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Effect of Different Types of Water on Workability and Compressive Strength of Concrete

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ABSTRACT

The water sustainability issue has become an important subject because of the scarcity of water sources and the shortage of potable water (PW), leading to the search for alternate solutions. This study searches using various water sources (tap, distilled, river, lake, and wastewater) as alternative freshwater in the production of concrete. These types were collected from different locations in Kut City, Iraq. It was used to cast sixty concrete specimens, and each specimen tested workability and compression strength after being cast at the 3, 7, 28, and 120 days of concrete age. The slump test results observed of all types of water specimens had little effect on the workability except for specimens of wastewater, which caused a reduction of 8.28%. For compressive strength, water river samples increased from 15%-29% compared with tap water samples until 28 days of age. At a later age, these decreased by about 7%. During an early age, wastewater samples' compressive strength increased by about 14%-50%. These data showed a slight 2.3% decrease after the 28th day. The lake water sample's compressive strength improved by 15% at three days of age. However, as compared to the control sample, the compressive strength at ages 7, 28, and 120 days was shown to have decreased 6%-22%. In conclusion, water quality affects the fresh and hardened properties of concrete, especially if it contains substantial amounts of impurities. Employing various water sources in the production of concrete helps protect the environment and reduce some of the strain on fresh water, consequently achieving sustainable development goals.

1. INTRODUCTION

Water is an essential resource for life. Today, climate change and inadequate rainfall are decreasing the supply of natural water resources. This resource depletion increased, thus resulting in a scarcity of fresh water. One industry that significantly contributes to this issue is the concrete industry, which is a widely used material in construction worldwide and consumes substantial quantities of freshwater [1-5]. Consequently, due to the limited availability of fresh water, the sustainability of water has gained significant attention, leading to the search for alternative solutions [6]. Therefore, various sources of water were recently tested thoroughly for quantity and quality to determine their suitability for concrete construction. These sources included canal water, rainwater seawater, river water, alkaline water, deep well water, car wash effluent, textile emissions, and treated wastewater (TWW) [7, 8], industrial and domestic wastewater, another type of water used in producing concrete [9-11].

Typical contaminants in water include chloride, sulfate, salts, alkaline waters, silt or suspended particles, alkali bicarbonate carbonate, algae, impurities of organic, and various other salts [12]. The presence of contaminants in water affects the quality of the mixing water utilized in concrete production. It also has a direct impact on the mechanical properties of concrete, including its workability, compressive strength, splitting strength, and water adsorption in the proper setting of cement, as well as perhaps causing corrosion of the reinforcing. Consequently, the quality of water for mixing must be considered [13-16]. Many researchers have studied the effects of different types of water.

The impact of washing, tap, and groundwater as mixing water on the concrete properties was examined in a study conducted by Su et al. [17]. The results revealed that the contaminants in the water mix directly affect the fresh and hardened properties of concrete.

Chatveera et al. [18] conducted an experimental study using sludge water as the mixing water for concrete production. The results showed a significant reduction in the concrete's slump and strength due to some components in this type of water.

The influence of municipal wastewater usage in concrete casting has been investigated by Thaw and Tu [19]. The test results illustrated that municipal wastewater on concrete quality has a significant effect.

Seawater can be used as concrete mixing water, according to research by Younis et al. [20]. The findings revealed that saltwater did not affect workability but that compressive strength had decreased.

In another study, Babu and Ramana [21] conducted an experimental study on the effect of different wastewater resources. The results showed no apparent change in the compressive strengths at 90 days. The conclusion was reached that wastewater obtained from four treatment facilities might be used as mixing water in the manufacturing of concrete.

In this study, Ghrair et al. [22] experimented to evaluate the possibility of recycling waste wash water (WWW) in ready-mix concrete facilities. The obtained samples of WWW were used to substitute the mixing water at different ratios. The findings show that even after dilution, the WWW was not appropriate for mixing water because of its negative impact on the concrete's strength and workability.

