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Review

A Comprehensive Review on the Use of Wastewater in the Manufacturing of Concrete: Fostering Sustainability through Recycling

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Abstract: The primary aim of this review article is to find the influence of wastewater and its characteristics on recycling as an alternative to potable water for concrete preparation. On the other hand, scarcity, and the demand for freshwater for drinking are also increasing day by day around the globe. About a billion tons of freshwater is consumed daily for concrete preparation for various operations such as mixing and curing, to name a few. The rapid development of certain industries such as textile, casting, stone cutting, and concrete production has caused the water supply to be severely affected. Recycling wastewater in concrete offers various potential benefits like resource conservation, environmental protection, cost savings, and enhanced sustainability. This article reviews the effect of various types of wastewater on various physical and chemical properties of wastewater, rheological characteristics, strength, durability, and microstructure properties of concrete. It also explores the potential effects of decomposing agents on enhancing concrete properties. Currently, limited research is available on the use of various types of wastewater in concrete. Hence, there is a need to develop various methods and procedures to ensure that the utilization of wastewater and treated wastewater is carried out in the production of concrete in a sustainable manner. Although wastewater can reduce the workability of fresh concrete, it can also increase its strength and long-term performance of concrete. The use of various types of wastewater, such as reclaimed water and tertiary-treated wastewater, was found to be superior compared to those using industrial- or secondary-treated wastewater. Researchers around the globe agree that wastewater can cause various detrimental effects on the mechanical and physical properties of concrete, but the reductions were not significant. To overcome limited scientific contributions, this article reviews all the available methods of using various types of wastewater to make concrete economically and environmentally friendly. This research also addresses possible challenges with respect to the demand for freshwater and the water crisis.

Keywords: wastewater; concrete; fresh properties; durability; water scarcity; environment; hardened properties; microstructural analysis

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1. Introduction

Due to the increase in domestic and commercial demand around the world, the depletion of water sources continues to increase [1,2]. It is noted that approximately

4.3 billion people around the world experience moderate-to-severe paucity conditions every month [3]. Half a billion individuals are experiencing water scarcity, especially in monsoon season. The increase in population, lack of proper management of water resources, and the pollution of ground and surface water have a large impact on global water scarcity [4]. As a result, researchers are working to find possible ways to reduce consumption to overcome the scarcity of freshwater and to make concrete sustainable and environmentally friendly [5]. Figure 1 highlights the framework followed for collecting published articles on the use of wastewater from various databases.

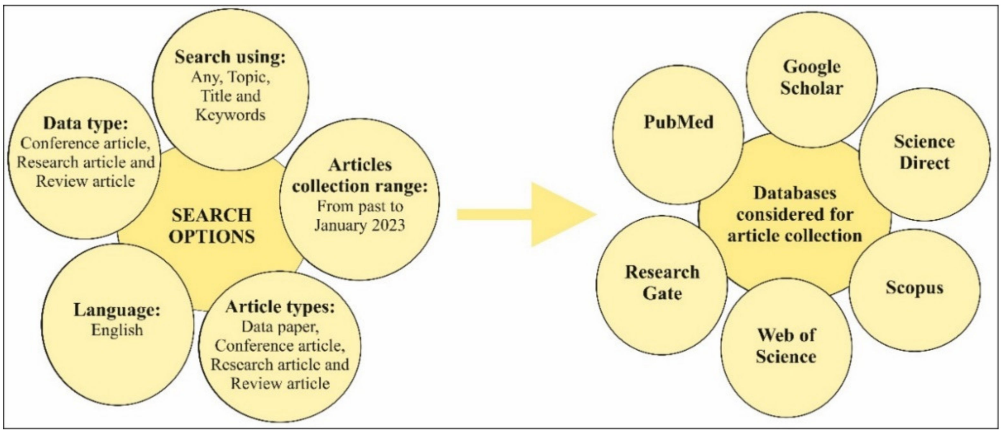

Figure 1. Framework followed for collecting research articles from various databases.

One of the most important sources of drinking water is treated wastewater. This is a type of water that has been treated to remove various impurities, foreign matter, and other components, such as microorganisms and inorganic particles, to minimize its impact on the environment and public health [6]. Although it is usually discharged into bodies of water, treated wastewater can still be used for various industrial, agricultural, and urban occupations, with minimal hazards to the environment and the health of human beings [7]. Regarding the Indian scenario, around half of the country is currently experiencing drinking water scarcity, with major cities such as Bengaluru and Chennai bearing the brunt of the issue due to delayed monsoons. As a developing nation, India is the largest groundwater consumer in the world; it is also noted that global water shortages are expected to occur by 2025. It is also estimated that about 1800 million people would be effected due to the scarcity of freshwater [3,8,9].

According to researchers, about 500 L of freshwater is used for one-meter cube of concrete preparation. This includes various operations like mixing, cleaning, and curing. The consumption of potable water by the construction sector is also one of the major factors in the degradation of the environment [10–12]. Rapid industrialization and population growth have led to the growth of domestic and industrial wastewater generation [13,14]. Unfortunately, many developing countries such as India have poor control over the treatment of industrial and household wastewater. Similarly, many households do not have the proper facilities to treat wastewater generated [15]. This leads to the pollution of various water bodies, such as rivers, canals, and groundwater, to name a few. Hence, urgent action is needed, especially in developing countries, to save these bodies of water. Furthermore, to reduce water consumption, the concrete production process, and the use of wastewater for curing can also help address the global water crisis. Hence, as a sustainable approach, this process will also reduce the contamination of freshwater sources and improve the availability of drinking water resources [16].

Similarly, ready-mix concrete plants (RMCPs) use freshwater and non-potable water for concrete production and cleaning of concrete mixer trucks [17]. This can cause problems in the future since it can take up to 300 gallons of freshwater to clean and wash concrete mixer trucks. The disposal of wash water from a concrete plant in an open area can cause the contamination of freshwater. Similarly, most RMCPs discharge these wash water directly to common drainages. Due to its high pH level and the contaminants present in wash water, the act of directly discharging drainages has been banned in several countries. Before it can be discharged, the water must first be treated. Researcher [17] concluded that the use of concrete mixer wash water as an alternative to freshwater in the production of concrete will overcome the scarcity of freshwater. Worldwide studies on the use of wastewater in concrete are presented in Figure 2.

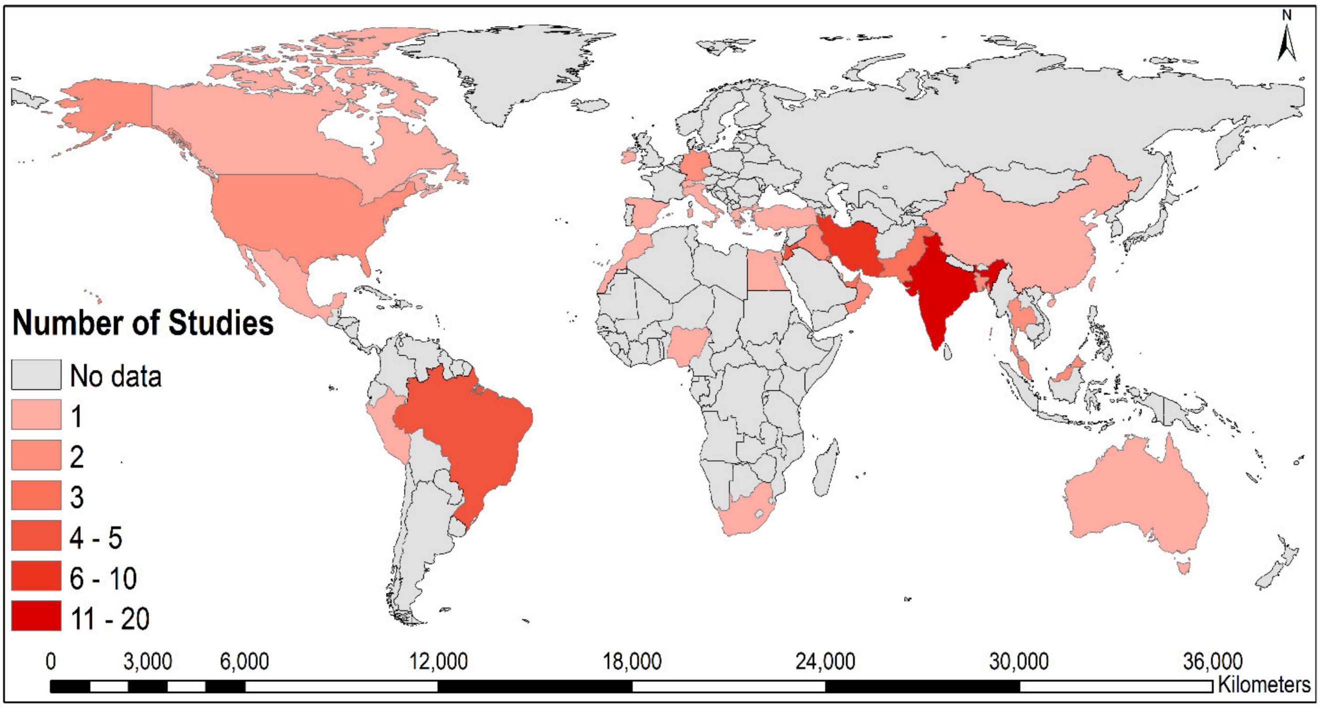

Figure 2. Global studies on use of wastewater in concrete.

