RESEARCH ARTICLE

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Feasibility of Using Harvested Rainwater and Stormwater in Concrete Mixtures

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Abstract

Freshwater preservation and conservation are becoming more and more imperative as worldwide populations increase. Nowadays, making concrete needs huge quantities of freshwater. The present research shows research findings on the feasibility of substituting freshwater in concrete mixing with surface runoff water, RCC rooftop harvested rainwater and conventional water. RCC rooftop harvested water(HRW), surface runoff water(SW), bore well (BW) water, and potable water (PW) were the four sources from which samples were collected. Physical and chemical analysis was carried out on four various sources as per standard methods [APHA]. The performance of four different sources of water on physical properties i.e., setting time, workability, and mechanical properties of ordinary Portable cement (OPC) were examined and compared with conventional concrete specimens. According to the findings, all of the water's qualities from the various sources satisfy the recommended IS 456 (2012) and other standards for concrete-quality water. No significant change was observed in the mechanical properties of four different sources of water samples that were superior to those of conventional concrete. utilizing HRW and SW as alternatives to freshwater could save a lot of freshwater while also protecting the environment.

Keywords: Freshwater, stormwater, harvested rainwater, Setting time, Compressive strength.

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Introduction

Concrete and each individual consumes about 2.5 tons (more than one cubic meter) of cement annually to manufacture concrete. One billion tons of mixing water for concrete are used annually; each cubic meter uses 150–210 liters of water. Water is required in huge quantities for the production of concrete, and freshwater is often only used. In the year 1997, the manufacture of concrete consumed over 800 billion liters of water (Aitcin, 2000). According to additional estimates (Tony and Jenn, 2008), the quantity reached 825 billion liters in 2010. As a result, the concrete industry has a major adverse impact on the environment especially in terms of water use. On the other hand, as a result of growing urbanization and population, freshwater resources are becoming increasingly depleted. Concrete preparation depends substantially on the water's quality. The performance of mixing water in both fresh and hardened phases is one of the main factors to take into account. One way to address the issue of water scarcity is to use unconventional water, such as reusing industrially processed effluent (Asadollahfardi et al. 2015). The inorganic and organic substances in the water used for mixing can delay the setting time of cement by hindering its hydration process. Performance in both fresh and hardened phases is one of the main factors affecting water quality. One of the best solutions to the issue of water scarcity is the utilization of harvested rainfall and stormwater. Government agencies like the Bangalore Water Supply and Sewerage Board (BWSSB 2011), which is responsible for providing water and managing waste in the Indian city of Bengaluru, have made rainwater harvesting mandatory. This study sought to assess whether conventional water, bore well water, harvested rainwater, and runoff could all be used as concrete mixing water.

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Literature Review

(Tobby Michael Agwe 2022) To compare the impact of wastewater solid content on concrete, various research studies were reviewed. Concrete was prepared by substituting wastewater for tap water in specific proportions. The change in concrete slump is within 30 mm when the combined water's solid content is less than 6%. Concrete's fluidity and compressive strength remain consistent when compared to tap water concrete at the ideal solid content. Wastewater particles can enhance concrete toughness to some extent. However, limited research exists on frost and sulfate resistance in wastewater concrete. (Babar Ali 2021) considering the effects of different treated and untreated wastewater types. We decided whether each property should be improved, reduced, or remain unchanged based on average values from available literature. However, due to limited reliable research, we couldn't make decisions for specific wastewater types. Concrete slump wasn't affected by most treated and untreated wastewater types, but slumping decreased for water with high electrical conductivity (dissolved minerals). Additionally, concrete with a high water-cement ratio (W/C) had less slump compared to low W/C concrete. Therefore, wastewater may not be suitable for low W/C concrete mixtures. Moreover, adding wastewater slowed down concrete setting, particularly when there were high levels of total solids or heavy metals like Pb, Cu, or Zn. Untreated wastewater, rich in organic content, significantly reduced compressive and tensile strength, especially in the early stages. Substances like fluorides, bicarbonates, salt, heavy solids, chlorides, and highly acidic water had a notable impact.

(Khushboo Meena 2018) The strength and durability characteristics of the recycled wastewater concrete mixture have been modified by substituting 0% to 100% of the treated wastewater with tap water and curing in it. The slump value of concrete that has been mixed with secondary or tertiary treated wastewater is reduced by 50% and by 25%, respectively. To encourage workability, plasticizers are necessary. Once the sewage has been treated, the alteration won't be visible.

