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Regression Analysis of Concrete Produced from Selected Wastewater Types

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ABSTRACT

This study investigates the effects of using various wastewater types on the strength characteristics of concrete through regression analysis. Given the construction industry's substantial freshwater consumption and the increasing scarcity of potable water, the research explores the viability of substituting wastewater in concrete production. Materials tested include cement, aggregates, and wastewater from kitchen, laundry, fish-pond, and paint industry, alongside potable water for control. Comprehensive tests on these materials, including physical, chemical, and bacteriological assessments, preceded the concrete mixing and casting process. The study involved curing concrete specimens and performing compressive and tensile strength tests at intervals of 7, 14, 21, and 28 days. Results indicated that while concrete made with potable water exhibited superior performance, wastewaters significantly influenced the mechanical properties of concrete, with potable water achieving the highest compressive and tensile strengths. Regression analysis confirmed a substantial impact of curing duration on strength development. The research concludes that water quality is crucial for concrete performance and suggests potable water for optimal strength, though wastewaters present a potential alternative, highlighting the need for further evaluation and adherence to quality standards.

Keywords: Wastewater, Concrete, Compressive and tensile strength, Regression analysis.

INTRODUCTION

Concrete is a widely used building material in the world. The population growth and rapid development have led to the massive use of concrete as the construction industry's key material. The biggest negative effects of this industry are environmental contaminants such as air and water pollution and the shortage of preliminary sources. The deficiency of sources of drinking water is deliberated today to be one of the world's biggest complications. However, the worldwide water consumption from industrial operations will rise to 1500 billion m^3 by 2030, from 800 billion m^3 in 2009 (De Matos et al., 2020). Some researchers estimated that water shortages will occur by the end of 2025 and around 1800 million people will be affected worldwide (Fattah et al., 2017). Approximately, one trillion cubic meters of freshwater is being used in the construction industry per year and nearly 500 L of freshwater has been estimated to produce every cubic meter of concrete (Peighambarzadeh et al., 2020). Besides the water in the production of concrete, freshwater is also utilized for cleaning aggregates before casting and the water needed for cleaning of mixing truck and batching plant (Peighambarzadeh et al., 2020). A large amount of freshwater is also used for concrete curing. Therefore, the concrete industry is a significant factor affecting the environmental condition through the consumption of water. A solution must be found to eliminate the use of freshwater for mixing and curing the concrete. Owing to rapid population growth and faster industrialization rate, impressive growth has been seen for industrial and domestic wastewater generation in recent decades. Due to improper wastewater treatment facilities, a considerable amount approximately 80% of wastewater from households is being drained out to pollute other water bodies to be polluted including rivers and even land as waste flows (Mane et al., 2019). Therefore, rapid action must be taken to save the underground and other water bodies in developing countries. The use of wastewater in making concrete may reduce the crisis for water up to certain limits. Also, it may reduce the outcome of contamination of surface or groundwater bodies and

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insufficiency of drinkable water resources. It is significant to ease its depletion and waste in all sectors counting the construction and infrastructure sectors (Meena and Luhar, 2019). The utilization of wastewater in concrete production for investigating its impact on concrete strength characteristics presents a significant research gap and raises concerns about the potential implications on structural performance, durability, and environmental sustainability. Despite the increasing interest in sustainable construction practices, there is a lack of comprehensive understanding regarding the effects of incorporating wastewater into the concrete mix, posing a challenge to the construction industry's efforts to balance environmental considerations with structural performance requirements. This research aims to address these knowledge gaps by systematically investigating the concrete strength characteristics when wastewater is introduced into the production process, contributing valuable insights to sustainable construction practices and guiding the development of guidelines for responsible and effective wastewater utilization in concrete manufacturing. This research aims to explore the impact of incorporating wastewater in concrete production on the strength characteristics through regression analysis. The objectives are to assess the influence of selected wastewaters in concrete mixes on compressive and tensile strengths and determine sustainability benefits and challenges associated with this alternative approach. The study addresses the pressing need for environmentally friendly construction materials and practices by exploring the use of wastewater, a readily available resource, in concrete production. Findings from this research could contribute to reducing the environmental impact of concrete production by minimizing the demand for traditional water sources and mitigating wastewater disposal issues. The study adds to the academic knowledge base by expanding our understanding of the relationship between wastewater and concrete characteristics. It provides a foundation for further research and encourages academic discourse on sustainable construction practices.