Besides being harmful to the environment, wastewater also affects the durability of concrete. According to the ACI committee, concrete's ability to endure various environmental conditions such as weathering, chemical attack, and abrasion consistency is its most important attribute. However, it can deteriorate quickly in waste treatment plants [18]. Additionally, research is needed on the use of wastewater in concrete making. Although concrete's durability is a major concern, there is still a lot of research that needs to be conducted to determine the effects of various types of wastewater on its properties [19,20]. Some of these include acid attack, sulfate resistance, water absorption, and chloride permeability.

2. Various Types of Wastewater Are Used in Concrete and Its Properties

Effluents from commercial and industrial facilities, households, and institutions are known as wastewater. In addition, sewage from bathing, laundry, and kitchens is also considered to be a type of wastewater. Due to the increasing demand for water, the amount of wastewater that will be produced is expected to rise significantly. The energy and industry sectors are expected to see a significant increase in their water consumption. In 2017, a report released by the UN revealed that around 80% of the world's wastewater is not being treated [21]. Around two-thirds of the world's population lives in areas where there is a scarcity of water for at least a month each year. On average, about 70% of the wastewater that is generated in industrial and municipal areas is treated in high-income countries [21]. According to the report, around 8% of the wastewater in low-income countries is treated. This implies that over 80% of the wastewater in the world is not being treated properly. In India, various industries such as sugar, textile, chemical, pulp and paper, and tannery are expected to contribute over 600,000 million liters of wastewater per day in 2019. Due to the presence of this wastewater, it can affect marine and freshwater bodies that are safe for human consumption. It can also be used in construction projects since it has chemical and physical characteristics that range from 6.5 to 8. High limits of salt, chloride, sulfate, alkali, and potassium are specified for the concrete production process [22].

In total, sewage water contains around 0.1% inorganic and biological particles. It is mainly produced from domestic sources; it is important that it is treated before it enters bodies of water [23]. The mixing of water in concrete production has a significant effect on its properties. Contaminated wastewater can affect the reinforcement's corrosion resistance. It can also impact the final setting times of cement. The effluent's color is usually yellow-brown, and its total hardness, chloride, sodium, and alkalinity are higher than those of untreated water. Due to the presence of salts that are higher than those found in water from a potable source, the compressive and setting time of concrete increased [24]. Researcher [25] studied the effects of treated wastewater on concrete mixing. They found it to be a suitable material for their projects. Although the use of treated wastewater in concrete production has a minimal effect on its rheological properties, it is still important to follow standard recommendations when it comes to water usage. Some of the factors that can affect the quality of concrete include the pH value, total solids, chloride content, and turbidity. Unfortunately, the standards for various water elements do not reflect the actual effects of their usage on concrete's properties [26]. A study conducted by Su et al. revealed that the concrete produced from a ready-mix concrete plant had higher strength values than that of potable water [27]. The presence of impurities in the wastewater can have a negative effect on the concrete's strength. There are no standards or recommendations for the quality of concrete mixing water.

3. Quality Standards of Wastewater

The standards for the mixing of water in concrete vary depending on the country. Partially treated and treated wastewater will have to be reused in large quantities for the curing and mixing of concrete [27]. A study is necessary to determine the permissible limits of mixing concrete in certain codes. The pH level of the mixture should be around 6.5 to 12.8. Ideally, the pH range of water suitable for construction should be between 7.2 and 7.6 [13]. There are no limits on the permissible sizes of various solid components, such as inorganic and organic compounds. The permissible limits of sulfate and chloride are not the same in all the codes. In addition, the limits of chlorides in RCC and plain concrete are different. Magnesium chloride, calcium chloride, and sodium chloride are commonly found in water. Researcher [28] compared the properties of both treated and non-treated domestic water. They found that the former's total alkalinity, chloride, conductivity, and sulfate were 313.6 mg/L, 1193 µs/cm, 519 mg/L, 50 mg/L, and 113 mg/L, respectively. In a study conducted by Mane et al. [29], they found that treated wastewater was suitable for chemical analysis. The values of various constituents, such as sulfate, chloride, alkalinity, and TSS, were in the range of pH values except for the former. For the properties of domestic wastewater, According to researcher [30], organic matter is a contributing factor to the total solid body of the wastewater, and the obligation to mix it in compliance with the standards is greater. In a study conducted by Researcher [31], it was found that the chemical composition of treated wastewater was higher than that of tap water. They also noted that the chloride concentration in the water was within the IS code's range of 200 to 1000 mg/L. Compared to the study conducted by Al-Jabri et al. [32], the quantity of sulfate in the treated water was higher. On the other hand, the total solids and chloride content were lower in the treated water as compared to the results of the study by Al-Ghusain and Terro [33]. Table 1 shows the various standards of quality of water for mixing concrete. Specific scientific and technical contributions to the use of wastewater in concrete are presented in Table 2.

Table 1. International standards on quality of water for concrete mixing.

Parameter	Australia [34]	India [35]	Qatar [36]	ISO [37]	British [38]	Brazil [39]
pH	≥5	≥6	6.5–9	≥5	≥4	≥5
Color	-	-	-	Pale yellow or paler		
Odor	-	-	-	Odorless		
Organic matter (mg/L)	-	≤200	-	After sodium hydroxide has been added, the water should be a lighter color than the standard solution.		
Solids (mg/L)	-	≤2000	-	≤4000	≤4000	≤50,000
Chloride (mgCl/L)	≤800	≤500	≤500	≤500	≤500	≤500
Nitrates ($mgNO_3$/L)	-	-	-	≤500	≤500	≤500
Phosphates (mgP_2O_5/L)	≤100	-	≤30	≤100	≤100	≤100
Zinc ($mgZn^{2+}$/L)	-	-	≤100	≤100	≤100	≤100
Lead ($mgPb^{2+}$/L)	-	-	≤100	≤100	≤100	≤100
Sugar (mg/L)	≤100	-	-	≤100	≤100	≤100

Table 2. Scientific contribution on use of wastewater in concrete.

Author	Year	Country	Replacement (%)	Investigated Parameters
By Joo-Hwa Tay and Woon-Kwong Yip [40]	1987	Singapore	0, 25, 50, 75, and 100.	Compressive strength (CS).
Aboelkheir et al. [41]	2021	Brazil	100	Water-accessible porosity, flexural strength (FS), split tensile strength (SPT), and CS.
Tanol Tanlı et al. [42]	2022	Cyprus	100	Slump, compaction factor (CF), CS, FS, and thermal conductivity (TC).
Ali Raza et al. [43]	2020	Pakistan	100	CS, SPT, water absorption (WA), acid attack, chloride penetration, and ANOVA.
Sara Ahmed et al. [15]	2021	UAE	100	Slump, CS, SPT, rapid chloride permeability (RCPT), surface resistivity, volume resistivity, chloride ingress, and scanning electron microscopy (SEM).
Abolfazl Taherlou et al. [44]	2021	Iran	100	Workability, CS, RCPT, SPT, WA, SEM, and toxicity characteristic leaching.
Zainab Z. Ismail and Enas A. Al-Hashmi [45]	2011	Iraq	100	Slump, CF, CS, SPT, FS, waste materials leaching test, and color effect.
K S Al-Jabri et al. [32]	2011	Oman	25–100	Slump, CS, SPT, FS, and WA.
Kami Kaboosia and Khashayar Emami [46]	2019	Iran	100	CS, FS, SPT, ANOVA, and SEM.
Tao Meng et al. [47]	2021	China	100	Carbonation depth, CS, XRD, pore structure, and SEM.
Khushboo Meena and Salmabanu Luhar [31]	2019	India	0, 25, 50, and 100	Workability, CS, FS, SPT, carbonation, RCPT, and abrasion resistance.
Abdelrahman Abushanab and Wael Alnahhal [48]	2021	Qatar	0, 25, 50, and 100	Slump, density, CS, FS, SPT, RCPT, porosity, SEM, EDAX, and XRD.
Naser Alenezi [49]	2010	Kuwait	0, 25, 50, and 100	CS, WA, density, and RCPT.
Stamatis Tsimas and Monika Zervaki [50]	2010	Greece	100	CS, setting time, and slump.
Ibrahim Al-Ghusan and Mohammad J Terro [51]	2003	Kuwait	100	CS, setting time, slump, and corrosion of reinforcing steel bar.