(Ayoup M. Ghrair 2018) The initial setting time and concrete slump value both increased significantly when treated greywater and untreated greywater were used. Additionally, the mortar's soundness attributes were unaffected. Results for the compressive strength of mortar and concrete after 7 days of moist curing time indicated a substantial improvement. Compressive strength was unaffected significantly by the use of Treated Grey Water in the mortar and concrete mixtures that were cast at cure durations of 28, 120, and 200 days. On the other hand, Raw Grey Water marginally decreased compressive strength across the board of curing ages. The water/cement ratio slightly delayed the initial setting time of cement paste with both raw and treated greywater.

(G. Reddy Babu 2017), Portland pozzolana cement (PPC) was tested using different types of water plant outlet water (POW), lime water (LM), and plant outlet water with lime (POWL). These were compared with reference samples made with distilled water (DW). The study found no significant difference in setting times between DW and POW, LW, and (POWL). However, LW and (POWL) specimens showed significantly higher compressive strength compared to the reference samples. The conclusions are based on an examination of influencing wastewater quality and its effects on specific properties of concrete, such as initial setting and compressive strength. During the financial crisis, the separation of less contaminated wastewater from highly polluted streams without facing treatment challenges, there will be no treatment issue for using harvested rainwater and stormwater in the manufacturing of concrete, In this study, an effort is being made to manufacture concrete using harvested rainwater, and stormwater that has been collected. To reduce potable water usage in concrete, it is essential to assess water quality and its influence on concrete properties. Evaluate the setting time, workability, and mechanical properties of cement concrete using harvested rainwater, stormwater, bore well water, and potable water. Compare M30 grade concrete using potable water with concrete made from harvested rainwater, stormwater, and bore well water.

Materials and Experimental Program

Materials

Collection of Harvested Rainwater, stormwater and Conventional water

To identify the sampling points in the research area of the AIEMS campus, Bidadi, Ramanagara, Figure 1 depicts the rainwater harvesting system taken into consideration in the study for the collection of captured rainfall during the monsoon season from June to October 2022. Rainwater runoff from the RCC roof was collected in clean polyethylene cans and directed through a PVC gutter pipe. Two containers, arranged in a staggered configuration, were utilized for the first and second flushes. Second flush samples were collected and stored for examination in a larger container.

Surface runoff samples from the stormwater drainage were taken on wet days in order to determine the best locations at the AIEMS campus in Bidadi (Study area) for the collection of stormwater during the monsoon season from June to October 2022. The surface runoff water was collected in polyethylene bottles, and any floating matter and coarse solids were removed using a screening device. These samples were then stored in a large container. Borewell water and potable water were separately collected and stored in polypropylene containers. Throughout the study period, 10 samples were collected from various sources in sufficient amounts for mixing and curing. These samples assisted in comparing and understanding the variations in quality,

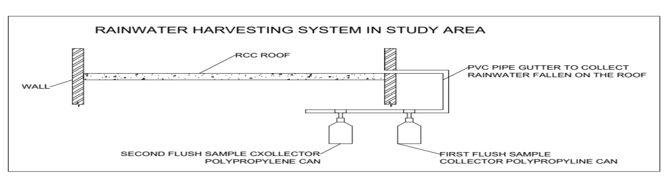

Figure 1: Rainwater harvesting system at sampling point

ultimately allowing for the determination of average values.

Cement

In the current work, Ordinary Portland Cement (OPC) of grade 53 was utilized. OPC features were within the permissible range, having a specific gravity of 3.14, a surface area of 2960 cm^2/g, and behaviour that met with IS: 12269. The concrete mixture takes 40 minutes to set up initially and 330 minutes to set up completely.

Natural aggregates

They were used as both coarse and fine natural aggregates and originated from a nearby granite source in Karnataka, India. According to IS: 383 research, coarse and fine aggregate have specific gravities of 2.67 and 2.62 respectively, along with bulk densities of 1.675 and 1.780 (kg/m^3) and water absorption rates of 1 and 2%.

Experimental Program

Immediately after collection, water samples from various sources including HRW (Harvested Rainwater), SW (Surface Water), and conventional water were transported to the laboratory for analysis of pH, conductivity, TDS (Total Dissolved Solids), and BOD (Biochemical Oxygen Demand). All Samples were refrigerated at 4°C until analysis. To assess metals, samples were acidified with 2% concentrated nitric acid. Various parameters, including total solids, alkalinity, calcium, magnesium, hardness, sulfate, potassium, ammonia, chloride ions, and contaminants like lead, copper, manganese, and iron, were analyzed using standard procedures outlined in "Standard Methods for the Examination of Water and Wastewater of the American Public Health and American Water Work Association and Water Environment Federation pollution." A comprehensive review of national and international standards was conducted to compare permitted contaminant limits in concrete mixing water with the quality of the studied waters.