MATERIALS AND METHODS

Materials

The materials that were used in this research study constitute the concrete mixture ingredients which include; cement, fine and coarse aggregates, and water. All materials were collected/procured within Akure, Ondo state Nigeria. The cement that was used in the course of this research is Dangote limestone Portland cement with a strength class of 42.5R. This is the most commonly used brand of cement in Nigeria. River sand was used as fine aggregate in this study. Granites 19 mm diameter in size was used in the course of this research. Wastewater was collected from five different sources which are kitchen, laundry, fish-pond and paint industry. Potable water from the tap was also collected for control.

Material tests

Tests were conducted on the conventional material for concrete procured to verify their quality.

Various tests were conducted on the fine aggregate, including particle size distribution, moisture content, bulk density, silt/clay content and specific gravity (ASTM, 2003). Some tests were carried out on the coarse aggregate to ascertain its quality. They include specific gravity, aggregate crushing value and aggregate impact value. Setting time, soundness and fineness tests were conducted on cement to determine its key properties and ensure its suitability for use in concrete production (ASTM, 2016). Physio-chemical tests were carried out on each wastewater sample to know their physical, chemical and bacteriological contents. These tests were also carried out on the potable water to be used as a control. The tests were as follows: Physical tests (temperature, turbidity, total dissolved solids, total suspended solids), Chemical tests (pH, electrical conductivity, oil and grease, biological oxygen demand, chemical oxygen demand, chloride, nitrate, sulphate, phosphate) and Heavy metals (cadmium, chromium, iron, lead, zinc, manganese)

Concrete mixing and casting

A comprehensive concrete mixing operation was carried out in the course of this research. The mix ratio used was 1:2:4, meaning 1 part cement, 2 parts sand, and 4 parts granite, with batching performed by volume to ensure precise proportions. The procedure began with the preparation of materials: various proportions of the materials were mixed together on the ground. Potable water was then gradually incorporated into the dry mix until the desired consistency was achieved. To identify the quality and density of the mix, a full compaction factor test was conducted. Initially, the upper hopper was filled with concrete without compaction, allowing it to fall freely into the lower hopper and subsequently into a cylinder. The cylinder was weighed, providing a baseline measurement. The process was repeated with full compaction, where the concrete in the cylinder was rodded and tapped to remove air pockets. The second weight measurement, post-compaction, was used to determine the full compaction factor. Following this, a partial compaction factor test was performed. Concrete was filled into the cylinder in three layers, with each layer lightly tamped 25 times using a tamping rod. The cylinder was then weighed and recorded. Lastly, a slump test was conducted to assess the workability of the concrete mix. The slump cone was filled in three layers, each rodded 25 times to eliminate air voids. Upon removing the cone, the slump height was measured and recorded. Afterward, the concrete was placed in the formworks already prepared in the form of cubes and cylinders. In the course of this research, concrete cubes (150mm × 150mm × 150mm) and cylinders (200mm × 100mm) were cast using five different types of water: fish-pond wastewater, paint wastewater, kitchen wastewater, laundry wastewater, and potable water. A total of 12 cubes and 12 cylinders were produced from each water type, resulting in 60 cubes and 60 cylinders.

Concrete curing

After casting, the concrete specimens were demolded from the formworks and placed into curing tanks. Table 1 exhibits the curing schedule of the concrete specimens.

Table 1: Concrete Curing Schedule

S/N	Water samples	No. of concrete cubes/cylinders	Curing days			
			7	14	21	28
1	Kitchen Wastewater	12	3	3	3	3
2	Laundry Wastewater	12	3	3	3	3
3	Fish-pond Wastewater	12	3	3	3	3
4	Paint Wastewater	12	3	3	3	3
5	Potable Water	12	3	3	3	3
	Total	60				

