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Research Article

Statistical analysis of the effect of different water for mixing and curing on the mechanical properties of M-sand concrete

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Abstract

The production of concrete involves the consumption of a large quantity of water, from the mixing process to the curing stage. Due to the scarcity of potable water, various waste and treated water sources are utilized in concrete production. The quality of water used affects the strength parameters of the concrete produced, as well as its properties during the curing stage. This study conducted experimental and statistical analyses to examine the feasibility of using different types of water in the concrete production process. Three types of water (tap water, grey water, and reverse osmosis (RO) waste water) were used for mixing and curing, and their chemical properties were analyzed using standard laboratory procedures. Concrete of grade M30 was prepared using all three types of water, and nine different mixes were created to test the mechanical performance of the concrete produced using different water types. The mechanical properties, such as compression, split tensile, and flexural strength, were analyzed experimentally to determine the practical impact of the water type used for mixing and curing. The results of the mechanical tests showed that using RO waste water for both mixing and curing improved the mechanical properties of the concrete. However, statistical analysis revealed that the use of different types of water for mixing and curing had no significant effect on the strength parameters of the concrete.

Keywords

RO waste water, Grey water, Mechanical strength, Statistical analysis, M-sand concrete.

1.Introduction

The presence of water is vital for human survival on this planet. However, only a small fraction of the water on Earth is usable for essential human activities. In India, which is home to almost 16.5% of the world's population, only 4.5% of the world's water resources are available. The increasing demand for water due to population growth and the development of more industries has further exacerbated the water scarcity issue [1]. The availability of clean drinking water is a major challenge faced by almost every part of the world. In 2009, the water requirement for industries was approximately 800 billion m3 and is projected to increase to 1500 billion m3 by 2030 [2]. Several regions in India, including major cities such as Chennai and Bengaluru, are facing water scarcity issues due to various reasons, including inadequate rainfall during the monsoon season.

India, in its developing phase, has a high demand for water, making it the top user of groundwater. India draws more groundwater compared to other countries such as the United States and China [3]. Studies suggest that around 1800 million people globally will face water shortages by the end of 2025 [4]. Concrete production requires a significant amount of water, with 500 litres consumed in the production of 1 m^3 of concrete. The concrete production industry uses approximately 1 trillion m^3 of fresh water every year, including for cleaning raw materials and equipment [5]. The curing process of concrete also consumes fresh water, leading to a significant environmental impact. To reduce the use of fresh water in concrete production and curing, alternative methods should be considered [6].

In recent decades, there has been substantial development in industrial and household wastewater output due to population growth and industrialization rates. However, inadequate control facilities for wastewater treatment and recycling in developing

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countries like India have resulted in the direct discharge of wastewater into contaminated water bodies, leading to land, river, and other freshwater body pollution [7]. This raises concerns about securing water sources in developing countries. The incorporation of wastewater in the process of curing and production of concrete can lower pollution impacts on water bodies, reduce the impact on drinking water availability, and minimize waste production in industries [8].

Concrete can be produced using water that is not suitable for human consumption [9]. However, the production process generates a significant amount of wash water, and an empty ready mix concrete truck drum must be cleaned with water to prevent remaining concrete from setting. This cleaning process can require 150-300 gallons of water, which could become a serious issue for ready-mix plants in the future [10]. Unfortunately, the resulting wash water is often drained directly onto open land, leading to pollution and elevated potential of hydrogen (pH) levels that can harm the surrounding environment. Consequently, many countries have banned the untreated disposal of waste water to mitigate these negative impacts.

Recent studies have shown that various types of wastewaters can be used in concrete production and curing processes, serving multiple purposes. Utilizing treated water from wastewater treatment plants has been found to increase compressive strength and cement paste setting time compared to potable water [11]. Furthermore, treated wastewater from concrete production plants does not significantly alter the rheological parameters of fresh concrete, nor does it have a significant impact on mechanical properties when used for curing purposes [12]. Thus, it is feasible to use properly treated wastewater in concrete manufacturing without any negative impacts. An increase of 8 to 17% in compressive strength was observed in specimens tested after 28 days, with the use of 25-100% treated wastewater in preparation [13]. Incorporating wastewater in the process of concrete production and curing can reduce environmental disposal consequences, minimize the use and waste of fresh water, and ultimately reduce the cost of construction [6].

The objective of this study is to investigate the impact of different types of water used for mixing and curing on the mechanical performance of concrete. The study specifically focuses on the use of tap water, grey water, and reverse osmosis (RO) waste water for mixing and curing concrete. Statistical analysis was conducted to examine the influence and contribution of each water type on concrete performance.

The present study is organized into six sections. The introduction section provides an overview of the research objective and its significance, along with the problem statement. The literature review section presents the previous findings and observations related to the research topic. The materials and methods section describes the characteristics of materials used for the study and outlines the testing procedures undertaken to achieve the research objectives. The results section summarizes the experimental findings. The discussion section interprets the results and compares them with previous research outcomes. Finally, the conclusion and future work section summarizes the key findings of the study.

2.Literature review

Various studies, however, reveal that employing different types of water in concrete produces effective results. However, mechanical behaviour of the concrete is found with some statistical evidence for concrete prepared by mixing and curing purposes with various water sources.

Thangamani (2023) [14] focuses on using neem leaves ash as a concrete additive, in varying percentages (0-15%) while using M20 mix design as a reference. Both ordinary and magnetized water (MW) were used in the concrete mix. Results showed that 10% replacement of neem leaves ash with magnetic water resulted in the highest strength. This percentage was determined as the optimal replacement.

Zhang and Zhu (2023) [15] investigated calcium aluminate cement (CAC) mechanical properties and lifespan during seawater immersion and dry-wet cycle circumstances. CAC's mechanical properties declined with age and exposure temperature. After 12 months in a dry-wet cycle at 60 °C, CAC's compressive strength dropped 14.4%, elastic modulus 13.0%, and axial compressive strength 16.9%. This performance drop was caused by chemical interactions between concrete's internal hydration products and seawater's corrosive ions.

Wang et al. (2023) [16] studied textile reinforced engineering (TRE) to saltwater sea-sand concrete interfacial bonding in a chloride salt dry-wet condition using a single shear test. After 270 days of environmental activity, the dry-wet environment had 15.94% greater interfacial average bond strength than the immersion environment, and TRE thickness improved bond strength. Smaller TRE thicknesses had smoother load-slip curves and greater interfacial fracture energy at different rates during dry-wet cycles.