P438, P394, P358. – Concrete samples produced and curing of potable water samples, and 438, 398, and 358 indicate the kg/m^3 of cement in one cubic meter of concrete. H 438, H394, H358 - Concrete sample produced and curing of harvested rainwater. S 438, S394, S358 - Concrete sample produced and curing of Stormwater. B 438, S394, B358 - Concrete sample produced and curing of Bore well water.

Initial setting time

Cement specimens were cast using (PW), (HRW), (SW), and (BW). The test uses a Vicat apparatus according to IS: 5513-1998 to determine the initial and final setting time of cement and check if the values meet the IS standards outlined in IS 4031 (Part-5):1988.

Workability test

The study assessed concrete workability, measuring how easily freshly mixed concrete can be placed and finished while minimizing homogeneity loss. This evaluation was done using the Slump cone test and compaction factor test following BS EN 12350-2 (2009) standards.

Compressive strength test

Compressive strength tests were conducted on cubes according to BS EN 12390-3 (2009) standards at 7, 28, and 90 days. Concrete cube compressive strength was tested using a 100-tonne compression machine at a loading rate of 4 tonnes per minute. Cubes were maintained in a compression testing machine for testing after their dimensions were measured. Cubes are maintained in the location while being loaded until the specimen fails. The strength value at each position is represented by the average compressive strength of three cubes.

Split tensile strength test

Concrete cylinder split tensile strength was measured using a 100-tonne compression testing machine at a loading rate of 4 tonnes per minute. A properly positioned cylinder specimen was retained on the machine before testing. The specimen was loaded till it broke.

Flexural strength test

The flexural strength of the concrete beam was measured using a 100kN capacity flexural testing machine employing the two-point loading method. Load was applied at two points over a 400 mm effective span until the beam failed.

Statistical Analysis

The workability and mechanical properties of concrete mixes with different proportions of harvested rainwater (HRW), stormwater (SW), bore well water (BW), and potable water (PW), along with various curing durations, were statistically analyzed. Mix proportions and curing days were considered independent variables, while slump cone, compaction factor, compressive strength, split tensile strength, and flexural strength were the response factors.

Results and Discussion

Qualitative characterization of different sources of water and comparison with water quality

Table 1: The design details of different types of water are mixed in concrete samples.

Concrete samples	*W/C Ratio*	*Cement (kg/m^3)*	*Fine aggregate (kg/m^3)*	*Coarse aggregate (kg/m^3)*	*Water (kg/m^3)*
P438, H438, S438, B438	0.45	438	708	1028	197
P394, H394, S394, B394	0.5	394	737	1033	197
P358, H358, S358, B358	0.55	358	765	1034	197

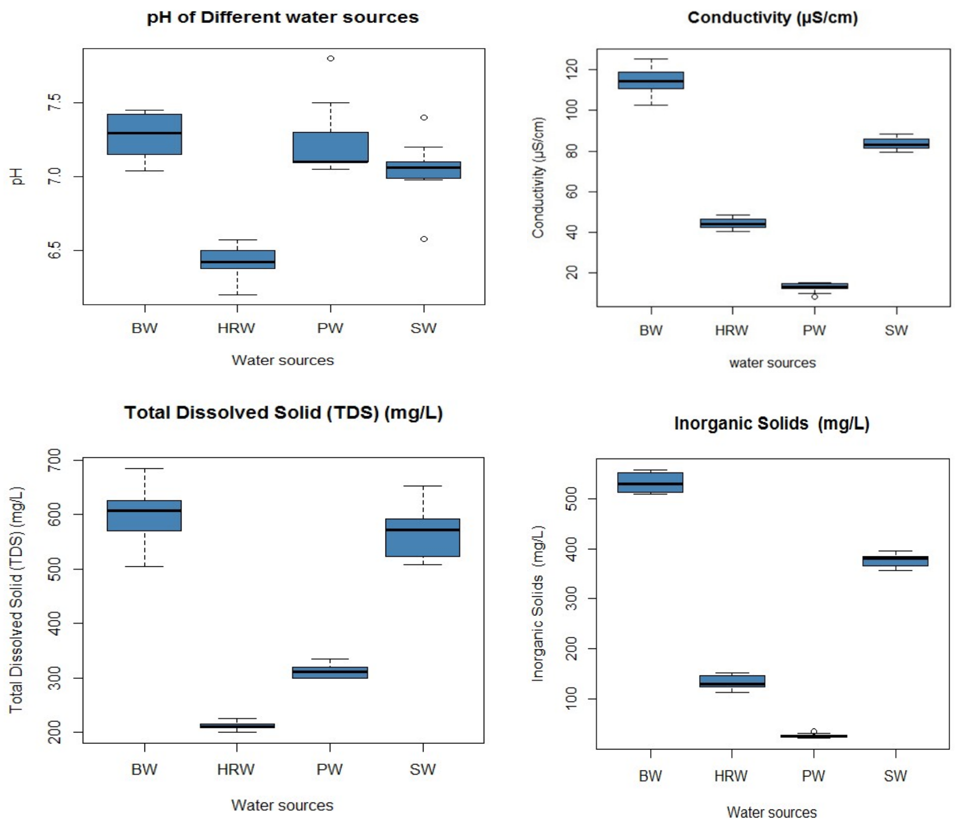

Figure 2: Concentration of pH, Conductivity, TDS and inorganic solids for water sources

