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Review Article

Concrete Production and Curing with Recycled Wastewater: A Review on the Current State of Knowledge and Practice

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A number of factors have combined to put excessive pressure on the finite available freshwater resources. These include increasing population, rapid urbanization, industrialization, changed land pattern usage and land cover, change in the overall ecological system, and increased temperature and unscientific compromises in the extraction of water are at alarming threshold putting pressure on the finite available freshwater resources. As a result, many countries have been stressed or are at the verge of being stressed. The problem is worsened day by day by prolonged drought, unchecked discharge of untreated or partially treated wastewater to the freshwater reservoirs and lack of proper water quality control measures and management. Many initiatives such as Zero Liquid Discharge of industrial wastewater into freshwater bodies such as reservoirs, lakes, and ponds, and the use of recycled wastewater for irrigation and domestic purposes have started to be embraced as measures to put a check on the fast depleting freshwater resources for sustainable socio-economic development. The construction industry is the second largest consumer of freshwater just after agriculture. Concreting alone consumes, annually, over one trillion m^3 of freshwater globally while the concept of the use of wastewater and/or recycled water in the concrete-making processes is yet to be adopted. Hence, this paper presents a general review of the current state of knowledge and practice on concrete production and curing using recycled wastewater from industrial, commercial, and domestic activities. An extensive review of the existing literature revealed that recycled water is fit for concrete production and curing purposes. The observations made are based on the assessment of wastewater quality parameters and their impacts on some selected concrete properties such as initial setting time and compressive strength. Due to scanty research on the impacts of varying concentrations of different ingredients in any questionable water on selected properties of reinforced concrete and its durability, thus, further research is recommended.

1. Introduction

The oceans, comprising the largest single body of water, encompass 70.8% of the Earth's surface area [1, 2] and stores 97.6% of the Earth's water resources. Unfortunately, this huge volume of water is saline and it is not only just unreadily available for various uses, but it also further affects the quality of the surface and groundwater near coastal areas through saline water intrusions. This further reduces the volume of available freshwater around such areas and also increases the costs of providing freshwater for day to day routine activities to the people in the vicinity at the cost of heavy investment in infrastructures and technical expertise to avoid or minimize the saline water intrusion from the oceans.

Out of the 2.4% available freshwater, 68.7% is stored in the ice caps and glaciers and 30.1% is stored up as groundwater. This implies that only about 1.2% of the available freshwater is stored in the soil moisture, ground ice and permafrost, lakes, atmosphere, swamps, rivers, and as biological water [3–5]. Just like ocean water, the freshwater stored in ice caps and glaciers are not also readily available for use and even if it were available, it is not well spatially distributed as they are only concentrated in the North and South Poles of the Earth. The problem of freshwater availability is further aggravated by the fact that only 50% of the groundwater can be easily and economically extracted (i.e., up to a depth of 800 m only).

Deducting the ocean water, water stored in the ice caps and glaciers, and groundwater stored in aquifers deeper than 800 m from the Earth surface, makes the volume of freshwater available for domestic use and other usages to stand at a meagre 0.39% of the total global water resources. This meagre proportion of freshwater is also rapidly getting depleted due to too much pressure on it due to rapid population increase, urbanization, industrialization, prolonged draught, and change in land use cover. Concomitantly, rivers, lakes, ponds, glaciers, and freshwater bodies are suffering from pollution due to unregulated discharge of contamination into them.

The issues highlighted above-given including others, thus, have caused every continent to be affected by water scarcity. According to [6], about 2,300 billion people of the world's population already live in areas of physical water scarcity of which 733 million people live in high and critically water stressed countries. As per an estimate, about 1,600 million people (that is, one out of every four persons of the existing world population) are already facing economic water shortage This is a situation where countries/societies lack necessary infrastructure to draw from the available freshwater deposits. The available data showed that in the 21st century, the majority of the societies of the world are going to face a major challenge of water scarcity. This has resulted partly due to the water use rate doubling as the growth of the population in the last century. Despite the fact that there is no global water scarcity as such, but due to uneven distribution of this precious commodity, an increasing number of regions are becoming chronically short of water [6–9]. According to Global Water Institute, it has been projected that by the year 2030, about 700 million people worldwide could be displaced by intense water scarcity [10].