Compressive and tensile strength tests

After 7 days of curing, 3 cubes and 3 cylinders from each water type were removed from the curing tanks. For the compressive strength test, the cubes were subjected to a compression testing machine. Each cube was positioned centrally on the lower platen of the machine, and the load was applied at a constant rate until the cube failed. The maximum load at failure and the compressive strength were recorded for each cube. Simultaneously, the cylinders were prepared for tensile strength testing using the split tensile strength method. Each cylinder was placed horizontally in the testing machine, and a diametral compressive load was applied along the length of the cylinder at a uniform rate until failure occurred. The maximum load at failure was recorded, and the tensile strength was calculated based on the applied load, the length, and the diameter of the cylinder. This procedure was repeated after 14, 21, and 28 days of curing. At each interval, 3 cubes and 3 cylinders from each water type were removed from the curing tanks and tested for compressive and tensile strengths following the same procedures. The data collected from these tests provided insights into the development of concrete strength over time and the impact of using different types of wastewater on the concrete's performance. By comparing the results at different curing periods, the progression of strength for each water type was analyzed, allowing for a comprehensive evaluation of the effectiveness of wastewater in concrete production relative to potable water

Statistical analysis

A linear regression curve estimation analysis to investigate the relationship between the compressive strength of concrete and the curing period was conducted. This analysis aimed to understand how the duration of curing influences the strength development of concrete over time. It will also provide insight on how each of the selected wastewater types affects the strength characteristics of concrete. Additionally, the same analysis will be conducted to explore the relationship between the curing period and the tensile strength of concrete.

RESULTS AND DISCUSSION

Test result on fine aggregate

Data collected from the tests conducted on the fine aggregate were analysed to derive insights

Particle size distribution test was conducted on the fine aggregate to determine its gradation characteristics. From the results, the cumulative percentage retained on each sieve was calculated and a particle size distribution curve was plotted. More than 50% of the aggregate's particles were retained on sieve number 200 which indicated that the aggregate is a coarse-grained soil. Less than 50% of the aggregate sample was retained on sieve number 4 which further indicated that the aggregate is sand (ASTM, 2021). Figure 1 exhibits the particle size distribution curve.

Table 2 displays the summary of results from fine modulus, moisture content, bulk density, silt/clay content and specific gravity tests carried out on the fine aggregate.

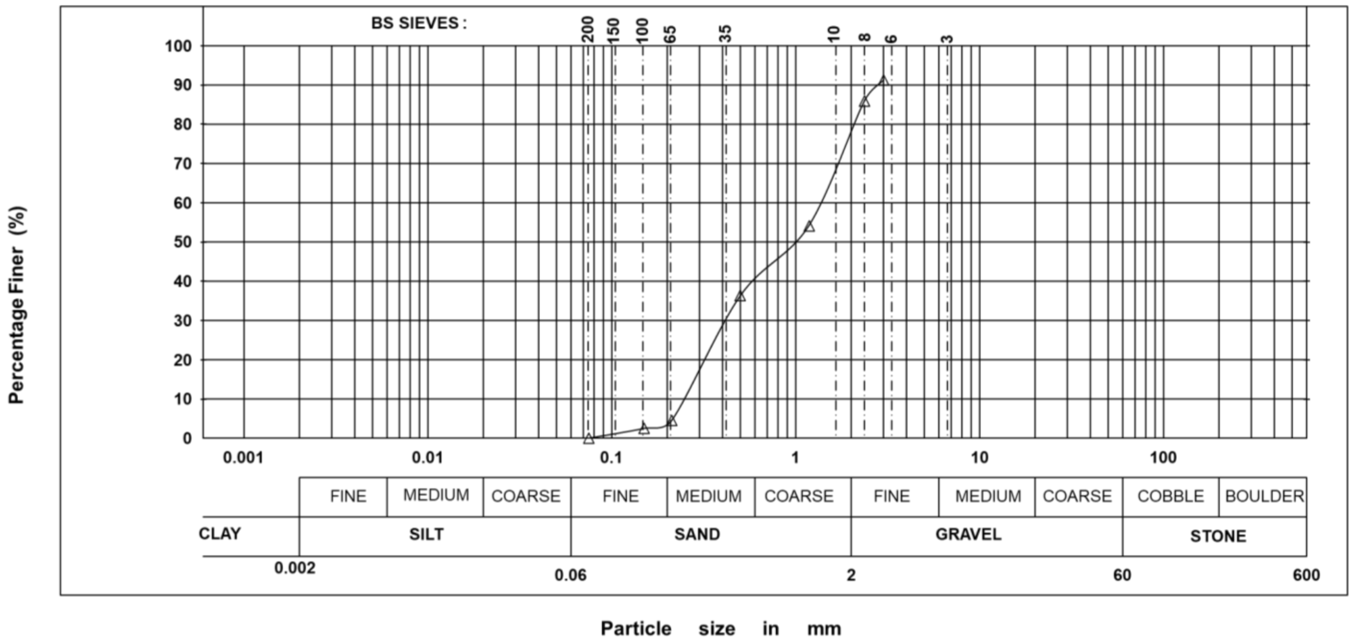

Figure 1. Particle size distribution of fine aggregate (River Sand)

Coarse aggregate

Information obtained from the tests conducted on the coarse aggregate was analysed and summarised in Table 3.

