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ORIGINAL RESEARCH ARTICLE

Utilization of treated wastewater from sewage treatment plants as a replacement for potable water in concrete mix

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Abstract: With only 0.5% of Earth's water being potable and increasing demand driven by urbanization and construction, there is an urgent need to identify sustainable alternatives to freshwater for concrete production. This study examines the use of purified sewage water from a 10 million liters-per-day sewage treatment plant at Bambianwali, which employs sequential batch reactor technology, as a substitute for potable water in concrete mixing. An extensive analysis was conducted over a 3-year period (2021 – 2023) to evaluate the suitability of treated sewage water for concrete production. Water quality parameters analyzed included pH, temperature, total suspended solids, chemical oxygen demand, biological oxygen demand, fecal coliform, and total Kjeldahl nitrogen. Plain cement concrete cubes were prepared and tested for compressive strength using three different water mixtures: 100% potable water, a 60:40 mixture of primary treated wastewater and potable water, and a 60:40 mixture of secondary treated wastewater and potable water. After 28 days of curing, the concrete cubes prepared with secondary treated wastewater in a ratio of 60:40 achieved a characteristic strength of 22.03 N/mm^2, compared to 23.96 N/mm^2 for cubes made with 100% potable water. In contrast, cubes made with primary treated wastewater showed a reduced strength of 17.30 N/mm^2. These findings indicate that secondary treated sewage water can serve as a feasible substitute for potable water in concrete mixing, though the compressive strength of resulting concrete may vary depending on the extent of treatment applied to the water.

Keywords: Sewage water; Concrete production; pH; Temperature; Total suspended solids; Chemical oxygen demand; Biological oxygen demand; Fecal coliform

1. Introduction

The phrase "elixir of life" aptly describes water. Although water covers over 71% of the Earth's surface, only 3% of it is categorized as freshwater. Of this small fraction, roughly 80% is locked in polar ice caps and remains inaccessible. As a result, only approximately 0.5% of the Earth's water is considered potable and safe for human consumption.[1]

Over the past century, global water scarcity has become a critical issue, driven by factors such as overcrowding, urbanization, pollution, climate change, inadequate freshwater management, and environmental degradation.[2] In parallel, water plays an important role in the production of cement-based materials, such as paste, mortar, and concrete.[3] Concrete is produced by combining water with inert ingredients (coarse and fine particles) and binding agents (Portland cement or asphalt). Globally, the concrete industry consumes almost one trillion gallons of water annually.[4]

While an adequate water supply is essential to generate a workable concrete mix that can be properly mixed, placed, compacted, and finished, using less water generally results in superior concrete with improved strength characteristics.[5] Water is also required for various concrete-related processes, including aggregate washing, cleaning of batching plants, and rinsing of concrete mixer trucks.[6]

Cement-based materials can be produced using any potable water, provided it contains no harmful levels of acids, salts, alkalis, oils, sugar, or organic compounds.[7] Water that is highly alkaline or acidic, contains algae, or has elevated chloride concentrations[8] should be avoided, as it can negatively impact the setting, hardening, and strength development of concrete.

Due to the increasing scarcity of potable water, the search for alternative sources has gained momentum.[9] Potential substitutes often contain higher concentrations of dissolved chemicals and suspended particulates and include sources such as saltwater, treated industrial wastewater, treated sewage wastewater, wastewater from carwash service stations, runoff from ready-mix concrete plants, and wastewater from stone-cutting operations.[10] When adequately treated, all of these water resources have been shown to produce concrete with acceptable strength and durability.[6] Water usage in the construction industry is nearly proportional to concrete production.[7] As a result, using partially or fully treated wastewater in concrete manufacturing could reduce the demand for potable water and lower the cost associated with wastewater treatment.[11] Despite environmental and public health concerns, wastewater continues to be used in concrete applications in various regions. Treated sewage wastewater refers to domestic, municipal, and industrial wastewater that has undergone treatment to remove all pollutants and suspended particles before discharge into the environment.[12] Producing such treated effluent requires a combination of physical, chemical, and biological treatment processes to ensure compliance with environmental safety standards.[13] A by-product of this process is sewage sludge, a semi-solid waste that requires further treatment before it can be safely disposed of on land.[12]

Reclaimed water, often referred to as recycled water, is wastewater that has been treated to remove suspended and solid particles. It has a wide range of applications, such as irrigation, concrete production, groundwater replenishment, and landscaping.[14] Sludge generated during this process is often mixed with biowaste to produce compost, which is widely used in agriculture.[15] In some cases, reclaimed wastewater can even be used to cultivate spirulina.[16]