Table 2. *Cont.*

Author	Year	Country	Replacement (%)	Investigated Parameters
Mohammad J Terro and Ibrahim Al-Ghusan [33]	2003	Kuwait	100	CS, setting time, slump, corrosion of reinforcing steel bar, and fire resistance.
Mohammad Shekarchi et al. [52]	2012	Iran	100	Setting time, slump. CS, FS, WA, and electrical resistivity.
OA Ahmad and SM Ayyad [53]	2021	Jordan	25–100	CS, FS, SPT, and economic feasibility.
Devendra Swami et al. [54]	2015	India	100	CS, pull-out strength, rebound, hammer test, UPV, WA, porosity, and sorptivity.
Aamer N. Abbas et al. [26]	2019	Iraq	100	Load displacement responses, load behavior of slabs, stiffness, and energy absorption.
Fatima Zahra Bouaich et al. [55]	2022	Morocco	100	Setting time, slump, density, SPT, CS, SEM, and ANOVA.
Sachin Mane et al. [29]	2019	India	100	CS and cost analysis
AR Chini et al. [56]	2001	USA	100	Setting time, CS, FS, SPT, RCPT, and drying shrinkage.
Ehsan Nasseralshariati et al. [57]	2021	Germany	0, 50, and 75	Slump, CS, FS, RCPT, WA, SPT, rapid freezing and thawing, half-cell potential, and statistical analysis.
Gholamreza Asadollahfardi and Amir R. Mahdavi [58]	2018	Iran	100	Slump, SPT, CS, density, WA, electrical resistivity, SEM, EDAX, and XRD.
Fahimeh Sadat Peighambarzadeh et al. [16]	2020	Iran	0, 50, and 100	Setting time, slump, fracture toughness, and SEM.
Ramkar AP and Ansari US [59]	2016	India	100	CS, FS and SPT.
Ahmed Reem and Afifi Mohamed [60]	2019	Canada	100	CS, FS, SPT, and feasibility analysis.
Ayoup M Ghrair and Othman Al-Mashaqbeh [7]	2016	Jordan	100	CS, SPT, FS, and SEM.
Paulo Ricardo de Matos et al. [61]	2020	Brazil	0, 25, 50, 75, and 100	Slump, TGA, CS, FS, SPT, and isothermal calorimetry.
Kazi P. Fattah et al. [62]	2017	UAE	100	RCPT, CS, FS, SPT, environmental and economic impacts analysis.
Jeff Borge et al. [17]	1994	USA	100	CS and Setting time.
G. Asadollahfardi et al. [63]	2016	Iran	100	Setting time, slump, FS, CS, SPT surface electrical resistivity, WA, rapid freezing and thawing, SEM, EDAX, XRD, and ANOVA.
Joo-Hwatay [64]	1989	Singapore	100	CS.
A.B. More et al. [65]	2014	India	100	Slump, CS, FS, and SPT.
Nan Su et al. [27]	2002	Taiwan	100	Setting time, CS, FS, and slump.
B Chatveera and P Lertwattanaruk [66]	2009	Thailand	100	Setting time, slump, CS, water permeability, and resistance to acid attack.
Ainul Haezah Noruzman et al. [67]	2012	Malaysia	100	Setting time, CS, slump, initial surface absorption, and RCPT.
Shiqin Yan et al. [68]	2012	Australia	0, 10, 25, 50, 75, and 100	CS, drying shrinkage, WA, bulk density, volume of permeable voids, and SEM.
Gholamreza Asadollahfardi et al. [69]	2015	Iran	0, 30, 50, 70, and 100	Setting time, FS, CS, and SPT.

Table 2. *Cont.*

Author	Year	Country	Replacement (%)	Investigated Parameters
Shekhar Saxena and AR Tembhurkar [30]	2018	India	0, 50, and 100	Slump, air content, fresh density, hardened density, CS, FS, modulus of elasticity, SEM, UPV, and RCPT.
B. Chatveera et al. [70]	2006	Thailand	0, 10, 20, 30, 40, 60, 80, and 100	Slump, unit weight, temperature rise of concrete, CS, modulus of elasticity, FS, drying shrinkage, and resistance to acid attack.
Ayoup M. Ghrair et al. [6]	2018	Jordan	100	CS, FS, SEM, and SPT.
Tanvir Manzur et al. [71]	2018	Bangladesh	100	CS, FS, SPT, weight loss, SEM, XRD, and EDAX.
E.W. Gadzama et al. [72]	2015	Nigeria	0, 75, and 100	Setting time, volume change in concrete, CS, FS, and SPT.
Nabil M.A. Al-Joulani [73]	2015	Palestine	100	Slump, CS, FS, and SPT.
Nikhil TR et al. [74]	2014	India	100	CS, FS, and SPT.
Bassam Z. Mahasneh [75]	2014	Jordan	100	CS, FS, and SPT.
Manjunatha M and Dhanraj MR [76]	2017	India	100	CS, FS, SEM and SPT.
Ramzi A. Taha et al. [77]	2010	Oman	100	Slump, CS, FS, and SPT
Shahiron Shahidan et al. [78]	2017	Malaysia	0, 10, 20, 30, and 40	Slump, CS, FS, and SPT.
Mohammad Sheikh Hassani et al. [79]	2020	Iran	100	Slump, CS, FS, SPT, RCPT, SEM and ANOVA.
NJ Gulamussen et al. [80]	2021	Netherland	100	Slump, CS, FS, SPT, WA and SEM
G. Reddy Babu and N Venkata Ramana [81]	2016	India	100	Setting time, CS, FS, SEM, and XRD.

4. Effect of Wastewater on Fresh Properties of Concrete

4.1. Workability

The durability of concrete depends on its ability to be worked on properly. Without a compaction of concrete, the strength of the material can be affected due to the presence of voids. Researcher [70] studied the slump of concrete with varying amounts of sewage water. The findings of this study indicate that the increase in the w/c ratio and the rise in sewage water levels led to a decrease in the slump values. The reason for this is that the cement particles in the sludge water absorb some of the water. According to researcher [58], concrete made from industrial effluent has a 12.5% decrease in slump value. The study performed by Ghrair et al. [6] revealed that the presence of dissolved particles in raw and treated greywater resulted in a 30–35 mm decrease in the concrete's slump value. Similar results were also reported by Luhar and Meena [31]. Compared to drinking water, the presence of wastewater in concrete has a negative impact on its workability. The increase in the concrete's surface area and the volume of sludge are some of the factors that caused the decrease in its slump value. Researcher Asadollahfardi et al. [82] noted that the chlorination of the wastewater before it is used for concrete production did not affect the concrete's slump values. However, they noted that the setting time of the concrete was increased after the chlorination process. The researchers concluded that the concrete's slumping values varied from 80 to 120 mm. According to Noruzman et al. [67], the slump values were between 25 and 50 mm when treated effluents from various industries, such as a palm oil mill, domestic sewage, and heavy industry, were used. Their study revealed that the lower slump values were produced by the mixtures of effluents compared to potable water. The only mixed wastewater from the palm oil mill is below the designed slump of 30 to 60 mm. In addition, Su et al. [27] designed three concrete grades: C14, C21, and C28.

The researchers found that the slump values for various types of water, such as tap water, underground water, and wastewater from the tank's top settling area, were between 210 and 240 mm. The outcomes of the study indicate that the workability of the concrete was affected by the presence of a certain type of ash. The increase in the percentage of PSA used in the concrete resulted in higher workability. However, when the sample was inspected, the results did not show segregation. Compared to normal concrete, the slump value decreased due to the presence of solid and fine particles in the effluent [64]. Workability test results of mixes prepared with different proportions of wastewater are presented in Figure 3.

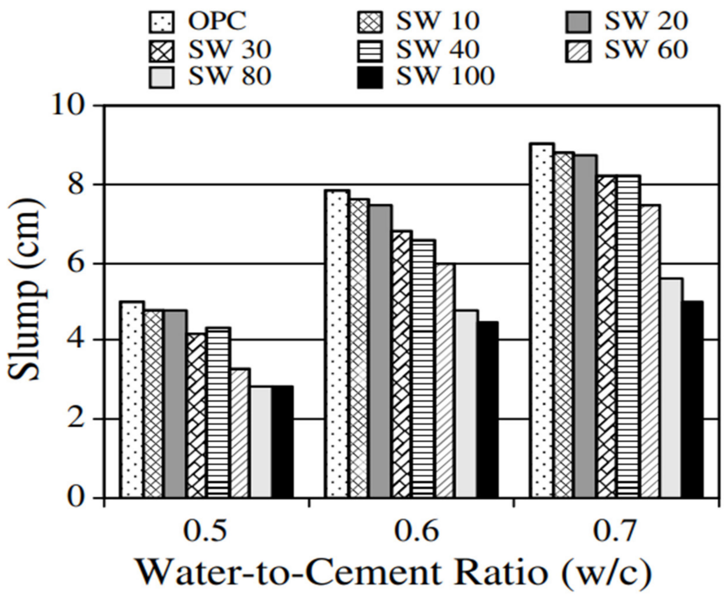

Figure 3. Effect of workability on different proportions of wastewater [70].

4.2. Setting Time

Compared to freshwater, concrete that is made using primary-, secondary-, and tertiary-treated wastewater has different characteristics [83]. In addition to affecting the water quality, these varying stages also have an impact on the concrete's properties, such as its setting time. Through various physical processes, such as sedimentation and screening, large particles and organic matter can be removed from wastewater. However, the effluent still contains dissolved solids and some impurities [84]. When used in concrete, the elevated levels of suspended solids and organic impurities can affect the cement's hydration process [84]. The presence of impurities can help slow down the cement hydration process by reducing the chemical reactions that occur. They can also be removed via secondary treatment, which involves the use of biological processes. Compared to freshwater, the quality of secondary- and tertiary-treated wastewater is generally better. However, it still has some nutrients and biological materials that can act as minor contaminants [85].

The setting time of concrete is not significantly different from that of primary wastewater. The advanced stage of wastewater treatment known as tertiary treatment involves the use of various methods to remove remaining nutrients, pathogens, and suspended solids from the effluent [86]. Some of these include chemical treatment, UV disinfection, and filtration. Compared to untreated wastewater, the quality of tertiary effluent is generally better. The minimal impact of tertiary- and primary-treated wastewater on the setting time is minimal [86]. Compared to freshwater, tertiary effluents are generally of comparable quality. As a result, the hydration process and concrete's setting time remain the same. The impurities present in the latter's batch influence the concrete's setting time. The setting time of concrete is affected by various factors, such as the presence of suspended solids and organic impurities [87]. The elevated levels of these substances can prevent the cement's hydration process from progressing properly, which can result in delays in the construction schedule. Although the extension in the concrete's set time is minimal when compared to freshwater, it still feels noticeable due to how high the level of treatment is that can remove most of the impurities. Because of this, concrete made from tertiary wastewater is generally closer to that of freshwater when it comes to construction [88].