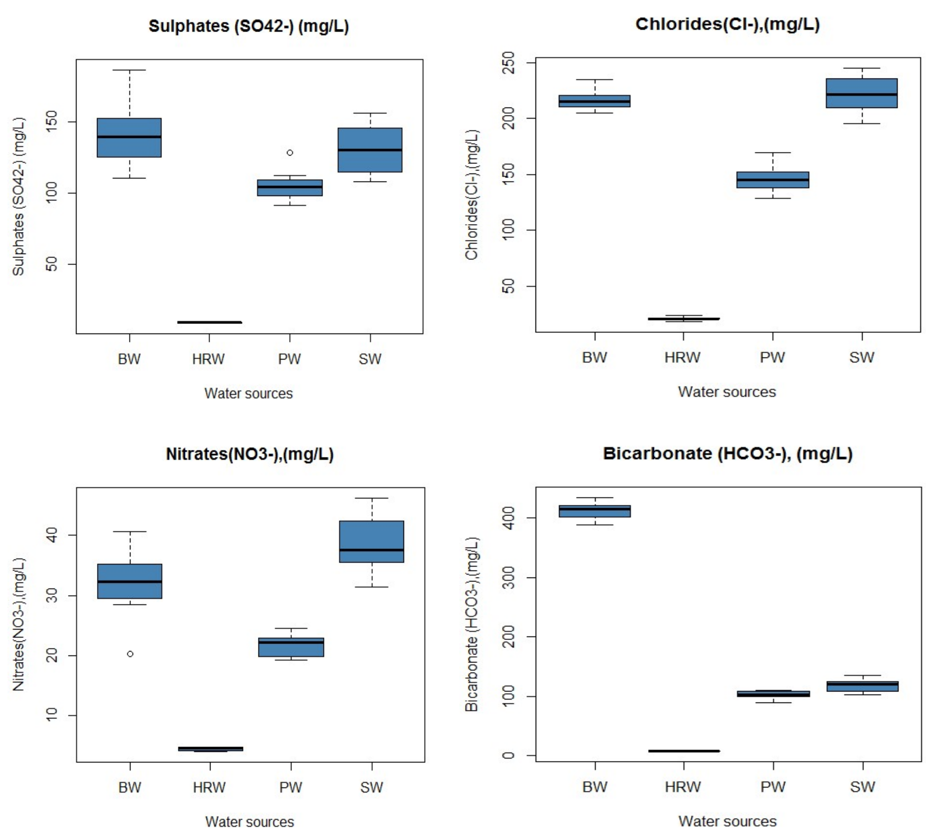

Figure 3: Concentration of sulphates, Chloride, nitrates and bicarbonate for water sources

standards

R version 4.3.1 software was utilized to create box plots displaying water quality data from different sources. Figure 2 displays the concentration of major water quality parameters, including pH, conductivity, TDS, and inorganic solids for water sources, while Figure 3 illustrates the concentrations of sulfates, chloride, nitrates, and bicarbonate. The results of the qualitative analysis, showing the mean values of HRW, SW, BW, and PW, are presented in Table 2. All water properties were found to be within the acceptable limits established by IS 456-2000, ASTM C1602, BIS Drinking Water 2012, and other published references.

The findings showed that the average pH ranged from 6.42 to 7.28 for different water sources. PW (Potable Water), HRW (Harvested Rainwater), SW (Surface runoff water), and BW (Borewell Water) all had pH readings that were within the advised range. Higher pH levels can influence the maturation reactions of concrete, in contrast to lower pH values below 7.0, which denote acidic solutions. According to Yilmaz et al. (1997), this often happens in a fundamental environmental circumstance. Additionally, it was found that higher pH levels

Table 2: Mean values of Various water quality parameters for the production of concrete as per available standard IS 456:2000, ASTM C1602, and IS drinking water 2012 and other references.