This study focuses on the use of recycled wastewater in the production and curing of concrete. In addition to environmental benefits, the use of treated wastewater in concrete manufacturing may offer financial advantages. By introducing the construction industry—a constantly expanding sector in most economies – as a key consumer of treated wastewater, investment in wastewater treatment and reuse technologies can be further incentivized.[17,18]

The current research aims to:

- Investigate the potential applications of various wastewater sources, including treated industrial and sewage water, for use in the production and curing of concrete.
- Evaluate the durability and strength of concrete structures when treated wastewater is used in place of potable water.
- Analyze the economic benefits of employing sewage treatment plants (STPs) in concrete manufacturing, particularly in reducing potable water consumption and sewage water treatment costs.
- Assess the potential health risks and environmental impacts associated with the use of treated wastewater in concrete construction.
- Explore the potential for expanding treated wastewater markets and investment opportunities by targeting the construction sector as a major consumer.

2. Materials and methods

This study was based on the characterization of wastewater and the evaluation of concrete prepared using treated wastewater as a replacement for potable water. The primary materials investigated were treated wastewater and concrete, both of which underwent detailed laboratory analysis.

2.1. Sampling

To ensure high quality and strict compliance with environmental standards, treated sewage water samples were collected daily from the outlet of 10 million liters-per-day (MLD) STP in Bambianwali. These samples underwent comprehensive and rigorous laboratory analysis to determine critical parameters, such as pH, total suspended solids (TSS), chemical (COD) and biological oxygen demand (BOD), and the concentrations of key nutrients such as sulfate, chloride, sodium, nitrate, and fecal coliform (F. coli) (Figure 1 & 2).

2.2. Concrete cube sampling and curing

Concrete was prepared by mixing cement with samples of both primary and secondary treated wastewater. The fresh concrete was then cast into standard molds. These molds were subsequently cured in water for 7, 14, and 28 days. After each curing period, the concrete cubes were tested to evaluate their physical and mechanical properties.

2.3. Analysis of concrete cubes

To evaluate the properties of cement concrete, various laboratory tests were performed. The parameters tested and the associated test methods are listed in Table 1.

To prepare the concrete samples, treated wastewater obtained from the 10 MLD STP at Bambianwali was mixed with potable water in the following ratios:

(i) 100% potable water
(ii) 60:40 mixture of primary treated domestic wastewater (mechanical) and potable water
(iii) 60:40 mixture of secondary treated domestic wastewater (biological) and potable water.

Concrete cubes were cast using each water combination and subsequently tested to assess their properties.

Table 1. Tests conducted for concrete property analysis

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

3. Results and discussion

This section presents a comprehensive analysis of the wastewater samples collected over a 3-year period from the outlet of the 10 MLD STP at Bambianwali. It also includes a performance assessment of concrete cubes prepared using 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 values of the treated wastewater from the 10 MLD STP at Bambianwali (Figure 3) were monitored monthly and exhibited consistent results throughout the year. In April, the mean pH was 7.15, closely aligning with the median of 7.16, indicating slightly alkaline conditions. May recorded a mean and median of 7.18, indicating stable pH levels. In June, the mean pH was 7.16, and the median was 7.17, maintaining the same trend. A slight decrease was observed in July, with both mean and median values at 7.13. In August, the mean was 7.15, and the median was 7.16, while in September, both values stood at 7.14. In October, the mean was 7.13, with a median of 7.14. November showed a slight increase, with a mean of 7.17 and a median of 7.13. Finally, in December, the mean pH was 7.13, and the median was 7.14. Overall, the pH values remained within a narrow range, demonstrating effective treatment and consistent effluent quality. The complete pH values for the 31-months period (April 2021 to October 2023) are presented in Figure 4.

3.1.2. Temperature

Figure 5 presents the monthly mean and median temperatures over the 3-year study period, including April 2021 – March 2022. In April, the mean temperature was 26.82°C, with a slightly higher median of 27.355°C. Temperatures increased in May, reaching a mean of 28.09°C and a median of 28.22°C. This upward trend continued in June (mean: 28.66°C; median: 28.81°C) and July (mean: 28.80°C; median: 28.90°C). The highest temperatures were recorded in August, with a mean of 29.42°C and a median of 29.35°C. A gradual decline began in September (mean: 28.46°C; median: 28.62°C), followed by a more noticeable decrease in October (mean and median: 27.00°C). Cooling continued through November (mean: 25.93°C; median: 26.10°C), and reached the lowest values in December (mean: 20.68°C; median: 20.29°C). A slight increase was observed in January (mean: 21.14°C; median: 21.19°C), with further increases in February (mean: 21.39°C; median: 20.94°C) and March (mean: 23.29°C; median: 23.11°C). Overall, the data exhibit a clear seasonal pattern, with peak temperatures in the summer and lower values in the winter, consistent with the regional climate.