In order to reduce the burden on available scarce freshwater resources, the concept of wastewater utilization has been actuated and encouraged by recycling the raw, partially treated, or fully treated water from the source of its generation or away from the source of generation. Industries, for example, have started to embrace the concept of wastewater recycling through practicing Zero Liquid Discharge (ZLD). By this practice, all the wastewater generated within the premises is reused or recycled as either raw or after some level of treatment to make it fit for use in allied industrial uses. Qatar's Ministry of Environment, on the same concept, issued a directive that requires energy and industry sectors in Qatar to work towards the ZLD of process wastewater by December 2016. Jasim et al. [11] cited [12] to have reported that these sectors recycled about 24.5 million m^3 of water in 2013. It is imperative to note that many countries in the world have made regulations for the effective utilization of wastewater. A literature survey revealed the usage of treated wastewater by many countries for irrigation, toilet flushing, lawn sprinkling, etc. For instance, the government of Israel for example in 1994, through its Ministry of Health, State of Israel, issued the first permit allowing the use of shower wastewater for sprinkling on public sports centres [13]. The European Council Directive also permitted wastewater recycling by stating that "*Treated wastewater shall be reused wherever appropriate*" [13–15].

The construction industry is the second largest consumer of freshwater just after Agricultural consumption. Water is as an essential element in the strengthening of concrete for acceptable quality for the intended purpose. Concreting is the lead consumers using over one trillion m^3 of freshwater globally for production and curing [16, 17]. This could be attributed to the abundance and less pressure on freshwater availability in the past. In the past decades, there was practical believe, i.e., "conventional wisdom" that water fit for human consumption is suitable for all construction purposes and concreting works [18–20]. However, this belief can no longer be wholly relied on as water containing sugar may be potable but harmful for concrete structures and concreting works. According to EN:1008 [21] and AS1379 [22], sugar concentration of more than 100 mg/l in mixing water is detrimental to concrete. Furthermore, various research studies show successful results by using the treated wastewater in concrete [23–28]. In recent times, there has been a growing concept of use of wastewater and/or recycle wastewater in concrete-making processes [19, 27, 29–34]. The conventional knowledge seemed to have been arrived at and exercised by the people based on the ease in availability of indigenous water resources without any serious scientific justifications. Though, there are few studies that examined the effects of sludge water or recycled waste water on the durability of concrete [31, 35]. This could be due to the nonavailability of adequate technologies at that time to analyze the impacts of varying concentrations of different water quality parameters on the physical and mechanical strength of the durability of concrete.

This paper reviews the current state of knowledge and practices related to the use of recycled wastewater for concrete production and allied activities. In addition, aspects related to quality parameters of water with respect to their impacts as specified in major national and international codes and practices for mixing, curing, and production of concrete as a composite material have also been discussed while considering the findings on the initial setting time and compressive strength of concrete. These are the two most pronounced parameters being considered essential all over the world by the concrete technologists.

2. Literature Survey and Analysis of Findings

2.1. Standard Limits for Different Constituents in Water for Mixing and Curing of Concrete. Table 1 summarises the tolerable limits of different constituents in water to be used in mixing and curing of concrete. It is based on the following specifications: [21, 22, 36–39].

It is seen in Table 1 that the permissible limits of different constituents as per these specifications are much higher than those of the potable water standards set by the

Table 1: Tolerable limits of different constituents in water for concrete mixing.

Constituents in mixing water	Tolerable limits as per different specifications	References	WHO standards for drinking [40]
pH	3–9	[22, 36, 39]	6.5–8.5
Suspended solids	2000 (mg/l)	[36]	
Dissolved solids	2000–50000 (mg/l)	[36, 39]	500–1500
Organic solids	200 (mg/l)	[36]	
In-organic solids	3000 (mg/l)	[36]	
Sulphates	400–3000 (mg/l)	[21, 22, 36]	200–400 mg/l
Chlorides for plain concrete	360 to 4500 (mg/l)	[21, 22, 36]	
Chlorides for reinforced concrete	500–1000 (mg/l)	[21, 36, 39]	
Chlorides as cl, for prestressed concrete or bridge decks	500 (ppm)	[38]	200–600 g/l
Chlorides as cl, for other reinforced concrete in moist environments or containing aluminum embedment or dissimilar metals or with stay-in-place galvanized metal forms	1000 (ppm)	[38]	
Zinc and lead	100–600 each (mg/l)	[21]	Zinc = 3 mg/l Lead = 0.01 mg/l
Copper and manganese	500–600 each (mg/l)	Concrete prentice Hall, [41]	150 mg/l for Mg
Phosphates	100 (mg/l)	[21, 22]	0.4 mg/l max.
Nitrates	500 (mg/l)	[21]	10 mg/l max.
Sugars	100 (mg/l)	[21, 22]	-
Turbidity	2000 (NTU)	ACI, 1924:20: 442–486	5–25 NTU max.
Sulphuric acid	6250 (mg/l)	ACI, 1924:20: 442–486	—
Oil and grease	50 (mg/l)	[22]	—
Na + K + Ca + Mg	2000 (mg/l)	[39]	437 mg/l max.
Carbonates	1000 (mg/l)	Concrete prentice Hall, [41]	30–400 ppm
Bicarbonates	400 (mg/l)	Concrete prentice Hall, [41]	See total alkalinity
Sodium & hydrogen carbonates	2000 mg/l	[22]	Sodium = 200 mg/l max.
Alkalis as (Na_2O + 0.658 K_2O)	600 ppm	[38]	—
Total alkalinity as calcium carbonates	500 mg/l	[39], concrete prentice Hall, [41]	250 mg/l max.
Total solids	50,000 ppm	[38]	500–1500 mg/l

