# Review of Circular Economy in urban water sector: Challenges and opportunities in India

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# Review of Circular Economy in Urban Water Sector: Challenges and Opportunities in India

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# Abstract

Increasing urbanization and rapid depletion of resources have forced authorities to shift from traditional linear system of take-make-use-dispose to circular system of resource conservation. Circular Economy (CE) is a sustainable development approach that works on the waste management strategy of reduce, reuse, recycle, and recover. Considerable work has been performed on CE in various sectors such as in electronic sector, construction sector, automotive sector, etc. However, CE in the water sector is gaining rapid attention, because of imbalance in water resources and the prevailing linear approach. The aim of this study is to review the world-wide growth of CE concept in the water sector from an economic, environmental, social, and technical perspective. 98 publications were selected by systematic literature review and categorized in economic, environmental, social, and technical criteria including a combination of multiple criteria. In this study, the world-wide status of CE implementation in the water sector is assessed and strategies to encourage and enhance CE implementation are proposed. The six BS8001:2017 principles and 6Rs (reduce, reuse, recycle, reclaim, recover, restore) of waste management are critically analyzed for deriving recommendations and successful implementation of CE in water sector. Finally, challenges and opportunities to implement CE in the water sector in India are discussed.

*Keywords:* Circular Economy; Water; Wastewater; Resources; Sustainability; India

*Abbreviations:* 6Rs: reduce, reuse, recycle, reclaim, recover, restore; C: Carbon; CE: Circular Economy; CW: Constructed Wetland; LCA: Life Cycle Assessment; N: Nitrogen; P: Phosphorus; ULB: Urban Local Bodies; WWTP: Wastewater Treatment Plant.

# 1. Introduction

Urbanization is increasing at a rapid rate worldwide, 55% of the global population resided in urban areas in 2018 and it is projected that by 2050, it will reach 68% (UN-DESA, 2018). With the increase in population, consumption of resources has also increased and it is expected that total global material consumption will reach approximately 90 billion tons by 2050 (Swilling et al., 2018). One of the essential, limited, and renewable natural resource "Water" is the focus of the current study.

Water plays an important role as the basis of life on planet earth and is broadly used for domestic, irrigation, and industrial purposes. Thousand years ago, the earth's stock of water was circulated through multiple processes and stages of the hydrological cycle. However, since last few hundred years, this valuable resource and its cycle is disturbed because of increasing population and anthropogenic activities (Vörösmarty and Sahagian, 2000). It is continuing since many years leading to water crises and may lead to worse conditions if not managed properly (Fitzhugh and Richter, 2004). Water scarcity occurs when water demand is more than available water resources.

Internationally, a country is categorized as "water-stressed" if per capita available water resources is in the range of 1000–1700 m3/year and "water-scarce" if it is less than 1000 m3/year (Damkjaer and Taylor, 2017). India accounts for 4% of the world's water resources with 17% of the global population and 2.4% of the total area (WRIS, 2015). With a population of 1.34 billion and water availability of 1427 m3/capita/year, India is in the category water stress region (FAO, 2016)

Climate change is posing additional stress on global hydrological cycle and urban water resources (Arnell, 1999; Oki and Kanae, 2006). The hydrological cycle is getting disturbed because of more moisture, more evaporation, unevenly distributed precipitation pattern, higher temperature, snow-melt, and extreme events (Shastri et al., 2015). Global climate change also has implications on regional water balance affecting water availability at a basin level (Gleick, 1986). Some of the major impacts of climate change are on water resources and hence, urban water cycle (Gleick, 1989). Thus, with accelerating urbanization (population) and climate change risks, the balance between water demand and available water resources is disturbed (Arnell, 1999; Falkenmark and Widstrand, 1992).

Apart from quantity, quality of water plays a significant role in satisfying basic human needs. Water quality is in threat because of increasing urbanization, climate change, industrial, and agricultural activities (Gleick, 2014). It is observed that globally around 80% of the wastewater is directly disposed of into the environment (WWAP, 2017) and approximately 2 billion people globally use drinking water sources polluted with feces (WHO, 2018).

These water quantity stress and quality issues in urban water resources previals because of the linear approach of extracting freshwater, using potable water for all purposes, and disposing it to natural water bodies (Daigger, 2009). There is a need to understand urban water balance to monitor, manage, and assess the inflow and outflow of water within the urban area (Kenway et al., 2011). Water is circular in nature, and water cycle is the evidence of nature's circularity. The principle of Circular Economy (CE) can be implemented in the water sector to combat the current problem of water scarcity because of a linear approach (IWA, 2016; Voulvoulis, 2018).

## 1.1. Circular Economy

The CE concept was first introduced by Pearce and Turner in "Economics of Natural Resources and the Environment" in 1990 (Pearce and Turner, 1990). Later, since 2010 Ellen MacArthur Foundation has significantly contributed to the development of CE practices in multiple sectors such as waste management, sustainable design and construction, food production, indicator development, etc (EMF, 2017). CE is a sustainable development strategy wherein economic benefits are increased while reducing the burden on natural resources. The alternative/technology/practice that allows shifting of focus from non-renewable natural resources to recovery of resources from the waste thereby generating economic, social, and environmental benefits is the basic idea behind the CE concept (Lieder and Rashid, 2016). CE is a sort of rethinking, in a way to cycle valuable materials from one product at the end of its life and reuse the same material for another product manufacturing so as to maintain the ecology and continue to be useful beyond the useful life of individual products. In this way, the goods of today can become the resources for tomorrow (Stahel, 1982). The CE concept works on the waste management principles of reduce, reuse, recycle, and recover (Hu et al., 2011; Winans et al., 2017).

Within the CE paradigm, waste is considered as a resource and with the above-discussed challenges in water sector, there exist certain opportunities to manage wastewater sustainably from CE perspective. Wastewater is a valuable resource for water, energy, and material (Mo and Zhang, 2013; Verstraete et al., 2009). Water can be reclaimed from wastewater for the potable or non-potable purpose (Angelakis et al., 2018), energy can be recovered from sludge (Rulkens, 2008; McCarty et al., 2011; Batstone and Virdis, 2014), nutrients recovered can be used for agricultural purpose (Vaneeckhaute et al., 2018a). Thus, it is essential to manage the water and wastewater resources following reduce, reuse, recycle, reclaim, recover, and restore (6Rs) strategies of CE.

## 1.2. Need for the review of CE in water sector

In a review by Prieto-Sandoval et al. (2018), varying approaches and numerous applications on the CE concept were assessed and consensus on the notion of CE and its relationship with eco-innovation was proposed. Even if the CE strategy is applied, its assessment approach or extent of implementation in any sector is not uniformly developed. BS8001:2017 provided comprehensive guidelines for the implementation of CE in organizations based on six CE principles. However, monitoring the implementation strategies of CE still remains unclear (Pauliuk, 2018). There is a lack of consensus on a framework and measures to assess the implementation of CE. Thus, the development of sector-specific framework or indicators can be beneficial to foster their adoption at a larger scale (Saidani et al., 2019).

There has been considerable work on CE in almost all parts of the world in many sectors (Prieto-Sandoval et al., 2018). CE in the water sector is gaining rapid attention recently because of the imbalance in water resources and prevailing wide-scale linear approach in this sector.

Extensive work has been carried out in a disaggregated form on wastewater 6Rs; however, the role of CE in integrating these strategies requires multidimensional perspective. Also, there is an ambiguity in the use of terminology of 6Rs such as reuse and recycle (Blomsma and Tennant, 2020) in general in all sectors and it is more evident in water sector. The past literature on CE does not focus specifically on the water sector, challenges in the implementation of CE in the water sector, opportunities involved from CE perspective, and the monitoring framework. Thus to fill this gap, review of CE in the water sector is primarily required to assess the potential of CE in the water sector.