3.1.3. TSS

Figure 6 illustrates the monthly mean and median values of TSS for April 2021 – March 2022, highlighting trends in water quality. The mean TSS values ranged from 16.42 to 17.14 mg/L, with the lowest observed in November and the highest in December. Median values were relatively stable around 17 mg/L, except in August, where a drop to 16.5 mg/L indicated a slight decline in central tendency. In other months – April, May, June, July, September, and October – the median remained stable (17 mg/L),

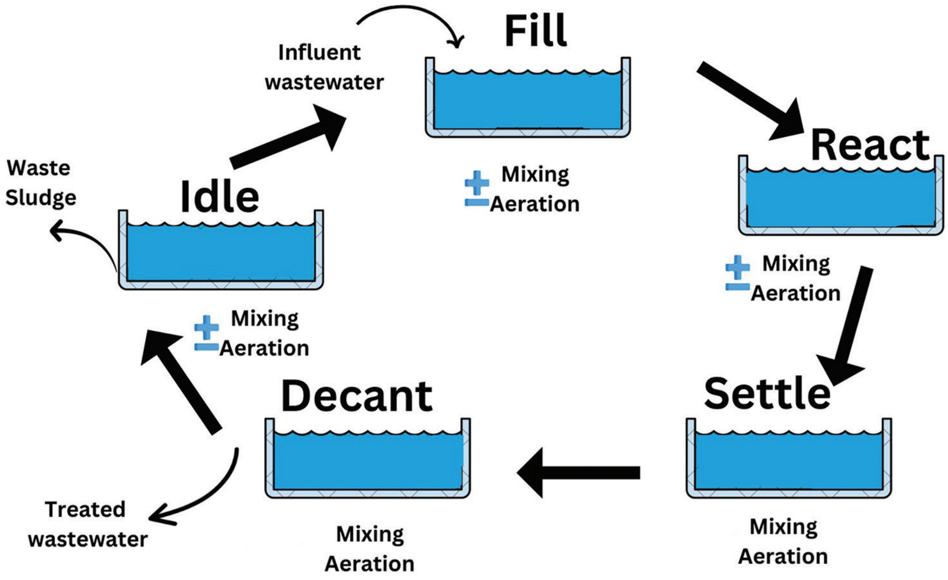

Figure 1. Phases of sequencing batch reactor operational cycle

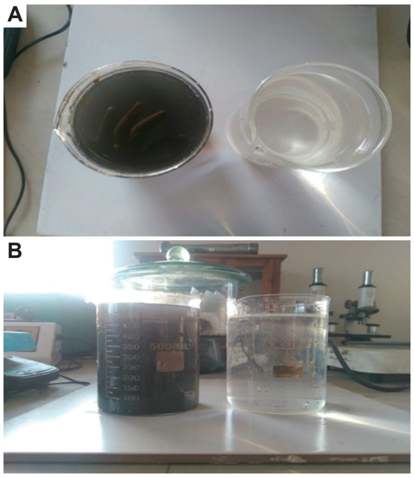

Figure 2. (A and B) Represent both Inlet and Outlet samples from the 10 million liters-per-day sewage treatment plant at Bambianwali, Jalandhar

Figure 3. Sequencing batch reactor basin of the 10 mL/day sewage treatment plant at Bambianwali, Jalandhar, during the aeration and filling phase

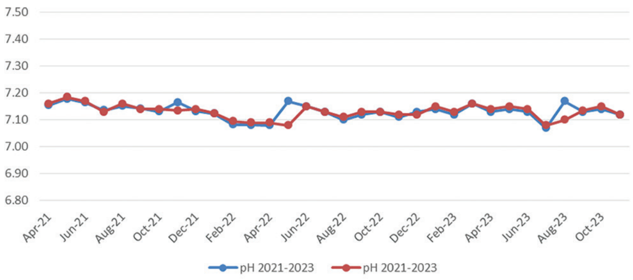

Figure 4. pH values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

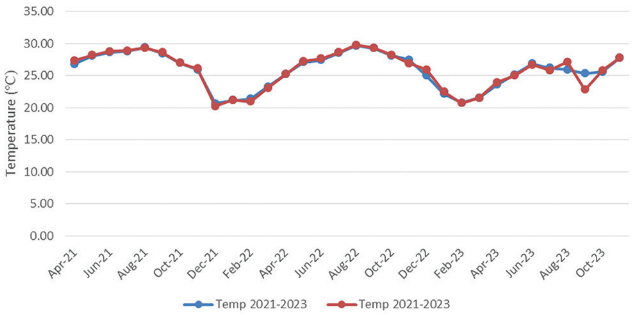

Figure 5. Temperature (Temp) values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

suggesting consistent water quality despite minor fluctuations in mean values. These TSS measurements are important for environmental monitoring, regulatory compliance, and water resources management.