Fattouh et al. (2023) [17] found in his research that adding steel fiber or steel fiber with silica fume to concrete improves compressive strength and flexural behavior, with the strongest results seen in tap water-cured concrete. Compressive strength increased by 23-25% from 7 to 28 days for tap water-cured concrete and 23-26% for SW-cured concrete. SW-cured concrete had decreased compressive strength of 11-18% compared to tap water-cured concrete.

Sevim et al. (2023) [18] examines in his study that the impact of magnetized water on the properties of fly ash (FA)/blast furnace slag (BFS)-based cement composites. 22 different mixture groups were made using tap water and MW, and properties such as setting times, consistency, compressive strength, water absorption, and chloride permeability were tested. Results show that MW improves the properties of the cement composites, and using up to 25% FA/BFS in MW-mixed composites is recommended.

Lardhi and Mukhtar (2023) [19] examines the efficacy of various waste coarse aggregates, such as recycled aggregate and electric arc furnace steel slag, in freshwater and seawater-mixed concrete mixes for radiation shielding. Ten concrete mixtures were developed and produced to address material sustainability by combining different types of normal and waste coarse aggregates with different mixing waters while keeping the cement amount and water/cement ratio constant. All of the mixes had compressive strengths between 30 and 49.8 MPa, making them suitable for use in structural concrete.

Preethi et al. (2022) [20] examines compressive, tensile, and flexural strengths of concrete formed with magnetic water after being exposed to magnetic field treated water (MFTW). Testing reveals that samples of concrete made using magnetic water are more durable than those made with regular water. Furthermore, compared to conventional concrete, steel fibre reinforced concrete (SFRC) is much less likely to crack and spread once it does. Because of their high extensibility and tensile strength, fibre composites are able to hold the matrix together despite severe damage. When compared to regular concrete, this gives the fibre composite more post-cracking ductility.

Mohe et al. (2022) [21] experimentally assessed the setting time of cement and mechanical properties along with the workability for samples prepared with water collected from rain water collection, river and deep-well. The impacts on samples tested for compressive strength were observed with 90% of control mix sample strength for 7 and 28 days.

Saha et al. (2022) [22] studied the impact of deionised water, algae containing water and alkaline substance on concrete and mortar samples for compressive strength and setting time. They have concluded in their study that Na2CO3 presence higher than 10g/L reduces compressive strength as well as initial and final setting times. Also, NaHCO3 presence higher than 4g/L reduces compressive strength, whereas, it tones up the initial as well as the final setting times.

Mangi et al. (2021) [23] analysis of existing data and recommendations revealed that natural seawater can have a negative impact on concrete. However, the use of supplementary cementitious materials such as copper slag, coal bottom ash, and FA can enhance resistance. Additionally, corrosion inhibitors or resistant reinforcement can prevent reinforcement corrosion. The study found that incorporating these components improves the strength and durability of concrete in coastal conditions and suggests potential areas for future research.

Gupta et al. (2021) [1] have experimentally studied various physical as well as the mechanical properties of concrete with utilisation of various types of water. Their conclusions revealed that 2.1% increment were observed in mechanical properties when grey-water is incorporated, whereas, 0.51% decrement were observed in strength when the pond-water were incorporated, furthermore, comparing to tap water 6.9% strength enhancement were observed when sewage water was incorporated after treatment.

Varshney et al. (2021) [24] have investigated the durability, rheological properties along with the physio-chemical parameter analysis of waste water for impact assessment on concrete. After the incorporation of the waste water the decomposing agents were discerned and effects on concrete were assessed. The workability is found to be lowered and compressive strength observed with enhancement due to the incorporation of wash water. Strength properties are impacted on very minor scale when secondary treated sewage water and the wastage water from industries were utilised. When mixing process is done by utilisation of wash water, reclaimed water feasible results obtained for strength, also similar trend were observed for tertiary treated and polyvinyl aerated waste (PVA) water.

De et. al. (2020) [2] have studied the recycle water that has been obtained from the washing process of the mixer trucks, they have analysed the concrete as well as the cement paste properties. For this whole and partial substitution were incorporated for potable water. Their finding depicted 92% of strength achievement after 28 days testing of sample prepared with 100% recycled water and 94% for the samples prepared with the 50% recycled water.

Khatibmasjedi et al. (2020) [25] investigated seawater-mixed concrete was found to function equally to or better than concrete made with potable water throughout a wide range of environmental conditions. In addition to having a greater compressive strength when exposed to seawater at 60°C, the electrical resistivity and calcium hydroxide leaching of the seawater-mixed concrete were both improved by 33 percent compared to the reference concrete. From these findings, it appears that concrete made with seawater could be used successfully in underwater and maritime settings.

Dasar et al. (2020) [26] examined seawater-exposed reinforced masonry sample durability. Ordinary Portland cement (OPC), ground granulated blast-furnace slag (GGBFS), and reinforced concrete with plain, epoxy-coated, or stainless-steel bars were examples. They were lab-wet-dried to replicate tidal/splash conditions. Electrochemical methods assessed corrosion. Seawater cured corrosion better than mixing. GGBFS outperformed OPC, and epoxy-coated and stainless-steel bars outperformed plain steel bars in corrosion resistance. The study emphasizes the need for seawater concrete mixing research.

Guo et al. (2020) [27] researches a sustainable and environment concrete built from sea sand and seawater. It examines the impact of these ingredients on the concrete's mechanical properties and finds that incorporating seawater in particular increases the strength of the concrete at early stages, but may impede strength enhancement over time. Despite this, the overall mechanical performance of the seawater-infused concrete is similar to traditional concrete. The study suggests that using sea sand and seawater in concrete production is a promising way to make it more environmentally friendly.

Meena and Luhar (2019) [8] conducted a study on the use of treated waste water as an alternative to potable water in concrete production. They evaluated the mechanical properties and durability of samples prepared with the incorporation of treated waste water. The study found that samples prepared with tertiary treated waste water substituted for tap water at 100% achieved 85-94% of the strength of the control mix.

Mane et al. (2019) [28] investigated the use of treated sewage water in concrete production after conducting chemical tests to ensure that impurities were within permissible limits. The study found that concrete made with treated sewage water had higher compressive strength than that made with tap water. The use of treated sewage water in concrete production can promote sustainable development through water recycling and the conservation of fresh water.

Ghrair et al. (2018) [29] aims to use grey water in concrete and mortar to conserve fresh water. Results show increased setting time and decreased concrete slump with both treated and raw grey water (RGW), no effect on mortar properties, and improved compressive strength in mortar and concrete at 7 days of curing with treated grey water (TGW). However, RGW had slight negative impact on compressive strength at all curing ages.