The aim of this study is to conduct first of its kind review on the world-wide growth of CE concept in water sector from an economic, environmental, social, and technical perspective. This review will be helpful to understand CE strategies that can enable successful implementation along with the challenges and opportunities involved in the water sector in India.

## 1.3. Organization of paper

The article is divided into seven sections. The second section discusses the strategies applicable to CE in the water sector; the third section is the review methodology followed by discussion on papers in fourth section. The role of BS8001:2017 principles and CE strategies for CE implementation in water sector are discussed in fifth section, and the sixth section deals with the challenges and opportunities of CE implementation in the water sector in India. Conclusions are described in the last section, based on the findings and analysis of papers considered for the review.

# 2. CE in the urban water sector

Water sector involves the exchanges of water within various components such as surface water, groundwater, and urban water. These exchanges induce a change in the quantity and quality of water in these components. The water is used by humans and hence, the behavioral and management aspects also become dominant in the urban water sector. A conventional flow of water and its exchange between various components is illustrated with the help of Fig. 1.

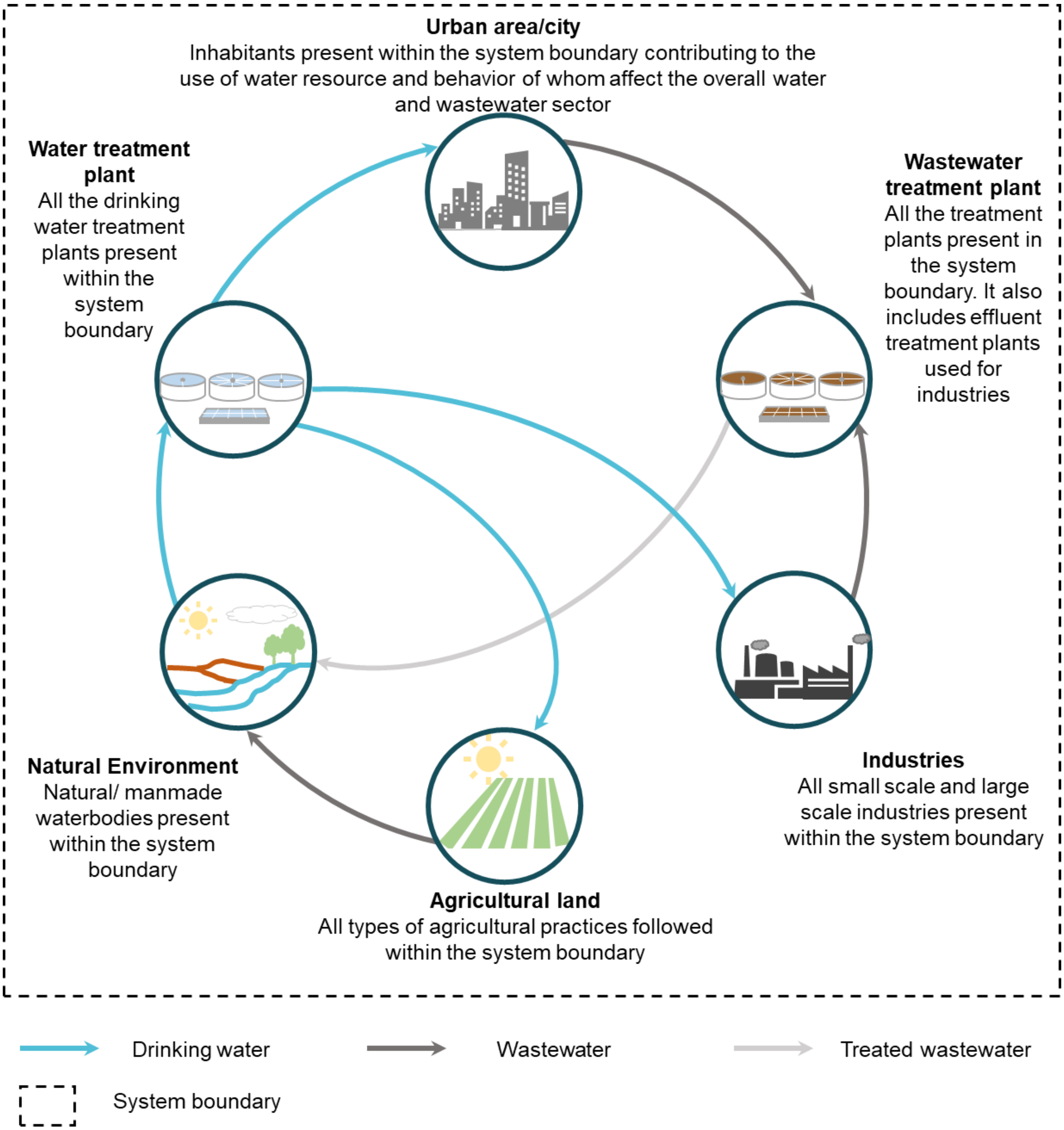


**Fig 1:** Conventional urban water cycle with exchange of water and wastewater within the system boundary.

The interrelations and exchange between these components make an intrinsically complicated urban water cycle and it gets further affected by the linear approach of managing water resources. Thus, the concept of CE provides pathways towards sustainable water resource management. 6Rs strategies can be implemented in the water sector to achieve circularity of water and wastewater resources as shown in Fig. 2. Although considerable research is performed in the field of water conservation, wastewater reduce, reuse, recycle, reclamation, recovery, and restoration, contextualizing these efforts from CE perspective is needed. Thus, 6Rs relevant to the water sector to achieve CE implementation are illustrated with the help Fig. 2. Also, the terminology for 6Rs is not clearly stated in the literature and reuse, recycle, and reclaim have been used synonymously in the literature which does not follow the waste management terminology. Hence, from the context of CE in urban water sector, 6Rs are defined in Table 1, which will be used throughout this work.

**Table 1:** Definition of 6Rs

| **Sr. No.** | **Rs** | **Definition** |
|---|---|---|
| **1** | Reduce | Decrease in the consumption of freshwater by creating awareness in consumer, by applying efficient fixtures or appliances, reducing leakages, thereby reducing wastewater generation. |
| **2** | Reuse | Reuse of used water in its crude form (no treatment/processing involved) for multiple purposes inside or outside the loop. |
| **3** | Recycle | Use of treated wastewater within the same loop or in the same process. |
| **4** | Reclaim | Treatment of wastewater and its use outside the loop/process. |
| **5** | Recovery | Extraction of valuable resources (e.g. energy, material) present in wastewater. |
| **6** | Restore | Replenish the water resources through artificial interventions (e.g. managed aquifer recharge, rainwater harvesting, afforestation, rejuvenation of water bodies) |

