Alqalam Journal of Medical and Applied Sciences. 2026;9(11):3927-3933
https://doi.org/10.54361/ajmas.261150

Original article

Experimental Assessment of the Effect of Different Water Sources on the Strength of Ordinary Concrete

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Abstract
This experimental study evaluates the effect of five locally available water sources on the workability and mechanical performance of ordinary concrete. Desalinated drinking water was used as the reference, while desalination brine, artesian-well water, Matlawi-well water, and man-made river water were investigated as alternatives. Water samples were characterised using pH, total dissolved solids (TDS), suspended solids, sulfate, carbonate, bicarbonate, chloride, calcium, magnesium, iron, and aluminium measurements. Five concrete mixtures were produced with identical cement, fine aggregate, coarse aggregate, and water-to-cement ratio of 0.50, so that the water source was the principal experimental variable. Forty-five 150-mm concrete cubes were tested for compressive strength at 7, 14, and 28 days, and fifteen 150 × 300-mm cylinders were tested for splitting tensile strength at 28 days; slump was also measured. All slump values ranged from 60 to 90 mm. At 28 days, compressive strength ranged from 29.796 to 37.970 MPa, with Matlawi-well water producing the highest value. Splitting tensile strength ranged from 0.73 to 1.11 MPa, with artesian-well water producing the highest value. The results indicate that the tested alternative sources can be used for concrete production within the scope of the experimental program, provided that water quality is chemically verified before use and long-term durability, particularly reinforcement corrosion, is considered.
Keywords. Concrete, Mixing Water, Water Quality, Compressive Strength, Splitting Tensile Strength

Introduction

Concrete is one of the principal construction materials used in buildings and infrastructure, and its performance depends strongly on the quality and proportions of its constituent materials. Water has a dual role in concrete: it participates in cement hydration and provides the fluidity required for mixing, placing, and compaction. Consequently, the chemical composition of mixing water can influence both fresh and hardened concrete properties [1]. The increasing pressure on freshwater resources creates a practical incentive to investigate alternative water sources for concrete production. The present project considers five water sources available in the Libyan context: desalinated drinking water, desalination brine, artesian-well water, Matlawi-well water, and man-made river water. The study was designed so that the concrete ingredients and mixture proportions remained constant while the water source changed, allowing the observed differences to be attributed primarily to water quality [2].

Water quality plays a significant role in determining the mechanical properties and durability of concrete. Kokoszka reported that the use of contaminated and recycled water resulted in lower concrete strength compared with drinking water, whereas the use of groundwater was associated with relatively minor reductions in strength [3]. Mama et al. similarly found that drinking water produced higher strength than some river and rainwater mixtures and emphasised the need to assess water quality before mixing [4]. Studies using seawater and treated wastewater further demonstrate that water chemistry can have limited effects on early strength while creating important long-term durability concerns, especially chloride-induced reinforcement corrosion [5,6]. The objective of this study is therefore to experimentally compare the selected water sources with a desalinated-water reference mixture, focusing on slump, compressive strength at 7, 14, and 28 days, and splitting tensile strength at 28 days. The contribution is a direct comparison of several locally relevant water sources under controlled mixture proportions, providing an evidence base for preliminary assessment of water reuse in ordinary concrete production. The literature reviewed in the project indicates that the effect of mixing water is not governed by a single parameter. Dissolved salts, sulfates, chlorides, alkalinity, suspended matter, and other contaminants may alter hydration, setting, pore structure, and long-term durability [7,8].