Hasan et al. [23] evaluated the differences in compressive strength resulting from the use of greywater. This water was obtained from a residence where blackwater and greywater had been disposed of separately. The results demonstrated a 4% drop in compressive strength when greywater was used. This study indicates that raw greywater can be utilized to produce concrete for specific types of structures, taking into account its reduced compressive strength.

Dhondy et al. [24] carried out the first comprehensive investigation of the impact of mixing water salinity on concrete characteristics. The study examined the effect of various concentrations of salinity, ranging from 16.5 g/l to 82.5 g/l, on concrete properties (compressive strength). According to the test results, the compressive strength of concrete that was more than 14 days age was slightly changed by the salinity of the mixing water.

Shamilah and Norfathin [25] tested the compressive strength of concrete samples made with lake water by replacing 50%, 80%, and 100% of fresh water. The study's results showed that the samples made of 100% lake water increased in compressive strength compared to the freshwater sample.

Michael et al. [26] examined the recycled wastewater employed for the production of concrete. They used a 25%, 50%, and 100% mixture of the TWW with PW. For comparison, control specimens were cast using just potable water. The findings indicate that the TWW's compressive strength has not significantly decreased.

This study conducted by Rakshit Jain et al. [27] examined concrete mixes that use varying amounts of domestic water, ranging from 25% to 100% PW. The findings demonstrated that concrete mixtures made from treated domestic water exhibited strength characteristics comparable to those of concrete made from PW.

AlAyyash et al. [28] investigated the impact of TWW in concrete mixes as a replacement for PW on the compressive strength of hardened concrete. PW is replaced with TWW in ratios ranging from 30% to 100%. According to the findings, TWW slightly decreased the concrete's compressive strength by roughly 11%. Acceptable levels of concrete quality will be impacted by the use of recycled materials.

Fadil et al. [29] conducted a study to examine the impact of the Tigris River, tap water, and the factory of Pepsi Company's mixing water on the characteristics of concrete. The results show a substantial impact on concrete compressive strength specimens mixed with Tigris River which can be seen at early ages. When compared to other types of water, specimens of Tigris River water show higher strength values. In contrast with concrete mixed and cured in the factory of Pepsi Baghdad wastewater compared with tap water and Tigris River water, the concrete strength values obtained are lower.

The literature survey in the introduction uses different water sources and alternative fresh water to achieve sustainability development goals. These studies were carried out at various locations, but no studies were conducted in this region despite its significance. The aim is to fill the knowledge gap in this area by investigating the impact of different types of water obtained from five sources, tap, river, lake, distilled, and wastewater, as an alternative fresh water on concrete's fresh and hardened properties. The current study covers this region and offers the first attempt to look into the use of alternative water sources in the production of concrete.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The experimental work includes a comprehensive description of the materials used and their physical and chemical characteristics with the respective standards. For all specimens, Type I Portland cement by Iraqi requirements of Standard Specifications No. 5:1984 [30] was used. Tables 1 and 2 list the cement's chemical and physical characteristics.

Table 1. Chemical characteristics of cement

Compounds	Abbreviation	Weight (%)	Limit of I.Q.S [30]
Lime	CaO	64.54	–
Silica	SiO_2	19.70	–
Alumina	Al_2O_2	5.2	–
Iron oxide	Fe_2O_3	3.27	–
Sulfite	SO_3	2.54	≤ 2.5%
Magnesia	MgO	1.77	≤ 5%
Loss of ignition	L.O.I	3.12	≤ 4%
Lime saturation	L.S.F	0.97	0.66–1.02
Factor insoluble residue	I.R	1.05	≤ 1.5
Tricalcium silicate	C3S	38.54	–
Dicalcium silicate	C2S	33.16	–
Tricalcium aluminate	C3A	8.57	–
Tetra calcium aluminoferrite	C4AF	10.74	–

Table 2. Cement physical characteristics

Physical Properties			Test Result	Limit of I.Q.S [30]
Specific surface area	kg/m^2		231	383 ≥
Setting time	hour	Initial	1:57	00:45 (min)
		Final	4:25	10:00 (max)
Compressive strength	MPa	3 days	25.84	15.00 (min)
		7 days	28.40	23.00 (min)