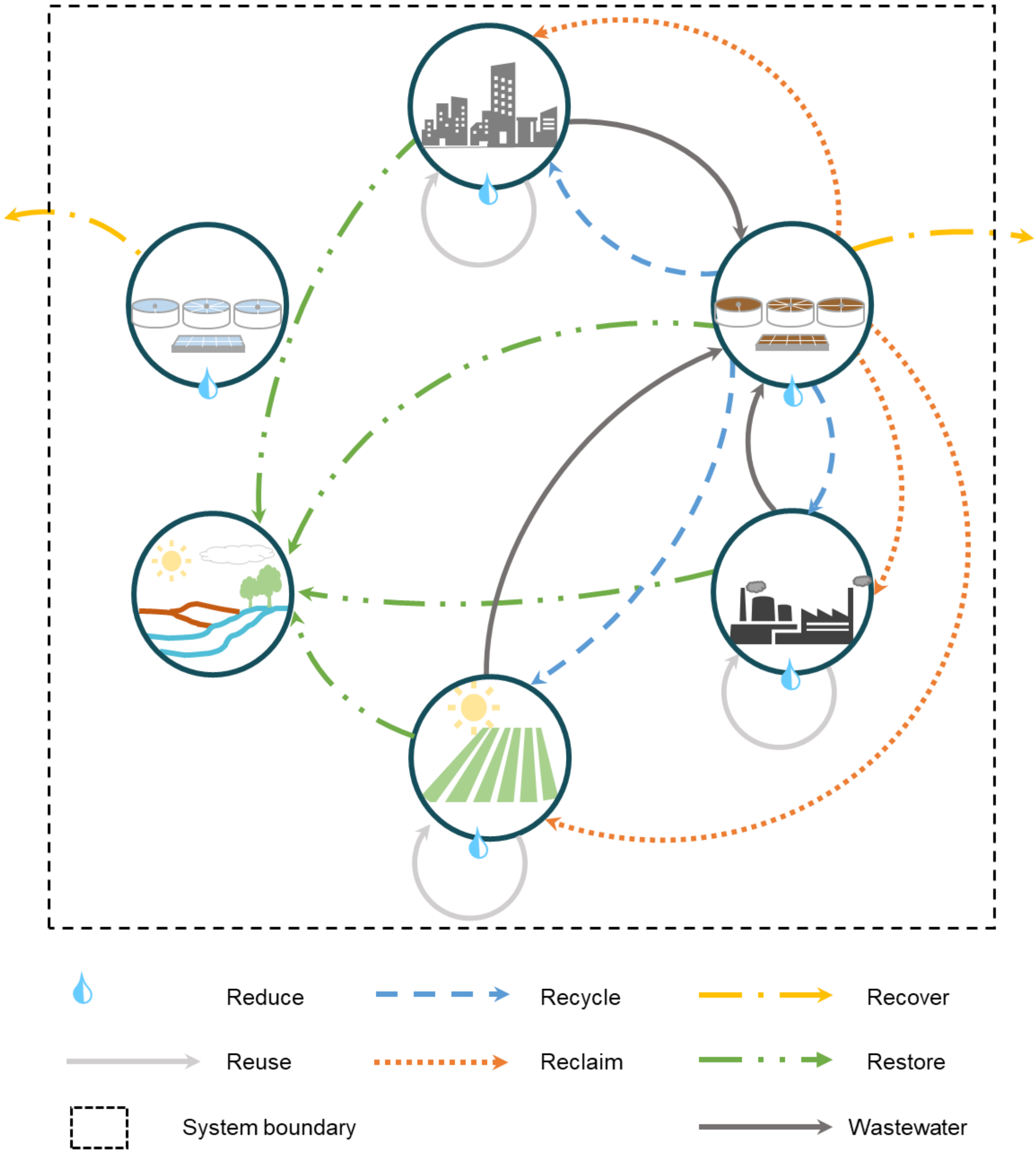


**Fig 2:** Urban water cycle considering 6Rs strategies of Circular Economy in urban water sector

Reducing the freshwater consumption which will result in reduction in the wastewater generation is the first strategy in 6Rs. Reduction in sewage can be accomplished by consumer awareness and developing responsible behavior in industries and organizations. Reduction in water consumption is possible by installing efficient plumbing fixtures/appliances for example dual flush system in place of conventional flushing (Bari et al., 2015). Demand management using smart meters can also help in reducing water consumption (Liu et al., 2016) and hence reduce the wastewater generation. In India, leakages in distribution network contribute to 30–40% water losses (Kalbar et al., 2014), thus reducing leakages will also achieve freshwater demand reduction. By applying water efficient devices and prevention or conservation at the source, wastewater generation can be significantly reduced, thus reducing the load on wastewater treatment facilities (Arceivala and Asolekar, 2007).

Reuse involves cascading use of used water in its crude form for multiple purposes so as to reduce the freshwater demand (Yang, 2012). Wastewater reuse is an alternate water supply to increasing water demand in water-scarce regions; however, its tremendous potential has not been recognized in many areas of the world (Voulvoulis, 2018). For example, the wastewater generated in the Hyderabad city, India is discharged in the Musi River and is utilized for agricultural activities downstream of the city (Van Rooijen et al., 2005). Thus, the rivers receive partially treated sewage which is indirectly reused for agricultural purposes enabling the availability of nutrients required for agriculture and utilizing wastewater reduces the freshwater demand (Wintgens et al., 2016). However, direct reuse poses environmental and health risks (Srinivasan and Reddy, 2009) and hence needs comprehensive assessment before devising such practice.

Recycle is the use of treated wastewater for the same purpose (or loop) from where it is generated (Jimenez and Asano, 2008). Efficient recycling plays an important role in the overall reduction in freshwater demand. For example, using treated industrial wastewater within the same industry for the same purpose from where it is generated. In India and many parts of the world, the increasing freshwater demand has forced municipalities to use treated greywater for secondary purposes i. e. toilet flushing purpose. A study by Jefferson et al. (2004), highlights the importance of greywater for recycling purpose and its characterization for appropriate treatment.

Wastewater reclamation includes the treatment of wastewater and its use outside the loop/process, as shown in Fig. 2. With the rapid development and improvement in treatment technologies, wastewater can be treated to a quality equivalent to potable water quality (Asano et al., 2007). The extent of reclamation depends on the pollution status of the wastewater and the purpose for which reclaimed water is used. Treated wastewater can be used for direct potable purpose, indirect potable purpose, or non-potable purpose (Jimenez and Asano, 2008). For example, wastewater generated in residential builidings can be utilized after appropriate treatment i.e. reclamation in industries or agriculture as shown in Fig. 2.

Recovery is the extraction of valuable resources (e.g. energy, materials) present in wastewater. Resource recovery from wastewater is one of the important steps towards sustainability in the current era of depleting resources. As in CE paradigm, waste is considered to be a valuable resource; wastewater is also a valuable resource (Puyol et al., 2017). It is a resource for water, energy, and materials such as fertilizer, bioplastics, metals, protein-based food, building materials, and other consumer products depending on the pollutants present (Guest et al., 2009). In olden times, the concept of considering urine, feces, and greywater as a resource was a well-known and adopted practice. However, the obvious benefits of the closed-loop system were recognized in the past and forgotten in present (Bracken et al., 2007).

Restore involves the process of artificially restoring or replenishing the sources of water such as groundwater, river water, water in lakes to enhance the availability of water in the dry season and also to maintain the water balance in the region. Artificial recharge strategies are used for replenishing the water resources. For example, rainwater harvesting involving preliminary treatment of rainwater is commonly used for groundwater recharge, making it available in the dry season. Also, the managed aquifer recharge is practiced for restoration of lakes and rivers. One such example includes work related to conservation of lakes in Bangalore city where restoration of bunds and spillways contributed towards groundwater recharge (Gowda and Sridhara, 2007). Another example, rejuvenation of Mansagar lake in Jaipur, India using Constructed Wetland (CW) technology, i.e. tertiary treatment of wastewater entering into the lake (Asolekar et al., 2014) is a successful example of wastewater restoration.

Thus, CE in the water sector can contribute immensely to the reduction of freshwater demand alternatively providing numerous resources such as energy, bioplastics, nutrients, etc. Technology plays an important role to enhance the implementation of CE in the water sector. The role and growth in technology to shift from treatment to recycle and recovery is tremendous (Villarín and Merel, 2020). Conventionally, wastewater treatment technologies were designed to remove contaminants (For example, Carbon (C), Nitrogen (N), and Phosphorus (P)) for environmental protection. However, in the current era of depleting natural resources, energy crises, water scarcity, imbalance in N and P cycle, it has become important to shift from linear system of treatment and disposal to treatment and recovery paradigm of cradle to cradle bio-based economy (Puyol et al., 2017). Thus, the contaminants (C, N, and P) in wastewater has become resources for water, energy, and nutrient (fertilizer) (Verstraete et al., 2009).