The effects of mixing-water quality on concrete strength have been demonstrated in several investigations. Concrete prepared with drinking water achieved a 28-day compressive strength of 39.5 MPa, compared with 26.3 MPa for concrete mixed with recycled wastewater, while mixtures prepared with groundwater exhibited comparatively minor reductions in strength [9]. Other experimental findings have shown that variations in water sources, including drinking water, river water, and rainwater, influence the development of compressive strength at different curing ages (7, 14, and 28 days) [10]. These findings highlight the importance of assessing the chemical characteristics of mixing water and maintaining consistent mixture proportions when evaluating its influence on concrete performance. Seawater has been investigated as an alternative source of mixing water for concrete, with findings indicating that compressive strength may remain comparable to that of conventional concrete under certain cement conditions. However, chloride accumulation remains a major concern, particularly in reinforced concrete, due to its potential to accelerate reinforcement corrosion [11]. Similarly, the use of treated wastewater in concrete production has been shown to yield acceptable properties when adequate treatment is achieved, although the risk of reinforcement corrosion remains dependent on water quality and concrete cover

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Received*: 20-09-2026 -* ***Accepted****: 18-11-2026 -* ***Published****: 25-11-2026*

conditions [12]. In the Libyan context, electromagnetic treatment has also been investigated as a potential approach for reducing groundwater salinity, highlighting the importance of characterising locally available water resources and assessing their suitability for different applications. This provides a relevant background for investigating alternative water sources for concrete production, particularly in regions where groundwater salinity represents a significant challenge [13]. The gap addressed by the present study is the limited experimental comparison of several water sources relevant to Libya, particularly desalination brine and local well waters—under a common ordinary-concrete mixture. The study therefore complements the international literature by providing comparative local measurements rather than relying only on generic water-quality criteria.

Materials and Methods

A controlled laboratory experimental design was used. Five concrete mixtures, identified as A–E, were prepared with the same cement, fine aggregate, coarse aggregate, aggregate-to-cement ratio, and water-to-cement ratio. Only the source of mixing water was changed. The experimental program comprised water-quality characterisation, aggregate grading, slump testing, compressive-strength testing, and splitting-tensile-strength testing. The cement was ordinary Portland cement supplied by Al-Burj Cement Factory in Zliten and reported in the project as strength class 42.5, with a specific gravity of 3.12, following Libyan Standard No. 340. The fine aggregate was obtained from Al-Ruhaybat (Wadi Al-Shiyab), with a reported specific gravity of 2.6 and grading conforming to BS 882:1992. The coarse aggregate was obtained from Al-Ruhaybat and was also reported to conform to BS 882:1992 [16,17]. The five water sources were desalinated drinking water (A), desalination brine (B), artesian-well water (C), Matlawi-well water (D), and man-made river water (E). The project reports measurements of pH, TDS, suspended solids, iron, sulfate, carbonate, bicarbonate, chloride, calcium, magnesium, and aluminium. The reported water-quality data are reproduced in (Table 1).

Table 1. Reported chemical characteristics of the five water sources

Code	Water source	pH	TDS (ppm)	TSS (ppm)	Fe (ppm)	SO_4^{2-} (ppm)	CO_3^{2-} (ppm)	HCO_3^- (ppm)	Cl^- (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Al (ppm)
A	Desalinated drinking water	7.309	13.80	>5	>0.01	>2	0	15.25	14.2	3.8	0.36	>0.01
B	Desalination brine	6.418	1803	>5	>0.01	860	21	216.5	417.1	213.0	96.60	>0.01
C	Artesian well water	6.490	1484	>5	>0.01	790	0	222.7	342.6	163.0	78.00	>0.01
D	Matlawi well water	6.364	1778	>5	>0.01	580	12	183.0	459.7	207.0	88.80	>0.01
E	Man-Made River water	6.420	1029	>5	>0.01	210	6	176.9	292.8	114.0	27.60	>0.01

Chemical Acceptance Criteria for Concrete Mixing Water

The chemical suitability of the investigated water sources was assessed with reference to ISO 12439:2025 [18], which specifies requirements for water used in concrete production. According to this standard, the maximum recommended chloride concentrations in mixing water are 500 ppm for prestressed concrete or grout, 1,000 ppm for concrete containing reinforcement or embedded metal, and 4,500 ppm for concrete without reinforcement or embedded metal. The maximum permissible sulfate concentration, expressed as SO_4^{2-}, is 2,000 ppm. As shown in Table 2, comparing the measured chemical characteristics with the specified reference limits showed that the chloride concentrations of the investigated water sources (14.2–459.7 ppm) and sulfate concentrations (less than 2–860 ppm) were below the corresponding limits specified for mixing water. Therefore, based on these two chemical parameters alone, the investigated sources met the cited mixing-water concentration limits for reinforced and unreinforced concrete.

