Replacing drinking water in blended concrete with processed waste water from STP

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Abstract - With only a small fraction—about 0.5 %—of the Earth's total water being drinkable, and with the rapid rise in demand caused by urban growth and ongoing construction activities, identifying sustainable alternatives to freshwater in concrete manufacturing has become critical. This research explores the potential of using 10 million liters of treated wastewater generated daily by a sewage treatment facility located in Patna, Bihar, which operates on consecutive batch reactor device (SBR) equipment, as a replacement for common water in tangible production. A comprehensive investigation was carried out over a span of three years (2021 – 2023) to assess the appropriateness of the purified wastewater for concrete mixing. The study analyzed key water quality indicators such as pH, temperature, TSS (total suspended solids), COD, BOD, coliform count, and total Kjeldahl nitrogen. Concrete blocks were molded using three different types of water: pure common water, a 60:40 mix of drinkable water and principal processed wastewater, as well as a 60: 40 mixture of intermediate processed wastewater and drinkable water. Following a 28-day cure time, the concrete samples produced with the 60:40 secondary treated water mixture attained a compressive strength of 23.5 N/mm², compared to 24.56 N/mm² attained using just potable water. Conversely, cube blocks prepared with the basic processed water mix recorded a lower strength of 18.57 N/mm². The results suggest that subordinate processed sewage water can be effectively utilized as a partial auxiliary for drinkable water in concrete production, although the compression power of the concrete might differ based on the degree of water purification.

***Key Words*:** Sewage water; Treated wastewater; Concrete production; Sustainable construction; Water quality parameters; Compressive strength; Wastewater reuse.

1. INTRODUCTION

The term *"elixir of life"* accurately reflects the indispensable role of water in sustaining life. Although it covers about 71% of the Earth's surface, only 3% is classified as freshwater. Of this limited portion, nearly 80% remains trapped within polar ice caps, leaving only about 0.5% available as potable water suitable for human use.
Over the past hundred years, the world has faced a growing water crisis, primarily caused by rapid population growth, urban expansion, pollution, climate change, inefficient freshwater management, and widespread environmental degradation. Water also plays a fundamental role in producing cement-based materials such as paste, mortar, and concrete. Concrete is typically formed by combining water with binding agents—such as Portland cement—and inert aggregates of varying sizes. Globally, the concrete industry consumes close to one trillion gallons of water each year.

Adequate water availability is essential to produce workable concrete that can be mixed, placed, compacted, and finished effectively. However, lower water content generally enhances the concrete's mechanical strength. Water is further required for multiple construction-related operations, including washing aggregates, cleaning batching plants, and rinsing concrete mixers.

Potable water can generally be used in the preparation of cement-based materials, provided it is free from excessive amounts of acids, salts, alkalis, oils, sugars, or organic matter. Highly alkaline or acidic water, or water containing algae or high chloride concentrations, should be avoided, as these factors can adversely affect the setting, hardening, and strength development of concrete.

With the ongoing depletion of potable water sources, the need to identify suitable alternatives has become increasingly urgent. Potential substitute sources, often characterized by higher levels of dissolved and suspended solids, include seawater, treated industrial effluents, treated domestic sewage, wastewater from carwash stations, runoff from ready-mix plants, and effluents from stone-cutting industries. Studies have shown that properly treated wastewater from these sources can produce concrete with acceptable strength and durability properties. Since water usage in the construction sector is closely linked to the volume of concrete production, incorporating treated wastewater into concrete manufacturing can help conserve potable water and reduce the costs associated with wastewater treatment. Despite environmental and public health considerations, treated sewage water continues to be utilized for concrete production in several regions. This type of water generally originates from domestic, municipal, or industrial sources and undergoes a combination of physical, chemical, and biological treatment processes to remove contaminants and suspended matter before being discharged into the environment. One of the by-products of this treatment process is sewage sludge—a semi-solid residue that requires additional processing prior to safe disposal on land. Reclaimed water, also known as recycled water, refers to wastewater that has undergone treatment to eliminate suspended and solid impurities. It is utilized across multiple sectors, including irrigation, concrete manufacturing, groundwater recharge, and landscape maintenance. The sludge generated from this process is often combined with organic biowaste to produce compost, which is extensively applied in agricultural practices. In certain instances, treated wastewater has also been used for cultivating *Spirulina*.

The present study investigates the use of recycled wastewater in both the mixing and curing stages of concrete production. Beyond its environmental advantages, employing treated wastewater in the concrete industry may also yield significant economic benefits. Integrating the construction sector—one of the fastest-growing components of most economies—as a major consumer of treated wastewater can encourage greater investment in wastewater treatment and reuse technologies.

The objectives of this research are as follows:

• To examine the feasibility of using different wastewater sources, including treated industrial effluents and domestic sewage, in the preparation and curing of concrete.

• To assess the mechanical strength and durability of concrete when treated wastewater is substituted for potable water.