In 2009, Verstraete et al. (2009) reported that maximum resources can be recovered by separating the dilute and concentrated streams based on filtration processes and anaerobic digestion with a major focus on N and P recovery. Later, McCarty et al. (2011) proposed an important intervention in the wastewater sector with anaerobic treatment or low net energy wastewater treatment, majorly focusing on methane gas generation. Further, Batstone and Virdis (2014) highlighted the role of anaerobic digestion in a new resource recovery paradigm considering Low energy mainline approach and Partition release and recover method. However, Batstone et al. (2015) reviewed the proposal by Verstraete et al. (2009) and McCarty et al. (2011) practically and worked further on resource recovery platforms focusing on cost and energy criteria. Thus, technological development considering resource recovery has become a crucial aspect of wastewater management.

The tremendous technological development in wastewater treatment sector have multiple barriers, which are discussed in section 6. However, the CE strategy will help to address some of these barriers leading to improvements in water sector.

# 3. Review methodology

The publications considered in this study were collected from a detailed bibliometric search on Scopus using the keywords ‘Circular Economy’ and ‘Water’. Scopus is one of the most widely used and accepted database for the exploration of publications in science and technology journals. We included three types of publications in our study viz., journal articles, conference proceedings, and book chapters. The search was conducted for “Article title, Abstract, and Keywords”. Total of 625 publications were retrieved in the automatic search from 1976 to July 2019. The list was then refined by manual screening based on the objective of the study. In the first stage, around 359 publications were selected by the manual reading of title and abstract. Later, in the second stage, more detailed reading of title, abstract, introduction, and conclusion was performed reducing the number to 98 (2011–2019) for a detailed review.

The selected 98 publications were later segregated based on the four criteria i.e. Economic, Environmental, Social, and Technical. The segregation was based on either single or multiple criterion depending on the focused criteria by manual screening of each paper. Fig. 3 provides criteria-wise distribution of papers from the year 2011–2019 along with the publications which are screened out and the total number of publications in the particular year.

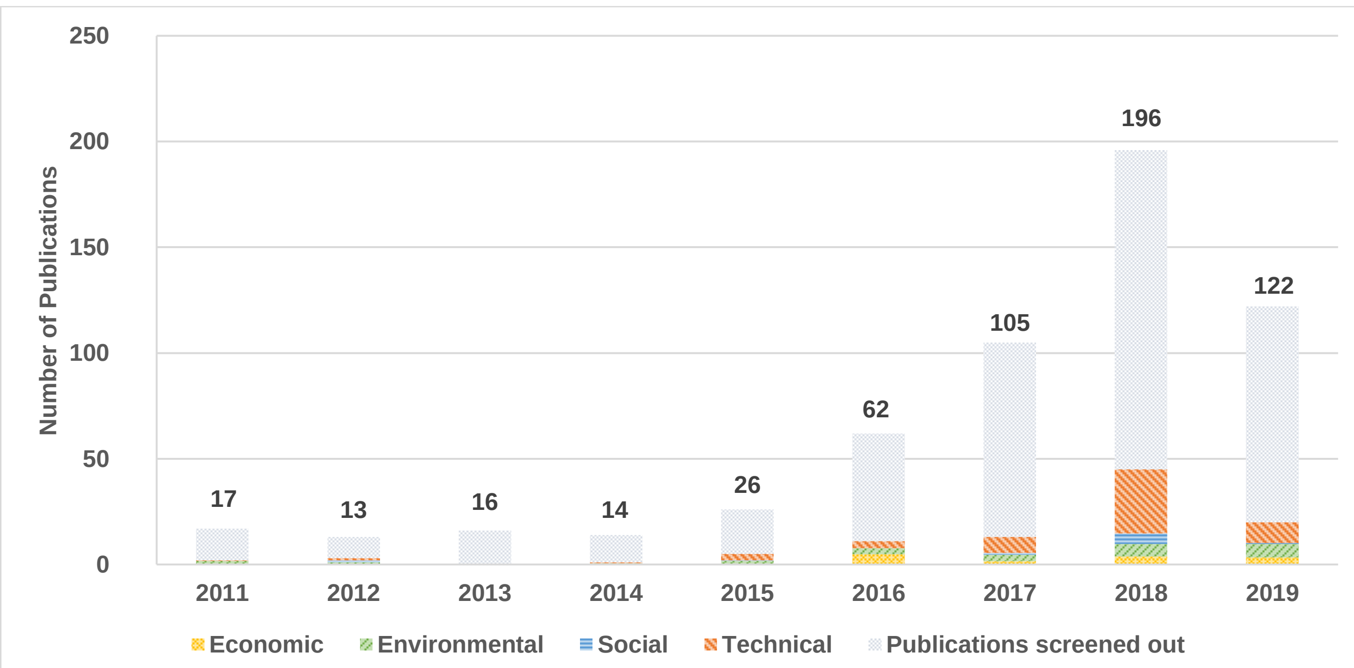


**Fig 3:** Year-wise number of publications based on criteria and the publications which are screened out. The total number of pulications retrieved in automatic search are shown at the top of each bar.

The total number of publications before 2011 were not significant (less than 10 a year); hence the representation in Fig. 3 is from 2011 to 2019. There were no suitable publications in the year 2013 and reduced publications in the year 2019 is because the screening was performed until July 2019. Thus, the criteria-wise distribution indicates that the significant work was performed on technical aspects of CE, and it was observed that major publications were from the countries in European region and China.

# 4. Studies on Circular Economy in water

The selected 98 publications are studied and analysis is presented in this section. The detailed list of publications with references is provided in Supplementary Information (SI-1). The studies which cover a single aspect of CE are discussed first and later the studies covering multiple aspects are discussed.

## 4.1. Studies covering economic aspects of CE

This section covers the studies concentrating more on economic aspects within the CE paradigm. A study by Maaβ and Grundmann (2016) highlighted the economic benefits of using reclaimed wastewater for agricultural purposes at Braunschweig in Germany. A cost-benefit analysis was performed and the positive outcomes were observed in the value chain of wastewater treatment, agricultural crop production, and energy generation as compared to conventional processes (Grundmann and Maaβ, 2017; Maaβ and Grundmann, 2016). Apart from agriculture, utilizing reclaimed wastewater for power plant cooling also generates economic benefits. However, the transportation of reclaimed wastewater from the origin (i.e. Wastewater Treatment Plant (WWTP)) to its destination (i.e. Power plant) can become uneconomical based on the location. Thus, to optimize the cost of pipe, reduce transport distance, and close the loop of water resource within the principle of CE, a transportation optimization model was applied by Okioga and Sireli (2016).

Although the above studies concentrate on financial investments, assessment of wastewater recycling initiatives by incorporating environmental issues using cost-benefit analysis provides useful insights from CE perspective (Villar, 2018). Abu-Ghunmi et al. (2016) worked on financial and environmental cost benefits associated with water and wastewater industry. The study was performed for Jordan's centralized wastewater treatment facilities. A methodology to determine the market value of water was provided and the cost-benefit analysis resulted in a net loss for not treating wastewater in the current linear economy situation at Jordan. Thus, the Abu-Ghunmi et al. (2016) emphasized on the net opportunity cost of the linear system and encouraged to move towards circularity in water industry looking at the economic benefits. In another study, Kayal et al., 2019 developed a "Circonomics Index" to assess the extent of circularity practiced in the WWTP and concluded that technology plays an important role in the overall cost-benefit of circularity.

These studies suggest that the economic aspects of CE are evaluated using cost-benefit analysis. However, the work on economic assessments suggests that Life Cycle Costing can provide valuable insights (Kalbar et al., 2012a; Lorenzo-Toja et al., 2016).