Cement

A. Setting Times

The setting times of concrete produced from various water types were analysed to understand the influence of different wastewaters on the consistency, initial setting, and final setting times of concrete. Figure 2 outlines the result for this experiment.

B. Soundness

A soundness test was conducted on cement using different water types to determine the potential for volumetric changes in cement paste, which can lead to expansion and cracking in hardened concrete (Swami *et al.*, 2015, Karthikeyan *et al.*, 2014). The analysis of the collected data is summarized figure 3.

C. Cement Fineness

A fineness test was conducted on cement to determine the particle size distribution and ensure the cement met the required standards for quality and performance (Sandrolini and Franzoni, 2001). The test was repeated three times to ensure accuracy and reliability of the results. Cement fineness in percentage was calculated to be 1.67.

Table 2. Summary of Tests Carried Out on Fine Aggregate

S/N	Test on Fine Aggregate	Value
1	Fine Modulus	2.15
2	Moisture content (%)	3.84
3	Bulk Density (kg/m^3)	1620.00
4	Silt/Clay Content (%)	5.00
5	Specific Gravity	2.89

Table 3. Summary of Tests Carried Out on Coarse Aggregate

S/N	Test on Coarse Aggregate	Value
1	Specific Gravity	2.79
2	Aggregate Crushing Value (%)	27.97
3	Aggregate Impact Value (%)	20.03