Table 3. Grading of coarse aggregate

Sieve Size (mm)	Passing by Weight (%)	Limit of I.Q.S [31]
18	99.6	100
9.5	85	85 -100
4.74	4.8	0 -25
2.36	1	0 -5
1.18	0	-

In this work, coarse aggregate with a maximum size of 18 mm taken from the Badra region was used. Table 3 shows the sieve analysis of the aggregate in accordance with Iraqi Standard Specification No. 45: 1984 [31]. Table 4 explains the analysis of the fine aggregate that was used in casting all specimens according to the standard of Iraqi Standard Specification No. 45: 1984-ZoneII [31].

The present study's water samples were taken from five different sources in Kut City, Iraq. The study area is located in the Wasit Governorate of Iraq [32].

Tap (potable) water was supplied from the municipal water supply system of Kut City. Distilled water is produced by Baghdad Soft Drinks Company. From the Tigris River at Kut City, river water was collected. With respect to Lake water was obtained from a southern city. Finally, wastewater was collected from a wastewater plant. After collecting these types of water samples, they were put in a polyethylene bottle with a capacity of 10 gallons and immediately transferred to the laboratory for analysis and casting. These samples underwent testing for various contaminants that might affect concrete mix design, and they were used in casting without pretreatment or filtration. Total dissolved solids (TDS), sulfate concentration (SO_4), chloride content, and nitrate content (NO_3) were all measured as well as measurements of PH, BOD, and COD were made. Table 5 displays the physical and chemical characteristics of various water samples [33].

Table 4. Fine aggregate grading

Sieve Size (mm)	Passing by Weight (%)	Limit of I.Q.S [31]
4.75	96.7	90-100
2.36	75.6	75-100
1.18	59.5	55-90
600	43.6	35-59
300	22.1	8-30

Table 5. Water test results

Parameter	Unit	Distilled Water	Tap Water	River Water	Wastewater	Lake Water	Max. Allowable Values in PN-EN 1008 [33]
BOD	Mg/l	0	0	35	200	40	
COD	Mg/l	0	0	80	325	90	
TDS	Mg/l	98	145	510	1580	612	
NO_3	Mg/l	0.05	0.1	50	9.26	56	
CL-1	Mg/l	0.5	0.1	45	32	40	500
SO_4	Mg/l	45	52	250	198	300	500
PH	-	7	7	8	7.2	7.5	≥4
Turbidity	NTU	0	1	4	182	4.5	

2.2 Mix design and sample preparation

Five groups were cast of the mix chosen for this work. The control mixture's mixing ratio by weight is (1: 2: 2.5) of cement, sand, and gravel, respectively. Moreover, the water content is 0.55 w/c. The target compressive strength in this study is not less than 25 MPa. The mixing weight per cubic meter is described in Table 6.

Table 6. Mix quantities in kg/ m³

Cement	Sand	Gravel	Water	w/c Ratio
382	764	955	210	0.55

The specific information about the mixes consists of tap water samples referred to in the reference group used to compare the main findings of the other groups. The distilled water samples were referred to as group two. Water sourced from the Tigris River was named as group three. Group four described water obtained from a lake near Kut City. Finally, group five utilized wastewater.

2.3 Mixing and casting of concrete specimens

The mixing process was conducted according to references [34, 35]. Twelve cubes with dimensions of 150*150 mm were cast for each type of water, and each result was based on an average of three specimens.

1. Prepare the tools and supplies needed to mix.
2. Supply the mix materials to the mixer in the laboratory in the ratio 1:2:2.5.
3. For 3 minutes, add the fine and coarse aggregate into the mixer, mixing them dry together.
4. Mix the cement with coarse material and continue for 2 to 3 minutes.
5. Sixty percent of the water is added and mixed slowly over 3 min to achieve a homogeneous mixture. After that, 40% of the remaining water for mixing is added gradually. The total time of the mixing process is five to eight minutes.
6. Twelve cubes were poured and compacted into each type of water, and a slump test was carried out simultaneously.
7. The molds are then left unoccupied for approximately 24 hours. Subsequent to demolding, the specimens were kept in water containers until the testing age specified. The curing water was kept at a temperature of around 20 ± 3°C.
8. Finally, the specimens are tested at the required age (3, 7, 28, and 120 days). Consequently, sixty cube specimens from the five water-type mixes were made and tested in this study.