3.1.4. Chemical oxygen demand

Figure 7 presents the monthly mean and median COD levels in wastewater used for cement production from April 2021 to March 2022, in reference to water transport standards. The mean COD values consistently ranged from 38 to 41 mg/L, indicating a stable central tendency across most months. COD is an important parameter for assessing the concentration of organic pollutants in wastewater, particularly in evaluating its suitability for industrial reuse, such as cement production. Maintaining COD levels within regulatory limits helps environmental degradation and ensures compliance with quality standards. The data reveal monthly fluctuations in COD levels and serve as a basis for informed environmental management decisions.

3.1.5. BOD

Figure 8 presents the monthly BOD values from April 2021 – March 2022. BOD levels ranged from a low of 7.0 mg/L in December to a high of 7.54 mg/L in October. Median BOD values remained relatively consistent between 7 mg/L and 8 mg/L across the study period, reflecting overall stability in organic pollutant load. July exhibited a median BOD of 8.0 mg/L, indicating a typical seasonal peak. BOD is a key indicator of organic contamination and plays a critical role in evaluating water quality, regulatory compliance, and environmental management. These monthly data highlight seasonal trends in BOD and offer insights for ongoing water quality monitoring and management.

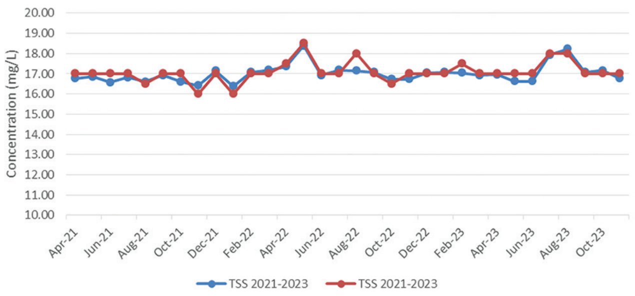

Figure 6. Total suspended solid values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

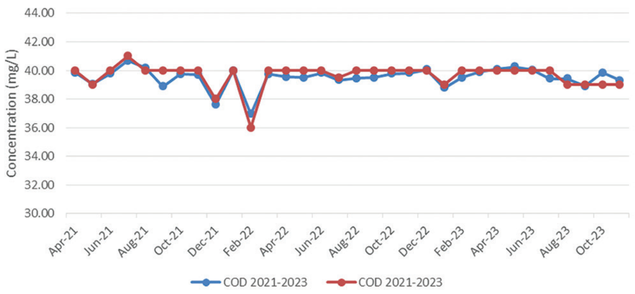

Figure 7. Chemical oxygen demand values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

3.1.6. F. coli

Figure 9 summarizes the monthly F. coli counts from April 2021 – March 2022, which are used to assess water quality, particularly in relation to potable water and public health standards. The mean F. coli counts ranged from 542.5 colony-forming units (CFU)/100 mL in December to 642.5 CFU/100 mL in June, indicating seasonal variability in bacterial contamination. Median values followed a similar trend, ranging from 540 CFU/100 mL in December to 645 CFU/100 mL in June. July recorded a median count of 595 CFU/100 mL, indicating heightened microbial presence during that period. F. coli levels are crucial indicators of potential waterborne health risks and are essential for environmental monitoring and regulatory compliance. The data highlight monthly fluctuations in F. coli levels and inform public health interventions aimed at safeguarding water quality year-round.

3.1.7. Total Kjeldahl nitrogen (TKN)

Figure 10 presents the monthly concentrations of TKN

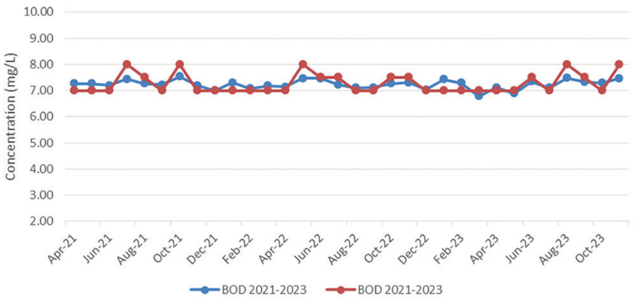

Figure 8. Biochemical oxygen demand (BOD) values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