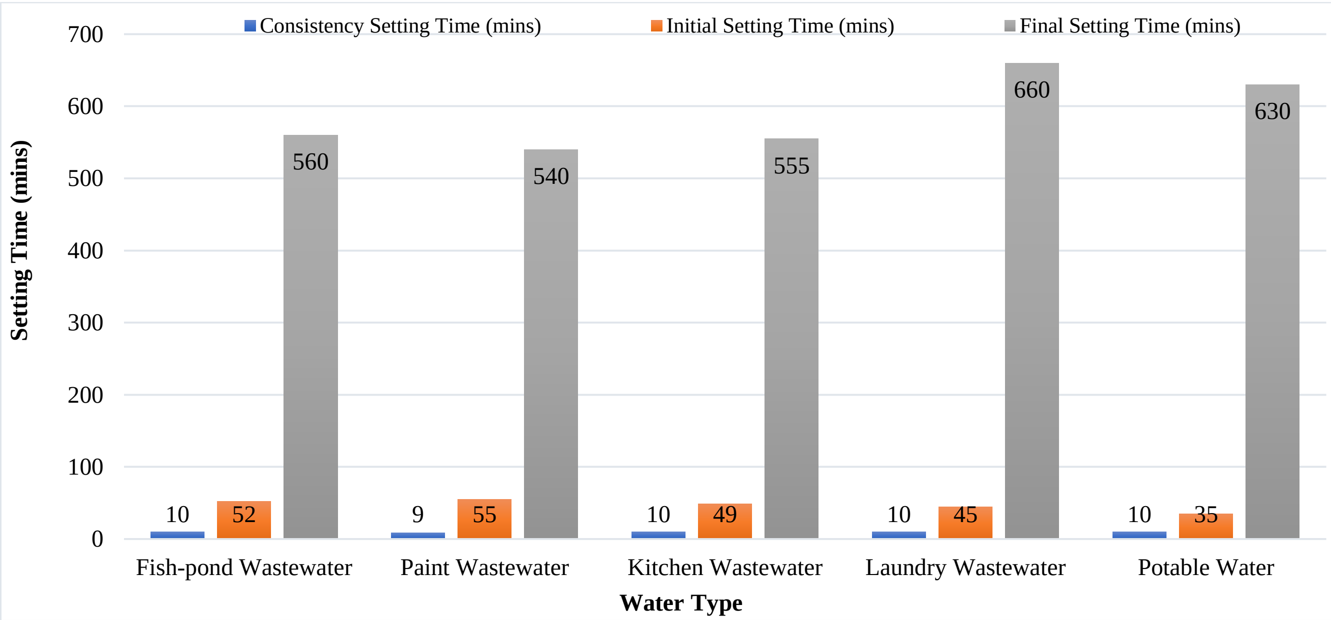

Figure 2. Chart of setting times of cement vs water types

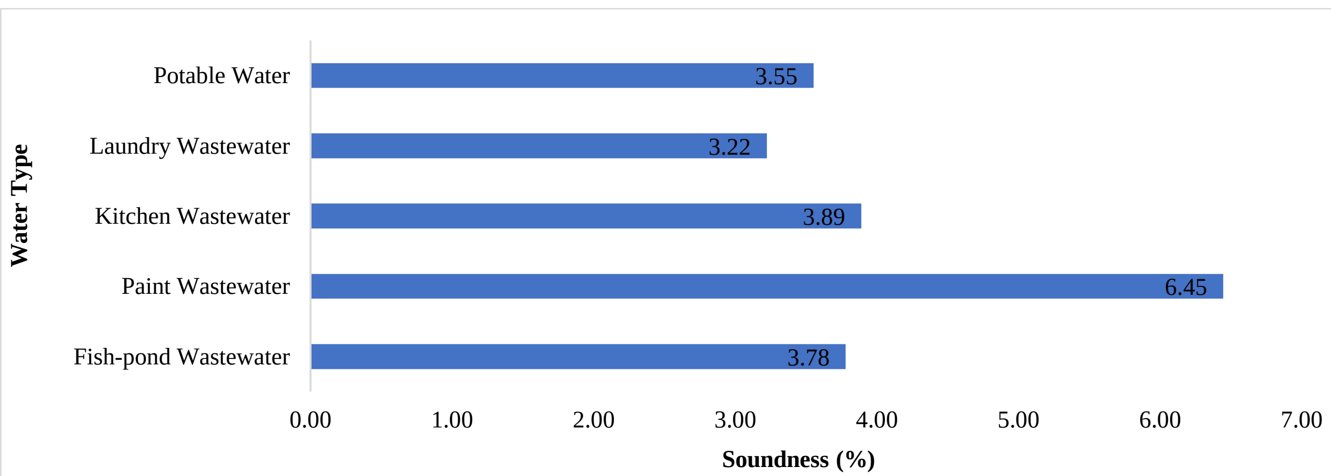

Figure 3. Chart of cement soundness analysis

Physio-chemical characteristics of selected water types

The physio-chemical properties of the selected water types used in this study are crucial in understanding their potential impact on the hydration process of the concrete specimens. These properties were summarised in the table 4.

The research evaluates the impact of various water qualities on concrete mixing, particularly focusing on chloride, sulphate, nitrate, and phosphate content, along with biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil, grease, total dissolved solids (TDS), total suspended solids (TSS), turbidity, conductivity, temperature, pH, and heavy metals. According to BS EN 1008:2002, chloride content should not exceed 500 mg/L for prestressed concrete, 1000 mg/L for reinforced concrete, and 4500 mg/L for unreinforced concrete, with laundry wastewater having the highest chloride content (1597.50 mg/L) and fish-pond wastewater the lowest (508.83 mg/L). Sulphate content, which must be below 2000 mg/L per British Standard (2002), is highest in fish-pond wastewater and lowest in potable water. Nitrate and phosphate are contaminants restricted to 500 mg/L and 100 mg/L, respectively, with laundry wastewater containing the most nitrate and fish-pond wastewater the most phosphate. High BOD and COD values indicate significant organic matter, which can hinder concrete hydration, and oil or grease can weaken concrete by coating aggregates and cement particles, with kitchen wastewater showing the highest concentrations. Elevated TDS and TSS levels can disrupt cement hydration, lowering compressive strength, while turbidity and conductivity indicate dissolved and suspended particles that can also affect hydration. Water temperature affects hydration rates, with higher temperatures accelerating setting but risking thermal cracking. Potable water's high pH suggests a strong alkaline environment conducive to faster setting and hardening. Heavy metals shown in table 5, which can interfere with hydration and reduce strength (Terro and Al-Ghusain, 2003), are lowest in potable water. Overall, potable water generally provides the best conditions for concrete mixing compared to various wastewaters.