2.4 Testing procedure

According to ASTM C 143 [36], the slump of the mixture was tested in the fresh state to determine the concrete workability of five types of water samples. Slump test includes a truncated cone (height 300 mm, top diameter 100 mm, bottom diameter 200 mm) and tamping rod. The cone is filled with concrete and, after that, elevated gradually. The unsupported concrete cone lowers under its weight, and the slumped cone is decreased, referred to as the slump of concrete. Then, the effect of different types of water on the workability of concrete is compared. After the concrete hardened, a compressive strength test was carried out on the concrete samples at 3, 7, 28, and 120 days of age. A Matest compression testing machine with a capacity of 1500 kN was utilized to measure the compressive strength of the cubes. For each mixture, twelve cubes with three cubes for each group were measured under a constant load of 20 MPa/min according to BS 1881: Part116 [37] as seen Figure 1.

Figure 1. Test of compressive strength

3. RESULTS AND DISCUSSION

3.1 Compressive strength and slump test of each water type sample

3.1.1 Tap water sample

Table 7 shows that the slump value of tap water samples is 16.9 cm, and compressive strength results using tap water samples as the control mixing water at ages 3, 7, 28, and 120 days. The compressive strength of the control mixture gradually developed at an early age at 11.31 MPa and continued until the 120th day to reach 35 MPa, see Figure 2. The compressive strength growth with age is attributed to the cement hydration process. Moreover, fresh water is suitable for utilization in the production of concrete.

Table 7. Compressive strength values of tap water samples at different ages

Tap Water			
Age	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Slump (cm)
	13.3		
3 days	9.5	11.31	
	11.1		
	13.5		
7 days	14.9	14.8	
	16.1		16.9
	31.2		
28 days	32.3	31.8	
	31.9		
120 days	34.3	35	
	35.5		

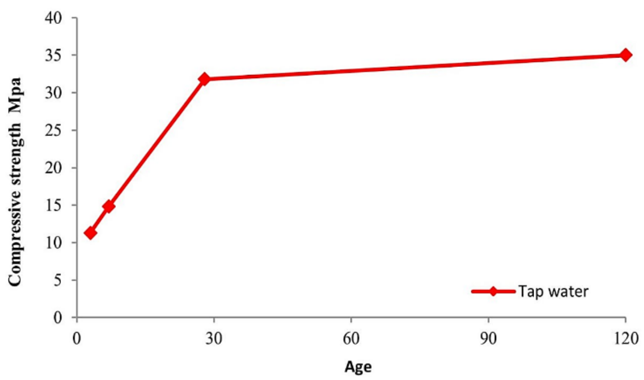

Figure 2. Relationship between compressive strength and age of tap water sample

3.1.2 Distilled water samples

The compressive strength of distilled and tap (control) water was graphed to help explain the differences in compressive strength with age, as illustrated in Figure 3. Table 8 displays the results of the data obtained from the compressive strength and slump test. Distilled water mixing had no significant effect on compressive strength and slump values compared with tap water mixing at different ages. These results were attributed to the similarity of distilled and tap water's chemical and physical properties.

3.1.3 River water samples

The data obtained from the slump and compressive strength test was adopted in Table 9 and Figure 4. The slump value was 16.8 cm, and the compressive strength of samples mixed with river water were recorded at ages 3, 7, 28, and 120 days (13, 19.1, 24.7, 32.7 MPa), respectively. The compressive strength was increased by 15% and 29% compared with tap water samples at age 3 and 7 days, respectively. While at age 28- and 120-days compressive strength decreased by about 22% and 7%, respectively. The presence of some elements such as Cl, Ca, Na, and K, as shown in Table 1, causes an increase in the hydration rate, which helps compressive strength to develop at an early age. Then, it witnessed decreases due to this element [29, 38]. Moreover, the decreased compressive strength noted in river water is attributable to the higher concentrations of TDS, which adversely affect concrete compressive strength, as indicated by the study [39].