• To analyze the economic implications of utilizing sewage treatment plant (STP) effluents in concrete production, with emphasis on reducing potable water consumption and treatment costs.

• To evaluate the potential health hazards and environmental effects associated with incorporating treated wastewater in concrete construction.

• To explore opportunities for expanding treated wastewater markets and promoting investment by positioning the construction industry as a primary end-user.

2. Materials and Methods

This research focused on the characterization of wastewater and the assessment of concrete produced using treated wastewater as a substitute for potable water. The principal materials examined in this study were treated wastewater and concrete, both of which were subjected to comprehensive laboratory testing and analysis.

2.1. Sampling

To maintain data accuracy and ensure adherence to environmental quality standards, treated sewage water samples were collected daily from the outlet of a 10 million liters per day (MLD) sewage treatment plant (STP) located in Patna, Bihar. These samples were subjected to detailed laboratory testing to evaluate essential water quality parameters, including pH, total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), and the concentrations of key nutrients such as sulfate, chloride, sodium, nitrate, and fecal coliform (*F. coli*) (Figures 1 and 2).

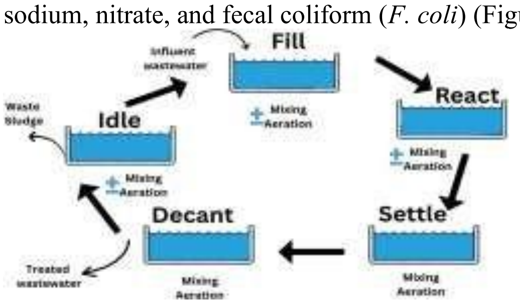

Figure 1. Phases of the sequencing batch reactor (SBR) operational cycle.

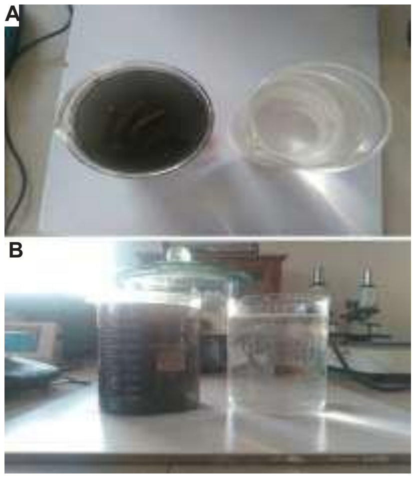

Figure 2. (A) Inlet and (B) outlet samples from the 10 million liters per day (MLD) sewage treatment plant at Patna, Bihar.

2.2. Concrete cube sampling and curing

Concrete specimens were prepared by mixing cement with samples of both primary and secondary treated wastewater. The freshly mixed concrete was poured into standard molds and allowed to set. Following casting, the specimens were cured in water for periods of 7, 14, and 28 days. After each curing interval, the concrete cubes were tested to assess their physical and mechanical properties.

2.3. Analysis of concrete cubes

To determine the engineering properties of cement concrete, a series of laboratory tests were conducted. The parameters analyzed and the corresponding testing procedures are summarized in Table 1. Concrete samples were prepared using treated wastewater sourced from the 10 MLD sewage treatment plant (STP) at Patna, Bihar, blended with potable water in the following proportions:
(i) 100% potable water,
(ii) a 60:40 mixture of primary treated domestic wastewater (mechanically treated) and potable water, and
(iii) a 60:40 mixture of secondary treated domestic wastewater (biologically treated) and potable water.
Concrete cubes were cast for each water combination and later tested to evaluate their physical and mechanical characteristics.

3. Results and discussion

This section provides a detailed analysis of the wastewater samples collected over a three-year period from the outlet of the 10 MLD sewage treatment plant (STP) at Patna, Bihar. It also presents a performance evaluation of concrete specimens prepared using three types of water: potable water, primary treated wastewater, and secondary treated wastewater.

3.1. Analysis of treated sewage water parameters (April 2021 – March 2022)

3.1.1. pH

The pH of the treated wastewater from the 10 MLD sewage treatment plant (STP) at Patna, Bihar (Figure 3) was monitored on a monthly basis and showed consistent results throughout the observation period. In April, the mean pH value was 7.65, closely matching the median value of 7.66, reflecting slightly alkaline conditions. Similar stability was observed in May, with both the mean and median recorded at 7.68. In June, the mean pH was 7.66 and the median 7.67, maintaining a consistent trend. A marginal decline was noted in July, when both values

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reached 7.63. In August, the mean and median were 7.65 and 7.66, respectively, while in September both remained steady at 7.14. October recorded a mean of 7.63 and a median of 7.14, followed by a minor increase in November with a mean of 7.67 and a median of 7.63. In December, the mean and median values returned to 7.63 and 7.14, respectively. Overall, the pH values fluctuated only slightly within a narrow range, indicating effective wastewater treatment and stable effluent quality. The complete pH dataset for the 31-month monitoring period (April 2021–October 2023) is illustrated in Figure 4.