Zheng et al. (2018) [30] by contrasting the mechanical characteristics and permeability resistance of sea water curing (SWC)-cured green artificial reef concrete (GARC) with those of SWC-cured and fresh water curing (FWC)-cured GARC, we determined the viability of SWC in coastal environments FWC. The results showed that the strength of GARC was virtually unchanged under SWC, although the permeability marginally increased. Microstructure research indicated that SWC is an efficient method for curing GARC in maritime settings.

Fattah et al. (2017) [4] found that replacing cement with GGBFS and water with reject brine can significantly reduce concrete's carbon footprint. Replacing 50% of the cement with GGBFS and using reject brine as water boosted concrete strength by 16.5% and reduced CO_2 emissions by 176 kg and CO_2 equivalents by 3.5 kg per cubic meter. This study demonstrates that using GGBFS and reject brine in concrete production has environmental and economic benefits.

Shi et al. (2015) [31] found in his study that adding 0-6% metakaolin and mixing with seawater improves the compressive strength, hydration, and microstructure of concrete. The combination of both methods led to a 52% increase in compressive strength, with an improvement in the pore structure and chloride resistance. Overall, the use of metakaolin and seawater can enhance the performance of concrete.

Overall, the literature on the use of various forms of water in concrete building indicates that sea water and magnetic water can be utilized in some instances, but they can also have detrimental effects on the strength and longevity of the concrete. Although treated water and RO waste water can be used, they are not as readily available or cost-effective as fresh water. Grey water, or recycled waste water, has been investigated as a potential replacement for fresh water in the making of concrete, with mixed results. Some studies have indicated that grey water can be successfully used in the manufacturing of concrete, while others have discovered that it can have a negative impact on the strength and durability of the concrete. More research is needed to completely understand the impacts of employing various types of water in concrete building, as well as to provide standards for their safe and effective use.

3.Material and methodology

According to IS 383, the binding material utilized in this experimental work is pozzolana Portland cement, coarse aggregate was used for sample preparation, and manufacturing sand was used instead of natural sand. The gradation of coarse aggregate (20 mm and 10 mm) and manufacturing sand (M-sand) is validated in accordance with IS 383. *Figure 1* depicts images of fine and coarse aggregate. *Figure 2* depicts the particle size distribution of an individual aggregate. To obtain the desired gradation as per IS 383 for the preparation of appropriate quality concrete, coarse aggregate of sizes 10 mm and 20 mm are combined in equal proportions. The physical properties of raw ingredients are depicted below in the *Table 1*. Three different types of water have been utilized for mixing and curing purposes those chemical properties are mentioned in *Table 2*. From *Table 2* it can be depicted that quality water used for this research are fulfilling the conditions specified by Indian standards. *Figure 3* represents the proposed methodology used in this research. As shown in *Figure 3*, concrete grade of M30 is prepared by using different type water for mixing and curing purpose. These prepared concretes were tested as per testing program discussed in section 3.2.

Figure 1 Picture of M-sand and coarse aggregate

Table 1 Physical properties of raw material

Property	Cement	Fine aggregate	Coarse aggregate (10 mm)	Coarse aggregate (20 mm)
Specific Gravity	3.12	2.61	2.71	2.69
Water Absorption (%)	-	1	0.34	0.32
Fineness Modulus	-	2.23	4.98	7.22

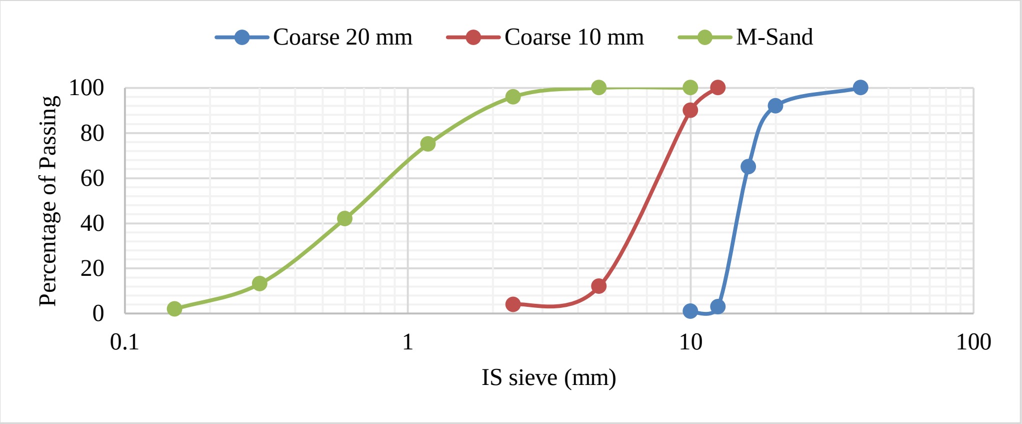

Figure 2 Particle size distribution curve of aggregate

Table 2 Chemical properties of various water type

Properties	Tap water	Grey water	RO waste water
pH	7.54	7.83	7.21
Biochemical oxygen Demand (BOD) (mg/l)	-	20	-
Chlorides (mg/l)	442.3	276.23	456.5
Hardness (mg/l)	132	219	128
Turbidity (NTU)	0.11	0.421	0.154

3.1Mix proportioning

In this study, the influence of water type for mixing and curing of concrete was investigated using M30 grade. *Table 3* presents the mixing details for different mixes with different types of water used for concrete mixing. The workability of fresh concrete, which determines the ease of preparation of concrete, was measured in slump value. In this research, the workability of concrete for all three types of mixing water was kept constant and adjusted by varying the superplasticizer dosage. *Table 3* also displays the individual dosage of superplasticizer required to achieve a slump of 100-110 mm. The variation seen in superplasticizer dosage is due to the quality of water, which influences the workability of the mixes. Concrete samples were prepared using the raw ingredients in the quantities shown in *Table 3*.

