Experimental Investigation on Durability Studies on Concrete with Treated Wastewater Mixing

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Abstract: ***The increasing demand for freshwater resources has created a need to explore alternative sources of water for concrete production. Treated wastewater can be considered as a potential replacement for potable water in concrete mixing, provided its quality does not adversely affect the properties of concrete. The present study experimentally investigates the performance of M30 grade concrete prepared by using treated wastewater at different replacement levels. Potable water was used, while first treated wastewater and second treated wastewater were used at 25%, 50%, and 100% replacement levels. The quality of the mixing water was examined through parameters such as pH, total dissolved solids, electrical conductivity, nitrates, lead, chromium, sulphates, alkalinity, BOD and COD. The compressive strength of the concrete specimens was evaluated at 7, 14, 28, 56 and 90 days to study the effect of treated wastewater on strength development. Microstructural investigations were also carried out using Standard consistency, Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD). The results showed that the use of treated wastewater caused a gradual reduction in compressive strength with increasing replacement level, although the concrete maintained satisfactory strength development with age. At 28 days, the concrete achieved a compressive strength of 35.63 MPa, while the first treated wastewater specimens recorded 34.50, 34.00 and 32.47 MPa for 25%, 50% and 100% replacement, respectively. The second treated wastewater specimens achieved 34.47, 33.57 and 32.83 MPa at the same replacement levels. The results indicate that treated wastewater, particularly at controlled replacement levels, can be considered for concrete production without causing a significant reduction in compressive strength. The study also highlights the importance of assessing the chemical characteristics of treated wastewater before its use as mixing water in concrete.***

Keywords: Treated wastewater, concrete, potable water, M30 grade, compressive strength, SEM, XRD, sustainable construction

1. Introduction

Water scarcity represents one of the most pressing challenges confronting civil engineering infrastructure development in India. Recent national assessments show that a large share of India's population already lives under high to extreme water stress, and overall water demand across agriculture, industry, and cities is projected to outstrip available supplies in the coming decades. At the same time, urban India generates about 72,368 million litres per day of municipal wastewater, of which only around 28% is effectively treated, leaving nearly 72% to pollute rivers, lakes, and groundwater. These twin pressures of declining freshwater reliability and rising wastewater volumes create a critical context for innovation in Indian construction materials. When treated wastewater from sewage treatment plants and industrial effluent treatment facilities is subjected to rigorous technical analysis and safely integrated into Indian civil engineering systems, it can operate as a multi-dimensional solution, simultaneously addressing freshwater scarcity, lowering project costs, and advancing environmental sustainability objectives for national infrastructure development.

2. Literature Review

Gupta et al. (2022) reported that treated sewage water improved the compressive and tensile strength of concrete compared with potable water. Shinde et al. (2023) found that treated wastewater from car-washing stations had a negligible effect on concrete strength. Lokesh B. K. et al. (2024) observed positive strength and durability performance using treated sewage water. Humood et al. (2024) reported that different water sources significantly affected the strength and workability of concrete. Rajiv K. N. et al. (2025) found that secondary-treated wastewater increased concrete workability. Vidya Belur Raju et al. (2025) concluded that most alternative water sources were suitable for concrete based on chloride penetration. Manish Singh Jadon et al. (2025) reported a reduction in compressive strength with sewage effluent, while permeability remained nearly similar to tap-water concrete.

Research Gap
Limited studies have combined wastewater quality characterization, long-term strength development and microstructural investigation. Therefore, the present study evaluates treated wastewater in M30 concrete through water-quality analysis, compressive strength testing and SEM/XRD characterization.

3. Objective of the Study

1) To characterize the quality of treated wastewater used for concrete mixing.
2) To evaluate the effect of treated wastewater on the compressive strength of M30 concrete at different curing ages.
3) To study the influence of different treated wastewater replacement levels on concrete performance.
4) To investigate the microstructural characteristics of concrete using SEM and XRD.
5) To assess the suitability of treated wastewater as an alternative to potable water for concrete production.

Significance of the Study

This study focuses on the practical use of treated wastewater as an alternative to potable water in concrete production. With increasing water demand and limited freshwater resources, reusing treated wastewater can help reduce the consumption of drinking-quality water in construction. The study also helps understand how different treated wastewater replacement levels affect the strength and internal structure of concrete. The findings can support the safe and sustainable use of treated wastewater in concrete while reducing the environmental impact associated with freshwater consumption and wastewater disposal.