Setting time refers to the amount of time it takes to compact, cast, and convey concrete. It can be calculated using the Vicat apparatus as per Indian standards [89]. Al-Ghusain and Terro [33] observed that concrete made from tertiary-, secondary-, and primary-treated wastewater has a significant influence on setting time. The higher COD in partially treated water means that the organic matter in it is higher. The final setting of concrete made from treated wastewater was reported to be 20%, 19%, and 7.5% lower compared to concrete made using tap water [51]. The study conducted by Chini et al. [56] revealed that the setting time tests for various types of mixtures were within the ASTM C403 standard's limits. Researchers also reported the change in the final setting time between variations of effluent and potable water. According to researcher Dhanraj et al. [9], the effects of zinc and copper salts on the final setting time of concrete had a marginal effect on the setting time. The study also reported that the setting time for treated and potable effluents increased, maybe due to the presence of organic matter in the effluent. The study also noted that the use of untreated wastewater could lead to the maximum final setting time due to the entrained air inside the concrete. They also found that the use of recycled wash water can accelerate the setting times. The researchers [56] estimated the initial and final setting time of cement at different temperatures and conditions and found that the results were within 30–75 min compared to the reference. The study also indicates that the addition of treated wastewater increased the initial and final set time of cement. On the other hand, researchers [56] found that the addition of tertiary- and secondary-treated wastewater resulted in an inferior value in comparison to primary-treated wastewater. Even though the final setting time for primary-treated concrete was lower than the reference mix. The study performed by More et al. [65] proved that the use of primary- and secondary-treated wastewater had a considerable effect on the setting time of concrete. If the stone sludge wastewater is used in a mixing process, the workability of the finished product notably decreased. According to researcher Joulani et al. [90], the use of 30% replacement resulted in a significant reduction in the final setting time of cement. The outcome of this study also observed that the presence of fine and salt particles delayed the hydration of cement. The influence of the setting time on concrete prepared with treated domestic water like primary-treated (PT), secondary-treated (ST), and tertiary-treated (TT) water is presented in Figure 4.

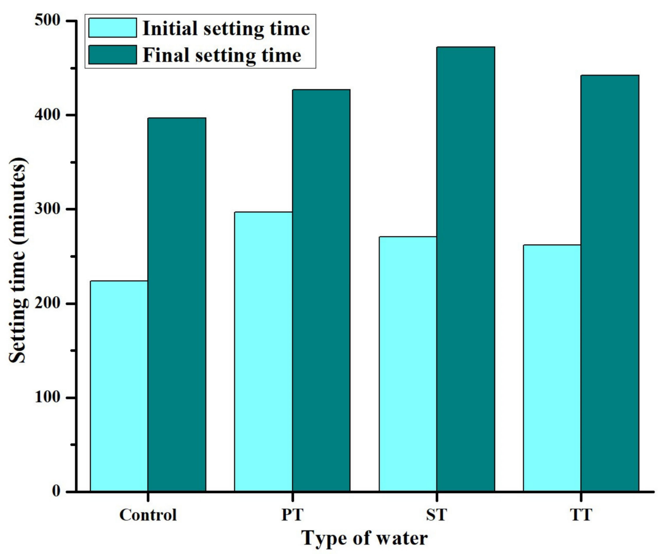

Figure 4. Influence of setting time on concrete prepared with treated domestic water [52].

5. Effect of Wastewater on Hardened Properties of Concrete

5.1. Compressive and Tensile Strength (CS)

The CS of concrete is the most valuable design characteristic of a concrete mix. CS is usually evaluated in terms of grades and is restricted to certain functions. Researcher [9] analyzed the influences of different types of domestic wastewater on the CS of concrete. They found that the CS of the tertiary-treated wastewater increased by 7%, while that of the secondary-treated wastewater decreased by more than 10%. Although the primary-treated wastewater showed a slight increase in CS, the strength of the secondary wastewater was still lower. Researchers [52] noted that the CS of the tertiary-treated wastewater increased by 7%. On the other hand, the strength of the secondary-treated wastewater decreased significantly compared to the control concrete, as highlighted in Figure 5. The strength of the concrete prepared with secondary wastewater was lower than that of the tertiary-treated material. In a study conducted by O'Connell et al. [91], it was discovered that the CS of concrete was reduced by 8% when it was exposed to secondary-treated wastewater for 60 days. This improvement was attributed to the presence of particles in the wastewater that can pack the voids in the concrete. The presence of high sodium chloride levels in the concrete can also improve its compressive strength.

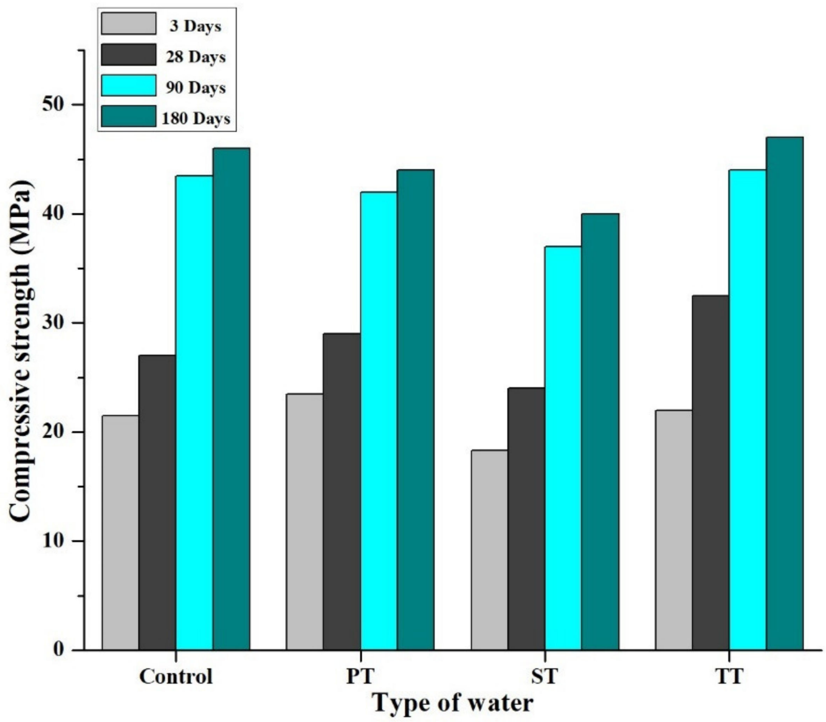

Figure 5. Influence of treated wastewater on CS of concrete [52].

According to Asadollahfardi et al. [69], specimens that had 350 kg/m^3 of cement exhibited similar results when tested at 28 days. The CS of the samples at 90 days was 44 MPa when using 100% tap water and 40 MPa when using 100% wash water. For 90 days, they were able to report almost equal strength when concrete is made with 400 kg/m^3 of cement and various water combinations. Mahdavi and Asadollahfardi [92] noted a reduction in the tensile strength and CS when using industrial-treated wastewater. The former showed a decrease of 8.4%, 7.9%, and 9.7 for CS, while the latter had a reduction of 11.8%. Before chlorination, some experiments were carried out on domestic wastewater. They discovered that the chlorine reduced the CS and tensile strength of concrete. The researchers attributed this to the reduction in the volume of treated wastewater. The researchers conducted a study to analyze the effects of increasing the BOD and COD in wastewater on the CS. They found that the strength of the samples decreased with the addition of these substances, but it increased with age [63,82]. Researchers Luhar and Meena [31] noted that concrete made with tertiary wastewater showed a reduction of 6.41 percent in its strength when it was tested at 90 days. Compared to the concrete made using tertiary wastewater, the materials with secondary treatment had less CS.

According to Mane et al. [29], using sewage-treated water for 28 days resulted in a significant increase in CS. This type of wastewater can be utilized for curing purposes since it only has a small change in strength. The researchers conducted a study to investigate the effects of wastewater on the strength of concrete. They found that it had no significant effect on the concrete's properties. In terms of the strength of the mixtures, the researchers found that the 50% substitution of wastewater provided comparable results to the control mix. However, the CS of the concrete samples produced with wastewater was lower. Researchers [93] found that CS and tensile strength were higher for 25% and 50% replacement of wastewater, respectively, when compared to the control mix. Compared to the control mix, the use of polyvinyl aerated wastewater did not have a negative effect on the CS of concrete. However, its weak bonding force between the cement and the fine polymer particles in the wastewater can cause the concrete to experience a decrease in strength [45].

The study conducted by Yip and Tay [40] revealed that combining freshwater and reclaimed wastewater can improve the CS of both materials. The outcome of this research work signifies that the combined strength of the type of wastewater increases 8%, 14%, 15%, and 17% of CS after 28 days. Compared to the control mix, concrete prepared with reclaimed wastewater had a CS of 3 to 12 months was similar. There was no apparent difference in the long-term strength when it was used for concrete production. The strength of different types of wash water was also higher when collected from a depth of more than 2 m. The privileged alkalinity of wastewater, which contains dissolved calcium and sodium hydroxide, can help in improving the CS of concrete. Similarly, the presence of salt and other organic matter in wastewater can accelerate the pozzolanic reactions of mineral additives used [94]. Based on their findings, the researchers concluded that the overall CS of the concrete increased by 6%, 6.23%, and 8.24% at 7, 28, and 90 days of curing, respectively. The increase in CS was mainly due to densification caused by the presence of suspended and dissolved solids in the wastewater. It is also found that the presence of a higher chloride level in wastewater can also help in enhancing the hydration of cement [95]. Chlorides can have a significant impact on the durability and hydration process of concrete. They can accelerate the cement's hydration, especially in the initial stages. This is because the catalytic activity of these substances affects the reactions of C3S and C2S, which are the two main components of Portland Cement. The presence of small chloride ions in the concrete can help accelerate the development of the concrete's early strength. Research has shown that the contents of around 0.1% and 0.5% cement can help improve the hydration and strength of the concrete. This range is typically regarded as beneficial for the early gains without compromising the concrete's overall performance [96]. Although lower chloride levels can help accelerate the development of concrete's early strength and hydration, the higher content can lead to poor durability. For instance, they can cause the embedded steel reinforcement to corrode [97].