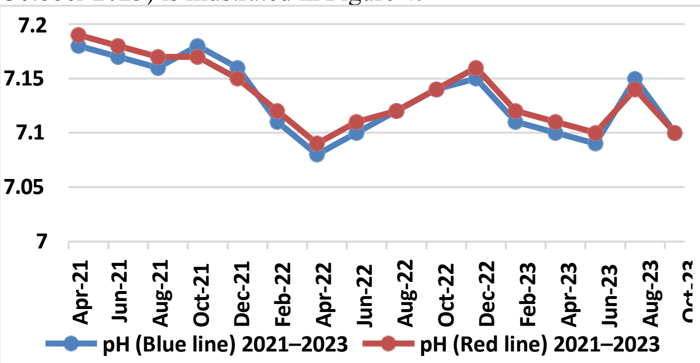

Figure 4. pH values of treated wastewater from the 10 MLD sewage treatment plant at Patna, Bihar (2021–2023).

Table 1. Tests conducted for concrete property analysis

Serial no.	Parameter	Test performed
1	Workability	Slump test
2	Compressive strength	Load test

3.1.2. Temperature

Figure 5 illustrates the monthly mean and median temperatures recorded over the three-year monitoring period (April 2021–March 2022). In April, the mean temperature was 26.82°C, with a slightly higher median of 27.36°C. Temperatures rose steadily in May (mean: 28.09°C; median: 28.22°C) and continued this upward trend through June (mean: 28.66°C; median: 28.81°C) and July (mean: 28.80°C; median: 28.90°C). The highest values were observed in August, with a mean of 29.42°C and a median of 29.35°C. A gradual decline followed in September (mean: 28.46°C; median: 28.62°C), becoming more pronounced in October (mean and median: 27.00°C). Cooling persisted into November (mean: 25.93°C; median: 26.10°C), reaching the lowest levels in December (mean: 20.68°C; median: 20.29°C). Temperatures began to rise again in January (mean: 21.14°C; median: 21.19°C), with further increases observed in February (mean: 21.39°C; median: 20.94°C) and March (mean: 23.29°C; median: 23.11°C). Overall, the data reveal a distinct seasonal variation, characterized by peak temperatures during the summer months and lower readings in winter, which aligns with the regional climatic pattern.

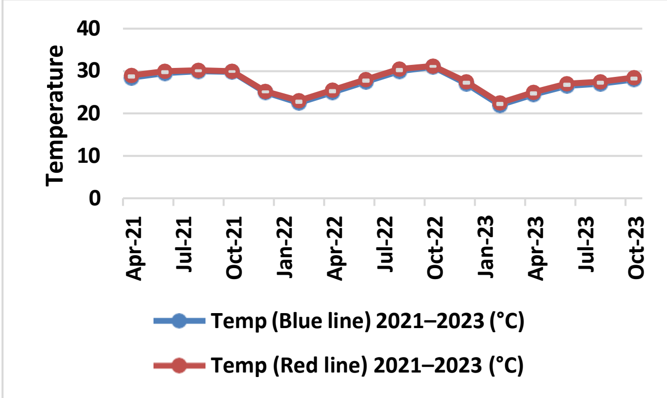

Figure 5. Temperature values of treated wastewater from the 10 MLD sewage treatment plant at Patna, Bihar (2021–2023).

3.1.3. TSS

Figure 6 presents the monthly mean and median total suspended solids (TSS) values for the period April 2021 to March 2022, illustrating the overall trend in water quality. The mean TSS values varied between 16.42 mg/L and 17.14 mg/L, with the lowest concentration recorded in November and the highest in December. Median values remained relatively stable around 17 mg/L, except in August, when a slight decrease to 16.5 mg/L was observed, indicating a minor decline in central tendency. Despite these small fluctuations, TSS levels remained consistent throughout the year, reflecting stable treatment performance and uniform effluent quality. Monitoring TSS is essential for assessing environmental compliance and ensuring the effectiveness of wastewater treatment processes.

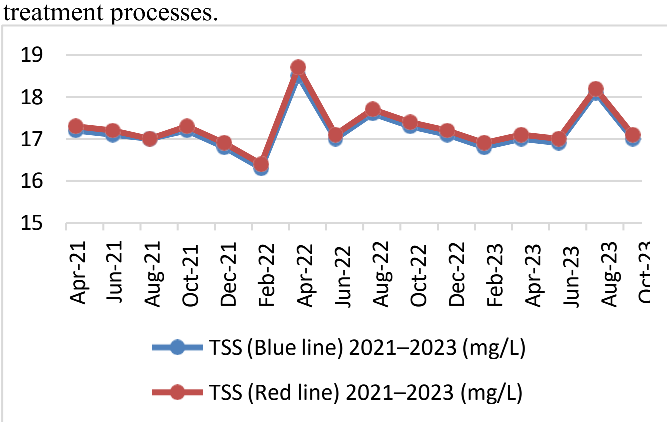

Figure 6. Total suspended solids (TSS) values of treated wastewater from the 10 MLD sewage treatment plant at Patna, Bihar (2021–2023).

