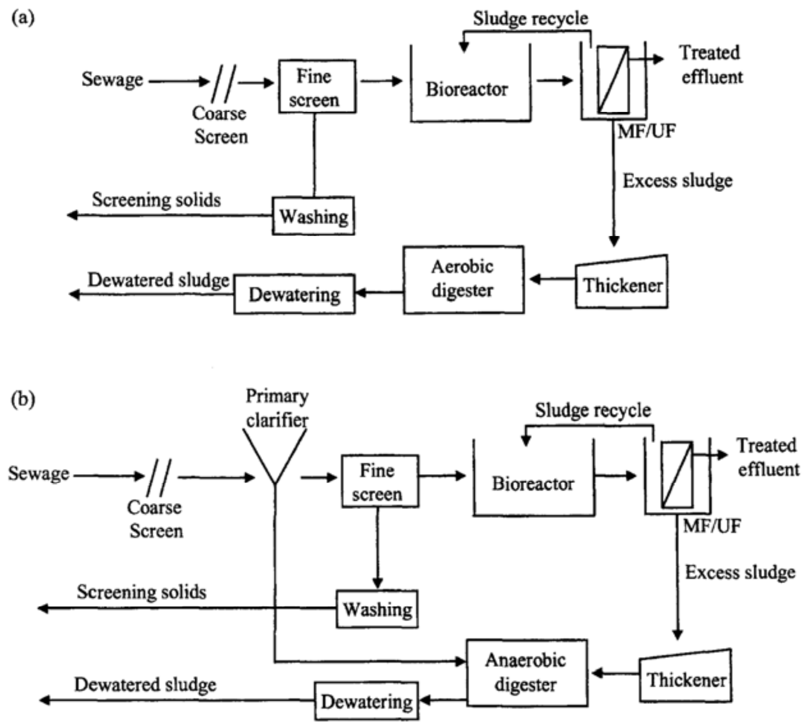

Figure 6. *Process flow diagram for the membrane bioreactor option (MBR): (a) small plants; (b) large plants [70].*

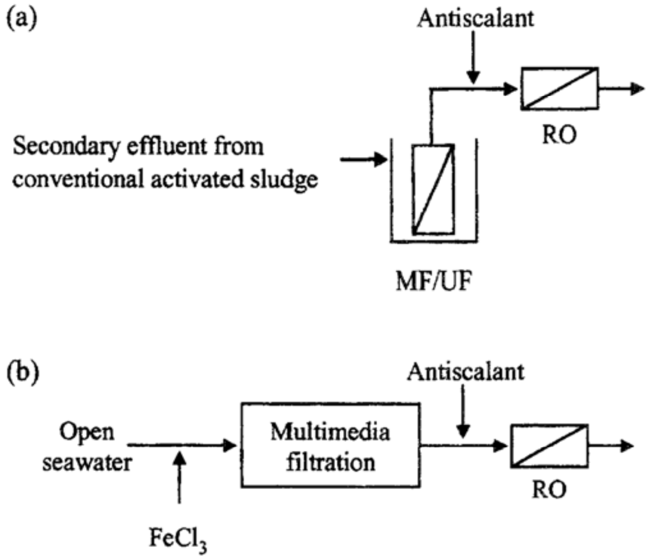

Figure 7. *Process flow diagrams for comparison of WR and seawater desalination: (a) WR; (b) Seawater desalination [70].*

Table 1. *Design process parameters for the RO facilities [70].*

Unit process	Parameter	Water reuse (WR)	Desalination
Coagulation	$FeCl_3$ dose, mg/L	No	5
Pretreatment		MBR* or CAS-TF effluent	Multimedia filtration
Anti-scalant addition	Dose, mg/L	2	5
Reverse osmosis (RO)	Stages, number	2	2
	Recovery, %	75	50
	Flux, L/m^2/h	20	13
	Feed pressure, bar (psi)	13.6 (200)	68 (1000)

*MBR (Membrane Bioreactor).
**CAS-TF effluent (Conventional Activated Sludge + Tertiary Membrane Filtration).

The total costs evaluated for treating RO water from secondary effluent and from seawater are confronted in Table 2 for 38,000 m^3/d facilities. The costs in column A do not comprise the cost linked to conventional activated sludge (CAS) since it was supposed that sewage would be treated to that degree for discharge; for simplicity, the cost for tertiary filtration assessed previously were employed as pretreatment cost for RO. It was hypothesized that the concentrate from both plants may be disposed of at no cost [70].

Table 2. *Costs of treating water from secondary effluent and from seawater for a 38,000 m^3/d factory [70].*

Component	A: from CAS effluent	B: from seawater	Ratio (B/A)
Capital costs, \$/m^3/d			
Pretreatment	161	238	1.48
Reverse osmosis (RO)	321	492	1.53
Total	482	730	1.51
Total life cycle costs, \$/m^3			
Capital	0.07	0.10	1.51
Operation and maintenance (O&M)	0.21	0.60	2.86
Total	0.28	0.70	2.50

The capital costs for a factory treating water from seawater are around 50% more elevated than the costs of a factory reusing secondary sewage. Both the pretreatment costs and RO costs are more elevated. In the situation of pretreatment, this is attributed to the gap in recuperation (75% for secondary effluent; 50% for seawater), which conducts to a bigger seawater setup. The capital cost for the seawater RO process is bigger than for the secondary effluent RO since it is working at a much more important pressure, lower permeate flux, lower recovery, and should be constituted of materials that resist corrosion in seawater [70].