World Health Organization (WHO), USEPA, and many other National and International organizations. This increase in permissible limits can be attributed to the availability of modern technologies and technical know-how. This facilitated in ascertaining the physical and mechanical parameters of the concrete produced using recycled and wastewater and further studies on the durability of concrete. The results are appreciable and have proved that even nonpotable water can also be used under certain conditions for the production of concrete as opposed to the "Conventional wisdom."

IS:456 [36] specifications further give the following as the yard stick to confirm the suitability of any questionable water for mixing and curing concrete.

(a) To neutralize a 100 ml sample of water, using phenolphthalein as an indicator, it should not require more than 5 ml of 0.02 normal sodium hydroxide solutions

(b) To neutralize a 100 ml sample of water, using a mixed indicator, it should not require more than 25 ml of 0.02 normal sulphuric acids

(c) The average 28 days compressive strength of at least 3, 150 mm concrete cubes prepared using questionable water shall not be less than 90% of the average of the strength of three similar concrete cubes prepared using distilled water

(d) The initial setting time of the test block made with appropriate cement and the questionable water shall not be less than 30 minutes and shall not differ by less or more than 30 minutes from the initial setting time of the control test block prepared with the same cement and distilled water

The above-given code also allows for use of sea water in mixing plain concrete after having considered possible disadvantages and precautions including the use of appropriate cement. Lastly, the code highlighted that any water which is suitable for mixing concrete is also suitable for curing but should not produce any objectionable stain or unsightly deposit on the concrete.

Similarly, ASTM C94/C94M-00 [38] also provides that any questionable water is considered deemed for concrete production if it meets the following requirements:

Table 2: Determined values of recycled wastewater quality parameters vs maximum allowable limits as per IS 456:2000 [36].

S/N	Author	Type of wastewater used to produce concrete	Parameters analysed	Values obtained			Max. tolerable limits	IS 456: 2000 limits [36]	Comparison with max. limits	Comparison with IS 456: 2000 limits [36]
1	Tay and Yip [29]	Wastewater is treated through coagulation, flocculation, sedimentation, filtration, aeration, and chlorination, at increasing concentrations from 25–100% of potable water.	Colour	13			—	—	—	—
			Turbidity	1.5			2000	—	Within	N/A
			BOD_5	2			—	—	N/A	N/A
			COD	35			—	—	N/A	N/A
			NO_2-N	0.2			—	—	N/A	N/A
			NH_4-N	16			—	—	N/A	N/A
			NO_3-N	2.5			—	—	N/A	N/A
			TH-$CaCO_3$	140			—	—	N/A	N/A
			pH	7.1			9	>6	Within	Within
			SS	3.2			2000	2000	Within	Within
			TS	670			50000	—	Within	N/A
			TA-$CaCO_3$	110			500	—	Within	N/A
			$CaCO_3$	—			1000	—	—	—
			HCO_3^-	102			400	—	Within	N/A
			Sulphates	56			3000	400	Within	Within
			Chlorides	240			4500	2000	Within	Within
2	Su, et al. [42]	The wash water from concrete mixer washout operations	pH	11.63			9	>6	Higher	Within
			Turbidity-	187.33			2000	—	Within	N/A
			TS	4196.67			50000	—	Within	N/A
			Chlorides	16.34			4500	2000	Within	Within
			Sulphates	216			3000	400	Within	Within
3	Al-Ghusain and Terro [19]	Preliminary (PT), secondary (ST) and tertiary (TT) treated wastewater		PT	ST	TT				
			TS	986	867	773	50000	—	Within	N/A
			Sulphate	230	180	160	3000	400	Within	Within
			NO_3-N	0	0.4	1.9	—	—	N/A	N/A
			NO_2-N	0	0	0.6	—	—	N/A	N/A
			Chloride	287	290	340	4500	2000	Within	Within
			NH_4	37	44	36	—	—	N/A	N/A
			COD	407	61	29	—	—	N/A	N/A
			Alkalinity-$CaCO_3$	228	66	57	500	—	Within	N/A
			Sulphide	0.9	0	0.2	—	—	N/A	N/A
			Total Cl	0	0	1.71	—	—	N/A	N/A
			Res. free Cl	0	0	0.18	—	—	N/A	N/A