Constituents	*Various sources*				*Various standards for the production of concrete*				
	HRW	*SW*	*BW*	*PW*	*IS 456:2000 Limits*	*ASTM C1602 Limits*	*BIS for drinking water – 2012*	*Max. Tolerable Limits for literature*	*Comparison with ASTM C1602, IS 456: 2000 limits*
	Average	*Average*	*Average*	*Average*					
pH	6.42	7.05	7.28	7.23	>6	6 - 8	6.5 - 8.5	3 - 9	Within
Turbidity	12.01	23.03	0.66	0	-	-	1 - 5	2000	N/A
Suspended Solid matter(SSM)	7.62	51.27	1.87	6.04	2000	50000	-	2000	Within
Total Dissolved Solid (TDS)	211.2	569.55	600.3	312.53	2000	-	500 - 2000	2000 - 50000	N/A
Inorganic Solids	132.68	377.30	532.83	26.69	3000	-	-	-	-
Organic Solids	11.45	92.57	107.71	5.55	200	-	-	-	-
Total Alkalinity	41.59	118.71	406.57	93.95	250	600	200 - 600	500 -1000	N/A
Calcium	20.46	135.95	100.63	72.8	-	-	75 - 200	<2000	N/A
Magnesium	2.02	51.51	50.06	26.13	-	-	30 – 100	<2000	N/A
Potassium	1.69	23.57	31.57	16.93	-	-	-	<2000	N/A
Sodium	2.38	32.17	94.34	19.81	-	-	-	2000	N/A
Bicarbonate	8.35	120.13	412.5	102.9	-	-	-	400	N/A
Chlorides	20.56	221.7	216.24	147.27	500- 2000	500 - 1000	250 - 1000	500 - 2000	Within
Sulphates	9.35	131.34	142.13	104.94	400	3000	200 - 400	400 - 3000	Within
Nitrates	4.48	38.52	32.11	21.78	-	-	45	500	N/A
Phosphate	0.05	0.34	0.24	0.08	-	-	-	100	N/A
Zinc	0.04	2.2	1.58	0.99	-	-	5 - 15	100 – 600	N/A
Lead	0.01	0.03	0.02	0	-	-	0.01	100 – 600	N/A
Manganese	0.01	0.02	0.01	0.17	-	-	0.1 – 0.3	500 – 600	N/A
Copper	0.01	1.5	1.03	0.05	-	-	0.05 – 1.5	500 – 600	N/A

(all parameters in mg/l except pH). – indicate the not recommended in codes.

Table 3: Initial setting time of cement prepared from HRW, SW, BW and PW

Mixing Water	*Setting time (minutes)*		*Requirement as per BIS: 12269-2013*	
	Initial	*Final*	*Initial*	*Final*
HRW	98	250.00	Min. 30 min	Max. 600 min
SW	95	245.00		
BW	90	180.00		
PW	92	193.00		

Table 4: Slump test results for HRW, SW, BW, and PW

Types of Mixing Water	*Water cement Ratio (%)*	*Slump (mm)*	*Compaction factor values*
Harvested Rainwater	0.45	85	0.85
	0.5	92	0.88
	0.55	102	0.91
Stormwater	0.45	95	0.92
	0.5	105	0.94
	0.55	135	0.95
Bore well water	0.45	78	0.91
	0.5	90	0.92
	0.55	118	0.94
Potable Water	0.45	78	0.90
	0.5	88	0.92
	0.55	120	0.94

made it easier for metals to precipitate, which lessened their ability to delay cement hydration (Boardman, 1999).

The analysis of the average total solid content in various water samples ranged from 211.42 to 600.03 mg/l. These values were found to be acceptable for PW (Potable Water) and HRW (Harvested Rainwater), SW (Surface Water), and BW (Borewell Water). SW's high total solids concentration (600 mg/l) may have resulted from runoff clogging grit particles. In fact, several of the components used are difficult to dissolve in water, increasing the overall solid concentration. SW's high total solids content didn't appear to have any negative impacts, either. The fundamental variances between HRW, SW, and PW may be to blame for this variation.

SW and HRW, with respective chloride concentrations of 221.7 mg/l and 20.56 mg/l, were determined to have the greatest and lowest levels. Notably, the slightly elevated quantity of chloride ions detected in SW is still below the permitted range according to IS456 (2012). AlHarthy et al. (2005) suggest that a high chloride content in mixing water contributes to high early strength in cement concrete.

Table 2 indicated that sulfate levels in each sample were slightly below the permitted maximum for concrete mixing. Elevated sulfate ($SO_2{}^4$) content leads to the formation of calcium sulfoaluminate (ettringite) during cement hydration, causing concrete expansion, uneven cracking, and subsequent strength loss (Yilmaz et al., 1997; Dhir and Newlands, 1992; Su et al., 2002). This reaction often accompanies a notable volume increase.