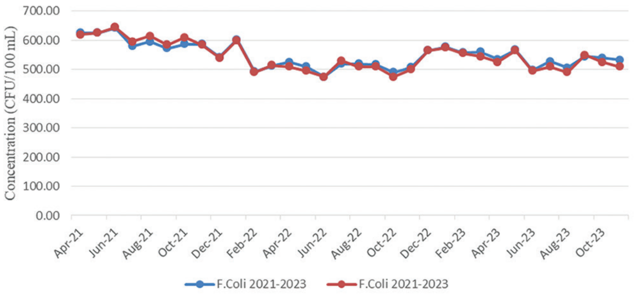

Figure 9. Fecal coliform values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

from April 2021 – March 2022. TKN is commonly used in water quality assessment and environmental monitoring as an indicator of nitrogen pollution. The mean and median TKN values ranged from 2.25 mg/L in May to 3.5 mg/L in December, showing notable variation across the year. Median TKN concentrations ranged from 2.0 mg/L in May to 3.5 mg/L in both June and September, indicating significant monthly trends. In July and November, TKN concentrations were 2.5 mg/L, reflecting relative stability in those months. These measurements are important for assessing nitrogen loading in water bodies, and can inform environmental policies and strategies for maintaining water quality standards. The data highlight monthly fluctuations in TKN, offering insights into seasonal variation in nitrogen levels over the 12-month period.

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

3.2.1. pH

The pH values from April 2022 to March 2023 show slight fluctuations, as indicated by the mean and median values. The mean of pH in April was 7.08, and the median was 7.09. This was slightly higher in May, with mean of 7.17 and median was 7.08. In June, the mean fell slightly to 7.15, although the median was also 7.15. A more notable improvement occurred in July, with mean value as 7.13 and a median of 7.13, and even further improved in August with the values of mean and median as 7.10 and 7.11 respectively. In September the pH values increased again, with mean as 7.12 and median as 7.13. This rise continued in October, with an mean of 7.13 and median also as 7.13. Finally, November pH levels dropped slightly to mean of 7.11 and a median of 7.12. The similar range was observed from December 2022 to March 2023. Overall, the data show small changes in pH levels over the period of 12 months, with values generally staying around a neutral pH of 7.

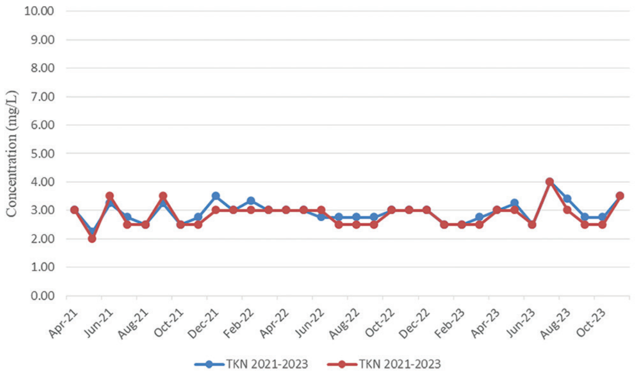

Figure 10. Total Kjeldahl nitrogen values of treated wastewater from the 10 million liters-per-day sewage treatment plant at Bambianwali (2021 – 2023)

3.2.2. Temperature

Figure 5 presents the monthly temperatures of treated sewage water over a 1-year period (April 2022 – March 2023). These data are important for assessing the suitability of sewage reuse in cement production, particularly from environmental and operational perspectives. Temperatures ranged from 20.71°C in February to 29.8°C in August, with a peak of 28.64°C recorded in July. Seasonal temperature fluctuations can affect sludge properties and influence the performance of cement manufacturing processes. The data highlight the importance of controlling temperature fluctuations throughout the year to ensure efficient sludge handling, consistent cement quality, and environmentally sustainable operations.

3.2.3. TSS

Figure 6 illustrates the monthly variation of TSS concentrations from April 2022 – March 2023, reflecting the quality of treated wastewater used in cement production. Mean TSS concentrations ranged from 16.73 mg/L in October to 18.38 mg/L in May, indicating seasonal variation in suspended solids. Median TSS values also fluctuated, ranging from 16.5 mg/L in October to 18.5 mg/L in May, with relatively stable levels of 17.5 mg/L in February and August. Monitoring TSS is critical for determining the suitability of wastewater in industrial processes, including cement production, and for ensuring compliance with environmental regulations. These data offer valuable insights into seasonal trends and help guide effective environmental management in industrial processes.