Table 2: Continued.

S/N	Author	Type of wastewater used to produce concrete	Parameters analysed	Values obtained			Max. tolerable limits	IS 456: 2000 limits [36]	Comparison with max. limits	Comparison with IS 456: 2000 limits [36]
				PT	ST	TT				
4	Silva and Naik [43]	Primary (PT), secondary (ST) and tertiary (TT) treated wastewater	TSS	86	—	6	2000	2000	Within	Within
			BOD_5	183	—	5	—	—	N/A	N/A
			NH4-N	—	—	0.2	—	—	N/A	N/A
			P	—	—	0.3	—	—	N/A	N/A
			Faecal coli MPN/100 ml	—	50000	40	—	—	N/A	N/A
5	Al-jabri and Taha [33]	Wastewater from car washing station	pH		6.94		9	>6	Within	Within
			Electrical resistivity (μs/cm)		498		—	—	N/A	N/A
			TDS		254		50000	—	Within	N/A
			Tot. Alkalinity		90		500	—	Within	N/A
			HCO_3^-		90		400	—	Within	N/A
			Carbonates		0		1000	—	Within	N/A
			Hydroxide		0		—	—	N/A	N/A
			Tot. Hardness		152		—	—	N/A	N/A
			Ca + Mg + Na + K		253.7		<2000	—	Within	N/A
			Iron		0.1		—	—	N/A	N/A
			F^-(PPM)		0.97		—	—	N/A	N/A
			Cl^-(PPM)		74.2		4500	2000	Within	Within
			Br^- (PPM)		0.22		—	—	N/A	N/A
			NO_3^- (PPM)		0.07		500	—	Within	N/A
			PO_4^{3-} (PPM)		8.14		100	—	Within	N/A
			SO_4 (PPM)		97.7		3000	400	Within	Within
			SiO_2 (PPM)		9.56		—	—	N/A	N/A
				HI	DS	POM				
6	Noruzman, et al. [44]	The secondary treated effluents from heavy industry (HI), a palm-oil mill (POM), and domestic sewage (DS)	pH	8.8	7.21	8.14	9	>6	Within	Within
			Total solids	3445	1121	240	50000	—	Within	N/A
			SS	178	23	20	2000	2000	Within	Within
			Total alkalinity	449	159	60	500	—	Within	N/A
			Sulphates	56.7	22.6	25.4	3000	400	Within	Within
			Chlorides	225	7.5	5.2	4500	2000	Within	Within
			Ca + Mg + Na + K	31.7	4.6	4.1	2000	—	Within	N/A
			Nitrate	113	7.5	45	500	—	Within	N/A
			Iron	1.52	0	0	—	—	N/A	N/A
			Copper	0.39	0	0	600	—	Within	N/A
			Lead	0.18	0.007	0.003	600	—	Within	N/A
			Zinc	0.44	0.21	0.13	600	—	Within	N/A
			Manganese	0.756	0.011	0.028	600	—	Within	N/A

Table 2: Continued.