4. Materials and Methodology

The study was carried out in different stages, starting with the collection and analysis of treated wastewater, followed by concrete preparation, curing, and testing.

1) Sample Collection

Treated wastewater was collected from the Nalla Cheruvu wastewater treatment plant in clean, labelled containers and transported to the laboratory. Potable water available at the NMREC campus was used for comparison.

2) Water Sample Preparation and Analysis

Different water combinations were prepared, namely 100% potable water, 25% treated wastewater + 75% potable water, 50% treated wastewater + 50% potable water, 75% treated wastewater + 25% potable water, and 100% treated wastewater. The samples were tested for pH, conductivity, TDS, alkalinity, total hardness, sulphate, nitrate, COD, BOD, chloride, lead, and chromium using standard laboratory methods.

3) Material Preparation

OPC 53-grade cement, fine aggregate, 20 mm coarse aggregate, treated wastewater, and potable water were used for the study. The materials were checked for their basic physical properties before concrete preparation. The concrete mix was designed for M30 grade as per relevant IS codes.

4) Concrete Preparation

M30 concrete cubes were prepared using the different proportions of treated wastewater and potable water. The materials were weighed, mixed thoroughly, placed in 150 x 150 x 150 mm cube moulds, and compacted properly.

5) Curing

After 24 hours, the specimens were demoulded and placed in curing tanks. The cubes were cured for the specified period using the respective water conditions.

6) Testing

After curing, the concrete cubes were tested for compressive strength. Selected specimens were further analysed using XRD and SEM to study their phase composition and microstructure.

7) Comparison and Evaluation

The results obtained from treated wastewater-based concrete were compared with the conventional potable-water concrete. The study evaluated the strength, microstructural characteristics, suitability, sustainability, and potential cost benefits of using treated wastewater in M30 concrete.

Figure 1: Collection of Water Samples

Physico-Chemical Properties of Water

1) pH of Treated Wastewater

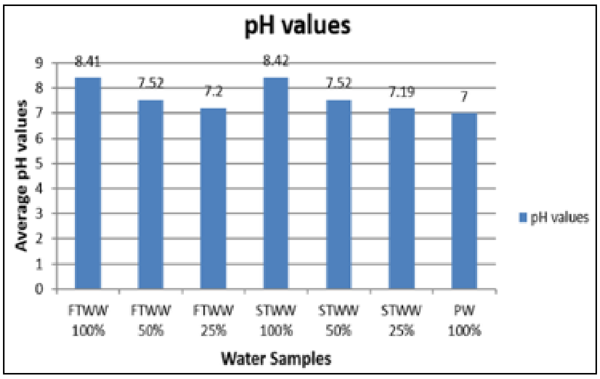

Figure 2: pH of treated wastewater

Table 1: pH values of water samples

Sample	1st	2nd	3rd	Avg.
FTWW 100%	8.4	8.41	8.42	8.41
FTWW 50%	7.55	7.5	7.52	7.52
FTWW 25%	7.23	7.19	7.2	7.2
STWW 100%	8.47	8.41	8.39	8.42
STWW 50%	7.55	7.5	7.52	7.52
STWW 25%	7.22	7.18	7.19	7.19
PW 100%	7	7	7	7

2) TDS of Treated Wastewater

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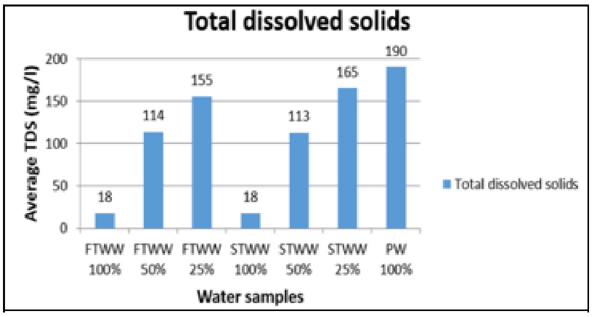