Table 2. Chloride and Sulfate Limits for Mixing Water.

Water source	Chloride (ppm)	Limit (ppm)	Sulfate (ppm)	Limit (ppm)
A	14.2	1000	less than 2	2000
B	417.1	1000	860	2000
C	342.6	1000	790	2000
D	459.7	1000	580	2000
E	292.8	1000	210	2000

Note: *Reference limits are based on ISO 12439:2025 [18].*

However, compliance with individual mixing-water limits does not, by itself, establish the overall suitability of water for every structural application. Before practical implementation, evaluate the total chloride content contributed by all

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concrete constituents, exposure conditions, reinforcement corrosion requirements, and long-term durability considerations.

Theory and Calculation

The mixture was proportioned by the absolute-volume method. The selected water-to-cement ratio was 0.50, and the aggregate-to-cement ratio was 5.0. Cement and aggregate specific gravities were 3.12 and 2.6, respectively. The calculated quantities reported in the project were 364.485 kg/m^3 of cement, 182.24 kg/m^3 of water, and 1822.425 kg/m^3 of aggregate. For each 150-mm cube, the reported quantities were 1.230 kg of cement, 0.615 L of water, and 6.150 kg of aggregate, divided into 2.05 kg of fine aggregate and 4.10 kg of coarse aggregate.

$$W/C = 0.50 \quad (1)$$

$$A/C = 5.0 \quad (2)$$

The compressive-strength calculation followed the ratio of maximum applied load to loaded area, while the splitting-tensile calculation used the standard cylindrical splitting relationship reported in the project [19].

$$f_c = P / A \quad (3)$$

$$f_t = 2P / (\pi L d) \quad (4)$$

Mathematical Expressions and Symbols

where f_c is compressive strength (MPa), f_t is splitting tensile strength (MPa), P is the maximum applied load (N), A is the loaded cross-sectional area (mm^2), L is cylinder length (mm), and d is cylinder diameter (mm).

The absolute-volume equation used for mixture proportioning was expressed in the project as:

$$W/(1000) + C/(1000P_c) + A/(1000P_a) = 1 \quad (5)$$

where W, C, and A represent water, cement, and aggregate masses per cubic metre, and P_c and P_a are the corresponding specific gravities. Slump was measured according to ASTM C143/C143M, while compressive strength was determined on 150-mm cubes at 7, 14, and 28 days [19].

Specimen Preparation and Testing

The concrete was mechanically mixed using a 65-kg-capacity electric mixer. The coarse aggregate was pre-wetted, followed by the addition of cement and fine aggregate, and then the mixing water was added gradually. Mixing continued for approximately 5 min. Cubes of 150 × 150 × 150 mm were prepared for compressive testing and cylinders of 150 × 300 mm for splitting tensile testing. Each mould was filled in three approximately equal layers, with 25 rod strokes per layer, followed by vibration and surface finishing. Specimens remained in the moulds for 24 h before demoulding and were then water-cured in desalinated water at room temperature for the required testing age. The project prepared 45 cubes, nine for each water source and 15 cylinders, three for each water source. Slump was measured immediately after mixing. Compressive strength was determined using a standard compression-testing machine, and splitting tensile strength was measured by diametrical loading of the cylinders. The experimental program did not report inferential statistical tests; therefore, the present article reports descriptive comparisons and percentage differences only. Three specimens were tested for each mixture at each compressive-strength testing age (7, 14, and 28 days), while three cylindrical specimens per mixture were tested for splitting tensile strength at 28 days. All specimens were cured by immersion in desalinated water at room temperature after demoulding. Accordingly, the experimental program comprised 45 cubes and 15 cylinders.