S/N	Author	Type of wastewater used to produce concrete	Parameters analysed	Values obtained		Max. tolerable limits	IS 456: 2000 limits [36]	Comparison with max. limits	Comparison with IS 456: 2000 limits [36]
7	Asadollahfardi, et al. [17]	Treated domestic wastewater before chlorination	pH	7.7		9	>6	Within	Within
			Turbidity	12		2000	—	Within	N/A
			Sulphates	180		3000	400	Within	Within
			Nitrates	14		500	—	Within	N/A
			Nitrites	3.6		—	—	N/A	N/A
			Chlorides	55		4500	2000	Within	Within
			Total solids	200		50000	—	Within	N/A
			TSD	30		2000	2000	Within	Within
			BOD_5	30		—	—	N/A	N/A
			TDS	170		50000	2000	Within	Within
			COD	93		—	—	N/A	N/A
8	Ghrair, et al. [45]	Raw (RGW) and treated grey (TGW) water from grey water treatment plant		RGW	TGW				
			TSD	436	2	2000	2000	Within	Within
			TDS	980	803	50000	2000	Within	Within
			COD	900	6.97	—	—	N/A	N/A
			BOD_5	536	2.98	—	—	N/A	N/A
			Chlorides	243	208	4500	2000	Within	Within
			Sulphates	222	137	3000	400	Within	Within
			pH	7.5	7.9	9	>6	Within	Within
			E. Coli (MPN/100 ml)	$1.70E+05$	<1	—	—	N/A	N/A
			NH_3	24	>4.5	—	—	N/A	N/A
9	Meena and Luhar [27]	Secondary (ST) and tertiary (TT) treated wastewater		ST	TT				
			BOD_5	20	14	—	—	N/A	N/A
			Hardness as $CaCO_3$	256	248	—	—	N/A	N/A
			Chlorides	269.91	257.92	4500	2000	Within	Within
			Turbidity (NTU)	0.305	0.586	2000	—	Within	N/A
			pH	7.48	7	9	>6	Within	Within
			Conductivity (μs/cm)	1.59	1.59	—	—	N/A	N/A

N/A = not available, SS = suspended solids; TS = total solids; TSS = total suspended solids.

Table 3: Impact of wastewater on selected properties of concrete against provisions of ASTM C94/C94m-00 [38] and IS 456-2000 [36].

S/N	Author	Type of wastewater used	Initial setting time, in minutes			7 Day compressive strength, in MPa			28 days compressive strength, in MPa		
			Control mix	Wastewater mix	ASTM C94/C94 satisfied	Control cubes	Wastewater cubes	ASTM C94/ C94m-00 satisfied [38]	Control cubes	Wastewater cubes	IS 456: 2000 satisfied [36]
1	Ghrair, et al. [45]	Raw grey water	180	200	Yes	1	+0.8 (RI) (%)	Yes	1	−7.7 (RI %)	Yes
		Treated grey water	180	205	Yes	1	+3.8 (R.I %)	Yes	1	−0.6 (R.I %)	Yes
2	Su, et al. [42]	Wash water	95	108.3	Yes	100	113.67, (R.I %)	Yes	100	107.67 (RI %)	Yes
3	Tay and Yip [29]	Wastewater treated by coagulation, flocculation, sedimentation, filtration, aeration, & chlorination at 25–100% concentrations	—	—	N/A	13.5	25.6 (25%), 26.4 (50%), 26.5 (75%) and 26.8 (100)	Yes	20	33.6 (25%), 35.3 (50%), 35.5 (75%) and 36.4 (100%)	Yes
4	Al-jabri and Taha [33]	WW from cars washing station at 25–100% concentrations	—	—	As per the graph, yes	66	64.3 (25%), 66.8 (50%) and 63.8 (100%)	Yes	77	70 (25%), 75 (50%), and 72 (100%)	Yes
5	Noruzman, et al. [44]	Secondary treated effluents from (HI), a (POM) and (DS)	117	110 (HI), 108 (DS) and 149 (POM)	Yes, except for POM	—	—	The graph shows, yes	—	—	POM almost failed
6	Asadollahfardi, et al. [17]	TDWW before chlorination	—	—	Yes	—	—	N/A	—	—	Yes
7	Meena and Luhar [27]	T And ST were used at 10%, 25%, 50% and 100% cons.				100%	85–94% of the normal for TT	Yes, except ST	100%	85–94% of the normal for TT	Yes, except ST

Note. HI = heavy industry, POM = palm oil mill, TT = tertiary treated wastewater, SS = secondary treated wastewater, TDWW = treated domestic wastewater, DS = domestic sewage and R.I. = relative index in (%).