3.1.4. Chemical oxygen demand

Figure 7 shows the monthly mean and median chemical oxygen demand (COD) levels in wastewater utilized for cement production between April 2021 and March 2022, evaluated in relation to water quality standards. The mean COD values remained consistently within the range of 38 to 41 mg/L, demonstrating a stable central tendency throughout the monitoring period. COD serves as a key indicator of the concentration of organic pollutants in wastewater and is crucial for determining its suitability for industrial reuse, particularly in cement manufacturing. Maintaining COD concentrations within prescribed regulatory limits is essential to prevent environmental degradation and ensure compliance with quality standards. The observed monthly variations in COD values reflect normal process fluctuations and provide valuable insight for effective environmental management and operational control.

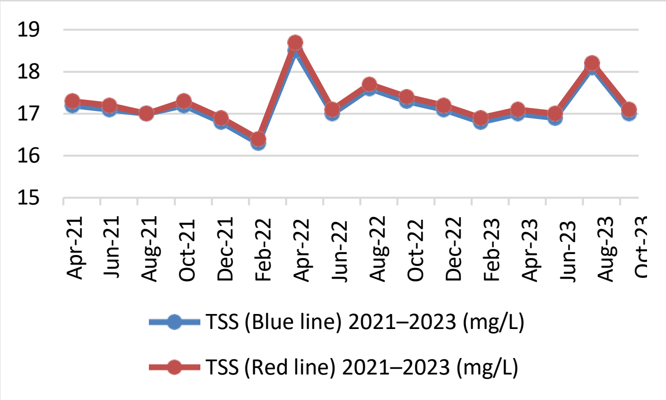

Figure 7. Chemical oxygen demand (COD) values of treated wastewater from the 10 MLD sewage treatment plant at Patna, Bihar (2021–2023).

3.1.5. BOD

Figure 8 illustrates the monthly variations in biological oxygen demand (BOD) from April 2021 to March 2022. The BOD values ranged from a minimum of 7.0 mg/L in December to a maximum of 7.54 mg/L in October. Median values remained fairly consistent between 7 and 8 mg/L throughout the study period, indicating stable organic load conditions. A slight seasonal increase was observed in July, with a median value of 8.0 mg/L, reflecting typical variations linked to temperature and biological activity. BOD serves as a key parameter for assessing the level of organic contamination in wastewater and is essential for evaluating water quality, regulatory compliance, and environmental management practices. The observed monthly variations provide valuable insights into seasonal patterns of organic matter degradation and support continued monitoring for process optimization and sustainable reuse.

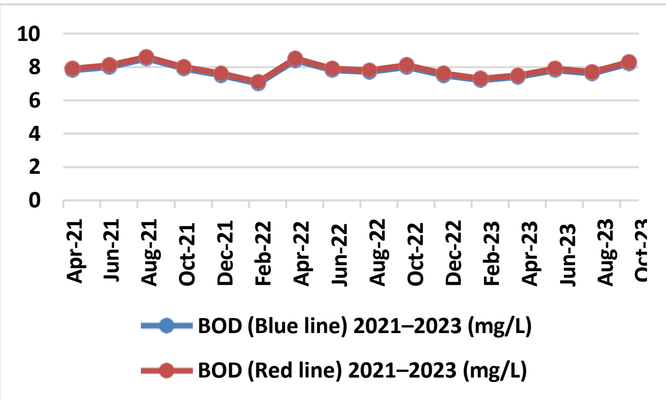

Figure 8. Biochemical oxygen demand (BOD) values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Patna, Bihar (2021–2023).

3.1.6. F. coli

Figure 9 presents the monthly variation in *Faecal coliform* (F. coli) counts from April 2021 to March 2022, used as an indicator of microbial water quality and public health risk. The mean F. coli concentrations ranged from 542.5 CFU/100 mL in December to 642.5 CFU/100 mL in June, reflecting seasonal fluctuations in bacterial contamination. Median counts showed a similar pattern, varying between 540 CFU/100 mL in December and 645 CFU/100 mL in June. A moderate rise was observed in July, with a median of 595 CFU/100 mL, indicating increased microbial activity during warmer months. F. coli levels are critical for assessing the sanitary quality of treated effluent and determining compliance with environmental and health standards. The observed variations emphasize the need for continuous monitoring to ensure consistent treatment performance and safeguard against potential public health risks.