Figure 1) summarises the experimental workflow from water characterisation through mixture preparation and mechanical testing. The design isolates the water source as the principal experimental variable.



Figure 1. Experimental workflow of the concrete preparation and testing programme.

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Results

The water analyses showed substantial differences among the sources. Desalinated drinking water had the lowest reported TDS (13.8 ppm) (Table 3), whereas desalination brine had 1803 ppm and Matlawi-well water had 1778 ppm (Figure 2). Artesian-well and man-made river waters had 1484 and 1029 ppm, respectively. Chloride concentrations were 14.2, 417.1, 342.6, 459.7, and 292.8 ppm for A–E, respectively. Sulfate concentrations were reported as >2, 860, 790, 580, and 210 ppm. These values demonstrate that the alternative waters had markedly different ionic compositions.

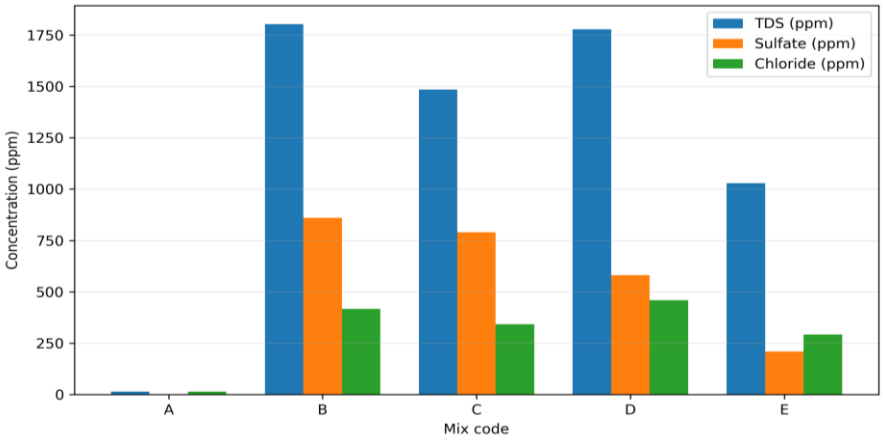


Figure 2. Comparison of reported TDS, sulfate, and chloride concentrations for the five water sources. The sulfate concentration for the reference water (A) was reported as >2 ppm.

Table 3. Concrete mixture proportions reported for the nine-cube batches

Code	Water source	Cubes	Water (L)	Fine agg. (kg)	Coarse agg. (kg)	Cement (kg)
A	Desalinated drinking water	9	5.535	18.45	36.90	11.07
B	Desalination brine	9	5.535	18.45	36.90	11.07
C	Artesian well water	9	5.535	18.45	36.90	11.07
D	Matlawi well water	9	5.535	18.45	36.90	11.07
E	Man-made river water	9	5.535	18.45	36.90	11.07

Table 4. Slump and mechanical-strength results

Code	Water source	Slump (mm)	f_c, 7 d (MPa)	f_c, 14 d (MPa)	f_c, 28 d (MPa)	f_t, 28 d (MPa)
A	Desalinated drinking water	90	18.890	29.425	30.880	0.73
B	Desalination brine	70	23.720	29.670	31.280	0.98
C	Artesian well water	70	21.710	29.625	33.998	1.11
D	Matlawi well water	80	20.970	30.768	37.970	0.75
E	Man-made river water	60	21.020	29.416	29.796	0.91

Slump values ranged from 60 to 90 mm (Figure 3). The desalinated-water reference mixture (A) had the highest slump at 90 mm, while the man-made river mixture (E) had the lowest at 60 mm. Mixtures B and C both recorded 70 mm, and D recorded 80 mm. All values were reported by the project as within the applicable operational range.