3.2Testing program

Mechanical characteristics of concrete were tested in accordance with IS 516:1959 and IS 5816:1999. Each combination was tested with three specimens for compressive, tensile, and flexural strength. The standard sample size for flexural strength was 500×100×100 mm, for compressive strength was 100×100×100 mm, and for tensile strength was 150 mm diameter and 300 mm height. A total of nine samplings were conducted in this research to examine the effect of water type used for mixing and curing on the behaviour of concrete. The preparation of samples was carried out in three stages. In the first step, tap water was used for mixing the concrete, and the prepared samples were demoulded and kept in tap water, grey water, and RO waste water curing tank individually. Similarly, in stage 2 and 3, mixing with grey water and RO waste water was used for mixing purpose, respectively. After that, the samples were marked and kept in respective curing tanks. The marking for individual mixes that were mixed and cured with different water types is mentioned in *Table 4*. The mixing and casted samples for testing are shown in *Figure 4*, while *Figure 5* displays the setup and machinery for compression and flexural tests. The samples were cured for 7 and 28 days in respective water tanks after testing was done. To inspect compressive and tensile strength, cube and cylinder samples were tested on a compressive testing machine with uniform loading of 140 kg/cm2/min. Meanwhile, the flexural strength of beam samples was inspected by four-point bending setup as per standard recommendation. The statistical analysis of mechanical strength results of different concrete mixes was done using the analysis of variance (ANOVA) method. The ANOVA analysis was carried out with MiniTab software. The ANOVA test was conducted to inspect the contribution level of ceramic and granite waste over the properties of concrete. The p-value indicates the significance of the independent variables on the dependent variables. If the p-value is less than 0.05, then the independent variable will be considered significant.

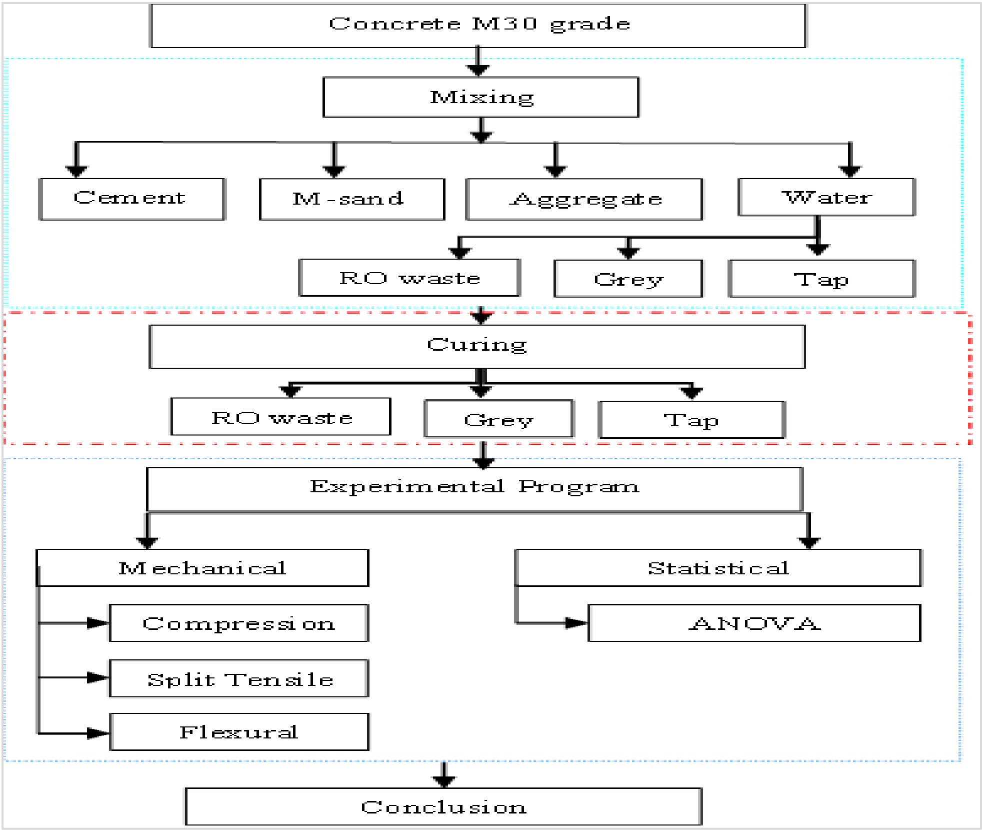

Figure 3 Proposed methodology for study

Figure 4 Sample mixing and casting with different type of water

Figure 5 Testing of samples

Table 3 Mixing Details for M30 concrete with different water type used for mixing in kg/mm^3

Water type	Cement (kg)	M-Sand (kg)	Coarse aggregate (kg)		Water (kg)	SP dosage (kg)
			20 mm	10 mm		
Tap water	392	613	691	455	177	3.14
Grey Water	392	613	691	455	177	4.22
RO waste	392	613	691	455	177	3.25

Table 4 Sample details for mixing and curing

Mix ID	Water type used for	
	Mixing	**Curing**
TWTW	Tap Water	Tap Water
TWGW	Tap Water	Grey Water
TWROW	Tap Water	RO Waste
GWTW	Grey Water	Tap Water
GWGW	Grey Water	Grey Water
GWROW	Grey Water	RO Waste
ROWTW	RO Waste	Tap Water
ROWGW	RO Waste	Grey Water
ROWROW	RO Waste	RO Waste

4.Results

4.1Slump test

The slump value of fresh concrete is inspected to ensure the required workability of concrete. For this study, a workable concrete with a slump value of 100-110 mm is desired as many constructions works require this exact slump value for molding of concrete. The slump value for all three mixes prepared with TW, grey water, and RO waste water is adjusted by varying the dosage of superplasticizer. The dosage of superplasticizer for individual mixes is shown in *Table 3*. It can be observed that the grey water mixed concrete demands a higher amount of superplasticizer to achieve the desirable slump value compared to the other mixes.

4.2Mechanical strength

The feasibility of using any type of water for mixing and curing concrete is evaluated by considering its preliminary impact on the mechanical strength of the concrete mix. The strength of various mixes is then compared to that of a conventional mix. The mechanical strength of concrete was evaluated through compression, split tensile, and flexural strength tests. The results of compressive, split tensile, and flexural strength tests are presented in *Figures 6*, *7*, and *8*, respectively. The averages of three specimen results are presented to increase the accuracy of the analysis. These results are used for statistical analysis to further understand the impact of water type on the properties of the concrete mix.