Table 4. Physio-chemical properties of selected water types

S/N	Physio-Chemical Properties	Fish-pond Wastewater	Paint Wastewater	Kitchen Wastewater	Laundry Wastewater	Potable Water
1	Chloride (mg/L)	508.83	745.50	591.67	1597.50	556.17
2	Sulphate (mg/L)	409.90	201.50	190.00	390.14	170.69
3	Nitrate (mg/L)	120.03	150.00	71.30	180.50	53.00
4	Phosphate (mg/L)	180.03	111.05	91.55	100.90	33.80
5	Biochemical Oxygen Demand (mg/L)	2.70	11.49	4.94	9.50	0.59
6	Chemical Oxygen Demand (mg/L)	198.00	3500.00	3800.00	1700.00	30.00
7	Oil/ Grease (mg/L)	0.02	0.31	1.54	0.71	0.00
8	Total Dissolved Solids (%)	0.014	0.019	0.018	0.017	0.012
9	Total Suspended Solids (%)	0.002	0.002	0.003	0.004	0.004
10	Turbidity (Units)	11.30	14.00	11.90	13.00	10.50
11	Conductivity (μS/cm)	32.00	370.00	2350.00	1330.00	470.00
12	Temperature (^{0}C)	25.00	35.00	34.00	33.00	29.00
13	pH	7.68	8.81	6.00	8.96	11.62

Table 5: Heavy metal analysis of the selected water types

S/N	Water Type	Lead Pb	Cadmium Cd	Chromium Cr	Zinc Zn	Iron Fe	Manganese Mn
1	Fish-pond Wastewater	0.00	0.00	0.04	1.40	0.51	0.00
2	Paint Wastewater	0.00	0.14	0.00	0.09	1.52	0.09
3	Kitchen Wastewater	0.00	0.00	0.00	0.71	1.24	0.02
4	Laundry Wastewater	0.00	0.07	0.01	0.55	0.26	0.30
5	Potable Water	0.00	0.00	0.00	0.36	0.83	0.00

Test results of concrete in hardened state

In this research, water absorption, compression, and tensile tests were carried out on hardened concrete to evaluate its performance and durability. The water absorption test involved measuring concrete specimens before and after curing, calculating the increase in weight to determine the porosity and potential durability of the concrete. The compression test was performed using a compression machine to apply axial load on concrete cubes until failure, which provided data on the compressive strength of the concrete. For the tensile test, cylindrical concrete specimens were subjected to indirect tension using the split cylinder method, revealing the tensile strength of the concrete. Overall, concrete specimens produced with potable water showed better performance with a good strength of 10.90, 12.27, 15.60 and 17.57 kN/mm^2 on 7, 14, 21 and 28 curing days respectively. This is acceptable for M20 grade of concrete which attains 50 – 60% of its strength at 7 days, 60 – 70% at 14 days, 70 – 80% at 21 days and 80 – 100% at 20 days curing period. The comparison of the compressive strength at different ages is presented in figure 4.

Although concrete is known for its high compressive strength, its tensile strength is significantly lower, making it more susceptible to cracking under tension. The comparison of tensile strength on 7, 14, 21 and 28 days for the concrete cylinder specimens is shown in Figure 5.