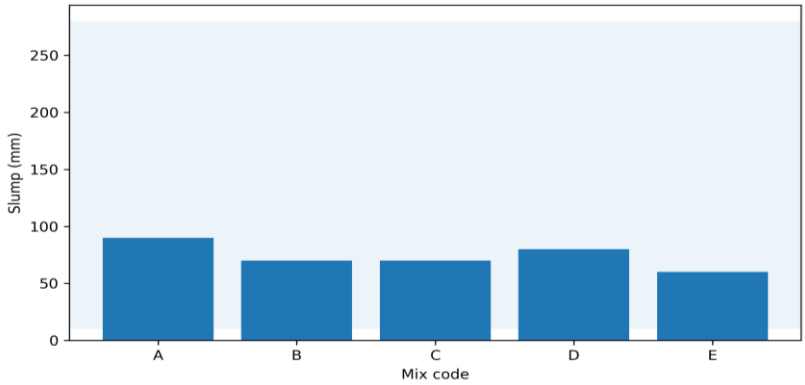


Figure 3. Slump values for the five concrete mixtures.

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Received: *20-09-2026 -* ***Accepted:*** *18-11-2026 -* ***Published:*** *25-11-2026*

https://doi.org/10.54361/ajmas.261150

The compressive-strength data are shown in (Figure 4). At 7 days, strengths were 18.89, 23.72, 21.71, 20.97, and 21.02 MPa for A–E. At 14 days, the corresponding values were 29.425, 29.67, 29.625, 30.768, and 29.416 MPa. At 28 days, the values were 30.88, 31.28, 33.998, 37.97, and 29.796 MPa. Thus, the Matlawi-well mixture (D) achieved the highest 28-day compressive strength, followed by the artesian-well mixture (C).

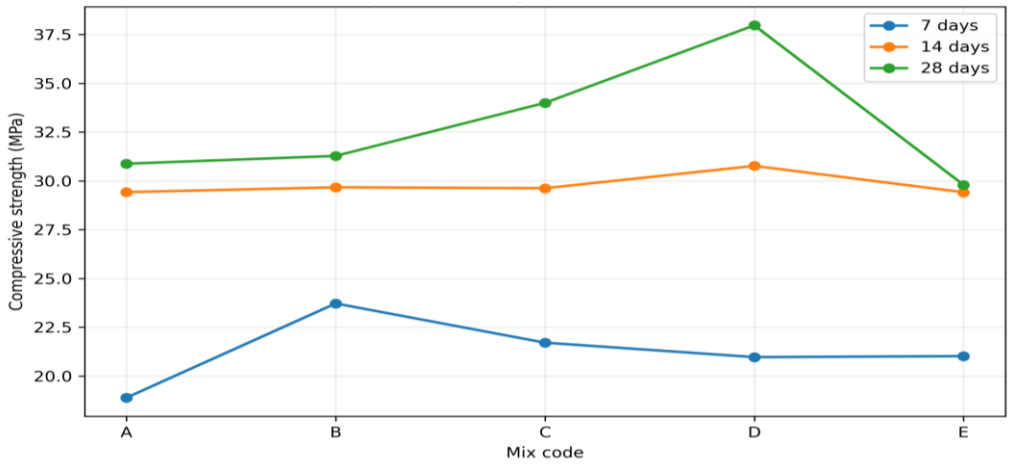


Figure 4. Compressive strength of the five mixtures at 7, 14, and 28 days.

At 28 days, splitting tensile strength was 0.73 MPa for A, 0.98 MPa for B, 1.11 MPa for C, 0.75 MPa for D, and 0.91 MPa for E. The artesian-well mixture (C) therefore produced the highest tensile value.