Figure 3: TDS of treated wastewater

3) Nitrates of Treated Wastewater

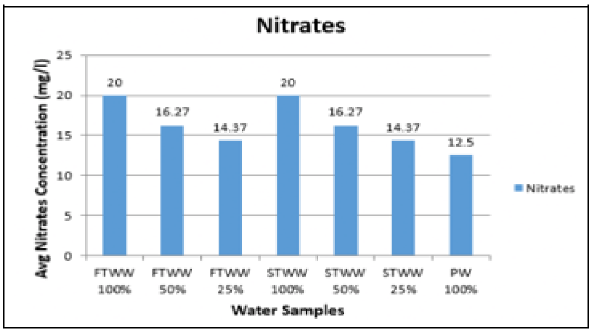

Figure 4: Nitrates of treated wastewater

Table 2: Nitrate content (mg/L) of water samples

Sample	1st	2nd	3rd	Avg.
FTWW 100%	19	20	21	20
FTWW 50%	16	16.2	16.6	16.27
FTWW 25%	14	14.4	14.7	14.37
STWW 100%	20	19	21	20
STWW 50%	16	16.3	16.5	16.27
STWW 25%	14	14.4	14.7	14.37
PW 100%	10	12.5	14	12.5

4) Alkalinity of Treated Wastewater

Table 3. Alkalinity (mg/L) of water samples

Sample	1st	2nd	3rd	Avg.
FTWW 100%	20	18	18	18
FTWW 50%	120	113	109	114
FTWW 25%	147	155	164	155
STWW 100%	18	20	18	18
STWW 50%	119	114	108	113
STWW 25%	170	167	159	165
PW 100%	190	190	190	190

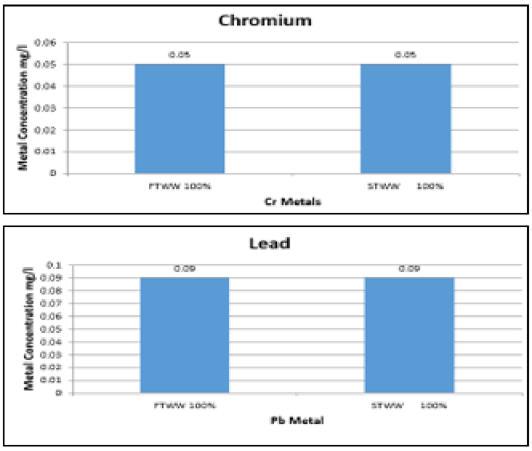

Figure 5: Metals content of treated wastewater

5) Concrete Mix Design and Water Composition

The concrete mix design was carried out for M30 grade concrete using OPC 53-grade cement and a maximum coarse aggregate size of 20 mm. To evaluate the suitability of treated wastewater for concrete production, different proportions of First Treated Wastewater (FTWW), Second Treated Wastewater (STWW), and potable water were used as mixing water. Seven water combinations were considered, including a 100% potable water control mix. The selected water proportions were 100% FTWW, 50% FTWW + 50% potable water, 25% FTWW + 75% potable water, 100% STWW, 50% STWW + 50% potable water, 25% STWW + 75% potable water, and 100% potable water. The compressive strength of the concrete specimens was evaluated at different curing ages to determine the influence of treated wastewater on concrete performance.

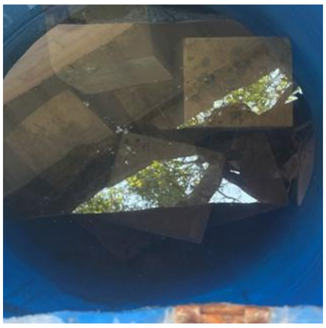

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Figure 6: Preparation of concrete cube specimens and testing

6) Concrete Strength Analysis

It is the systematic evaluation of the load-carrying capacity of concrete at different curing ages to assess its mechanical performance and suitability for structural applications. In this study, compressive strength analysis was carried out by testing concrete cubes at 7, 14, 28, and 56 days using a compression testing machine. The maximum failure load was recorded and converted into compressive strength in N/mm2 (MPa). The results were compared for different proportions of treated wastewater and potable water to determine their effect on the strength development of concrete.

7) Scanning Electron Microscopy (SEM) Analysis

Scanning Electron Microscopy (SEM) analysis was conducted on samples obtained from the optimized concrete mix to investigate its microstructural characteristics. The analysis focused on the morphology of hydration products, pore structure, particle packing, the interfacial transition zone (ITZ), and the formation of calcium silicate hydrate (C-S-H) gel. The SEM observations were used to correlate the microstructural characteristics and densification of the concrete matrix with its mechanical performance.