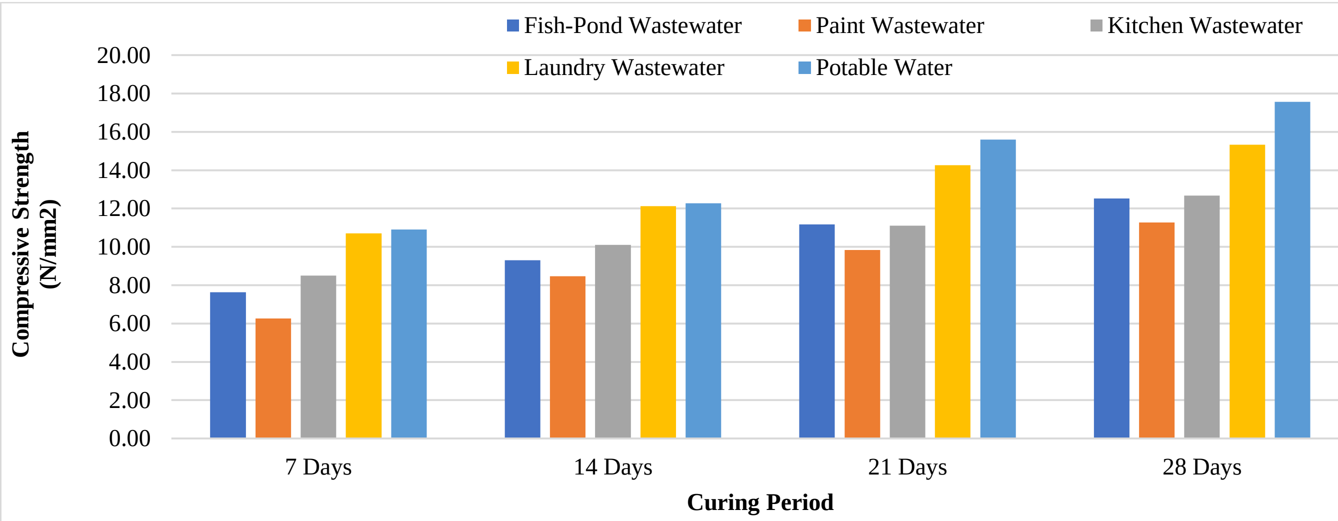

Figure 4. Chart showing comparison of average compressive strength of cubes

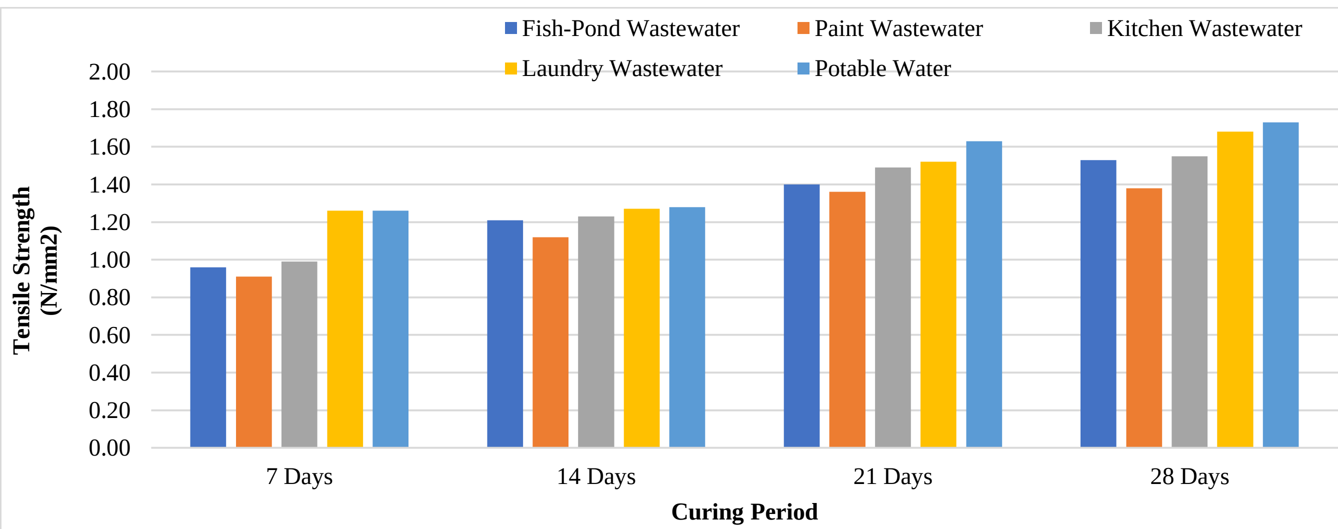

Figure 5. Comparison of average tensile strength of cylinders

Regression analysis

A linear regression curve estimation analysis was conducted to investigate the relationship between the compressive strength of concrete and the curing period. This analysis was performed using SPSS. As displayed in table 6, the results of the analysis indicated an R squared value of 0.489, suggesting that approximately 48.9% of the variability in compressive strength can be explained by the curing period. The F value was found to be 17.227, with degrees of freedom of 1 and 18. The significance value was less than 0.001, indicating a statistically significant relationship between the curing period and compressive strength. These findings demonstrate that the curing period has a substantial and statistically significant impact on the compressive strength of concrete. The relatively high R squared value implies a strong correlation, indicating that as the curing period increases, there is a notable increase in the compressive strength of concrete. The low significance value reinforces the reliability of this relationship, confirming that the observed effects are not due to random variation but rather a consistent trend. Figure 6 presents the linear regression estimation curve compressive strength against curing period.