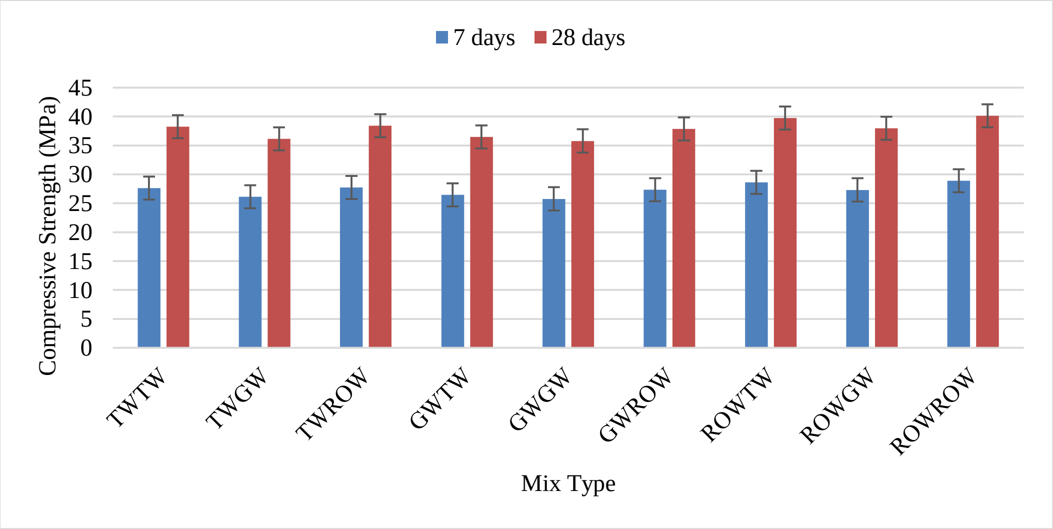

Figure 6 Compressive strength with different type of water used for mixing and curing

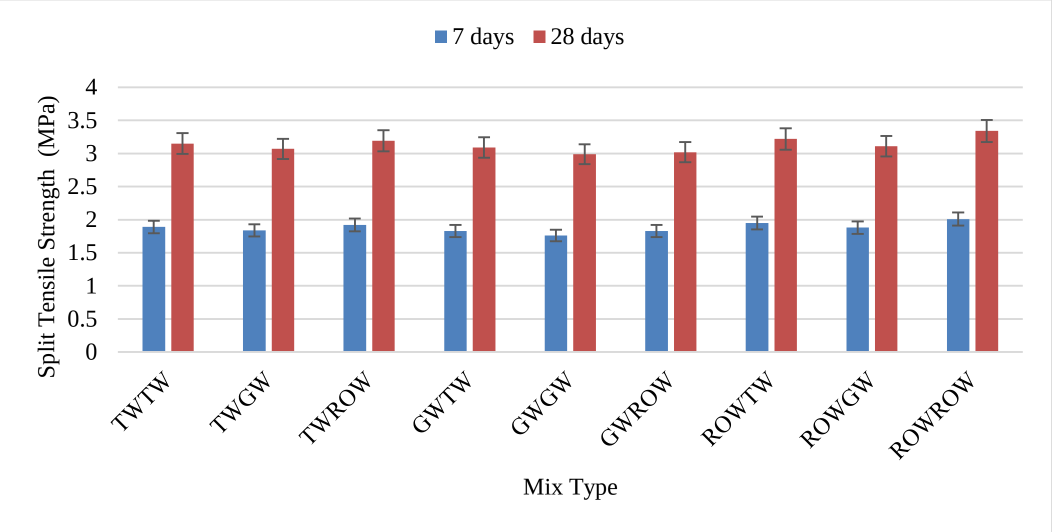

Figure 7 Split tensile strength with different type of water used for mixing and curing

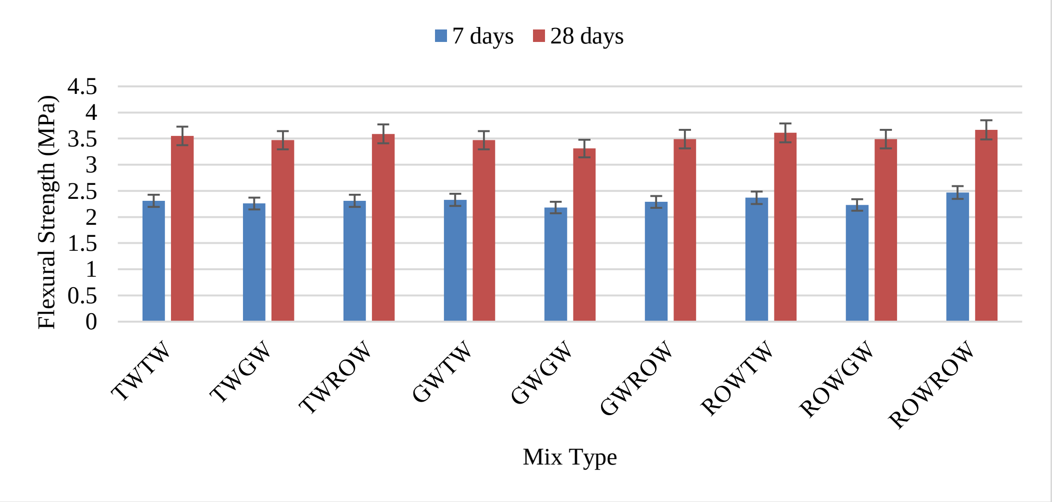

Figure 8 Flexural strength with different type of water used for mixing and curing

4.3ANOVA analysis

Statistical analysis was conducted on the outcomes of mechanical strength tests to examine the influence of the type of water used for mixing and curing the concrete. Two-way ANOVA analysis was performed on the individual outcomes of compression, tensile, and flexural strength at both 7 and 28 days. This method was used to estimate the contribution of the type of water used for mixing and curing to the mechanical behavior of concrete. Interaction effects between the type of water used for mixing and curing were also estimated to better understand their influence on concrete properties. *Table 5* shows the outcomes of statistical analysis, including the contribution level for better understanding. The interaction effect for 7 days and 28 days compressive strength is presented in *Figure 9* and *Figure 10*, respectively. Similarly, *Figure 11* and *Figure 12* display the 7 days and 28 days tensile strength, and *Figure 13* and *Figure 14* present the interaction effect for 7 days and 28 days flexural strength.