## 4.2. Studies covering environmental aspects of CE

Environmental aspect covers the studies evaluating the environmental performance of the solutions proposed to achieve CE. Li and Ma (2015) reported an example on successful implementation and exchange of water, energy, and material resources in an eco-industrial park to save energy and resource conservation. Exchange of resources in between industries where the waste of one industry is a resource to other industry i.e., industrial ecology can play a significant role in achieving CE. As per the study by Yang (2012), balanced utilization of water resource in the agricultural system, industrial park, and domestic purpose within the ideology of CE can be very well achieved and is explained with the help of existing case studies in China. Circular utilization of water and wastewater resources in between thermal power plant, desalination plant, salt making plant, and building material plant is an example in the same context (Dai et al., 2011). Another example case study with a similar purpose is the symbiotic relationship between sewage treatment plant, pig industry, planting industry, and other breeding industries along with a multi-objective optimization of cyclic paths is worked out by Liu and Xiao (2015). Utilizing sludge obtained from effluent treatment of paper and pulp industry to prepare carbon adsorbents by the process of pyrolysis is an idea proposed by Jaria et al. (2017) to achieve zero waste strategy for industries. Environmental advantages (from life cycle assessment (LCA) perspective) of using residual products/streams from industrial symbiosis is reported by Husgafvel et al. (2016) where fly ash residue from bioenergy production and sludge from wastewater treatment in forest industry can be utilized for the production of fertilizer.

Sustainable management of resources at a building scale by generating electricity using solar energy, reduce, reuse, and recycle of water and wastewater resources considering an idea wherein consumer is also a producer called as prosumer is reported by McLean and Roggema (2019). Similarly, Pimentel-Rodrigues and Siva-Afonso (2019) specifically worked on water resources to achieve CE at a building level. Implementation of CE in water supply and sanitation sector at a country level from green economy perspective, current challenges and the status of Finland is reported by Laitinen et al. (2020). A survey on small and medium enterprises at a regional level in Europe was performed in a study to assess the status of CE practices followed and policy implications to achieve successful implementation (Bassi and Dias, 2019).

Molina-Sánchez et al. (2018) developed CE indicators for quantitative measurement of the reusability of waste generated in the production process in the paper industry to enhance the implementation and monitoring of CE strategies. Similarly, Oliveira et al. (2019) provided indicators for water consumption and wastewater production in winery industry to create awareness among the winery authorities towards wastewater treatment and management.

Thus, the work on CE from environmental aspect addresses the role of industrial ecology, LCA, resource management, and indicators development to achieve sustainability at varying scales.

## 4.3. Studies covering social aspects of CE

Implementation of CE strategies in the water sector has implications on human health, behavioral changes, safety, rules and regulations, policy, and governance, which are clustered in social aspects. Da Rosa and Ramos (2018), emphasized the role of human behavior and water-related laws that can be imposed to address the problem of water resource scarcity in connection with the principle of CE. The role of water and wastewater management systems in the context of smart cities is discussed by Molina-Giménez (2018) from the governance and legal perspective stressing on the need for circularity of water and wastewater resources. Eneng et al. (2018) emphasized on the need for policies to utilize water resource and reduce its wastage by appropriate governance structure to fulfill future water demand in Indonesia. Villamar et al. (2018), studied the issue of wastewater reuse in Chile and reported that wastewater reuse is not organized due to lack of policies for implementation. In Chile, the untreated wastewater is used for cereal crops (animal feed), forests, and grasslands; and hence, the safety is not assured as no policies are available for such use. The study emphasized on the need to formulate policies for safe reuse, recycle, and reclamation to achieve sustainable use of wastewater in the context of CE. In a study by Christou et al. (2017), the impacts of using reclaimed wastewater for irrigation purpose is highlighted where the impact of antibiotics on the plant growth, plant uptake, and ultimate impact on the human being is critically reviewed.

Hence, there is a need to formulate policies, rules, regulations, and laws along with the strengthening of legal and governance structure to ensure CE implementation in water sector. Also, public acceptance and awareness play a significant role in the successful implementation of CE from social perspective.

## 4.4. Studies covering technical aspects of CE

Information about the studies covering technological and methodological aspects of water and wastewater industry including 6Rs strategies of CE concept are reported in this section. Potential and application of microbial biotechnology in wastewater management and the use of resources recovered from wastewater in the context of CE is briefly discussed by Nielsen (2017). Puyol et al. (2017) reviewed emerging biological technologies to recover valuable materials from wastewater and identified possible opportunities and challenges associated with the recovery. Akyol et al., 2020 reviewed approaches for anaerobic wastewater treatment and recovery of energy and material and recycle wastewater within the concept of biorefinery or water resource recovery facility. A review on various types of sludge produced from wastewater treatment and technologies to sustainably manage sludge for efficient recovery, including challenges involved is reported by Gherghel et al. (2019). Recovery of resources using sulfate-rich waste streams in wastewater facilities is proposed by Seco et al. (2018).

Energy recovery from wastewater using microbial fuel cell is one of the processes through which circularity of resources can be achieved. Although traditional methods for energy recovery are much better compared to the microbial fuel cell, it is claimed that further research can lead to sustainable development in the future (Cecconet et al., 2018). Integrated energy recovery from anaerobic co-digestion and photovoltaic energy inside the WWTP can contribute to achieve self-sufficient WWTP and hence CE (Duarte et al., 2018).

Recovery of nutrients especially P from wastewater is currently a critical topic of wide interest, as P is rapidly depleting non-renewable natural resource, and also causes eutrophication. An assessment of P globally with reference to production and consumption using spatial analysis reveals that there is a need for P recycling as there are increasing problems with P security (Kok et al., 2018). Thus, P recovery from wastewater contributes towards balanced utilization of P, leading to sustainable development. A review on P recovery technologies performed by Egle et al. (2015) provides a comprehensive summary of around 50 approaches for P recovery based on physicochemical and biological aspects considering the extent of pollution, resources required, P removal rates as well as effluent/product quality desired. Whereas, a review by Tarayre et al. (2016) emphasize on biological processes for P removal and recovery. Recovery of P with drivers and barriers involved is reviewed by de Boer et al. (2018) with an interview from the stakeholders involved in P recovery and usage.

Venkiteshwaran et al. (2018a) reviewed various technologies for P recovery based on chemical changes and conversion from non-reactive P to reactive P whereas Kasprzyk and Gajewska (2019) emphasized on adsorption using natural materials for removal and recovery of P. Wilfert et al. (2018) highlighted the role of Vivianite (a compound to which phosphate group is attached) in recovery of P. Role of immobilized phosphate-binding protein by adsorption and desorption process for removal and recovery of P investigated by Venkiteshwaran et al. (2018b) which is another crucial technique to achieve CE of P.

Other than P, N also contributes to environmental pollution as well as has a fertilizer value; thus, simultaneous analysis of N and P for the purpose of recovery is an important aspect that reveals valuable insights about recovery and co-benefits involved which can be missed in single substance analysis (Tanzer et al., 2018). Fertilizer value of N and P vary from waste to waste. Thus, a study on various combinations of waste to assess the fertilizer value suggests that sewage sludge proves to be economically beneficial (Kominko et al., 2018). Recovery of N from bio-sludge obtained from paper and pulp industry by the process of thermal drying is also found to have reasonable fertilizer value (Mustonen et al., 2018). A study by Vaneeckhaute et al. (2018b) provided a generic road map as a decision support tool for various actors working in the field of wastewater treatment, anaerobic digestion, and nutrient recovery to achieve optimum nutrient (N and P) recovery and a way to move towards CE. Another study wherein the utilization of industrial wastes for removal of N and P components in reject water from anaerobic digestion is performed using chemical precipitation process, and the precipitate thus obtained can be used as fertilizer within the context of CE (Myllymäki et al., 2019).

Decentralized treatment of source-separated black water for the removal of organic matter and recovery of nutrients using anaerobic treatment along with various filtration techniques is reported by Eshetu Moges et al. (2018). With a similar outlook, Ribera-Pi et al. (2020) worked on the role and potential of anaerobic membrane bioreactor for the treatment of dairy products to recover energy and water. The idea is to close the loop of resources and nutrients near the source of waste generation. However, there can be health hazards that need to be addressed for making decentralized systems reliable as compared to that of centralized systems (Roest et al., 2016).