Based on the results of the conducted analysis, it can be posited that the type of water used in mixing concrete has an effect on the strength of the concrete. If the water type did not influence the compressive strength, the concrete specimens would have exhibited similar or the same compressive strength results after curing. However, the data collected and analysed demonstrated variability in compressive strengths that can be attributed to the different water types used in the mixing process. This variability suggests that certain impurities or chemical compositions present in different water types can affect the hydration process and subsequent strength development of the concrete. Therefore, it is reasonable to conclude that the type of water used in mixing concrete does indeed impact its compressive strength, supporting the theory that water quality is a significant factor in concrete performance.

Linear regression curve estimation was also conducted to investigate the relationship between tensile strength of concrete and curing period. The result is displayed on Table 7 and Figure 7.

Despite concrete being generally known for its low tensile strength, the results demonstrate that the tensile strength improves substantially with increased curing time. This indicates that the curing period is a crucial factor in enhancing the tensile properties of concrete. The high R squared value reflects a strong correlation, implying that longer curing periods lead to significant improvements in tensile strength, thereby potentially offsetting some of the inherent weaknesses of concrete in tension. This analysis underscores the importance of adequate curing in achieving better tensile performance in concrete structures.

Table 6. Model summary of regression analysis on compressive strength

Equation	R Square	F-value	df1	df2	P-value
Linear	0.489	17.227	1	18	< 0.001

Note: df = Degree of freedom

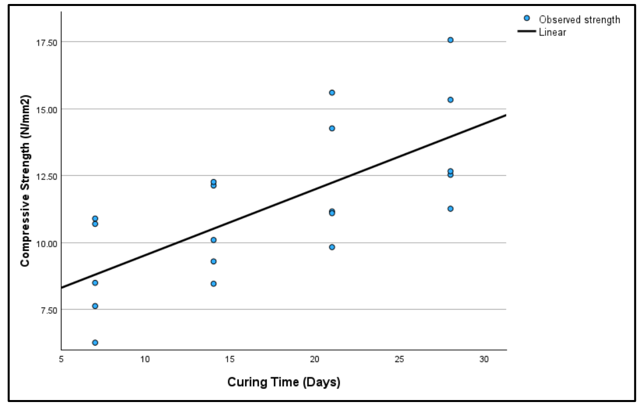

Figure 6. Linear regression curve estimation of compressive strength vs curing time

Table 7. Model summary of regression analysis on compressive strength

Equation	R Square	F-value	df1	df2	P-value
Linear	0.737	50.46	1	18	< 0.001

Note: df = Degree of freedom

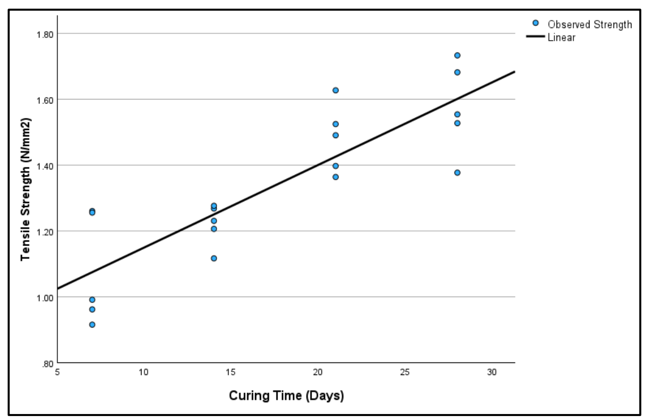

Figure 7. Linear regression curve estimation of tensile strength vs curing time

CONCLUSION

The research findings indicate that concrete strength increases with prolonged hydration due to the formation of cementitious products. Water quality significantly affects concrete's strength development, with potable water yielding better performance than wastewaters, which contain impurities that retard hydration. The maximum compressive strength (17.57 N/mm²) was observed with potable water, while the minimum (11.27 N/mm²) was with paint wastewater. Tensile strength also varied, with potable water showing the highest value (1.73 N/mm²). Linear regression analysis confirmed the significant impact of water type on compressive strength but not on tensile strength.

Contribution to knowledge

This research was able to provide an insight into the possibility of utilizing wastewater as substitute for the conventional potable water in concrete mixing and create a database for the effects of wastewater on the strength characteristics of concrete.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests in this research and publication.

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