Table 2 displays the identified inorganic compounds. It was found that these chemicals varied from one sample to another, with BW having the highest levels for the majority of the criteria. The inorganic components in all samples fall within acceptable limits. According to IS456 (2012), the combined amount of these chemicals must not exceed 3000 mg/l for water to be suitable for concrete mixing. By delaying cement hydration, excessive concentrations of inorganic components may cause the fresh mix to firm up more slowly and, in some cases, significantly

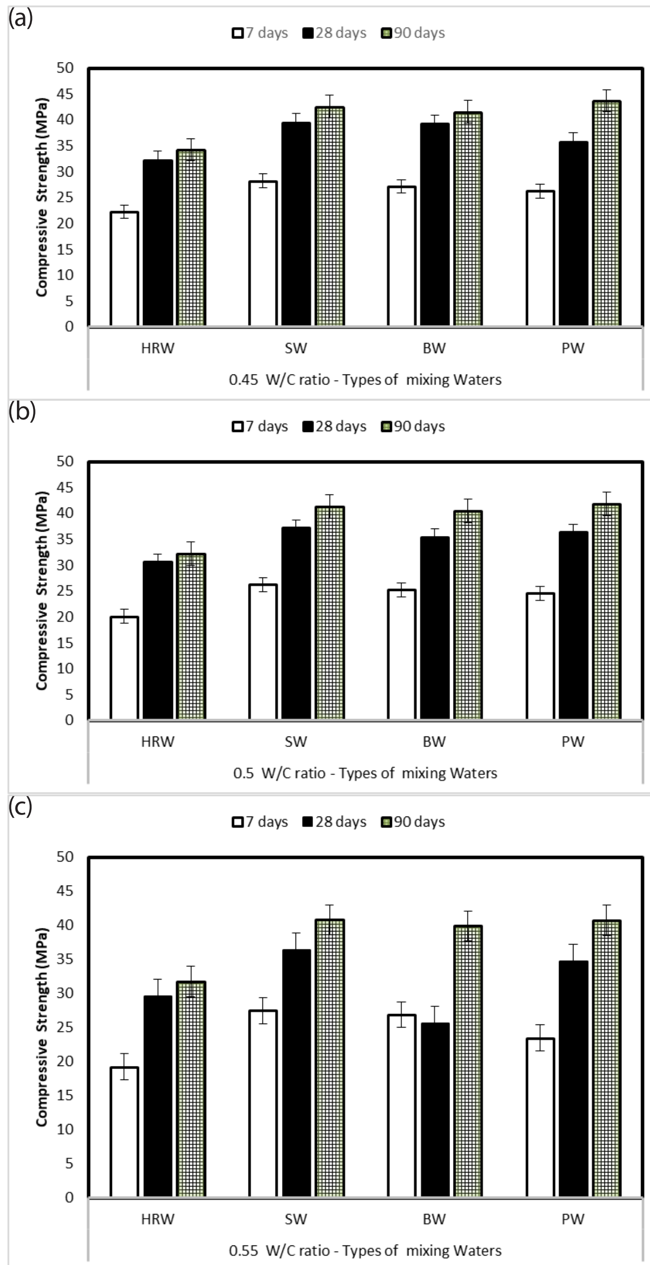

Figure 4: Compressive strength for different W/C ratio of concrete

lessen the strength of the hardened concrete.

Initial and Final Setting time of Cement Paste

Table 3 displays the findings of an initial setting time test conducted on samples of cement pastes prepared using mixing for HRW, SW, BW and PW containing different concentrations of TDS. As TDS concentration increases, cement sets more quickly. The two components can be to blame for cement setting settings more quickly. The hydration reaction of cement first moves along more swiftly when chloride is present as a part of the TDS [J. Cheung]. Second, the presence of more solid particles increased the contact between cement grains by reducing their initial proximity [C.F. Ferraris]. The initial setting time for a paste made with potable water (312.53 ppm TDS) was 92 minutes, and it slightly decreased as TDS concentration increased. Paste made with HRW (211.2 ppm), SW (569.55 ppm), and BW (600.3 ppm) had initial setting times of 98, 95, and 90 minutes, respectively. At TDS concentrations of 211.2 and 569.55 ppm, the loss in the initial setting time was 3 to 5 minutes, within the permissible tolerance according to ASTM C94.

Workability Test

Table 4 displays slump and compaction factor test results, ranging between 70 and 120 mm. Using stormwater in concrete mixing can increase slump due to its properties. Research by Chatveera and Lertwattanaruk (2009) showed that solid particles in mixed water affected slump, likely due to higher water value. Their study found an increased slump in mixtures with HRW, SW, and BW compared to those with PW.