The recommended chloride content level in concrete to prevent corrosion of reinforced steel is 0.4% by the weight of cement. If the level exceeds this threshold, it can cause various structural issues, such as spalling and cracking. The buildup of chlorides in the concrete can trigger corrosion [79]. The products of this process can occupy more volume and lead to various internal stresses and cracks. This can significantly affect the lifespan of concrete structures. The cost of repairs and maintenance can significantly increase due to the need to address the effects of corrosion on the concrete. In addition, the presence of chlorides can also contribute to the development of alkali–silica reactions, which can compromise the concrete's integrity [43].

It is important to keep in mind that the early gains from enhanced hydration should be balanced with the potential issues of durability. Although chloride accelerators can help improve the early strength of concrete in certain applications, their use must be monitored to ensure that the levels stay within acceptable limits [98]. When using these substances, the addition of other cementitious materials, such as silica fume, fly ash, and slag, can help minimize the negative effects [44]. Adding a corrosion inhibitor to the concrete mix can help protect the steel reinforcement from the effects of chlorides. Although the presence of chlorides in cement can enhance its early hydration, the effects can be seen at the chloride contents' level of around 0.1% to 0.5%. Maintaining the chloride level at 0.4% cement by weight is important to prevent the corrosion of the reinforced steel and ensure its long-term durability, even if the initial gains are beneficial. Undertaking this via a careful mix of design and protective measures can minimize the risks associated with the use of chloride accelerators [99].

5.2. Flexural Strength (FS)

FS is one of the most important factors considered the strength of concrete. Based on considered and published research articles indicate limited work has been done on the use of wastewater in concrete as an alternative for portable. In the literature, there are wide tolerance limits for certain types of materials. In a study conducted by Chatveera et al. [70], it was found that the FS of structures developed rapidly in the short term and was maintained for long-term use. The researchers attributed the strength gains to the slow reaction of the hydration rate to the sewage water. The graph shows the comparison of FS and various percentages of treated sewage water at different ratios. The increase in the volume of sludge water in the mixing process results in a reduction in flexural ability. This could be because the bond between aggregates and cement paste is weaker. According to Al-Hashmi and Ismail [45], the increase in the cement-water ratio to the volume of wastewater has affected FS. For instance, the strength of the concrete was lowered to 5.5% from 3.6% when the cement-water ratio was at 0.35. The researchers attributed the reduction in FS to the non-homogeneity of the water content in the cement. Fine particles of polyvinyl chloride that are used to alter the contact between w/c can reduce the C-H–S formation in the concrete.

In addition, researchers [26] noted that the stiffness of beams made from freshwater was higher than those cured with hospital effluent water and wastewater. Compared to untreated freshwater, specimens cured in hospital effluents and wastewater had a flexural strength of 2.78 and 3.04 MPa, respectively. On the other hand, they had a flexural stiffness of only 3.93 MPa when cured in freshwater. The researchers noted that the control mixture's lowest tensile strength was 4.39 MPa, while the maximum tensile strength was 5.32 MPa. In terms of FS, the use of treated wastewater in the mixing process reduced the strength by 7.71% and 13.91% at 28 and 90 days. However, when it was used for both curing and mixing, the reduction was 25.73% and 19.76%. Compared to the treated wastewater that was produced by tertiary facilities, the secondary wastewater had a lower FS. Significant work is needed in the field of concrete production using wastewater. A review of the literature on this subject revealed that there is still a lot of work to be done to improve the FS of concrete [9]. The variations in the FS of flexural structures exhibited by the samples subjected to wastewater were like those found in CS. In some cases, the enhanced FS can be achieved by the addition of dissolved and suspended solid particles. The chloride content of wastewater can also contribute to the development of a stronger FS.

6. Effect of Wastewater on Durability Properties of Concrete

While maintaining its engineering attributes, concrete can also endure various environmental conditions, such as exposure to chemical attacks and abrasion. This is why durability is a vital criterion when it comes to building structures.

6.1. Resistance to Chemical Attack

The chemical resistance of concrete is the most important aspect of its durability. Although concrete can endure various forces, it can be less resilient to chemical attacks than other types of materials. These attacks can be triggered by acid or sulfate buildup on the concrete surface [51]. Today, chemical attacks are considered one of the most common factors that can cause concrete degradation. These attacks are usually caused by the dissolution of products resulting from the interactions between chemicals and concrete components [33]. To study the effects of various chemicals on concrete, including chloride and sulfate, Kumar and Kumar conducted a study [100]. Their results revealed that the use of untreated and treated wastewater resulted in a weight gain of around 1.10% to 2%. They also found that when used in solid form, sulfate did not have a severe effect. When solid sulfate enters the concrete's pores, it creates severe effects due to its interaction with other chemicals. Sulfate usually reacts with hydrated aluminates, which are formed by the addition of calcium sulfoaluminate. A study conducted by Chini et al. [56] revealed that rapid chloride permeability can be improved by reducing exposure to chloride. The electrical conductance of concrete and chloride penetration resistance are also analyzed. The average values for 28 days were 2549 to 5667 °C. After 56 days, the concrete samples exhibited lower chemical values ranging from 1260 to 2910 degrees Celsius.

The effects of acid exposure on the weight loss of concrete were studied by Chatveera and colleagues [70]. Sludge water can have detrimental effects on acid resistance. The weight loss was observed in the form of hardened concrete, and it continued to slow down for a long time. The formation of a layer of calcium sulfate due to the reaction of H_2SO_4 and $Ca(OH_2)$ in concrete causes loose bonds to develop [66]. According to O'Connell et al. [91], the addition of GGBS reduced the effects of sulfate attack. For 420 days, the various binders were subjected to sulfate expansion tests. Sulfate expansion tests revealed that the mixes containing 70% and 50% GGBS had a minute expansion, while those with no cementitious materials experienced a maximum expansion. About 50% of the replacement of the GGBS showed little discoloration, while around 70% did not have any visual proof of an acid attack.

6.2. Water Absorption (WA) and Electrical Resistivity

A WA test is commonly used to determine the durability of concrete. The test involves exposing a concrete sample to water, and the lower the water absorption, the better the concrete's resistance. In a study conducted by Al-Jabri et al. [93], found that the effects of time on the concrete's strength were not significant. The graph shows the water absorption of different types of concrete mixtures. For instance, in concrete production, the use of 100% wastewater can lead to a reduction in surface WA of up to 120 min, but 25% wastewater can lead to a higher absorption until 30 min later. Based on the findings, the study concluded that the WA rate of the mixtures decreased significantly over a longer period. It is observed in the first 30 min, and then progressively decreases around 120 min later. All the mixes yielded flow rates that were within the precise limits. Researcher Mahdavi and Asadollahfardi [92] examined the effects of electrical resistivity and WA in concrete mixtures using industrial wastewater. The outcomes highlight that the specimens prepared with wastewater had no significant impact on the WA, while the latter experienced a significant increase in electrical resistance. The results of the study revealed that the WA and electrical resistance of concrete prepared with and without wastewater did not have a significant effect on the durability of concrete compared to controlled concrete. Similar studies also showed that the use of different wastewater can lead to the development of concrete pores and crystals [73,90]. The researchers also noted that an increase in the porosity of concrete leads to a higher WA rate.

7. Effect of Wastewater on Microstructural Properties of Concrete

The microstructure of concrete mainly demonstrates the densification, pores, and gel formation. Concrete microstructure prepared with wastewater rests on the type of waste or waste effluent employed in concrete and the presence of contaminants and additives in wastewater/concrete. Compared to control concrete, the microstructure of concrete of concrete developed based on the hydration, densification, compaction, and type of additives used. The presence of various contaminations, like organic matter and dissolved salts, may affect the delay or enhancement of hydration and further enhance or reduce the densification of the microstructure of concrete [16]. In addition to impacting the hydration of cement, the presence of certain impurities in the wastewater can also influence the densification of concrete [101]. The existence of impurities in the wastewater can affect the bonding between constituents of concrete. It is also noted that the composition of wastewater can influence the ITZ between the cement paste and aggregates, which could indicate various mechanical and microstructure modifications in the concrete, as described in Figure 6 [9]. The composition and quality of wastewater can influence the microstructure of concrete, which can lead to higher permeability and porosity. Researchers also highlighted that the reuse of wastewater can increase the permeability and porosity, which can mark its long-term durability [44].

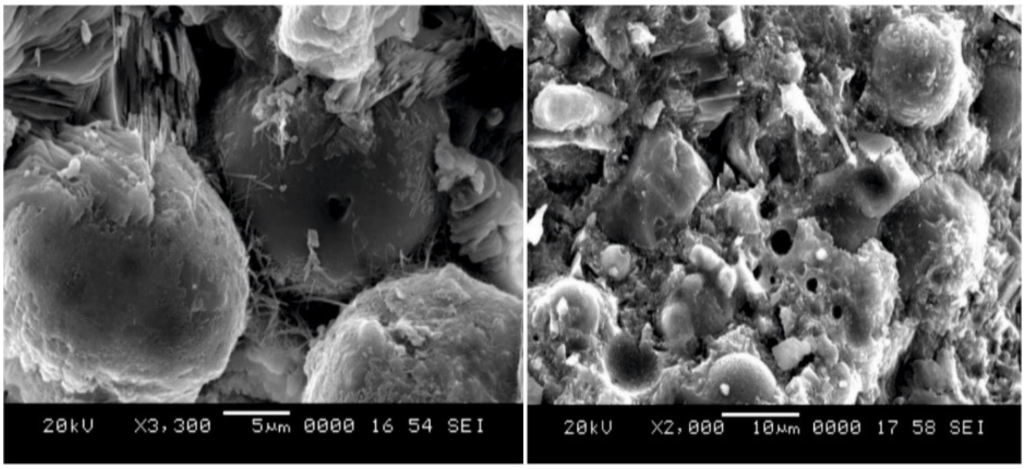

Figure 6. SEM micrographs of concrete prepared with tertiary-treated wastewater [9].