Table 8. Values of distilled water compressive strength samples at various age

Distilled Water			
Age	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Slump (cm)
	9.8		
3 days	14.7	11.9 5	
	11.1		
	13.2		
7 days	15.6	14.5	
	13.6		17
	31.7		
28 days	31.5	30.9	
	29.4		
	34.4		
120 days	33.3	34.4	
	35.6		

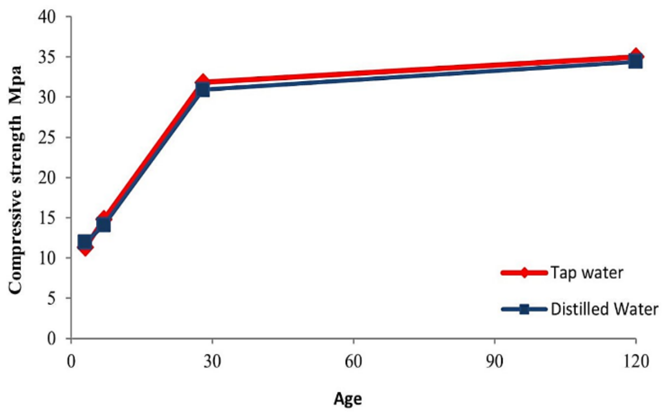

Figure 3. Relationship between tap and distilled water sample compressive strength at different ages

Table 9. Compressive strength values of river water samples at different ages

River Water			
Age	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**	**Slump (cm)**
3 days	12.7	13	16.8
	15		
	11.2		
7 days	20.1	19.1	
	18.4		
	18.8		
28 days	28	24.7	
	23.5		
	22.5		
120 days	32.9	32.7	
	32.4		
	32.9		

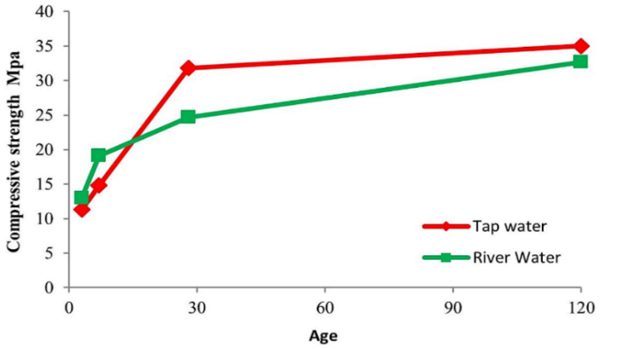

Figure 4. Relationship between tap and river water sample compressive strength at different ages

Table 10. Compressive strength values of wastewater samples at different ages

Wastewater			
Age	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**	**Slump (cm)**
3 days	14.8	16.9	15.5
	17.4		
	18.5		
7 days	17.9	18.8	
	22.3		
	16.3		
28 days	36	36.2	
	35.6		
	37		
120 days	35.6	34.2	
	31.1		
	36		

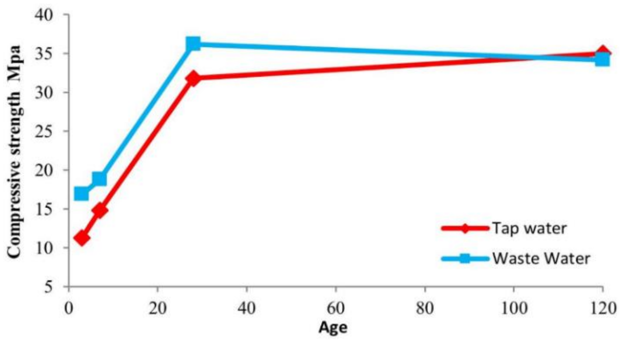

Figure 5. Relationship between tap and wastewater sample compressive strength at different ages