(a) The average 7 days compressive strength of concrete cubes prepared using questionable water shall not be less than 90% of the average of the strength of three similar concrete cubes prepared using distilled water/city water

(b) The setting time, deviation from control should be from 1 hour (early) to 1 hour and 30 minutes (later)

2.2. Concentrations of Different Constituents in Wastewater: Past Studies. Table 2 presented a comparison of the determined values of recycled wastewater quality parameters in previous laboratory scale studies with maximum allowable limits provided by other specifications and/or studies and IS: 456 [36] in Particular. Table 2 also prescribes concentrations of different constituents in wastewater to be used for the production and curing of concrete. These limits have been compared with the limits provided by IS:456 [36], an Indian code of practice for plain and reinforced concrete, and also with the maximum tolerable limits as provided by different specifications outlined in Table 1.

2.3. Impact of Recycled Wastewater on Initial Setting Time and Compressive Strength. According to the provisions of ASTM C94/C94M-00 [38] and IS:456 [36], the justification of choosing any questionable water for concrete production relies heavily on its impact on the initial setting time and compressive strengths at 7 and 28 days. Table 3 presents the results of some selected studies that evaluated the impacts of wastewater on the selected concrete properties against the specifications provided in the ASTM C94/C94m-00 [38] and IS:456 [36]. The test results on initial setting time at 7 and 28 days compressive strengths of concrete produced with questionable waters containing constituents in concentrations provided in Table 2 have been checked against the provisions of ASTM C94/C94m-00 [38] and IS:456 [36].

2.4. Current State of Practices for Use of Recycled Wastewater for Concrete Production. Enough evidence is available with respect to the potential usage of secondary and tertiary treated domestic wastewater, wash water from concrete mixer washout operations in ready-mixed concrete plants, treated grey water, wastewaters from car washing stations, and secondary treated effluents from heavy industry, among others for producing concrete. These wastewaters have no adverse effect on its initial setting time at 7 and 28 days compressive strengths as provided under the provisions of ASTM C94/C94m-00 [38] and IS:456 [36]. The literature revealed that hardly any completed project is involved in recycling these wastewaters in concrete works, be it on a small or large scale. It is only washed waters from concrete manufacturing which has started being used as mixing water for concrete in some countries, especially those in the semiarid regions.

3. Conclusion and Recommendations

The article presents a review on the current state of knowledge and practice of concrete production and curing with recycled wastewater. It is a known fact that freshwater is gradually becoming scarce at a much faster rate than has ever been envisaged. The problem is aggravated by increasing population, rapid urbanization, industrialization, changed land pattern usage and land cover, change in overall ecological system, and increased temperature and unscientific compromises in the extraction of water are at alarming threshold putting pressure on the finite available freshwater resources. A literature survey revealed that there is an insufficient research data pointing to the potentiality of recycling of raw light grey water (wastewater from showers, laundries, hand washing basins, and bath tabs only) for concrete production [46].

Outcomes of interactions at many levels including field engineers, contractors, academicians, students, and others in this investigation are mixed. The prominent and dominant views are regrettable to note that the "conventional wisdom" on concrete technology is that only potable water is most suitable in concrete production. Conversely, an extensive review of the existing literature revealed that recycled water is fit for concrete production and curing purposes. The observations made are based on the assessment of wastewater quality parameters and their impacts on some selected concrete properties such as initial setting time and compressive strength. Conclusively, in promoting the concept of wastewater recycling for concrete production, less polluted streams of wastewater should be separated from the more polluted ones right from the sources of generation. This will reduce, if not even eliminates completely, the need for costly treatments prior to its recycling.

It is also believed that decentralized management of wastewater especially for urbanized apartments, hotels, and hostels where large quantities of wastewater are generated if encouraged and legalized, will help in promoting the concept of recycling wastewater in concrete production. Recycling of wastewater near points of generation will eliminate the unnecessary costs of hauling of the same from distant centralized treatment stations. It is important to note that regular mass awareness programmes should be organized targeting government officials, clients, development partners, and practicing engineers, among others about the suitability of recycling wastewater for concrete production and curing.

After a comprehensive literature review, the following recommendations were drawn for use of recycled wastewater for construction purposes:

(i) Analysis of existing literature showed that there is a scanty research on the impacts of varying concentrations of different ingredients in any questionable water on selected properties of reinforced concrete and its durability. Thus, further research is needed for conclusive findings.

(ii) There is a need for the harmonization of various standards on the qualities of mixing water for concrete and on tolerable limits for some parameters which are not yet developed.

(iii) The recycled wastewater should meet the mandatory health-related requirements for wastewater reuse as provided in USEPA Report EPA/600R-12/618 [47], especially where the workers are likely to come in direct contact.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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