Other than energy and nutrients, bioplastics can also be recovered from wastewater. Technical feasibility to produce bioplastics using polyhydroxyalkanoate from wastewater and sludge is summarized by Arcos-Hernández et al. (2015). Although the idea is the production of a renewable product using waste, higher production costs with current technology make it economically challenging (Bluemink et al., 2016).

Phytoremediation is one of the approaches used to achieve CE (Pirrera and Pluchino, 2017). Treatment of wastewater using photo-bioreactor and cultivation of biomass (microalgae and/or duckweed) provides tremendous benefits from CE perspective where wastewater is used to produce bio-products such as bioenergy, bioplastic, fertilizers, and water (Ferreira et al., 2018; Sachdeva et al., 2018; Uggetti et al., 2018). However, the risks associated with the cultivation of biomass as food or feed and its treatment with anaerobic digestion including post-treatment is emphasized by Markou et al. (2018).

Pott et al. (2018) promoted the concept of wastewater biorefinery handling wastewater from various industries, thus producing clear output water and recover valuable resources. Example treatment flowsheets for biorefineries are also provided with the idea that cleaner production, industrial ecology, and CE can be combined as a proposal to move towards sustainability. The concept of converting existing WWTPs to biorefineries with innovative technologies and options to recover valuable materials in Italy by CAP Group is a valuable contribution to move towards CE (Russo, 2018). Another study with the idea of converting conventional wastewater treatment facilities to water resource recovery facilities provided a mini-review on anaerobic treatment technologies for efficient recovery of resources to achieve the goal of CE, sustainable treatment, and water reuse by Massara et al. (2017). One such example of waste biorefinery includes the use of anaerobically digested waste activated sludge as heavy metal (lead) adsorbent prepared by the process of pyrolysis (Ho et al., 2017). Thus, biorefineries prove to be helpful in the successful implementation of CE concept.

In a study by Simha et al. (2018), adsorption of source-separated urine using granular activated carbon produced from coconut shell is studied to produce urea, and thus fertilizer manufacturing is proposed. Langergraber and Masi (2018) provided a mini-review on the role of CWs in production of water for recycle, energy crops production, ecosystem services, nutrient, and carbon recovery. The contribution of CWs to shift from waste paradigm to a new paradigm involving circularity and sustainability is appreciable (Masi et al., 2018). Also, an innovative design combining CWs and modular living wall i.e. WETWALL at an urban scale to mitigate climate change, water scarcity, and food security promoting CE is theoretically discussed by Castellar Da Cunha et al. (2018). Castro- Muñoz et al. (2018) reviewed the role of membrane technology for the treatment and recovery of agro-industrial wastes. Chemical treatment of pickling solution to achieve recovery of raw materials is performed by Pietrelli et al. (2018). Removal of organic halogens from industrial wastewater for the purpose of recycling within the context of CE is presented by Toth et al. (2018). Wastewater treatment using biofilms has a long history, and biofilms are produced from extracellular polymeric substances; however, capabilities and benefits from extracellular polymeric substance to achieve wastewater treatment and recovery is not yet recognized (Seviour et al., 2019). Methodology and benefits of the production of volatile fatty acid from the anaerobic fermentation of wastewater sludge within the context of CE is provided by Esteban-Gutiérrez et al. (2018). Jain et al. (2019) proposed a technical solution for the recovery of Gallium from wafer fabrication industry wastewaters to achieve recycling of scarce resource Gallium. Implementation CE principle in drinking water treatment plants for water softening process is reported by Schetters et al. (2015).

Kanakoudis and Tsitsifli (2019) provided insights on the integration of information and communication technology and water sector for the reduction in water losses, contributing to the efficient management of water resources.

Thus, the technological and methodological contribution to achieve CE in water and wastewater sector is enormous. Wastewater biorefineries or resource recovery facilities, energy-positive wastewater treatment plant, production of bioadsorbents using waste, natural treatment systems are some of the key concepts discussed inthis section.

## 4.5. Studies covering multiple aspects of CE

In the systematic literature review process, it was found that several studies covered more than one aspect of CE from economic, environmental, social, and technical criteria. Thus, the studies covering a combination of multiple aspects are tabulated in Table 2 and some of these are discussed in this section.

**Table 2:** Studies based on combination of one or more of Economic, Environmental, Social, Technical aspects of CE

| Sr. No. | Criteria | Related studies |
|---|---|---|
| **1** | Economic<br>Environmental<br>Social<br>Technical | (Ait-Mouheb et al., 2018; Baleta et al., 2019; Bianco, 2018; Maestre-Valero et al., 2019) |
| **2** | Environmental<br>Technical | (Dominguez et al., 2018; Sánchez et al., 2017; Zouboulis and Peleka, 2018) |
| **3** | Economic<br>Technical | (Batlle-Vilanova et al., 2019; Haaz et al., 2019; Picardo et al., 2019) |
| **4** | Economic<br>Environmental<br>Technical | (Hu et al., 2011; Kacprzak et al., 2017; Makropoulos et al., 2018; Micari et al., 2019; Nizami et al., 2017; Reig et al., 2016; Thiel et al., 2017; Zhan et al., 2014) |
| **5** | Economic<br>Environmental<br>Social | (Brears, 2015; Casiano Flores et al., 2018; Lipińska, 2018; Maaß and Grundmann, 2018) |
| **6** | Environmental<br>Social | (Kjellén, 2018) |
| **7** | Economic<br>Environmental | (Gleason Espíndola et al., 2018; Lin et al., 2016; van der Hoek et al., 2017; van Leeuwen et al., 2018) |

Makropoulos et al. (2018) worked on the concept of sewer mining with a pilot study in Athens, Greece from economic, environmental, and technical perspective. In sewer mining, the wastewater is taken at the decentralized location and treated; further, the treated water can be used for the non-potable purpose. The study collaborated wastewater treatment and smart ICT technologies; thus, the idea of sewer mining will provide small and medium enterprises with an opportunity to become principal actors in the wastewater reuse sector with economic benefits. Also, costs reduction in wastewater treatment at the centralized facility as well as environmental pollution reduction within the CE paradigm can be achieved.

Impacts of using wastewater for irrigation purposes is reviewed by Ait-Mouheb et al. (2018), taking the example of Mediterranean countries. The authors highlight the disparity in governance and management of wastewater resources in the example countries. Another study by Maestre-Valero et al. (2019) highlighted the role of reclaimed wastewater for irrigation purpose reducing the cost of fertilizer; however, the related risks need to be controlled using irrigation management strategies for the crops. Although the wastewater is an alternative source of water in CE paradigm, it may have adverse public health and environmental impacts if not managed properly. Thus, to move towards CE paradigm, there is a need to rethink the water and wastewater systems in a more holistic and integrated manner i.e. from an economic, environmental, social, and technical approach. Another review by Baleta et al. (2019), stresses more on the integration of water, energy, and environmental systems to move towards circularity. For wholesome analysis, all the sustainability pillars are needed to be considered; however presently, technological advancement is given more importance. Application of water reuse strategy for agricultural purpose and biogas generation considering technical feasibility, cost-benefit analysis, social acceptance, and environmental impacts was demonstrated by Bianco (2018) on two case studies in Italy. Such case studies can help in the learning process to achieve successful implementation of CE, strengthening the role of Europe in water and CE sector.

# 5. Confluence of 6Rs and BS8001:2017 principles

From the above section, it is clear that the implementation of CE in the past studies incorporates either 1R, 2Rs or multiple Rs strategies of CE discussed in Section 2. However, other than 6Rs considered in this study, BS8001:2017 introduced six guiding principles such as systems thinking, value optimization, innovation, collaboration, stewardship, and transparency to achieve the implementation of CE practices in organizations (Niero and Rivera, 2018; British Standard, 2017). These six principles can also be helpful in accelerating the implementation of CE in the water sector. The CE practitioners can make use of these principles for changing the viewpoint of stakeholders such as consumers, government authorities/Urban Local Bodies (ULBs), industries, small and medium enterprises, water and wastewater treatment plant authorities. Thus, the confluence of 6Rs with BS8001:2017 six guiding principles (see Fig. 4) to achieve efficient implementation of CE in the water sector can be beneficial as explained with the help of examples in Table 3.