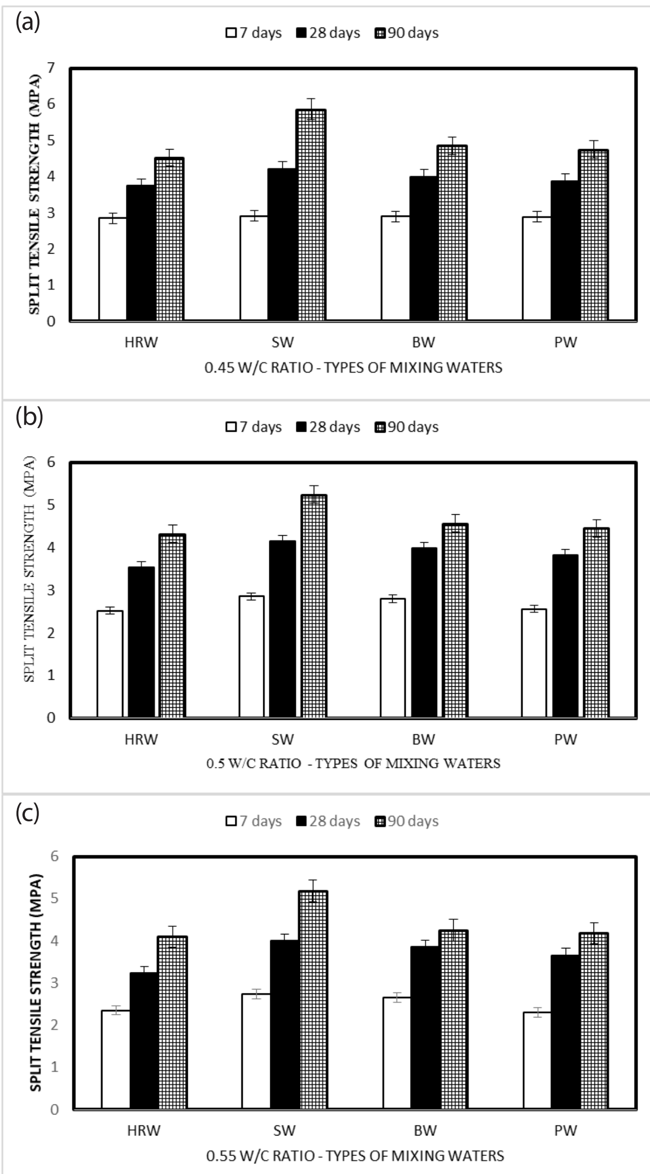

Figure 5: Split tensile strength for different W/C ratio of concrete

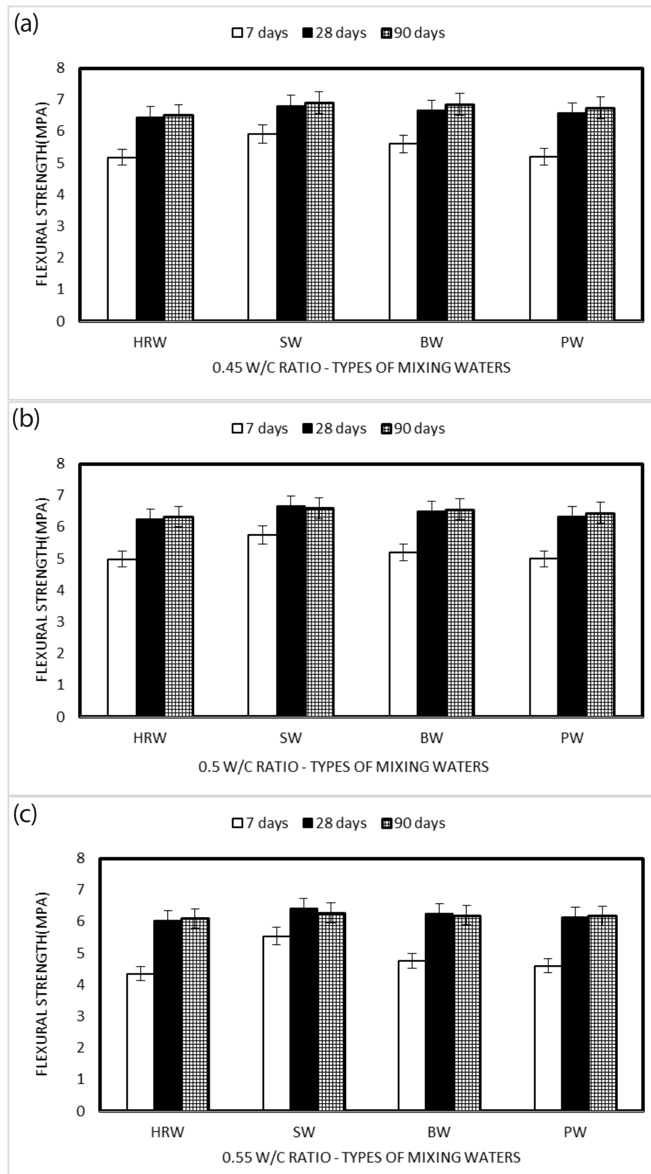

Figure 6: Flexural strength for different W/C ratio of concrete

Table 5: One-way ANOVA analysis results

Response factor		Types of water		W/C ratio		Curing days	
		F-value	p-value (<0.05)	F-value	p-value (<0.05)	F-value	p-value (<0.05)
Workability properties	Slump	0.63	0.614	12.61	0.002	--	--
	Compaction factor	2.53	0.135	4.53	0.045	--	--
Mechanical properties	Compressive strength	2.12	0.117	0.52	0.597	46.26	0.000
	Split tensile strength	0.89	0.458	0.60	0.556	92.38	0.000
	Flexural strength	0.9	0.512	0.70	0.650	94.58	0.000

Compressive Strength

Using HRW, SW and BW for casting and curing concrete samples had a relatively minor impact on the strength when compared to potable water concrete. Compressive strength results for the samples produced and cured with HRW, SW, BW, and PW with cement content at 438, 394, and 358 kg/m^3 without superplasticizer. The 28-day cube strength of HRW, SW and BW was found to be greater than 90% when compared to the cube strength of PW. The higher compressive strength associated with SW and BW concrete can be explained They have different physical and chemical properties of solids and chloride ions, oils, organic matter, and fine particles are crucial factors that might promote the strength of concrete. Instead of can fill cracks in the concrete matrix, reducing the number of voids and enhancing the strength properties. The strength of early concrete was increased by an increase in calcium and sodium chlorides present in water (Lee et al., 2001). However, the BOD and COD levels of the treated wastewater led to a 6% reduction in compressive strength. (Mehrdadi et al., 2009). By comparing the compressive strengths of specimens made with the HRW, SW, BW, and PW, water quality should then be clarified using performance tests like compressive strength. There isn't much difference between the HRW, SW, and BW concrete when comparing potable water concrete. findings that are practically identical. Comparing samples of potable water to HRW, SW, and BW samples with varied W/C ratios 0.45, 0.5, 0.55. Compressive strength decreases as the W/C ratio rises.

Split Tensile Strength