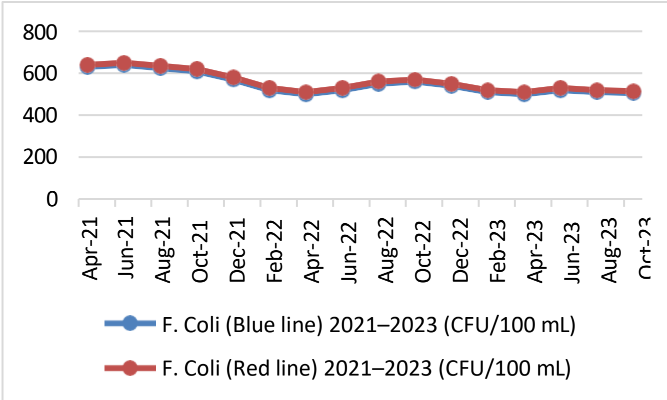

Figure 9. Fecal coliform (F. coli) values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Patna, Bihar (2021–2023).

3.17. Total Kjeldahl nitrogen (TKN)

Figure 10 illustrates the monthly variations in Total Kjeldahl Nitrogen (TKN) concentrations from April 2021 to March 2022. TKN is a key indicator of nitrogen pollution and plays an important role in water quality assessment and environmental monitoring. The mean and median TKN values ranged from 2.25 mg/L in May to 3.5 mg/L in December, showing clear seasonal variation. Median concentrations were lowest in May (2.0 mg/L) and peaked in June and September (3.5 mg/L), indicating increased nitrogen content during those months. Moderate stability was observed in July and November, with median values of 2.5 mg/L. These results provide valuable insights into nitrogen loading patterns and can help guide management strategies aimed at maintaining acceptable water quality standards throughout the year.

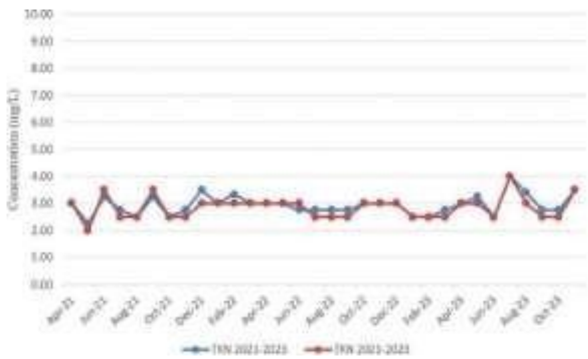

Figure 10. Total Kjeldahl Nitrogen (TKN) values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Patna, Bihar (2021–2023).

3.2. Analysis of treated sewage water parameters (April 2022 – March 2023)

3.2.1. pH

The pH values recorded from April 2022 to March 2023 showed only minor fluctuations, as reflected in the mean and median data. In April, the mean pH was 7.08, with a median of 7.09. A slight increase was noted in May (mean: 7.67; median: 7.08), followed by a small decline in June (mean and median: 7.65). In July, both the mean and median were 7.63, showing consistent neutral conditions, which persisted through August (mean: 7.10; median: 7.61). A modest rise was observed in September (mean: 7.62; median: 7.63) and continued into October (mean and median: 7.63). November showed a slight decrease (mean: 7.61; median: 7.62). From December 2022 to March 2023, the pH values remained within a similar range. Overall, the pH remained close to neutral throughout the 12-month period, indicating stable effluent quality and effective treatment performance.

3.2.2. Temperature

Figure 5 shows the monthly temperature variations of treated sewage water from April 2022 to March 2023. These readings are crucial for evaluating the feasibility of sewage reuse in cement production from both environmental and operational standpoints. Temperatures ranged from 20.71°C in February to a peak of 29.8°C in August, with 28.64°C recorded in July. Seasonal temperature changes can influence sludge characteristics and affect process efficiency in cement manufacturing. The results emphasize the need to monitor and manage temperature variations throughout the year to maintain stable sludge properties, consistent cement quality, and sustainable plant operations.

3.2.3. TSS

Figure 6 depicts the monthly variations in total suspended solids (TSS) concentrations from April 2022 to March 2023, reflecting the quality of treated wastewater utilized in cement production. The mean TSS values ranged from 16.73 mg/L in October to 18.38 mg/L in May, showing clear seasonal variability in suspended solids. Median concentrations followed a similar pattern, varying between 16.5 mg/L in October and 18.5 mg/L in May, with relatively consistent levels of 17.5 mg/L observed in February and August. Continuous monitoring of TSS is essential for assessing the suitability of treated wastewater for industrial applications such as cement manufacturing and ensuring compliance with environmental standards. These findings provide valuable insight into seasonal water quality fluctuations and support informed decision-making for sustainable industrial water management.

3.2.3. Chemical oxygen demand

Figure 7 presents the monthly chemical oxygen demand (COD) values of treated wastewater from April 2022 to March 2023. COD serves as a crucial parameter for assessing the concentration of organic pollutants and determining the environmental suitability of wastewater for reuse in cement production. Throughout the study period, COD levels remained largely consistent at around 40 mg/L, reflecting stable treatment efficiency. A minor decline to approximately 39 mg/L was observed in February, indicating slight seasonal variation while maintaining overall water quality within acceptable limits.