According to the study conducted by Hassani et al. [79], SEM micrographs of concrete samples prepared with wastewater demonstrate that the surface of the concrete was filled with voids and pores. On the other hand, the samples made from drinking water had an identical and compact surface. The results specify that the presence of impurities in the wastewater may have begun the incomplete formation of gel and other crystal structures. The presence of chloride ions in wastewater concrete impacted dense structures mainly due to the occurrence of impurities in the water. These substances prevent the formation of gel and crystal formations and enhance the concrete's permeability. These findings are consistent with previous studies. Similarly, FESEM images of various samples prepared with normal water (CW) and treated wastewater (CWW) are presented in Figure 7. Similarly, for better comparison SEM and EDX analysis of CW and CWW is presented in Figure 8. The blue colored arrows indicate the chloride ions observed in the concrete surface, while the salt crystals represent the drinking water and wastewater mixtures. The yellow color highlight indicates the CW (0.4) and CWW (0.4–2) micrographs representing the chloride content. Figure 8 illustrates that concrete samples prepared with drinking water have a standardized and compact surface. Salt crystals also formed uniformly on the central portion of the test specimen. This phenomenon is caused by the water's ability to penetrate the concrete's porous surface.

According to the study [63] SEM micrographs reveal that the concrete sample made from wastewater shows signs of well-formed crystals with sharp edges and corners and can be identified by their surfaces. On the other hand, the concrete sample made from drinking water exhibits unformed crystals that are called rocky soils with poor crystalline faces. Concrete structures made from drinking water have semi-shaped and unshaped facets. On the other hand, the structures made from industrial wastewater have good crystalline forms and are easily identifiable [102]. The SEM tests conducted on the samples revealed that the distance between the structures made from industrial wastewater and those made from drinking water is greater. The presence of additional vacant spaces in the concrete samples could contribute to the decreased compressive and tensile strength of concrete made from industrial wastewater. According to the study [68] SEM micrographs (Figure 9) highlights that the samples that were made with drinking wastewater had a more porous structure than the reference one. This suggests that the measurements of permeable voids and density have changed. According to researcher Delnavaz et al. [63], SEM micrographs of concrete samples, which were made from treated wastewater, revealed the formation of Euhedral crystals. The void between the crystals was different from that of concrete, which was made from drinking water. The images show the different characteristics of concrete samples made from drinking water and wastewater. For instance, the samples exhibited the formation of subhedral structures and higher density and less void than those made from treated wastewater. Similarly, according to researchers Shekhar Saxena and Temburkar [101], the pore structure of concrete is a vital characteristic that influences its mechanical and physical properties. Its durability is also influenced by this. Compared to concrete mix CC, the mixes prepared with wastewater revealed cracks and voids because of improper hydration. It could be that the presence of suspended and dissolved organic matter and total in wastewater makes the concrete mix more porous.

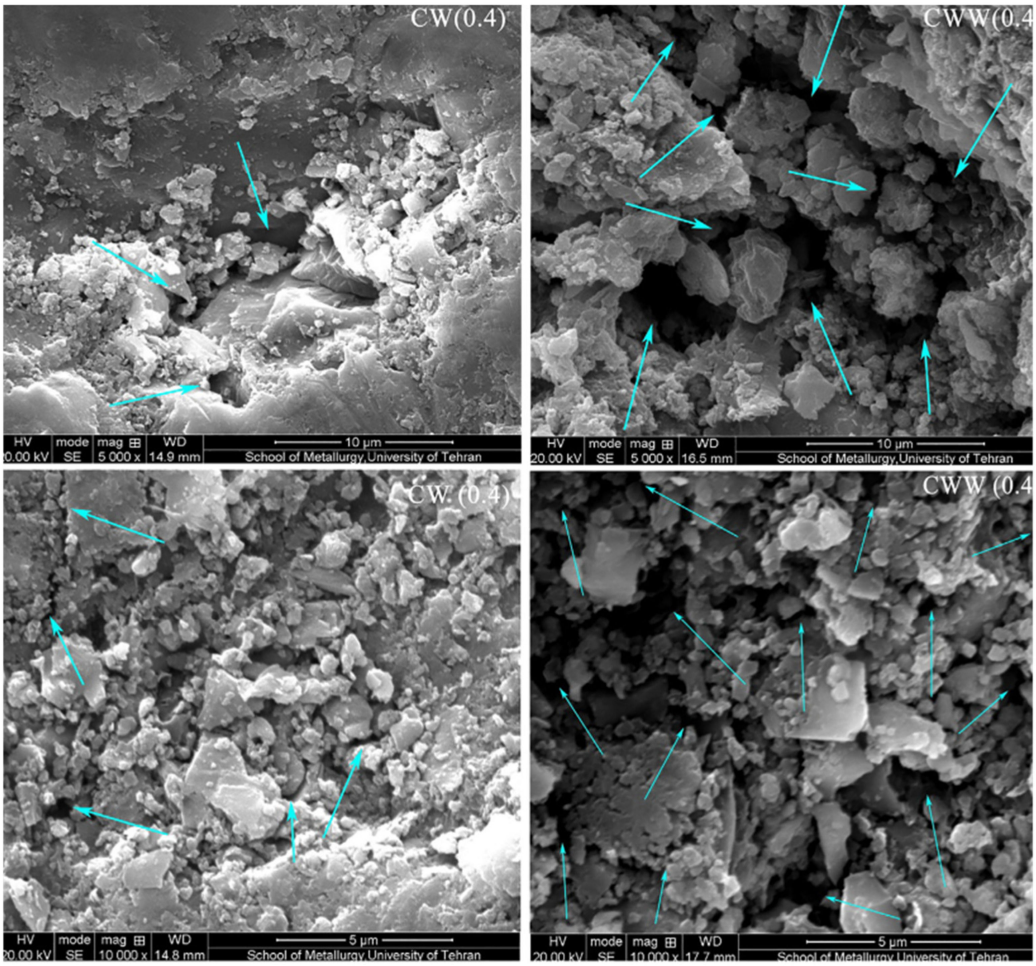

Figure 7. SEM micrographs of concrete prepared with CW and CWW [79].

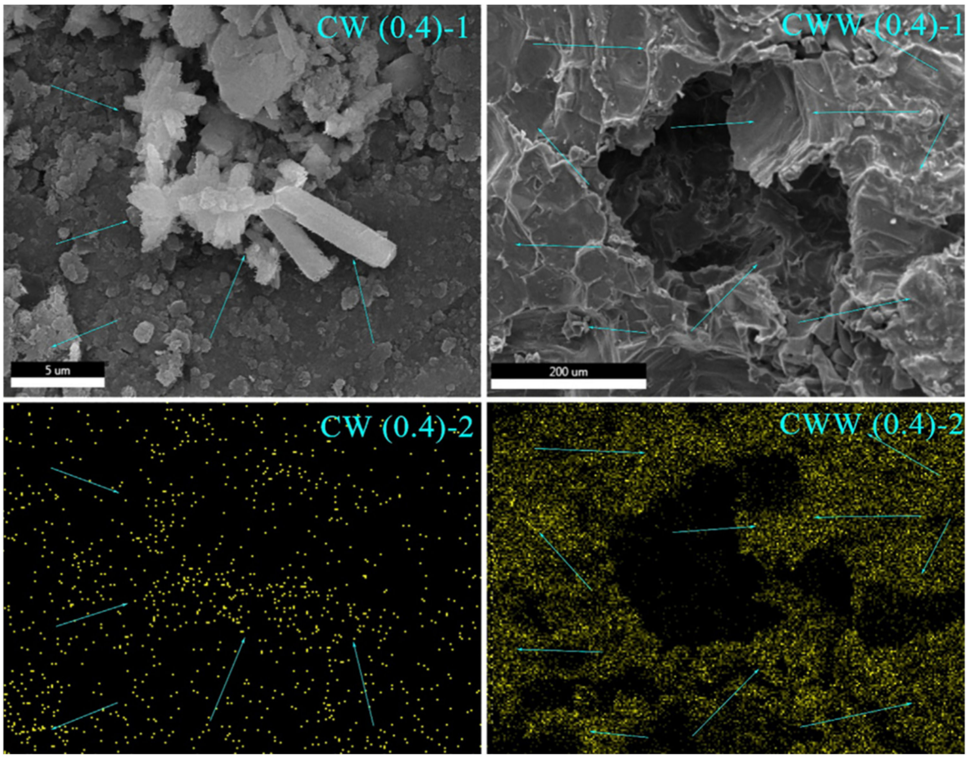

Figure 8. SEM micrographs and EDX mapping analysis of concrete prepared CW and CWW [79].