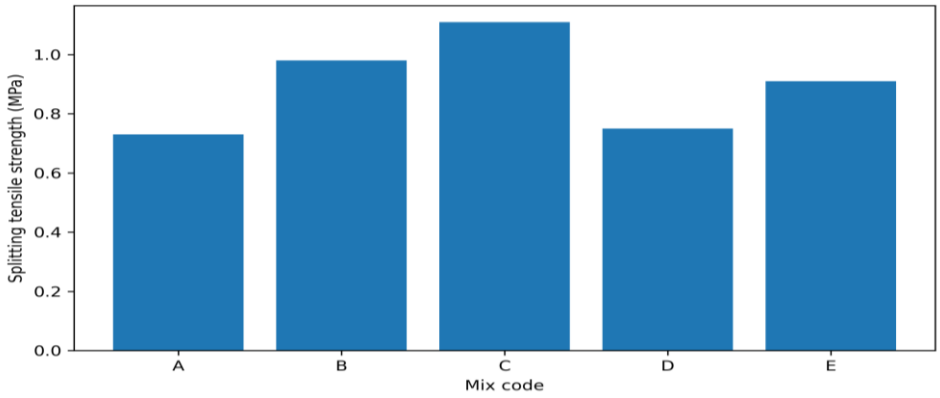


Figure 5. Splitting tensile strength at 28 days.

Discussion

Water Chemistry and Workability

The water analyses show that the reference desalinated water was chemically distinct from the alternative sources, particularly in TDS and major ions. The brine and Matlawi-well waters had the highest TDS values, while the desalinated water had the lowest. Despite these differences, the effect on slump was limited in practical terms: the five mixtures differed by 30 mm between the maximum and minimum values. This finding agrees with the literature summarised in the project, where treated or alternative water could produce acceptable fresh-concrete properties even when chemical composition differed from drinking water. The reported pH values ranged from 6.364 to 7.309. The study's reference criterion and water-quality discussion indicate the importance of chemical screening before use. Because the water table contains several values that are near or above individual constituent limits discussed in the theoretical chapter, acceptance should not be based on TDS alone. Instead, sulfate, chloride, alkalinity, and other constituents should be considered together, particularly when reinforced concrete is intended.

Distinction Between Mixing-Water Compliance and Long-Term Concrete Durability

Although the measured chloride and sulfate concentrations of all investigated, water sources were below the corresponding limits specified in ISO 12439:2025, compliance with these individual chemical limits should not be interpreted as definitive evidence of long-term durability or suitability for all reinforced concrete applications. In particular, the standard specifies maximum chloride concentrations in mixing water according to the intended use of concrete; however, it also requires consideration of the total chloride content of concrete from all constituent materials, in accordance with ISO 22965-2. This is important because chloride accumulation can increase the risk of reinforcement corrosion over time, depending on the concrete composition and exposure conditions. Similarly, compliance with the

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Received: *20-09-2026 -* ***Accepted:*** *18-11-2026 -* ***Published:*** *25-11-2026*

sulfate limit for mixing water does not eliminate the need to assess potential sulfate-related deterioration under aggressive exposure conditions. Therefore, although the investigated water sources met the specified chloride and sulfate concentration limits, further assessment of total concrete chloride content, reinforcement corrosion, permeability, and long-term durability is necessary before their suitability for reinforced structural applications can be conclusively established.

Compressive Strength

The 28-day results indicate a clear separation between the best-performing alternative waters and the reference. Relative to the 30.88-MPa reference value, B, C, and D produced increases of approximately 1.30%, 10.10%, and 22.95%, respectively, whereas E was approximately 3.51% lower. The highest result, 37.97 MPa for Matlawi-well water, is consistent with the project's conclusion that this source provided the best compressive performance in the tested mixtures. The strength development also shows that the water source did not affect all mixtures in the same way. All alternative mixtures increased from 7 to 28 days, while the reference mixture increased from 18.89 MPa at 7 days to 30.88 MPa at 28 days. The results support the view that water chemistry can modify hydration and the development of the cementitious matrix, but they do not establish a single monotonic relationship between any one measured ion and strength. The literature similarly reports that groundwater and treated alternative waters can produce results close to or, under some conditions, above drinking-water concrete.

Splitting Tensile Strength and Durability Implications

The splitting-tensile results provide a different ranking from compressive strength. Artesian-well water (C) produced the highest value, 1.11 MPa, followed by brine (B) at 0.98 MPa and man-made river water (E) at 0.91 MPa. Matlawi-well water (D) produced 0.75 MPa, only slightly above the reference value of 0.73 MPa. Therefore, the water source that maximised compressive strength was not the same source that maximised splitting tensile strength. This distinction is important for engineering interpretation. The higher strength values observed for some alternative waters should not be interpreted as proof of superior long-term durability. Chlorides can create reinforcement-corrosion risk, while sulfates can participate in expansive reactions and deterioration. The project recommends further investigation of reinforced concrete and its long-term performance, particularly regarding the potential effects of chloride-bearing mixing water. [20].