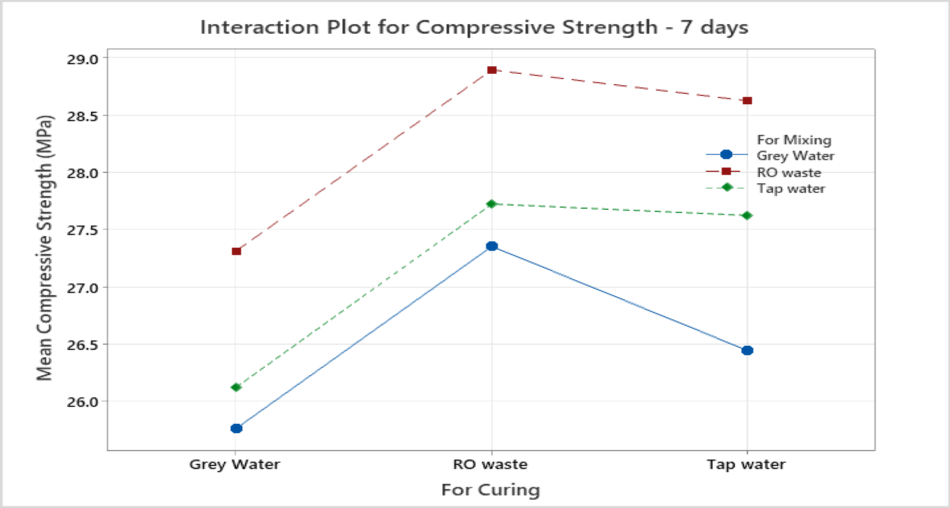

Figure 9 Interaction effect plot of 7 days compressive strength with different type of water used for mixing and curing

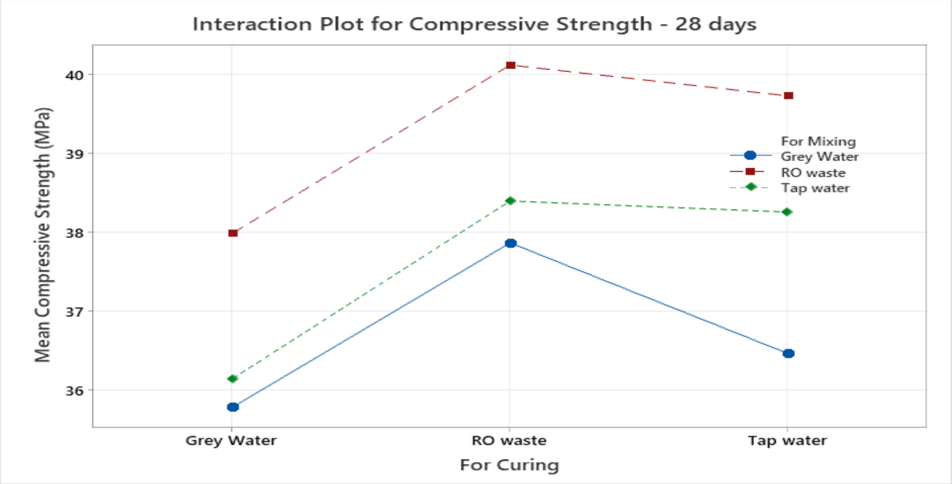

Figure 10 Interaction effect plot of 28 days compressive strength with different type of water used for mixing and curing

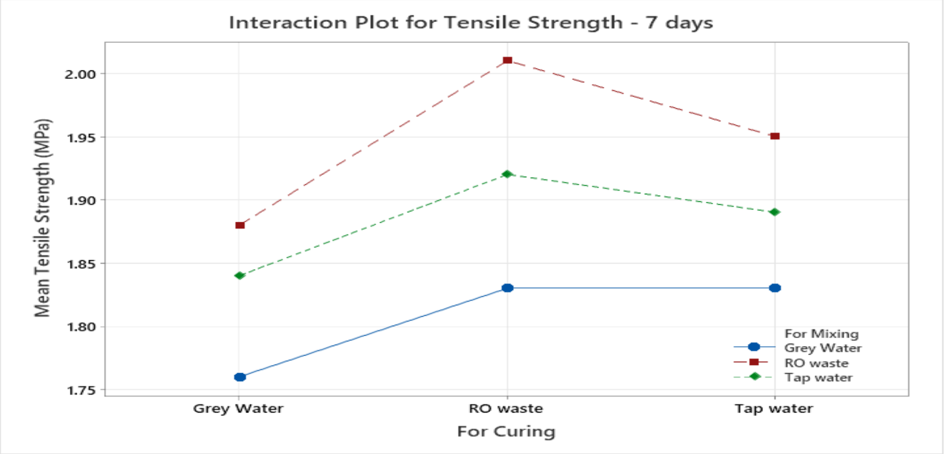

Figure 11 Interaction effect plot of 7 days tensile strength with different type of water used for mixing and curing

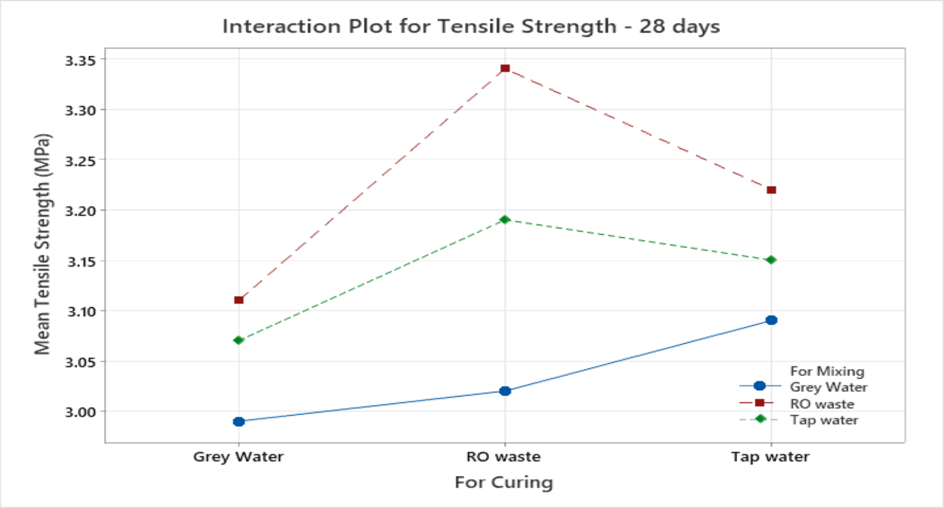

Figure 12 Interaction effect plot of 28 days tensile strength with different type of water used for mixing and curing