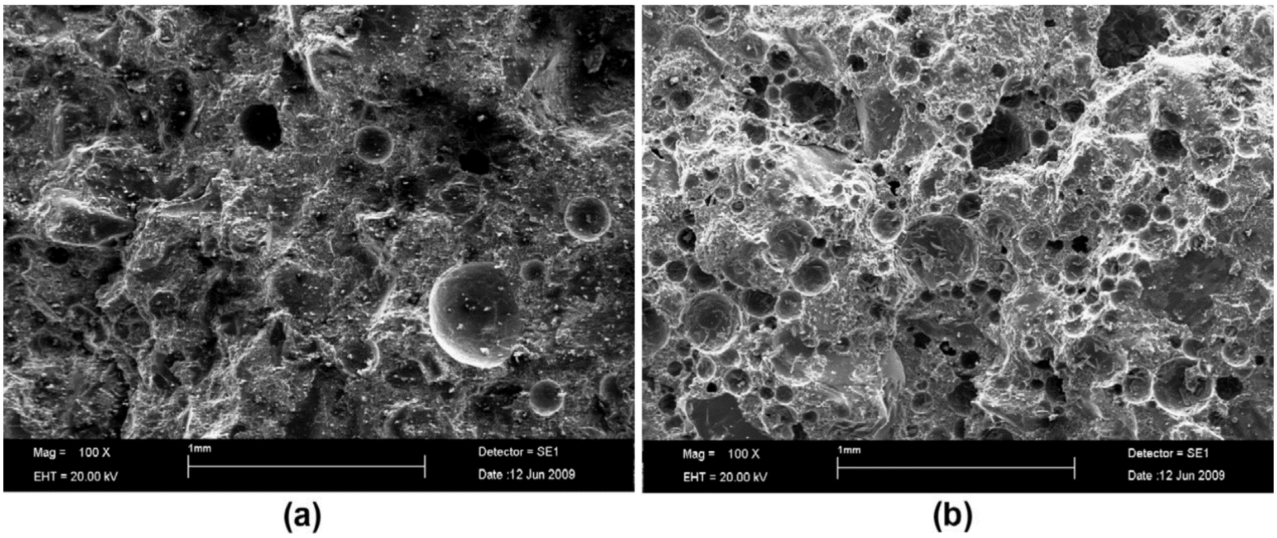

Figure 9. SEM micrographs of concrete prepared with 100% of (**a**) drinking and (**b**) wastewater [68].

8. Other Properties

8.1. Ultrasonic Pulse Velocity

The non-destructive UPV test is used to analyze the concrete's uniformity and the presence of various imperfections, such as cracks and voids. It can detect these internal flaws with an ultrasonic pulse, which diffracted around the defect's periphery. The pulse velocities of concrete are generally higher when its quality is good. This is because of its uniformity and homogeneity.

When treating concrete, the presence of treated wastewater can have an impact on the UPV test's results and the reinforcement's corrosion. This non-destructive test is performed to check the concrete's homogeneity and quality. The UPV test can analyze the various properties of concrete, such as its density and elasticity. The presence of suspended solids and impurities in the concrete can increase its porosity and heterogeneity. This can lead to lower UPV values, which suggests possible internal defects [55,103]. Compared to the primary-treated wastewater, the presence of secondary wastewater has a minimal impact on UPV [104]. Although the concrete may still exhibit microstructural and porosity changes, the UPV results are not significantly different from those of concrete made using freshwater [105]. The minimal presence of impurities in tertiary-treated wastewater produces concrete with characteristics that are like those obtained from fresh water. The UPV values exhibited by such concrete typically indicate good homogeneity and quality [102]. Compared to the primary wastewater, the secondary-treated wastewater has a slightly lower UPV value and a moderate chance of experiencing reinforcement corrosion. In addition, its minimal impact on UPV makes it an ideal alternative to freshwater. According to researchers Shekhar Saxena and Temburkar [80], compared to control concrete, the pulse velocity of mixtures containing wastewater and steel slag aggregate was reduced by up to 5%. The pulse velocity of mixtures containing different types of wastewater and steel slag aggregate was also increased. For 28 days, the pulse velocity of mixtures containing different types of wastewater was 6%. It was then increased to 2,6% for 56 days and 1 percent for 90 days. The study revealed that the pulse velocity of concrete was 8% higher when it was mixed with 50% SWC compared to the concrete mix. As the concrete's age increased, its pulse velocity also started to increase. In the present research, the various concrete mixtures exhibited good quality and produced 50% SWC concrete at 90 days. UPV test results of concrete prepared with wastewater are summarized in Figure 10.

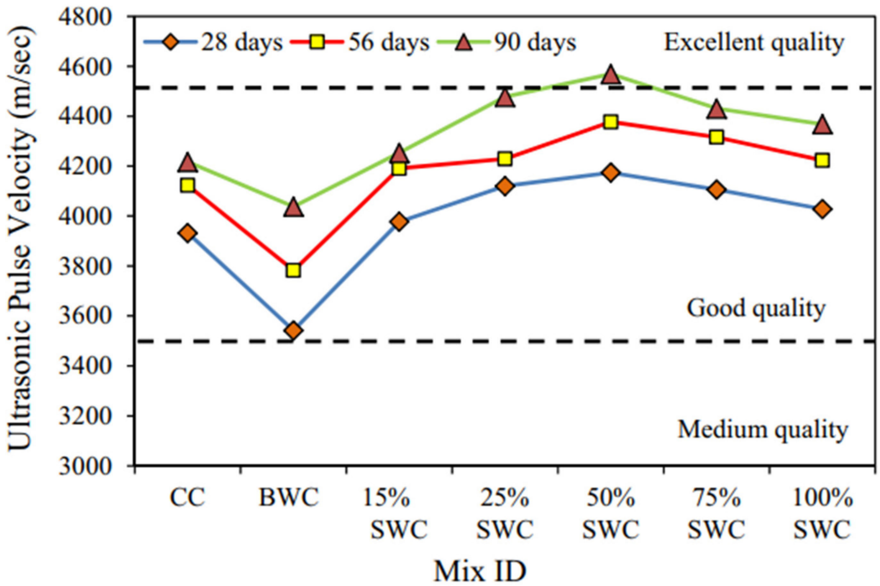

Figure 10. UPV test results of concrete prepared with wastewater [30].

8.2. Effect of Wastewater on Corrosion of Reinforcement

The presence of chlorides in the treated wastewater can have a significant impact on the corrosion of concrete reinforcing materials. The elevated chloride content can accelerate the process of corrosion, which can lead to structural issues and reduce the concrete's overall quality. Although the presence of fewer chlorides in the secondary wastewater compared to the primary wastewater can reduce the likelihood of corrosion, the residual chloride level still poses a risk. This is why it is important to use corrosion inhibitors and coatings [84]. The minimal chloride level and impurities present in the tertiary-treated wastewater can reduce the likelihood of steel reinforcement corrosion. Compared to freshwater, the concrete produced using this wastewater has better corrosion resistance [32]. The strength of the ultrasonic pulse and the degree of corrosion of reinforced concrete can be affected by the concrete's use of treated wastewater. The effects of this treatment on the reinforcement can vary depending on the grade of the wastewater [46]. According to the researchers Mohammad Terro and Ibrahim Ghusain [33], the quality of the mixing water and the age of the concrete can affect the development of corrosion. Figure 11 shows the effects of corrosion on the covers to steel reinforcing at a depth of 2.5 cm and 1.0 cm, respectively. These figures indicate that concrete with a cover of 1 cm exhibited a higher chance of experiencing this issue. The half-cell potential values of concrete after 1.5 years were lower than those of −200 mV, which indicates that no corrosion of reinforcing steel is occurring. However, these values were lower for concrete made with PTWW. The concrete with a reinforcement steel cover of 2.0 cm and 2.5 cm exhibited a half-cell potential of −227 and −229 mV, respectively, which suggests that the corrosion of the steel might not be apparent.

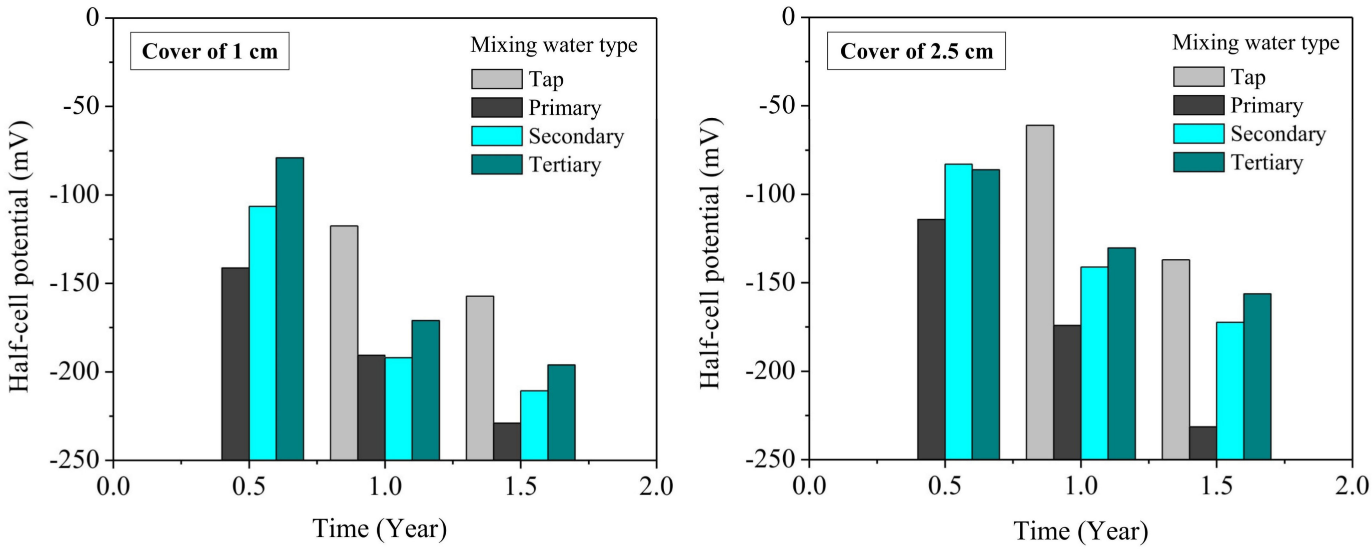

Figure 11. Corrosion effects of concrete prepared with primary-treated wastewater [33].