3.1.4 Wastewater samples

Table 10 and Figure 5 represent the compressive strength and slump test results for a concrete mixture made of wastewater. The slump test value of this sample was 15.5. The compressive strength of wastewater samples was rapidly increased at age 3 days to 16.9 MPa. At 7 days of age, compressive strength was recorded at 32.1 MPa. In addition, these values reached 36.2 MPa at age 28 days. The results values increased about 50%, 27%, and 14% from the control sample at the 3rd,7th, and 28th days of age, respectively. In contrast with the age of the 120th day, compressive strength decreased slightly to 34.2 MPa (2.3%) in the control samples. This decrease is attributed to the excessive quantities of sulfate, chloride, and other elements in wastewater, which lead to cracks and weak concrete [29, 38]. In addition, the rising amount of BOD and COD, as well as total dissolved solids in the wastewater samples, resulted in a reduction in the strength of these samples after 28 days of age [40, 41].

3.1.5 Lake water samples

Lake water samples recorded a slump value of 17cm, as presented in Table 11. Compared with the control samples on the 3rd day, the compressive strength of lake water samples is 13.1Mpa, which increased by 15%. With age, the compressive strength was 12.7, 30, and 27.4 MPa on the 7th, 28th, and 120th day, respectively. These samples recorded decreases in the compressive strength with control samples by about 14%, 6%, and 22%, respectively, as shown in Table 11 and Figure 6. This is attributed to the same reasons mentioned in river water: some competencies cause an increase in the hydration rate, which helps compressive strength develop at an early age. Then, it witnessed decreases due to these components.

Table 11. Compressive strength values of lake water samples at different ages

Lake Water			
Age	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**	**Slump (cm)**
3 days	11.8	13.1	17
	15.7		
	11.7		
7 days	13.2	12.7	
	12.9		
	12		
28 days	27.5	30	
	32.1		
	30.3		
120 days	23.2	27.4	
	30.7		
	28.4		

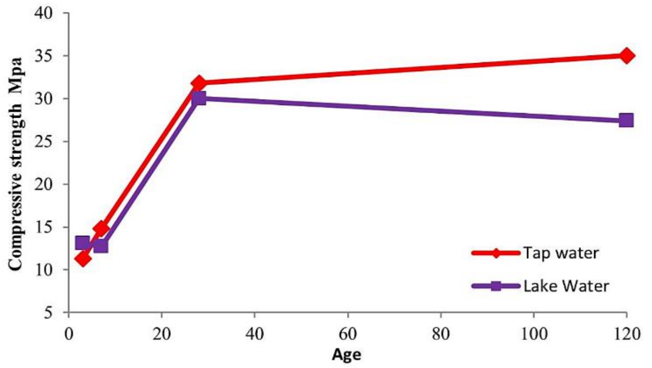

Figure 6. Relationship between tap and Lake water sample compressive strength at different ages

Table 12. Slump values for five types of water samples

Water Type	Slump Test (cm)
Tap water (control)	16.9
Distilled water	17
River water	16.8
Lake water	17
Wastewater	15.5