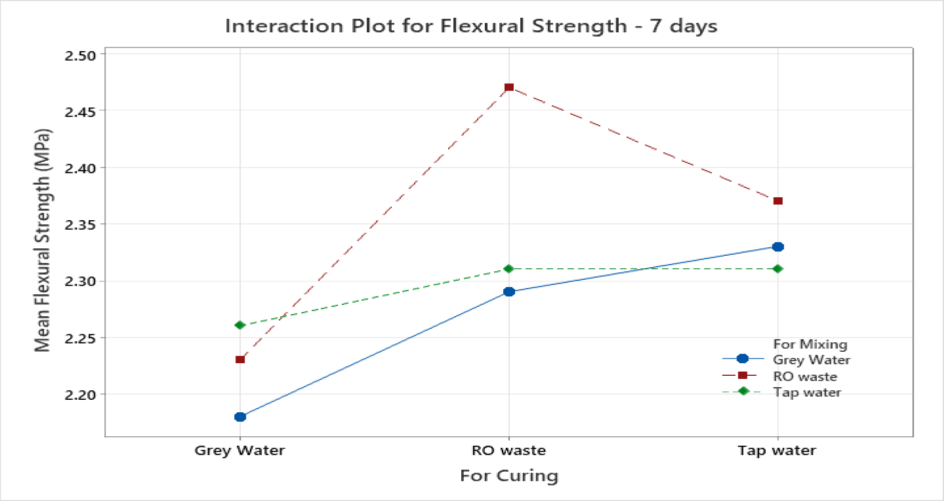

Figure 13 Interaction effect plot of 7 days flexural strength with different type of water used for mixing and curing

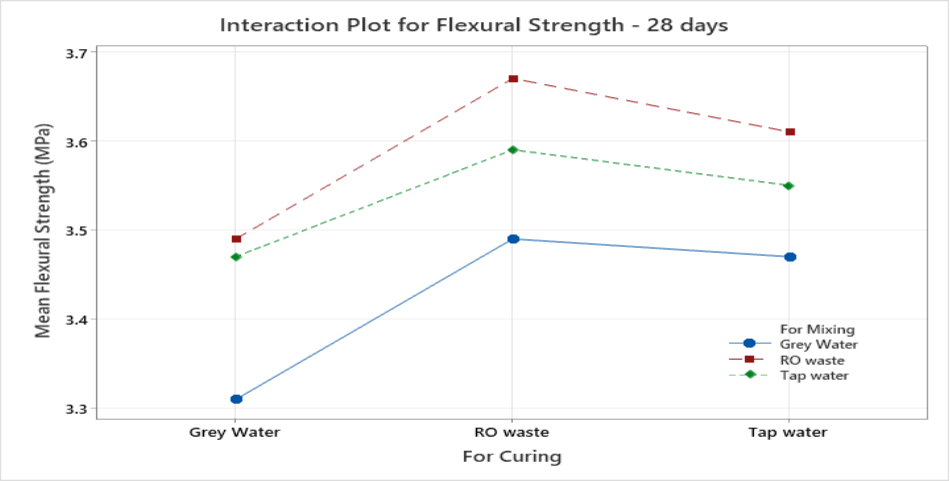

Figure 14 Interaction effect plot of 28 days compressive strength with different type of water used for mixing and curing

Table 5 Statistical analysis on mechanical strength of concrete produce with various water type

Parameter		Variable	Degree of freedom	Sum of Square	P-Value	Contribution
Compressive Strength	7 days	For Mixing	2	14.2	0.59	5.4%
		For Curing	2	12.2	0.64	4.6%
		For Mixing * For Curing	4	0.73	1	0.3%
		Error	18	235	-	-
		Total	26	262	-	-
	28 days	For Mixing	2	30.6	0.52	6.7%
		For Curing	2	22.0	0.62	4.8%
		For Mixing * For Curing	4	2.0	1	0.4%
		Error	18	402	-	-
		Total	26	457	-	-
Split Tensile Strength	7 days	For Mixing	2	0.09	0.50	7.1%
		For Curing	2	0.04	0.72	3.3%
		For Mixing * For Curing	4	0.00	1	0.3%
		Error	18	1.11	-	-
		Total	26	1.25	-	-
	28 days	For Mixing	2	0.16	0.63	4.8%
		For Curing	2	0.08	0.80	2.3%
		For Mixing * For Curing	4	0.04	1	1.1%
		Error	18	3.09	-	-
		Total	26	3.37	-	-
Flexural Strength	7 days	For Mixing	2	0.04	0.82	2.1%
		For Curing	2	0.09	0.62	5.0%
		For Mixing * For Curing	4	0.04	1	1.9%
		Error	18	1.68	-	-
		Total	26	1.84	-	-
	28 days	For Mixing	2	0.13	0.74	3.1%
		For Curing	2	0.12	0.75	3.0%
		For Mixing*For Curing	4	0.01	1	0.2%
		Error	18	3.90	-	-
		Total	26	4.16	-	-

5.Discussion

5.1Slump test

Table 3 indicates that greywater-mixed concrete has a higher demand compared to other mixes in achieving a similar slump value. This is primarily due to the higher hardness value of greywater compared to other water types. Additionally, the presence of chloride ions in water can affect the workability of concrete. A higher amount of chloride requires less superplasticizer for the concrete mixture.

5.2Mechanical strength

Effect of mixing water

In this scenario, various types of water from known sources (such as regular tap water, grey water, and RO waste water) were mixed to make concrete, but only regular tap water was used to cure the concrete. After 28 days of curing, the variation in compressive, tensile, and flexural strength for grey water mixed concrete, with respect to tap water mixed samples, was -4.7%, -1.9%, and -2.3%, respectively. For RO waste water mixed concrete, the variation in strength was 3.8%, 2.2%, and 1.7%, respectively. Similarly, for all grey water cured samples, the variation in strength with respect to tap water mixed samples was -1.0%, -2.6%, and -4.6%, respectively. For RO waste water cured samples, the variation in strength was -1.4%, -5.3%, and -2.8%, respectively, for grey water mixed samples and 4.5%, 4.7%, and 2.2%, respectively, for RO waste water mixed samples compared to tap water mixed concrete. The results indicate a reduction in mechanical strength for grey water mixed concrete under all curing conditions. This is primarily due to the higher hardness and turbidity value of grey water, which results in the formation of more voids. Mohe et al. [21] suggested that the presence of suspended solids in water used for mixing and curing concrete generates more voids. In contrast, RO waste water mixed samples exhibited enhanced mechanical performance compared to tap water mixed samples. Previous researchers have also observed this phenomenon due to the lower pH value of RO waste water [32, 33]. The presence of chloride ions helps in the formation of calcium silicate hydrate (CSH) gel, which leads to higher mechanical strength in concrete.