3.2.4. BOD

Figure 8 shows the monthly biological oxygen demand (BOD) levels of treated sewage water from April 2022 to March 2023. BOD is an important indicator for evaluating the suitability of treated wastewater for use in cement production, especially in relation to environmental standards and water quality compliance. The mean BOD values ranged from 6.78 mg/L in March to 7.47 mg/L in May and June, indicating moderate variation in organic load across the year. Median values followed a similar pattern, ranging from 7.00 mg/L in April and December to 7.50 mg/L in June, July, October, and November, reflecting overall stability with occasional seasonal peaks.

3.2.5. F. coli

Figure 9 presents the monthly mean and median concentrations of *F. coli* from April 2022 to March 2023. These measurements are essential for evaluating microbial contamination and determining the suitability of treated wastewater for industrial reuse in accordance with environmental and public health standards. In April, the mean *F. coli* count was 525 CFU/100 mL, with a median of 510 CFU/100 mL, reflecting a moderate bacterial presence. Mean counts decreased in May (510 CFU/100 mL) and June (475 CFU/100 mL), suggesting a temporary improvement in microbial quality. A slight increase was observed in July, followed by relatively stable concentrations in August (520 CFU/100 mL) and September (517.5 CFU/100 mL), with medians consistently near 510 CFU/100 mL. October recorded a minor decline (mean: 490; median: 475 CFU/100 mL), whereas November and December exhibited increases, reaching 507.5 and 565 CFU/100 mL, respectively. The highest bacterial counts occurred in January (mean: 577.5 CFU/100 mL; median: 575 CFU/100 mL) and February (mean: 557.5 CFU/100 mL; median: 555 CFU/100 mL), indicating elevated microbial activity during the winter months.

3.2.6. TKN

Figure 10 presents the monthly mean and median concentrations of Total Kjeldahl Nitrogen (TKN) from April 2022 to March 2023. TKN is a key indicator of nitrogen content in wastewater and is critical for evaluating its environmental suitability for reuse in cement production. Throughout the year, TKN levels remained relatively stable, generally ranging between 2.5 and 3.0 mg/L. Mean concentrations stayed close to 3.0 mg/L from April to November and again from December to March, with minor decreases observed during January, February, and March. Median values exhibited a similar pattern, maintaining around 3.0 mg/L for most of the year but dipping slightly to 2.5 mg/L in July, August, and September, indicating mild seasonal variation. Overall, the results reflect a consistent nitrogen profile in the treated sewage water, with minimal fluctuation across the 12-month period.

3.3. Analysis of treated sewage water parameters (April – November 2023)

3.3.1. pH

Figure 4 presents the monthly mean and median pH values from April to November 2023. The results show only minor fluctuations, with pH values remaining close to neutral throughout the monitoring period. In April, the mean and median were 7.63 and 7.14, respectively. A slight increase was observed in May, with values of 7.14 (mean) and 7.65 (median). In June, both values decreased slightly to 7.63 and 7.14, followed by a further decline in July, where the mean and median were 7.07 and 7.08. August recorded similar readings, with a mean of 7.07 and a median of 7.09. In September, both the mean and median rose again to 7.63, continuing the upward trend into October with values of 7.14 and 7.65, respectively. November showed a slight reduction, with both mean and median at 7.62. Overall, the pH remained stable and near neutral, reflecting consistent treatment performance and water quality during the study period.

3.3.2. Temperature

Figure 5 shows the monthly mean and median temperatures of treated sewage water from April to November 2023. In April, the mean temperature was 23.57°C, and the median was 23.96°C. Temperatures increased in May, reaching 25.16°C (mean) and 24.99°C (median), and continued to rise in June to 26.86°C and 26.73°C, respectively. A slight decline was observed in July, with mean and median values of 26.24°C and 25.86°C. August recorded mean and median temperatures of 25.92°C and 27.65°C, respectively, indicating an unexpected increase. In September, the mean fell slightly to 25.33°C, while the median dropped more sharply to 22.81°C. By October, temperatures stabilized at 25.62°C (mean) and 25.82°C (median). November recorded the highest temperatures during the study period, with both mean and median reaching 27.80°C. Overall, the results reveal moderate temperature fluctuations across the months, with notable irregularities observed in August and September.

3.3.3. TSS

Figure 6 presents the monthly mean and median concentrations of Total Suspended Solids (TSS) in treated sewage water from April to November 2023. In April, the mean TSS was 16.96 mg/L, with a median of 17 mg/L. A slight decline was observed in May, where the mean dropped to 16.63 mg/L, while the median remained constant at 17 mg/L. June recorded similar values, with a mean of 16.62 mg/L and a median of 17 mg/L. A noticeable increase occurred in July, as the mean rose to 17.94 mg/L and the median to 18 mg/L. This upward trend continued in August, with mean and median values of 18.23 mg/L and 18 mg/L, respectively. In September, the mean decreased to 17.07 mg/L, followed by a slight increase in October (mean: 17.66 mg/L; median: 17 mg/L). November recorded a mean of 16.77 mg/L and a median of 17 mg/L. Overall, TSS levels remained relatively stable, averaging around 17 mg/L throughout the monitoring period, with marginally higher values observed during July and August.