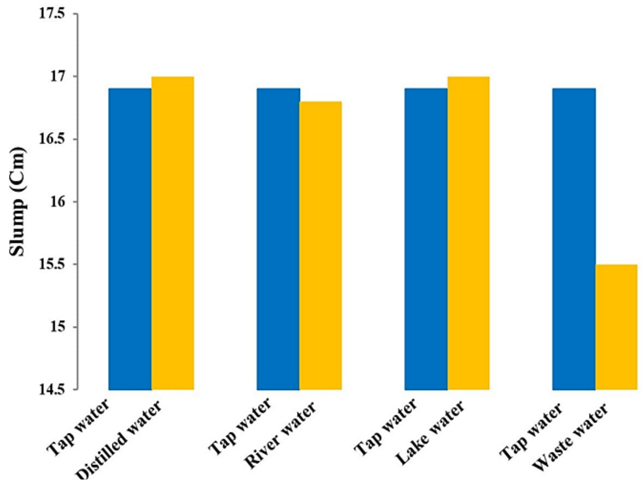

Figure 7. Relation between slump values for five types of water samples

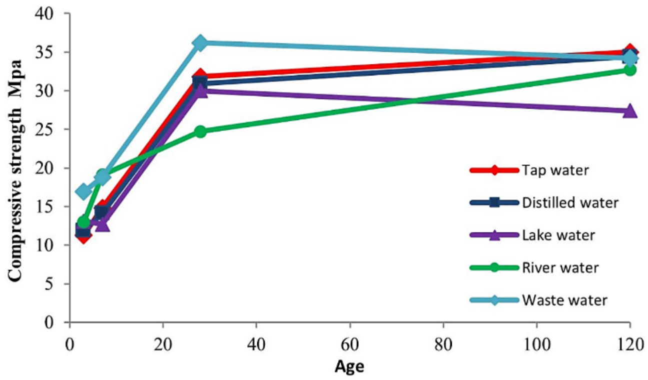

Figure 8. Relationship between different types of water at different ages

3.2 Relationship between five different types of water and slump values

Slump test results demonstrate the workability of fresh concrete. Table 12 displays the slump achieved in this investigation, which ranges from 15.5 to 17 cm. Concrete mixes made with distilled and lake water were better than those made from tap and river water. Wastewater with a drop of 15.5 mm has the lowest slump value. Figure 7 revealed the relation between the value of the slump test for five water types samples with a control sample. The slump value of the concrete mixture using the distilled and lake water showed little improvement in workability compared with the control mixing water sample (tap water). In contrast, wastewater led to a significant reduction in the slump of 8.28%. The slump value of the river water sample was less than that of the tap water sample, as shown in Table 12. These results match with the previous studies [42-44], which refer to these findings indicating that the concrete slump value is influenced by the quality of water. In addition, the quantity of the TDS and total solid suspension (TSS) content caused the water/cement ratio to decrease [22].

3.3 Relationship between different five water types and compressive strength

Figure 8 shows the compressive strength results of five various types of water. These results revealed that the distilled and tap water samples gave approximately the same results. Meanwhile, the compressive strength of other types of water samples increased by about 15%-50 % at age 3 days. At 7 days, the compressive strength of river and wastewater samples is higher than that of all types about 27%-29% of control samples.in contrast, the lake water samples decreased by 14% at the same age. On the 28th day, the river and lake water samples recorded reduced 6%-22% compared with tap water samples, while wastewater samples continued to increase by about 14% of the control sample. Finally, river, lake, and wastewater samples recorded a decrease of about 2.3%-22% of tap (control) water samples.

4. CONCLUSIONS

This study examines how various water sources affect the characteristics of both fresh and hardened concrete. The following are the main conclusions that are extracted from the present work:

1. Different water types used in concrete manufacturing promote environmental sustainability by reducing the demand for freshwater resources and facilitating the reuse of alternate water sources.
2. Slump test values of the different types of water samples were not significantly affected except for the slump value of wastewater. In addition, the slump value for five types of water ranges from 15.5 to 17 cm. The findings indicated that the quality of water influences the concrete slump value.
3. Compressive strength of distilled water samples values at various ages were not significantly affected as compared to control samples (tap water samples).
4. The compressive strength of water river samples increased from 15%-29% compared with tap water samples until 28 days of age. At a later age, these decreased by about 7%.
5. The compressive strength of wastewater samples increased by about 14%-50% compared with tap water samples at an early age. After the 28th day, these values recorded a slight decrement of 2.3%.
6. The lake water sample's compressive strength increased by 15% at three days of age. In contrast, the compressive strength at ages 7, 28, and 120 days was recorded as a decrease 6%-22% compared with the control sample.
7. On the 3rd and 7th days, the compressive strength of wastewater and river water samples was higher than all types. With age, at 28 days, the river water sample recorded a decrease in values while wastewater continued to increase.
8. The predominant pollutants, notably chlorides, sulfates, organic substances, solids, and heavy metals, adversely impact the mixture.

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NOMENCLATURE

BOD	Biochemical oxygen demand, mg/l
COD	Chemical oxygen demand, mg/l
TDS	Total dissolved solids, mg/l
NO_3	Nitrate, mg/l
CL^{-1}	Chloride content, mg/l
SO_4	Sulfate, mg/l