The results show that for M30 grade concrete, the split tensile strength ranged from 3.75 to 4.20 MPa. Among the different water types, SW concrete had the highest strength at 4.20 MPa, while HRW concrete had the lowest at 3.75 MPa. The suitability of water can be identified by carrying out performance tests such as split tensile strength, then water quality should be clarified by comparing the split tensile strength of specimens made with the HRW, SW, BW, and PW. With the comparison of potable water concrete not much variation between the HRW, SW, and BW concrete. Similar results were obtained for the 7 days' split tensile strength of concrete samples with different water-cement ratios (0.45, 0.5, 0.55) using HRW, SW, BW, and PW. The strengths in MPa were: HRW (2.85, 2.52, 2.35), SW (2.91, 2.85, 2.74), BW (2.9, 2.8, 2.65), and PW (2.88, 2.56, 2.3). higher water-cement ratios led to decreased split tensile strength in all samples.

Flexural strength

The study found that the flexural strength of M30 grade concrete, using HRW, SW, BW and PW, ranged from 4.35 to 6.92 MPa. (Figures). SW concrete mix had the highest split tensile strength of 6.92 MPa among all varieties of M30 grade concrete mixes, and HRW concrete mix had the lowest value of 4.35 MPa. Flexural strength tests can assess water suitability. Comparing HRW, SW, BW, and PW, the results were very similar. Like flexural strength, increasing the W/C ratio decreased concrete's flexural strength in all samples.

Conclusions

Conclusions The following findings are reached based on the experimental settings seen in this investigation.

- The HRW, SW, BW, and PW employed in this study all had physical and chemical characteristics that fell within acceptable ranges recognized by pertinent standards. The relative higher alkalinity found in BW, however, didn't seem to have any impact on the concrete's ability to generate strength.
- The setting time and workability of freshly mixed concrete including HRW, SW, BW, and PW were notably satisfactory and moderate. Therefore, it was found that the presence of solid particles in the water used to mix the concrete affected slump.
- Concrete made with SW and BW had higher strength (compressive, split tensile, and flexural) compared to PW-prepared concrete. Additionally, the SW concrete's strength was surprisingly higher than the potable concrete's. This suggests that SW can be utilized to mix concrete. This might lessen the requirement for freshwater use.
- Harvested rainwater and stormwater are emerging as imminent alternatives for water resource use, particularly in the era of mega-city development. Indian standards focus on health-oriented, chemical, economic, and environmentally-directed guidelines for their reuse.

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Ethical Standards

This article does not contain any studies involving human or animal subjects.

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