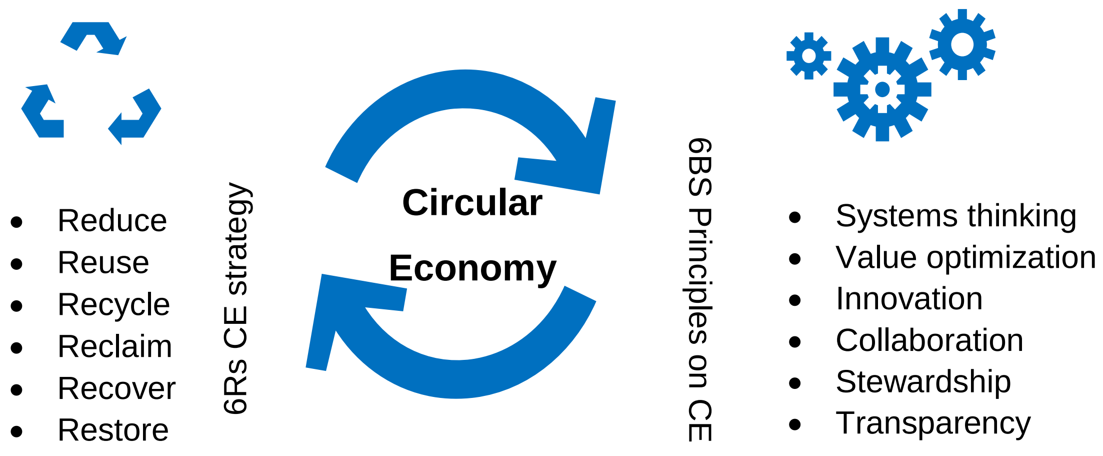


**Figure 4:** Confluence of 6Rs and BS8001:2017 principles

Thus, the transition to CE in water sector considering 6Rs and six BS principles can be achieved positively and effectively. The 98 publications considered in this study are further assessed and the list of some of the articles incorporating a combination of one or more of 6Rs strategies and six BS principles are identified and given in Table 4.

**Table 3:** Confluence of 6Rs and BS8001:2017 principles for CE in water

<table>
<tr><th></th><th>Systems thinking</th><th>Value optimization</th><th>Innovation</th><th>Collaboration</th><th>Stewardship</th><th>Transparency</th></tr>
<tr><td>Reduce</td><td colspan="2">Optimal utilization of freshwater by using water-efficient fixtures at household level enhances the overall availability of freshwater, reducing wastewater generation.</td><td colspan="2">Collaboration between consumers, suppliers, and government to provide innovative devices (e.g. smart meters) can reduce the water demand and enhance the value of water, which was otherwise ignored.</td><td colspan="2">Monitoring reduction at source level, thus assessing direct and indirect impacts of reducing consumption with an authentic and transparent exchange of information internally and externally.</td></tr>
<tr><td>Reuse</td><td colspan="2" rowspan="3">Cascading/reuse, recycling, and/or treatment/reclamation at household or industry level enhances the utility and value of used water thus significantly reducing the overall freshwater demand.</td><td colspan="2">Collaboration between water consumer and water utilities to design the reuse activity considering sustainable management of resources. For example, reusing water within the industry for cooling purpose enhances the value of used water.</td><td colspan="2">Assessing positive and negative impacts of wastewater reuse in its crude form and hence maintaining transparency among authorities about the characteristics of wastewater and % reuse adopted internally as well as externally.</td></tr>
<tr><td>Recycle</td><td colspan="2">Collaboration between WWTP, government, and consumer to design efficient and innovative recycling facility to enhances the value creation.</td><td rowspan="3">Monitoring recycle, reclamation, and recovery activities including direct and indirect impacts from economic, environmental and social aspects.</td><td rowspan="3">Transparency to exchange information about the methodology and extent of recycle, reclamation and recovery activities practiced.</td></tr>
<tr><td>Reclaim</td><td colspan="2" rowspan="2">Collaboration between waste management authorities, market, and consumer to design reclamation and/or recovery facilities to generate/recover products as per the market value and consumer requirement considering the sustainability aspect.</td></tr>
<tr><td>Recover</td><td colspan="2">Wastewater is a potential resource for water, energy, and material thus, recovery is an opportunity to keep the waste (resources) present in wastewater at its highest utility and value, eventually reducing the extraction of fresh resources.</td></tr>
<tr><td>Restore</td><td colspan="2">Utilizing rainwater or treated wastewater for groundwater restoration can enhance the groundwater level reducing the water scarcity in the dry season. Another example is afforestation that helps in restoring the water cycle, thus increasing the value of land as well as reducing environmental pollution.</td><td colspan="2">Collaboration in between government authorities and customer to devise innovative groundwater restoration model to enhance the availability of freshwater in future e.g. rainwater harvesting.</td><td>Responsible action towards the restoration activities at small scale as well as large scale for promoting water restoration in urban water cycle.</td><td>Transparency to share information about the methodology activities involved in restoration and the extent of restoration achieved on timely basis.</td></tr>
</table>

**Table 4:** Studies covering a combination of one or more of 6Rs strategies and six guiding principles proposed by BS8001:2017

| Sr. No. | Reference | Criteria | CE Strategies | BS8001: 2017 principles |
|---|---|---|---|---|
| 1 | Dominguez et al., 2018 | Environmental<br>Technical | Recycle<br>Reclamation | Value optimization<br>Innovation<br>Stewardship |
| 2 | Makropoulos et al., 2018 | Economic<br>Environmental<br>Technical | Reduce<br>Recycle<br>Reclamation | Systems thinking<br>Value optimization<br>Innovation<br>Collaboration |
| 3 | Gleason Espíndola et al., 2018 | Economic<br>Environmental | Restore<br>Reclamation | Systems thinking<br>Value optimization<br>Innovation |
| 4 | Eshetu Moges et al., 2018 | Technical | Reclamation<br>Recovery | Value optimization<br>Innovation |
| 5 | van der Hoek et al., 2017 | Economic<br>Environmental | Reuse<br>Reclamation<br>Recovery | Systems thinking<br>Innovation<br>Stewardship<br>Value optimization<br>Collaboration<br>Transparency |
| 6 | Puyol et al., 2017 | Technical | Recovery<br>Recycle | Value optimization<br>Innovation |
| 7 | Maaß and Grundmann, 2016 | Economic | Reclamation | Systems thinking<br>Value optimization<br>Collaboration<br>Stewardship |
| 8 | Liu and Xiao, 2015 | Environmental | Reclamation<br>Recycle | Innovation<br>Collaboration |

# 6. Challenges and opportunities in implementing CE in India

Water sector in India is currently facing issues such as growing water demand, intermittent water supply systems with high non-revenue water, lack of wastewater collection network, significant gap (about 60%) in the wastewater generation and treatment, and linear approach of water management. The ULBs in India do not have sufficient skilled staff to tackle all these issues and rely on external funding and agencies for implementing and operating the facilities related to the water sector. Industries are also lagging in the implementation of CE due to lack of supporting policies, availability of freshwater at a low price, weak enforcement of pollution-related regulations, no control on extraction of groundwater. In such a setting, numerous challenges exist in the successful implementation of CE in India, which needs to be overcome by careful assessment and collaborative efforts. Some of the challenges are categorically elaborated here.