3.2.4. Chemical oxygen demand

Figure 7 shows the monthly COD values of treated wastewater from April 2022 – March 2023. COD is a key indicator of organic pollutant load and is essential in evaluating the environmental suitability of wastewater for reuse in cement production. Most months showed relatively consistent COD values around 40 mg/L, indicating a stable central tendency. A slight decrease to approximately 39 mg/L was observed in February.

3.2.5. BOD

Figure 8 presents the monthly BOD levels from April 2022 – March 2023. These values are relevant for assessing the suitability of treated sewage water for cement production, particularly with respect to environmental regulations and water quality standards. Mean BOD values ranged from a low of 6.78 mg/L in March to a high of 7.47 mg/L in May and June, indicating moderate fluctuations in organic pollutant levels. Median BOD values followed a similar trend, ranging from 7.00 mg/L in April and December to 7.50 mg/L in June, July, October, and November, suggesting a generally consistent trend with occasional peaks.

3.2.6. F. coli

Figure 9 shows the monthly mean and median of F. coli concentrations from April 2022 – March 2023. These measurements are important for assessing microbial contamination and determining whether treated wastewater meets environmental and public health standards for industrial reuse. The mean F. coli count in April was 525 CFU/100 mL, with a median of 510, indicating a moderate bacterial load. In May and June, the means decreased to 510 CFU/100 mL and 475 CFU/100 mL, respectively, indicating a temporary reduction in bacterial contamination. A slight increase occurred in July, followed by relatively stable values in August (520 CFU/100 mL) and September (517.5 CFU/100 mL), with medians consistently around 510 CFU/100 mL. October shows a slight decrease, with a mean of 490 and a median of 475 CFU/100 mL. In contrast, November and December recorded increases, with mean values of 507.5 and 565 CFU/100 mL, respectively. January and February showed the highest levels, with means of 577.5 and 557.5 CFU/100 mL, and medians of 575 and 555 CFU/100 mL, respectively – indicating elevated bacterial contamination during winter.

3.2.7. TKN

Figure 10 provides the monthly mean and median concentrations of TKN from April 2022 – March 2023. These values are relevant for assessing nitrogen levels in wastewater and its potential environmental impact when reused in cement production. TKN concentrations remained relatively stable throughout the year, generally ranging between 2.5 and 3.0 mg/L. The mean values were consistently close to 3.0 mg/L from April to November and again from December to March, with slight decreases observed in January, February, and March. Median TKN values followed a similar trend, with TKN concentrations remaining around 3 mg/L for most of the year. However, in July, August, and September, the median values dropped slightly to 2.5 mg/L, indicating minor seasonal variation. Overall, the data suggest a relatively stable nitrogen profile in treated sewage water, with only limited fluctuation.

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

3.3.1. pH

Figure 4 displays the monthly mean and median pH values from April to November 2023. The pH values show minor fluctuations throughout the period, generally remaining close to neutral. In April, the mean and median pH were 7.13 and 7.14, respectively. May showed a slight increase, with values of 7.14 (mean) and 7.15 (median). In June, both the mean and median slightly declined to 7.13 and 7.14, respectively, with July recording a mean of 7.07 and a median of 7.08, and August showing values of 7.07 (mean) and 7.09 (median). In September, both the mean and median increased again to 7.13. This upward trend continued in October with mean and median values of 7.14 and 7.15, respectively. November recorded a slight drop to 7.12 for both mean and median. Overall, the data indicate minor monthly variations in pH, with values consistently near neutral.

3.3.2. Temperature

Figure 5 presents the monthly mean and median temperatures of treated sewage water from April to November 2023. In April, the mean temperature was 23.57°C, with a mean of 23.96°C. Temperatures rose in May, reaching 25.16°C (mean) and 24.99°C (median), and continued to increase in June to 26.86°C and 26.73°C, respectively. A slight decrease occurred in July, with temperatures of 26.24°C (mean) and 25.86°C (median). August showed mean and median temperatures of 25.92°C and 27.15°C, respectively, indicating an unusual spike. September recorded a slight decline, with a mean of 25.33°C and a sharp decline in the median to 22.81°C. October temperatures stabilized at 25.62°C (mean) and 25.82°C (median). November recorded the highest temperatures of the period, with both mean and median at 27.80°C. These data suggest fluctuations in temperature stability, particularly in August and September, where deviations from the overall trend were more pronounced.