In the same way, the O&M costs for treating RO water from seawater are around 3 times bigger than the cost of reusing secondary sewage. The bigger pretreatment costs are linked to chemicals, the continuous dosage of a coagulant and more important dosage of antiscalant. The bigger RO costs are linked mainly to energy (the working pressure is five times bigger and the feed flow is 1.5 times more important), but also to membrane replacement [70].

The total life cycle costs for treating RO water from secondary effluent and seawater are 0.285/m^3 and 0.705/m^3, respectively, a ratio of 2.55 [70].

8. Water Reuse (WR): Current Trends

As well concluded by Miller [68], current trends comprise: treating emerging pollutants of concern; the usage of advanced wastewater treatments [57] involving membranes;

indirect potable reuse; public recognition; appreciation of the financial aspects of WR; groundwater recharge and aquifer storage and reclamation; salinity disposal (comprising concentrate (brine) elimination [76]); augmentation in the employment of "alternative sources"; ecological system repair; original employments of non-potable WR; and decentralized and satellite systems. As these trends are rising expansions in the domain of water recovery and reuse, there are several research necessities related to such subjects. An investigation is required to better comprehend the problems, to expand original methods, and to present means and additional help for communities and water agencies to apply effective water recovery and reuse projects [68].

Recently, Chhipi-Shrestha et al. [77] suggested a multi-criteria multi-decision-makers framework integrating multicriteria decision analysis (MCDA) and game theory for choosing a potential WR implementation (Figure 8). The suggested framework was implemented for the City of Penticton, BC, Canada. The evaluation criteria comprised were environmental: freshwater saving, energy use [78, 79], and carbon emissions; economic: annualized life cycle cost; and social: government policy, public perception, and human health risk for three stakeholders: municipality, citizens, and farm operators. They implemented the game theory to eight WR options taking into account a cooperative game. Their finding establishes that lawn, golf course, and public park irrigation and toilet flushing with an equal sharing of municipal benefits between the municipality and citizens is the optimal solution. Via employing the solution, the municipality may obtain a supplementary saving of around $35/household/year and the citizens have to spend a supplementary amount of about $100/household/year for dual plumbing of toilet and lawn for reclaimed water use. The supplementary expenditure for the citizens is within Canada's public willingness to pay an additional charge for reclaimed water use. The scenario analysis proves that the weights of sustainability criteria are crucial in decision-making. Further, the sensitivity analysis establishes that the modification in the quantity of reclaimed water availability may touch WR sustainability efficiency. The suggested framework may also be employed in different usages by modifying the number of evaluation criteria and stakeholders as needed.

Figure 8. *Game theory used in determining optimal solution for all stakeholders [77].*

As a future trend, for WR implementations, disinfection remains a pivotal stage in treating wastewaters [80]. In this context, electrochemical technologies [81-83] have been proven highly efficient in killing pathogens [84-91]. Electrooxidation and electrocoagulation are expanding as potential electrodisinfection processes [92-96].

9. Conclusions

The main points drawn from this work may be given as:

1. Worldwide water lacks provoked by a speedily growing public, mounting water exhaustion, and diminishing water supplies have made WR a strategically noteworthy method to satisfy present-day and subsequent water need. WR must be considered as one of diverse substitutional sources of novel water, all of which will be substantial instruments in the toolkit of the water manager of the 21st century.
2. WR so far constitutes a vital water supply in several regions. Reuse is largely expanding in the US, Australia, Europe, and different countries. Its potential is largely unexploited; nevertheless, because of some handicaps, comprising a deficiency of policy from governments and the public's opposition to resolved indirect potable reuse. WR must not be considered as just the remedy and reuse of wastewater effluents. On the contrary, a larger concept, comprising the reclamation and reuse of brackish groundwater, usage of stormwater and agriculture return flows, and desalination of the oceans, must be adopted.
3. IMA was proved to at once eliminate a set of organic and inorganic chemical compounds (cationic, anionic, and neutral) and bacterial indices through chemical oxidation, precipitation, co-precipitation, coagulation,

volatilization, and adsorption. Such an exclusive potential is attributed mainly to the formation of ROS and the production of iron oxyhydroxide sludge throughout the IMA technology. In opposition with traditional coagulation method, this technique leaves no salts to the water, rendering it especially pleasant in closed or partially closed-loop drinking reuse usages in which salts may collect. These findings are encouraging for the implementation of IMA to water and wastewater treatment. Especially, if integrated with low energy membrane filtration IMA can provide holistic elimination of organics, inorganics, and some salts, without the injection of sulfates or chlorides, in drinking and non-drinking WR usages. More investigation of reactor conception is suggested, comprising the employment of low-cost iron sources.

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