3.3.4. Chemical oxygen demand

Figure 7 illustrates the monthly mean and median values of Chemical Oxygen Demand (COD) in treated sewage water from April to November 2023. In April, the mean COD was 40.08 mg/L, with a median of 40 mg/L. A slight increase was observed in May, where the mean rose to 40.26 mg/L, while the median remained constant. In June, the values stabilized at 40.04 mg/L (mean) and 40 mg/L (median). A noticeable decline occurred in July, as the mean dropped to 39.42 mg/L and the median to 39 mg/L. This downward trend continued in August, with mean and median values of 39 mg/L each, and further in September, where the mean fell to 38.9 mg/L and the median stayed constant at 39 mg/L. In October, a slight increase was noted, with a mean of 39.84 mg/L and the median unchanged at 39 mg/L. November recorded mean and median values of 39.3 mg/L and 39 mg/L, respectively. Overall, the COD values show a gradual decreasing trend throughout the period, with median values exhibiting minimal variation, suggesting consistent treatment efficiency and stable effluent quality.

3.3.5. Biochemical oxygen demand

Figure 8 shows the monthly mean and median values of Biochemical Oxygen Demand (BOD) in treated sewage water from April to November 2023, indicating overall stability with minor variations. In April, the mean BOD was 7.62 mg/L and the median was 7.00 mg/L. A slight decrease was observed in May, where the mean dropped to 6.89 mg/L while the median remained unchanged. In June, both values increased to 7.35 mg/L (mean) and 7.5 mg/L (median). July recorded a small decline, with the mean falling to 7.10 mg/L and the median returning to 7.00 mg/L. A distinct rise occurred in August, when the mean reached 7.48 mg/L and the median increased to 8.00 mg/L. In September, the mean was 7.33 mg/L and the median stabilized at 7.5 mg/L. October showed a minor drop in mean to 7.29 mg/L, with the median again at 7.00 mg/L. Overall, BOD levels remained relatively consistent throughout the study period, with noticeable peaks in August and November suggesting slight variations in organic load or treatment efficiency.

3.3.6. F. coli

Figure 9 presents the monthly mean and median concentrations of *Fecal coliform* (F. coli) in treated sewage water from April to November 2023. In April, the mean concentration was 535 CFU/100 mL and the median was 525 CFU/100 mL. Both values rose sharply in May to 567.5 CFU/100 mL (mean) and 565 CFU/100 mL (median). A decline followed in June, with mean and median values of 497.5 CFU/100 mL and 495 CFU/100 mL, respectively. The concentration increased again in September, reaching a mean of 550 CFU/100 mL. In October, the mean slightly decreased to 540 CFU/100 mL, while the median stabilized at 525 CFU/100 mL. By November, both values dropped further to 532.5 CFU/100 mL (mean) and 510 CFU/100 mL (median). Overall, the data show moderate monthly fluctuations in F. coli concentrations, with higher levels between May and September and relatively lower counts toward the end of the monitoring period.

3.3.7. TKN

Figure 10 illustrates the monthly mean and median concentrations of Total Kjeldahl Nitrogen (TKN) in treated sewage water from April to November 2023. In April, both the mean and median TKN values were 3.0 mg/L. A slight increase was observed in May, with the mean rising to 3.25 mg/L while the median remained unchanged. In June, both values declined to 2.5 mg/L. July recorded the highest TKN concentration of the period, with both the mean and median reaching 4.0 mg/L. In August, the mean decreased to 3.4 mg/L and the median to

3.0 mg/L. September and October showed similar trends, with mean values of 2.75 mg/L and median values of 2.5 mg/L. In November, both increased again to 3.5 mg/L. Overall, TKN levels remained relatively stable throughout the monitoring period, with moderate fluctuations and a distinct peak observed in July.

3.4. Concrete mixed with 100% potable water

Concrete cubes were prepared using a mix of cement, sand, and coarse aggregate with 100% potable water. The mixture was poured into 150 mm cube molds and manually mixed. After curing, the specimens were subjected to a compressive load test to determine the baseline strength for comparison in later tests (Figure 11 and Table 2).

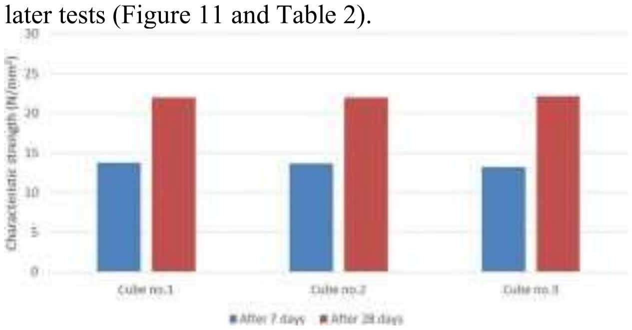

Figure 11. Characteristic strength of concrete prepared using 100% potable water.