5. Test Procedure

1) Mix Design

The compressive strength of concrete cubes increased progressively from 7 to 56 days for all mixes prepared using First Treated Wastewater (FTWW) and Second Treated Wastewater (STWW). For FTWW, the 100% FTWW mix increased from 20.33 N/mm2 at 7 days to 34.87 N/mm2 at 56 days, while the 50% FTWW + 50% potable water mix increased from 20.60 to 35.67 N/mm2. The 25% FTWW + 75% potable water mix exhibited the highest FTWW strength, increasing from 20.78 to 36.17 N/mm2. Similarly, for STWW, the 100% STWW mix increased from 20.53 to 35.44 N/mm2, the 50% STWW + 50% potable water mix increased from 20.77 to 35.94 N/mm2, and the 25% STWW + 75% potable water mix achieved the highest strength, increasing from 20.96 to 36.80 N/mm2. Overall, the results indicate that partial replacement of treated wastewater with potable water, particularly the 25% treated wastewater + 75% potable water combination, produced higher compressive strength, while all mixes demonstrated continuous strength development with curing age.

6. Results and Discussion

- 7Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
7days	446	459	468	458
Strength (N/mm^2)	19.80	20.40	20.80	20.33

- 14Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
14Days	641	650	650	647
Strength (N/mm^2)	28.50	20.89	28.9	28.76

- 28Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
28Days	716	729	747	731
Strength (N/mm^2)	31.80	32.40	33.20	32.47

- 90Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
56 Days	770	783	801	785
Strength (N/mm^2)	34.20	34.80	35.60	34.87

Figure 7: Compressive strength of 100% First Treated Wastewater (FTWW) cubes at 7, 14, 28, 56 and 90 days

- 7Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
7days	455	464	473	464
Strength (N/mm^2)	20.20	20.60	21	20.60

- 14Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
14Days	664	675	686	675
Strength (N/mm^2)	29.50	30	30.50	30

- 28Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
28Days	754	765	776	765
Strength (N/mm^2)	33.50	34	34.50	34.00

- 90Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
56 Days	799	787	821	802
Strength (N/mm^2)	35.50	35	36.50	35.67

Figure 8: Compressive strength of 50% FTWW + 50% Potable Water cubes at 7, 14, 28, 56 and 90 days

- 7Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
7days	459	468	477	468
Strength (N/mm^2)	20.40	20.78	21.19	20.78

- 14Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
14Days	675	680	698	686.3
Strength (N/mm^2)	30	30.4	31	30.47

- 28Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
28Days	765	776	788	776.3
Strength (N/mm^2)	34	34.5	35	34.5

- 90Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
56 Days	796	821	823	813
Strength (N/mm^2)	35.38	36.5	36.62	36.17

Figure 9: Compressive strength of 25% FTWW + 75% Potable Water cubes at 7, 14, 28, 56 and 90 days

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- 7Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
7days	463	474	486	474.3
Strength (N/mm²)	20.58	21.07	21.60	21.08

- 14Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
14Days	688	701	713	700.7
Strength (N/mm²)	30.58	31.16	31.69	31.14

- 28Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
28Days	788	802	815	801.7
Strength (N/mm²)	35.02	35.64	36.22	35.63

- 90 Days

Load (KN) →	1st Sample	2nd Sample	3rd Sample	Average values
90 Days	891	905	918	904.7
Strength (N/mm²)	39.60	40.22	40.80	40.21

Figure 10. Compressive strength of 100% Potable Water cubes at 7, 14, 28, 56 and 90 days

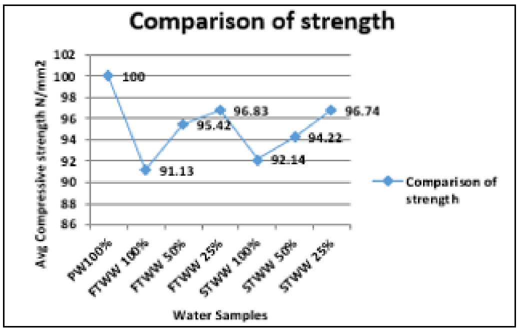

Figure 11: Strength comparison with potable water at 28 days

Table 4: Strength comparison with potable water at 28 days (N/mm2)

Sample	Strength (other)	Strength (PW)	% of PW
PW 100%	35.63	35.63	100%
FTWW 100%	32.47	35.63	91.13%
FTWW 50%	34	35.63	95.42%
FTWW 25%	34.5	35.63	96.83%
STWW 100%	32.83	35.63	92.14%
STWW 50%	33.57	35.63	94.22%
STWW 25%	34.47	35.63	96.74%