**Technological challenges:**

1. Technology plays an important role to convert waste into a resource and technological advancement has reached to a level where wastewater can be treated to potable water quality; however, technology readiness level of current technologies is low (Puyol et al., 2017). Also, there is a need to assess technology from reliability (e.g. doesn't pose any health hazard or consistent performance for a given condition), robustness (e.g. can manage multiple parameters removal/recovery), resilience (e.g. can manage variation in influent load), and redundancy (e.g. backup services) perspectives (Voulvoulis, 2018).
2. Selection of appropriate technology is one of the crucial challenges faced by authorities (Kalbar et al., 2012b) to successfully implement CE strategies of reclamation, recycle, and recovery.
3. Currently, the available conventional WWTPs are designed on a centralized level with the aim of removing BOD, N, and P; however, with increasing urbanization, the quantity and quality of wastewater generated is changing continuously and newer challenges are posed by emerging contaminants (Kalbar et al., 2018). Thus, the importance and role of natural treatment systems with decentralized treatment need to be recognized.
4. Even after extensive research on lab-scale technological advancement in nutrient recovery, onsite scaling up is not completely accomplished due to challenges related with suitability of such technologies in Indian conditions and high costs.
5. The energy efficiency of WWTPs is further challenging as in the current scenario, conversion of biogas to fuel is not practiced and flaring the biogas onsite is common. Thus, achieving net-positive wastewater treatment is a distant goal.
6. Collection system is another crucial challenge. The centralized treatment facilities remain under utilized because of the lack of collection infrastructure including the issues concerned with the maintenance of centralized sewerage system.

**Economic challenges:**

1. Conventionally the annual operation and maintenance cost of wastewater treatment per m3 is around Rs. 3.5, and the cost of wastewater treatment for recycling purpose is around Rs. 6.5 to 9 per m3 (Tare and Bose, 2009). Due to high technology and energy costs, the wastewater recycling plants in India are not scaling up and a stable market for recycled water is not established. Also, the freshwater tariff in India is remarkably low and varies significantly at a regional level, hence the recycled water price is not competitive enough.
2. In conventional wastewater treatment, energy recovery is not practiced; thus, the cost of energy for treatment is dominant. If energy is generated at WWTP, the overall energy costs can be significantly reduced.
3. Water distribution networks are in deteriorating conditions which results in significant leakages ultimately leading to high non-revenue water (Hastak et al., 2016). Substantial economic losses occur because of low revenue generation.

4. Use of recycled water in agricultural activities may hamper the market value of crops, thus affecting the overall revenue. Hence, the motivation to use recycled water in agriculture is minimum.
5. Exchange of water resources between industries/stakeholders incurs additional costs of transportation and distribution of reclaimed water and there is a need for case to case basis evaluation.

**Institutional/Governance challenges:**

1. Lack of expertise or the skilled manpower with ULBs and wastewater management authorities critically affect the efficient functioning of the infrastructure and thus the implementation of the CE.
2. There is a lack of detailed policies supporting the recycle and reclamation of wastewater. There is a need to provide comprehensive procedure/guidelines for the use of recycled water and recovered resources. The level of treatment required, its use after treatment, expenditure, responsibilities of regulating authorities, etc. are needed to be defined clearly.
3. There is a lack of policies promoting the use of recovered resources. The incentives or benefits of using recovered resources from wastewater are not adequately defined, hence affects the implementation.
4. Implementation of 6Rs is a major challenge as stakeholders are habituated to linear use of water resources. On one side, the environmental benefits are easier to understand; but on the other side, long term economic benefits are more difficult to quantify and envision. Large-scale implementation of treatment systems in a decentralized manner needs a drastic change in the way industry, business, and society operate with commitment from the higher authorities.

**Social challenges:**

1. Lack of awareness among the citizens about the water scarcity and benefits of recycling or CE on water resources.
2. Public acceptance to use reclaimed water for potable or non-potable purposes is a challenge. The perception of a common person plays a significant role in promoting the implementation of CE principles.
3. There is a lack of coordination/communication in between industries to enable successful exchange of resources i.e. the concept of industrial ecology.
4. Even if the recycled water is used for irrigation, there are still certain micro-pollutants that may affect the plant growth/quality and ultimately affecting human health and hence detail assessments considering local practices need to be carried out.

**Opportunities:**

Currently, in developing countries like India, the potential for CE implementation is not yet completely recognized. Some of the opportunities in implementing CE in the water sector are as below.

1. As per Central Pollution Control Board (CPCB), India, the treatment capacity of wastewater infrastructure is only around 37% (CPCB, 2016). Thus, this lack of infrastructure can become an opportunity to achieve the implementation of CE while creating new infrastructure for wastewater management.
2. Lack of collection infrastructure can become an opportunity by creating decentralized facilities at closed proximity reducing the burden of centralized facility also catalyzing the reclamation and recycling strategies of CE. However, the tradeoff between economic costs and environmental benefits needs to be assessed.
3. Mixed land-use pattern prevalent in India is an opportunity to implement CE strategies. For example, using reclaimed water from a residential area can be used in nearby commercial area or industries.
4. CE implementation develops an opportunity to extract resources such as water, energy, and materials (fertilizer, bioplastics, metals, protein-based food, building materials) (Guest et al., 2009) from which revenue can be generated.
5. Implementation of CE also enhances regional job creation (Lekshmi et al., 2020; Vanner et al., 2014) by encouraging small medium enterprises to become crucial actors in promoting the reduce, reuse, recycle, reclamation, recovery, and restoration practices at smaller and decentralized scale (Makropoulos et al., 2018).
6. Agriculture is the dominent sector in India, with around 70% of water consumption, utilizing reclaimed water for agricultural purposes can immensely contribute to the overall economy of India.

If the implementation of CE is successfully adopted by ULBs, it will provide impetus in developing sustainable infrastructure in the water sector. Assessment framework needs to be developed and indicators need to be identified for efficient implementation. If the above-discussed challenges are addressed, and opportunities are leveraged by creating required policies; the CE can contribute towards a successful move towards sustainable development in India.

# 7. Conclusion

In the current era of deteriorating and imbalanced water resources, there is a need to understand the urban water cycle in a comprehensive manner. Water scarcity has reached to a threshold level with excessive pressure on human wellbeing. Water resource management by all the stakeholders (consumers, government authorities, ULBs, industries, small and medium enterprises, water and wastewater treatment plant authorities) can play a crucial role to achieve sustainability. Qualitative and quantitative assessment of water resources entering and leaving from urban areas needs careful attention to move towards CE ideology. The implementation of CE also needs assessment or monitoring framework based on selected indicators. Incorporating 6Rs strategies in urban water sector can accelerate the transition towards CE. Also, confluence of 6Rs strategy and six BS8001:2017 principles can be helpful in achieving the targets and moving towards sustainable management of water resources.

From the comprehensive review carried out in this work, it is observed that there is a substantial technological and methodological growth of CE throughout the world in water sector. Also, the environmental aspect received adequate attention with the major focus on industrial ecology, LCA, and resource management, to achieve sustainability at varying scale. However, the review revealed that social and economic aspects require further attention. Thus, to achieve successful implementation of CE, a holistic approach is desired. Following are the findings from the literature review of 98 publications considered in this study:

1. Starting from 1990, the work on CE in water sector has increased steadily till 2015 and spontaneously from 2016 till 2019 which indicates increased interest in the research community to enable CE practices around the world.
2. Countries in the European region and China are highly active to implement CE initiatives as the awareness and policy reforms are efficient. Thus, there is a need to formulate policies and efficient enforcement in other parts of the world to provide an impetus for CE implementation.
3. Although technology advancement in wastewater reclamation, recycle, and recovery is enormous, there is a need to develop strong business models to maintain and sustain the technological solutions in various settings.

In the context of India, many challenges exist for enabling CE in water sector such as capacity with ULBs, supporting policies and governance structure, awareness, and innovative business models. However, CE in water sector also provides some opportunities such as job creation, planning of new water infrastructure with CE as the main theme, and mix land-use in cities can help in enabling CE. We hope that the present work will serve as a first step towards accelerating CE in the water sector in India.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Appendix A.**

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