3.3.3. TSS

Figure 6 presents the monthly mean and median values of 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. In May, the mean slightly decreased to 16.63 mg/L, while the median remained stable at 17 mg/L. June recorded a mean TSS of 16.62 mg/L, with the median again at 17 mg/L. A significant increase occurred in July, where the mean rose to 17.94 mg/L and the median to 18 mg/L. August continued this upward trend, with a mean of 18.23 mg/L and a median of 18 mg/L. In September, the mean decreased to 17.07 mg/L, and in October, the mean was 17.16 mg/L while the median returned to 17 mg/L. Finally, in November, the mean TSS was 16.77 mg/L, with the median still at 17 mg/L. Overall, while minor fluctuations were observed, the TSS values consistently hovered around 17 mg/L, with July and August showing slightly elevated levels (18 mg/L).

3.3.4. Chemical oxygen demand

Figure 7 presents the monthly mean and median values of COD in treated sewage water from April to November 2023. In April, the mean COD was 40.08 mg/L, and the median was 40 mg/L. A slight increase was recorded in May, with the mean rising to 40.26 mg/L, while the median remained unchanged. In June, values remained stable at 40.04 mg/L (mean) and 40 mg/L (median). A sharp decrease occurred in July, with the mean dropping to 39.42 mg/L and the median to 39 mg/L. In August, the mean further decreased to 39 mg/L, while the median remained stable at 39 mg/L. September showed a continued decrease, with a mean of 38.9 mg/L and a median of 39 mg/L. In October, the mean increased slightly to 39.84 mg/L, with the median remaining unchanged at 39 mg/L. Finally, in November, the mean and median values were 39.3 mg/L and 39 mg/L, respectively. These results indicate a gradual downward trend in COD levels over the study period, with relatively low variation in median values compared to the mean.

3.3.5. Biochemical oxygen demand

Figure 8 presents the monthly mean and median values of BOD from April to November 2023, showing generally stable trends with minor fluctuations. In April, the mean BOD was 7.12 mg/L and the median was 7.00 mg/L. In May, the mean slightly decreased to 6.89 mg/L, while the median remained stable at 7.00 mg/L. In June, the mean increased to 7.35 mg/L and the median rose to 7.5 mg/L. July recorded a slight decrease, with the mean dropping to 7.10 mg/L and the median returning to 7.00 mg/L. A noticeable increase occurred in August, with the mean reaching 7.48 mg/L and the median increasing to 8.00 mg/L. In September, the mean was 7.33 mg/L, and the median remained at 7.5 mg/L. October saw the mean drop slightly to 7.29 mg/L, while the median returned to 7.00 mg/L. Overall, the BOD values remained fairly consistent, with a peak observed in August and November.

3.3.6. F. coli

Figure 9 presents the monthly and median values of F. coli concentrations from April to November 2023. In April, the mean was 535 CFU/100 mL and the median was 525 CFU/100 mL. Both values increased sharply in May, with the mean reaching 567.5 CFU/100 mL and the median 565 CFU/100 mL. In June, values decreased to 497.5 CFU/100 mL (mean) and 495 CFU/100 mL (median). In September, the mean was 550 CFU/100 mL. In October, the mean slightly decreased to 540 CFU/100 mL, while the median settled at 525 CFU/100 mL. In November, both values decreased further, with the mean at 532.5 CFU/100 mL and the median at 510 CFU/100 mL. These data indicate general fluctuations in F. coli concentrations, with peaks occurring from May to September and relatively lower levels in June – August.

3.3.7. TKN

Figure 10 presents monthly variations in TKN concentrations from April to November 2023. In April, both the median and median TKN values were 3.0 mg/L. In May, the mean increased slightly to 3.25 mg/L, while the median remained at 3.0 mg/L. In June, both values decreased to 2.5 mg/L. July recorded the highest TKN values of the study period, with both the mean and median at 4.00 mg/L. In August, the mean decreased to 3.4 mg/L, while the median dropped to 3.0 mg/L. In September and October, the mean was 2.75 mg/L, and the median was 2.5 mg/L. Finally, in November, both values rose again to 3.5 mg/L. Overall, the TKN levels showed general stability, with moderate fluctuations and a peak observed in July.

3.4. Concrete mixed with 100% potable water

Concrete cubes were prepared using a mixture of cement, sand, and aggregate, combined with 100% potable water. The mixture was poured into 150 mm cube molds and manually mixed. After curing, a load test was performed to obtain baseline strength for comparison in future tests (Figure 11 and Table 2).