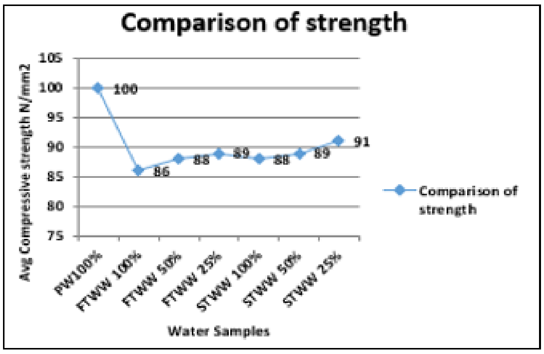

Figure 12: Strength comparison with potable water at 90 days

Table 5. Strength comparison with potable water at 90 days (N/mm2)

Sample	Strength (other)	Strength (PW)	% of PW
PW 100%	40.21	40.21	100%
FTWW 100%	34.87	40.21	86.72%
FTWW 50%	35.67	40.21	88.71%
FTWW 25%	36.17	40.21	89.95%
STWW 100%	35.44	40.21	88.14%
STWW 50%	35.94	40.21	89.38%
STWW 25%	36.8	40.21	91.52%

2) Scanning Electron Microscope (SEM)

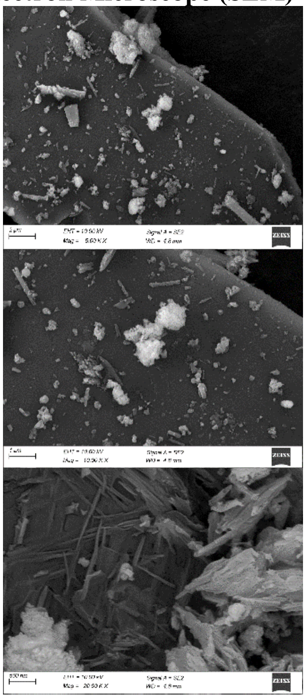

Figure 13: SEM images of concrete prepared with treated wastewater

The SEM analysis of concrete prepared with treated wastewater revealed the formation of a dense and well-developed hydrated cement matrix. Plate-like and needle/rod-shaped hydration products, along with agglomerated crystalline phases, were observed at higher magnifications. The microstructure showed relatively good particle bonding and matrix densification, although localized pores and voids were present. These observations indicate that the treated wastewater did not prevent the normal hydration process of cement. The formation and accumulation of hydration products may contribute to the development of compressive strength.

3) X-Ray Diffraction (XRD)

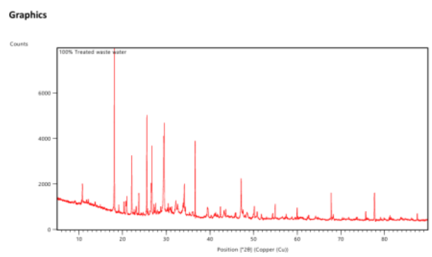

Figure 14: XRD pattern of concrete prepared with 100% treated wastewater

The XRD analysis of concrete prepared with treated wastewater showed a well-defined diffraction pattern containing several major crystalline peaks. The highest intensity peak was recorded at 18.1122 degrees 2-theta, while other prominent peaks were observed at 22.0860, 25.5290, 26.7121, 29.4677, and 36.5917 degrees. The peak near 26.71 degrees is consistent with quartz, while the peak near 29.47 degrees is consistent with calcite. Additional reflections indicate the presence of other crystalline calcium-containing and silicate phases within the hydrated concrete matrix. The results confirm the development of a stable crystalline mineral structure in the concrete made with 100% treated wastewater.

7. Conclusion

1) Physico-chemical analysis showed that pH, EC, alkalinity, TDS, nitrates, sulphates, COD, and BOD were within acceptable limits, while colour and odour exceeded permissible limits for potable/domestic use.
2) Trace heavy metals were detected, with Pb = 0.09 mg/L and Cr < 0.05 mg/L.
3) The standard consistency of cement was within the normal range.
4) Compressive strength results showed that treated wastewater concrete achieved approximately 86-96% of the strength of conventional M30 concrete, indicating its suitability as a replacement for potable water in concrete.
5) 25%, 50%, and 100% treated wastewater mixes demonstrated satisfactory strength development, confirming their potential for construction applications when water quality parameters are within acceptable limits.
6) SEM analysis revealed a dense hydrated cement matrix with good particle bonding and C-S-H formation, indicating that treated wastewater did not adversely affect cement hydration.
7) XRD analysis confirmed the presence of major crystalline phases, including quartz and calcite, demonstrating the development of a stable hydrated concrete matrix using treated wastewater.

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