Table 2. Compressive strength of concrete prepared using 100% potable water.

Characteristic strength of concrete (N/mm^2)	After 7 days	After 28 days
Cube no. 1	13.11	23.75
Cube no. 2	13.91	24.28
Cube no. 3	13.77	23.85

3.5. Concrete mixed with primary treated wastewater and potable water (60:40 ratio)

Concrete cubes were prepared using a mix of cement, sand, and coarse aggregate combined with 60% primary treated wastewater and 40% potable water. The mixture was poured into 150 mm cube molds and tested for compressive strength after curing. A bar chart was prepared to illustrate the results (Figure 12 and Table 3).

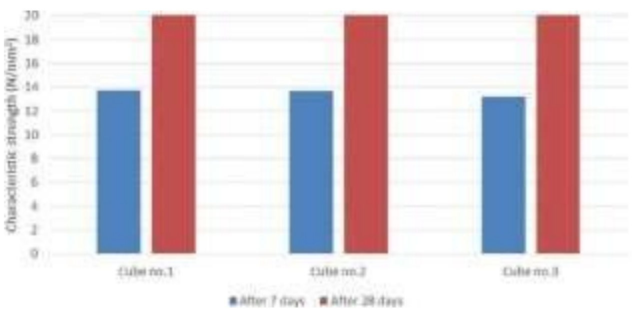

Figure 12. Characteristic strength of concrete prepared using a 60:40 mixture of primary treated wastewater and potable water.

Table 3. Compressive strength of concrete prepared using a 60:40 mixture of primary treated wastewater and potable water.

Characteristic strength of concrete (N/mm^2)	After 7 days	After 28 days
Cube no. 1	13.77	17.00
Cube no. 2	13.77	17.22
Cube no. 3	13.44	17.66

3.6. Concrete mixed with secondary treated wastewater and potable water (60:40 ratio)

Concrete cubes were prepared using a mix of cement, sand, and aggregate combined with a water blend containing 60% secondary treated wastewater and 40% potable water. The mixture was poured into 150 mm cube molds and tested under load. The results were presented in a bar chart (Figure 13 and Table 4).

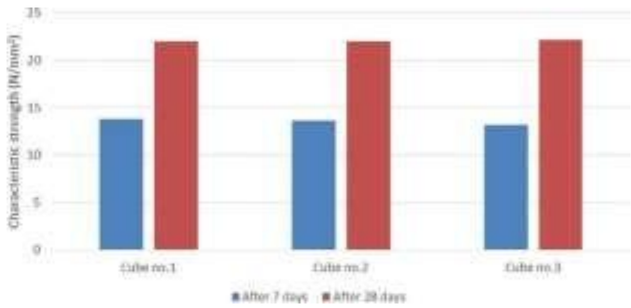

Figure 13. Compressive strength of concrete prepared using a 60:40 mixture of secondary treated wastewater and potable water.

Table 4. Compressive strength results of concrete prepared using a 60:40 mixture of secondary treated wastewater and potable water.

Characteristic strength of concrete (N/mm^2)	After 7 days	After 28 days
Cube no. 1	13.77	21.99
Cube no. 2	13.66	22.00
Cube no. 3	13.22	22.11

3.7. Economic consideration

Based on the M-20 concrete mix design, about 142 liters of water are needed per cubic meter of concrete. Using treated sewage water helps reduce potable water consumption and supports sustainability. Replacing 60% of the required water saves roughly 85 liters of freshwater per cubic meter. At the current rate of Rs. 20 per 1,000 liters, this equals a saving of Rs. 1.70 per cubic meter. For every 1,000 cubic meters of concrete produced, approximately 85 kiloliters of potable water can be conserved, resulting in a total saving of around Rs. 1,700. Beyond cost benefits, this approach helps preserve freshwater resources and supports long-term environmental balance amid increasing water treatment and distribution costs.

4. CONCLUSIONS

The study demonstrates that treated sewage water from the Patna, Bihar STP can effectively replace potable water in concrete production, promoting sustainable water management. Continuous monitoring of water quality over three years confirmed its reliability for industrial use. Concrete cubes prepared with secondary treated wastewater achieved compressive strengths comparable to those made with potable water, indicating its suitability as a viable substitute.

This approach not only reduces dependence on freshwater sources but also supports wastewater reuse in line with environmental sustainability goals. The use of treated sewage water can save about 85 liters of potable water per cubic meter of concrete, amounting to roughly Rs. 1,700 in savings for every 1,000 cubic meters produced. Beyond the economic benefits, this practice helps preserve critical freshwater resources amid rising treatment and distribution costs.

Future research should focus on evaluating the long-term durability and performance of concrete made with treated sewage water to confirm its broader applicability in the construction sector.

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