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

Concrete cubes were prepared by combining cement, sand, aggregate, and a mixture of 60% primary treated wastewater and 40% potable water. The mixture was

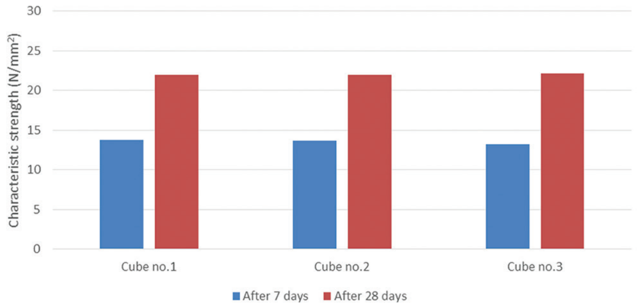

Figure 11. Characteristic strength of concrete mixed with 100% potable water

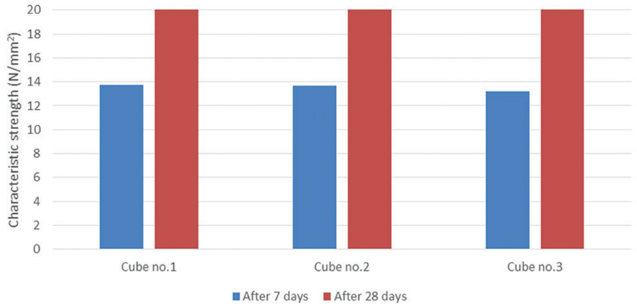

Figure 12. Characteristic strength of concrete mixed with primary treated wastewater and potable water (60:40 ratio)

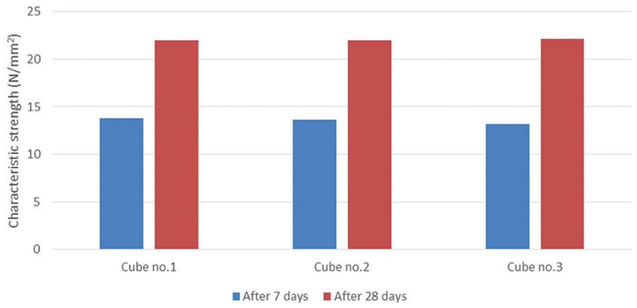

Figure 13. Characteristic strength of concrete mixed with secondary treated wastewater and potable water (60:40 ratio)

poured into a 150 mm cube mold and subsequently subjected to a load test. To facilitate interpretation of the results, a bar chart was created (Figure 12 and Table 3).

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

Concrete cubes were prepared by mixing cement, sand, aggregate, and a water blend consisting of 60% secondary treated wastewater and 40% potable water. The mixture was poured into 150 mm cube molds and subjected to load testing. The results were visualized using a bar chart (Figure 13 and Table 4).

Table 2. Strength of concrete mixed with 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

Table 3. Strength of concrete mixed with primary treated wastewater and potable water (60:40 ratio)

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

Table 4. Strength of concrete mixed with secondary treated wastewater and potable water (60:40 ratio)

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

According to the mix design for M-20 grade concrete, approximately 142 L of water is required per 1 cubic meter (cum) of concrete. The primary rationale for introducing treated sewage water is to reduce the consumption of potable water and promote sustainability. By replacing 60% of the required water, approximately 85 L of potable water can be saved per 1 cum of concrete. As the current commercial rate of Rs 20/1,000 L, this results in a saving of Rs 1.70/cum. Therefore, for 1,000 cum of concrete produced, 85 kL of potable water can be saved – resulting in a total cost saving of approximately Rs 1,700. This approach not only supports economic efficiency but also conserves vital freshwater resources for future generations, especially given the rising cost of water treatment and distribution.

4. Conclusion

The study showcases that treated sewage water from the STP at Bambianwali can efficiently substitute potable water in concrete production, thereby supporting sustainable water management practices. Continuous water quality monitoring over a 3-year period confirms the reliability of the treated sewage water for industrial uses. Concrete cubes mixed with secondary treated wastewater demonstrated strength comparable to those mixed with potable water, suggesting its viability as an alternative in concrete mixing. This strategy not only conserves potable water but also encourages the reuse of treated wastewater, in line with broader environmental sustainability goals. This practice could result in water savings of approximately 85 L/1 cum of concrete, translating to a cost saving of approximately Rs 1,700/1,000 cum of concrete. This approach can play a crucial role in ensuring the availability of potable water for future generations, especially given the rising cost associated with its treatment and distribution. Future research should prioritize the examination of the long-term durability and performance of concrete produced with treated sewage water to fully establish its suitability for widespread use in the construction industry.

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Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Conceptualization: All authors
Formal analysis: Jitin Vasudeva
Investigation: Jitin Vasudeva
Methodology: All authors
Writing – original draft: Jitin Vasudeva
Writing – review & editing: All authors

Availability of data

The data this article are available from the corresponding author upon reasonable request.

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