Effect of Curing Conditions on the Experimental Findings

All concrete specimens were cured by immersion in desalinated water at room temperature after demoulding, irrespective of the mixing-water source. Therefore, the experimental comparison reflects the influence of different mixing-water sources under a common curing condition. Maintaining the same curing-water source for all mixtures provided consistency in the experimental procedure and avoided introducing curing-water type as an additional variable. However, this approach does not establish the performance of concrete when the alternative mixing-water sources are also used for curing. Consequently, the findings should be interpreted within the specific curing conditions adopted in this study. Further investigations involving different combinations of mixing and curing water are required to distinguish their individual and combined effects on concrete strength and durability.

Engineering Significance and Study Limitations

The results support the preliminary use of the tested alternative waters for ordinary concrete within the specific mixture, curing, specimen dimensions, and testing ages investigated. However, the study has several limitations. It is based on a single mixture proportion, one cement source, local aggregates, a limited number of specimens, and testing up to 28 days. No long-term durability tests, reinforcement-corrosion tests, permeability tests, shrinkage tests, or statistical significance tests were reported. In addition, the specimens were cured in desalinated water rather than in the same water used for mixing, which the project identifies as an area for methodological improvement. Accordingly, the findings should be used as an experimental screening result rather than a universal approval for all concrete applications. For reinforced concrete, water chemistry should be evaluated against the relevant chloride and sulfate requirements before field use.

Conclusions

This study experimentally compared five water sources for ordinary concrete under controlled mixture proportions. The water sources differed substantially in pH, total dissolved solids (TDS), sulfate, chloride, bicarbonate, calcium, and magnesium concentrations, yet all five mixtures produced workable concrete within the reported slump range of 60–90 mm. The desalinated-water reference mixture had the highest slump, whereas the man-made river-water mixture had the lowest. At 28 days, Matlawi-well water produced the highest compressive strength of 37.97 MPa, followed by artesian-well water at 33.998 MPa and desalination brine at 31.28 MPa. Man-made river water produced 29.796 MPa, compared with 30.88 MPa for the reference mixture. Artesian-well water produced the highest splitting tensile strength at 1.11 MPa, followed by desalination brine at 0.98 MPa. Based on the measured chloride and sulfate concentrations and their comparison with the reference limits specified in ISO 12439:2025, all five investigated water sources satisfied the corresponding individual chemical concentration limits for concrete mixing water. However, compliance with these individual limits does not, by itself, establish overall suitability for all structural applications. In particular, the use of these

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Received*: 20-09-2026 -* ***Accepted****: 18-11-2026 -* ***Published****: 25-11-2026*

water sources in reinforced concrete requires consideration of the total chloride content contributed by all concrete constituents, applicable exposure conditions, reinforcement corrosion risks, and long-term durability requirements.

The results also demonstrate that compressive-strength and splitting-tensile-strength performance may rank the investigated water sources differently. Furthermore, all specimens were cured in desalinated water, providing a common curing condition for the experimental mixtures. Consequently, the findings represent the effects of different mixing-water sources under a common desalinated-water curing regime and should not be generalized to concrete cured using the same alternative water sources.

Overall, the findings provide preliminary experimental evidence regarding the potential use of the investigated alternative water sources in ordinary concrete production. Before extending these findings to long-term structural applications, further studies should examine total chloride content, reinforcement corrosion, permeability, water absorption, shrinkage, longer curing ages, and the effects of using alternative water sources for both mixing and curing. These investigations are necessary to establish the long-term durability and suitability of concrete produced with these water sources, particularly for reinforced concrete applications.

Conflict of interest. Nil

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