9. Concluding Remarks

9.1. Conclusions

The goal of this review is to provide an overview of the various characteristics of concrete made from wastewater. It explores the possibility of using wastewater in concrete curing or mixing to reduce water scarcity. Following the comprehensive analysis, the following results can be used to formulate a conclusion:

- The study revealed that concrete's slump value decreases with the use of various wastewater types. This can be attributed to the presence of microscopic, suspended particles in the wastewater. Pre-chlorinated and wash water used for concrete curing has no notable impact on the slump value when compared to raw water.
- The study did not encounter any noticeable changes in the rheology of the concrete. Compared to the secondary- and tertiary-treated wastewater, the former exhibited a 7% increase in its strength. On the other hand, reclaimed wastewater provided a 17% to 8% boost in strength when mixed with a 25% to 100% mixture.
- No notable changes were reported in the study's rheology results. The use of secondary and tertiary wastewater resulted in a reduction of around 9–18% in the concrete's compressive strength. But when reclaimed wastewater is used in a percentage range of 25% to 100%, the strength of the concrete increases by up to 17%.
- Only a few studies have examined the effects of wastewater on the concrete's flexural strength. Compared to potable water, concrete with tertiary, secondary, and primary wastewater shows a slightly lower flexural strength. Compared to secondary wastewater, reclaimed wastewater exhibited a higher value. However, the increase in the

amount of sludge in the water caused by its use negatively affected the flexural ability of the concrete.

- Although the use of sulfate in concrete in solid form does not cause a major impact, it can still be harmful to the concrete when it is exposed to other chemicals. This can lead to the formation of ettringite, which can cause weight gain. The concrete's acid resistance also suffered from the presence of sludge water.
- Scanning Electron Microscope tests revealed that when concrete is made from industrial wastewater, the specimens exhibited well-shaped crystals with sharp edges. On the contrary, concrete samples made from drinking water had unformed crystals. Although the specimens exhibited crystalline faces, those made from industrial wastewater had sharp edges and well-formed crystals. Other studies suggest that the concrete's lower mechanical strength and higher water absorption are caused by using industrial wastewater.
- To reduce the scarcity of freshwater and ensure the safe disposal of treated and untreated wastewater, researchers, academicians, and practitioners around the world should focus on reusing wastewater in the preparation and curing of concrete to save mother Earth.

9.2. Benefits of Use of Wastewater in Concrete

Various environmental, performance, and economic benefits can be achieved by mixing treated wastewater with concrete. Here is an overview of the main advantages of this process. Compared to the use of potable water, the demand for freshwater resources is greatly reduced, particularly in areas with limited water supplies. The goal of this project is to promote the use of resources that are available, in line with the principles of sustainability. Concrete production utilizes treated wastewater, which can be used to reduce the amount of water required to be treated, lessen pollution, and minimize the impact on the environment. The use of treated wastewater can minimize the environmental impact of water extraction. It is cheaper than potable water, which means concrete producers can save money. Moreover, it can lower the disposal costs for municipalities and treatment plants. In many countries, the government offers various subsidies and tax credits to encourage the utilization of recycled water. This process can also help improve the concrete properties. In addition, certain chemicals in the wastewater can speed up the concrete's early strength development. Mixes containing treated wastewater can be used for quick and easy removal of formwork and setting. Depending on their chemical composition, concrete mixes can be improved in their ability to work. In addition to reducing carbon emissions, the utilization of local wastewater also helps reduce the energy required to transport and extract water. It can help reduce the overall carbon footprint of concrete production. The UN has several SDGs that it supports, such as those for sanitation and water, responsible production and consumption, and cities and communities. Concrete production using treated wastewater highlights the concept of the circular economy, which involves the reuse and recycling of waste products. The Industrial Symbiosis project aims to enhance collaboration among various industries, including those involved in wastewater treatment, to improve sustainability and resource efficiency. By promoting sustainable methods, CSRs can raise awareness and support environmental endeavors. By incorporating wastewater in concrete production, companies can enhance their CSR profiles by emphasizing their dedication to minimizing environmental impact. Compared to water for drinking water, concrete production using wastewater offers numerous advantages, such as economic savings and environmental conservation. In addition, it conserves freshwater resources, supports sustainable growth by reducing disposal issues, and advocates circular economy practices. As the world experiences increasing water scarcity, it is important that construction practices adopt sustainable methods. This can help ensure that both built and natural environments are resilient and viable.

9.3. Limitations on Use of Wastewater in Concrete

Although concrete can be used as an alternative to water for various applications, there are still certain challenges and limitations that need to be overcome in order for it to be effective and safe. One of these is the variability in the quality of the treated wastewater. Unpredictable effects can be caused by this inconsistency. The presence of various impurities, such as sulfates, chlorides, and heavy metals, in wastewater can affect the concrete's durability and performance. Another issue with reinforced concrete is the increased chloride content, which can cause steel reinforcement to deteriorate. Although it is known that treated wastewater can improve the durability of concrete, it is not yet clear how this process will affect the long-term strength of the concrete. Another issue that can affect the concrete's performance is the presence of certain impurities, such as organic matter. The presence of contaminants in concrete can affect its long-term durability and early strength development. The lack of regulatory guidelines and standards for the utilization of treated wastewater has raised concerns about its safety. The lack of regulatory clarity can hinder the widespread adoption of concrete. It can also create confusion for producers as to how to comply with existing construction and environmental regulations. Designing concrete mixtures that use treated wastewater without compromising their desired properties can be a complex process. Optimization and testing can also be performed to ensure that the concrete maintains its desired characteristics. The use of additives and other chemicals can increase the complexity and cost of concrete production. Treating and monitoring the quality of the wastewater is important, and continuous monitoring is required in order to get the most out of the process. Quality Control, on the other hand, is a challenging process to maintain throughout the production run due to remote or large-scale projects. The acceptance and perception issues surrounding the use of treated wastewater in concrete can be caused by various factors. Some of these include the safety concerns of the concrete and the opinions of the public and construction professionals. To overcome these, education and awareness must be provided to the public and the construction industry about the advantages of this process. Although concrete production using treated wastewater can be considered sustainable, there are still various challenges that need to be resolved for it to be successful. These include managing the quality and variability of the concrete's treated wastewater, ensuring its durability, and developing guidelines and standards. Researchers, regulatory support, and technological advancements can help pave the way for concrete's widespread adoption in the construction industry by addressing these issues.

9.4. Scope for Future Work Use of Wastewater in Concrete

As an alternative to water for construction, the use of wastewater can be considered a game-changing innovation. But to fully realize its full potential, several key areas of research must be pursued. The development of guidelines and standards for the utilization of treated wastewater in the concrete production process is a vital step in ensuring its safety and effectiveness. A robust regulatory framework is also needed to facilitate its widespread adoption. Studies on the durability of concrete regarding the effects of sulfates, salts, and others on its reinforcement corrosion and overall insulating properties have been conducted for A long time. Field investigations into concrete structures using aerated water supply for the evaluation of their performance subsequently provide real-world data on the durability and longevity of their structures. In the design of concrete mixtures, it is important to consider the optimal utilization of treated wastewater for certain properties, such as strength and durability. The use of additives and other special chemicals can also help prevent the concrete from getting damaged by impurities. To maximize the effectiveness of the wastewater treatment process, various advanced technologies are being developed. These are designed to produce high-quality and safe treated wastewater that can be used in concrete production. Pre-treatment solutions are also being developed to remove certain contaminants from the wastewater before it is used in concrete. A comprehensive analysis of the life cycle of a concrete project, including its impact on the environment, can be performed using LCA studies. This process involves assessing the various factors that affect the concrete's impact on the planet, such as waste management and resource conservation. A carbon footprint analysis can also be carried out to evaluate the concrete's carbon emissions compared to conventional practices. Following up with pilot projects and studies can also be carried out to demonstrate the feasibility of using wastewater in concrete. These projects should also be able to provide concrete insights that can be beneficial for the construction industry. Case studies can be conducted to enhance confidence and provide concrete recommendations for the industry. Strong relationships can be built with various stakeholder groups, such as regulatory bodies and construction professionals, to inform the public about how beneficial and safe the utilization of treated wastewater can be for concrete production. Train workers, contractors, and engineers should be briefed on how to handle and use wastewater properly. Development and integration of monitoring and sensors systems should be carried out for the continuous evaluation of the quality of concrete made from treated wastewater. This technology will help ensure that the concrete is of consistent quality. Artificial intelligence and data analytics will be utilized for predicting and optimizing the concrete's performance using historical data. A comprehensive analysis of the economic benefits and costs of using wastewater in concrete production can be carried out. This process will analyze the difference between the cost of treating wastewater and the cost of doing so with respect to various factors, such as treatment expenses and enhanced durability. Incentives and subsidies can be established to encourage concrete producers to add treated wastewater to their production process. A multi-disciplinary research collaboration is also needed to address the various challenges that prevent concrete users from fully utilizing this resource. A research center or innovation hub may be established to develop sustainable materials, such as concrete incorporating treated wastewater. Although concrete's application of wastewater holds great potential, it requires dedicated efforts by regulators, researchers, and developers to fully realize its full potential. The construction industry can make significant progress toward becoming more resilient and sustainable by focusing on the various work areas that are in its future. These include waste minimization, water conservation, and overall ecological sustainability.

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