Effect of curing water

In this scenario, various types of water, including regular tap water, grey water, and RO waste water, are mixed to make concrete. However, only regular tap water is used to cure the concrete. The variation in compressive, tensile, and flexural strength after 28 days of curing with respect to tap water-cured samples are -5.5%, -2.5%, and -2.3% for grey water-cured concrete and 0.4%, 1.3%, and 1.1% for RO waste water-cured concrete. Similarly, for all grey water-mixed samples, the variation in compressive, tensile, and flexural strength is -1.9%, -3.2%, and -4.6% for grey water-cured concrete and 3.8%, -2.3%, and 0.6% for RO waste water-cured concrete with respect to tap water-cured concrete. For RO waste water-mixed samples, strength variation is -4.4%, -3.4%, and -3.3% for grey water-cured samples and 1%, 3.7%, and 1.7% for RO waste water-cured samples with respect to tap water-cured concrete. From the above results, the use of grey water for mixing and curing reduces the performance of concrete. This is mainly due to the higher hardness and turbidity value of grey water, which leads to the formation of higher voids. Mohe et al. [21] stated that the presence of suspended solids in water used for mixing and curing concrete generates higher voids. RO waste water mixed samples have enhanced mechanical performance compared to tap water mixed samples. This phenomenon was also observed by previous researchers due to the lower pH value of RO waste water. The presence of chloride ion helps in the formation of CSH gel, which leads to higher mechanical strength in concrete [34-36].

Analyzing the outcomes of mechanical strength, using grey water for mixing and curing reduces the performance of concrete. Utilizing RO waste water for both purposes of mixing and curing enhances the properties of concrete. The change in strength with respect to tap water mixed and tap water cured sample mix was calculated for all mixes to evaluate the effect of water for different purposes. *Figure 15* shows the percentage change in compressive, tensile, and flexural strength outcomes after 28 days of curing. It can be seen from *Figure 15* that using RO waste instead of tap water enhances mechanical behavior.

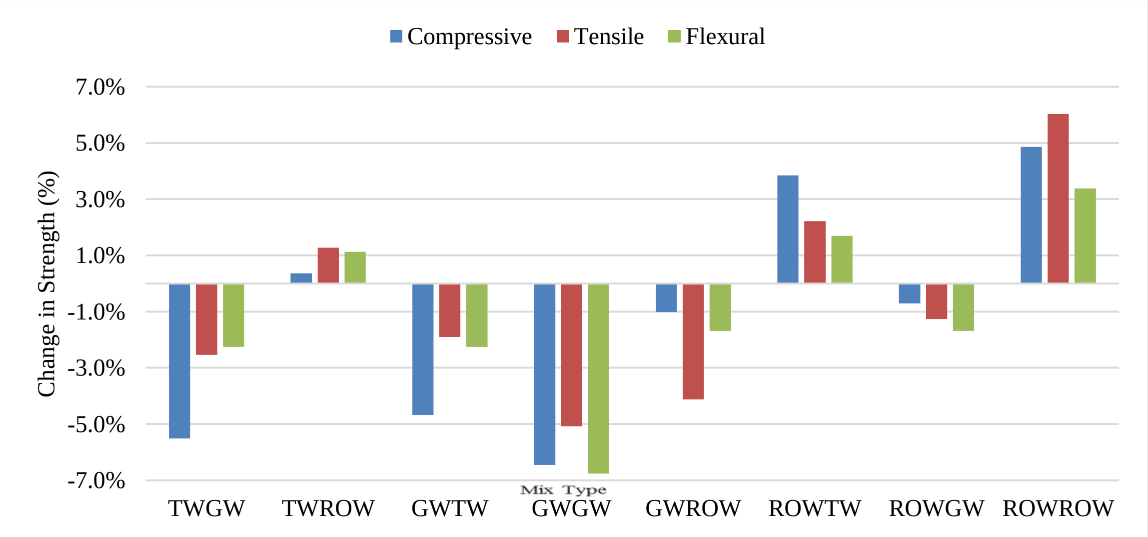

Figure 15 Variation in mechanical strength outcomes

5.3ANOVA analysis

Statistical analysis indicates that there is no significant effect on the mechanical properties of concrete when using different types of water for mixing and curing. This is because the p-value obtained from each ANOVA test for different concrete properties is greater than 0.05, meaning that any variation observed in the results due to the use of different water types is not statistically significant at a 95% confidence level. The contribution percentage of water for mixing and curing for all properties is less than 8%, which is considered insignificant. Furthermore, no significant interaction effect was observed between any type of water usage for mixing and curing, except for a small interaction effect observed in the 7-day flexural strength, which was corrected in the 28-day flexural strength test. A complete list of abbreviations is shown in *Appendix I.*

5.4 Limitation of study

The scope of this research is limited to evaluating the mechanical strength of concrete created using three different types of water for mixing and curing. Further research should explore the durability and microstructural behavior of concrete produced using varying types of mixing and curing water.

6.Conclusion

In this study, the mechanical properties and statistical analysis of concrete were examined to determine the effect of different amounts of water used for mixing and curing. The study concluded that using grey water for mixing and curing reduces the performance of concrete. However, utilizing RO waste water for both purposes enhance the mechanical properties of concrete. Additionally, statistical research revealed that utilizing different types of water for mixing and curing has no significant effect on the mechanical characteristics of concrete. Although there is some variance in findings when different types of water are used, it has no statistically significant effect on the mechanical characteristics of concrete. In summary, the study found that there is no significant difference in the performance of concrete when using grey water, RO waste water or tap water for mixing and curing. However, there is a slight decrement in mechanical behavior when using grey water and a slight increment when using RO waste water. Therefore, both types of water can be used for mixing and curing purposes in place of tap water based on their availability.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Ashish Mathur: Concept and formulation, method of analysis, writing-original draft, analysis and interpretation of results. **Dr. R. C. Chhipa:** Supervision, final correction, investigation on challenges and draft manuscript preparation.

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Appendix I

S. No.	Abbreviation	Description
1	ANOVA	Analysis of Variance
2	BFS	Blast Furnace Slag
3	BOD	Biochemical Oxygen Demand
4	CAC	Calcium Aluminate Cement
5	CSH	Calcium Silicate Hydrate
6	FA	Fly Ash
7	FWC	Fresh Water Curing
8	GARC	Green Artificial Reef Concrete
9	GGBFS	Ground Granulated Blast-Furnace Slag
10	MFTW	Magnetic Field Treated Water
11	OPC	Ordinary Portland Cement
12	pH	Potential of Hydrogen
13	PVA	Polyvinyl Aerated Waste
14	RGW	Raw Grey Water
15	RO	Reverse Osmosis
16	SFRC	Steel Fibre Reinforced Concrete
17	SWC	Sea Water Curing
18	TGW	Treated Grey Water
19	TRE	Textile Reinforced Engineering
20	TW	Tap Water