Impact Analysis of Water Quality on the Development of Construction Materials

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Keywords: strength, materials, water management, Wastewater, water quality

Abstract:

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Abstract: This research dealt with the impact of the quality of the water source on the mechanical properties of construction materials. The mechanical properties of construction materials include compressive, tensile, and flexural strength. Water samples were collected from different resources, these samples were then synthetically investigated to identify and compare their quality parameters. After a detailed chemical analysis of water samples from three sources—wastewater, surface or canal water, and ground water—construction concrete material samples were prepared. The construction materials were developed with the same water–cement ratio, i.e., 0.60 for each concrete mix sample at two mix ratios—M1 (1:2:4) and M2 (1:1.5:3). Slump cone and compacting factor tests were conducted on the fresh concrete to determine its workability prior to its hardening. Then, at 7, 14, 21, and 28 days for each mix, tests for mechanical properties were carried out to determine the compressive, tensile, and flexure strengths. Results showed that the mechanical properties of the concrete made by utilizing wastewater and surface water were more noteworthy as compared to the concrete made by groundwater. This study will help in the production of concrete which depends on waste and surface canal water, even for large projects like rigid pavement construction and water-related structures.

Keywords: water quality; wastewater; water management; materials; strength

1. Introduction

In the construction process, fresh or potable water is generally utilized for the development of concrete materials. Different sources of used water were recently tried for use in concrete construction. These incorporate ocean and alkali waters, canal, and stream water, Textile emanating, Treated Wastewater, car wash effluent, industrial wastewater, and so forth. Previously, water from different quality resources was utilized in the development of construction materials. Reclaimed wastewater was used in the concrete, in comparison with potable water [1]. Wastewater from car wash stations was used in high strength concrete and was compared, with reference to freshwater, on the basis of strength [2]. Textile effluent was also tested in comparison to ordinary water for the strength of concrete [3]. Primary treated wastewater, secondary treated wastewater, car wash wastewater, sugar wastewater, seawater, and treated sewage water were compared with potable water and domestic water for concrete development [4–10]. The effect of quality of water on the compressive strength of concrete was investigated [11,12]. So, water management, especially of wastewater, is also a problem, and wastewater management systems have been developed to deal with it [13–18]. Because of the various sorts of contaminants that exist in each water types, it is hard to make a sound determination concerning the utilization of non-fresh water in concrete. The research on the utilization of different water resources still has not compared the performance of developed concrete with help of groundwater, wastewater, and surface water (canal water connected with river-water source precipitation). Furthermore, this research gap can be studied under different mix design parameters and water resources to understand the utilization of developed concrete with the help of standard testing of mechanical properties, i.e., compressive strength, tensile strength, and flexural strength tests.

The primary goal of this examination is to study the potential utilization of various water resources collected from various sources for the development of concrete, with the following objectives:

1. Development of construction materials with different ratios with different water quality sources;
2. Determination of mechanical properties of concrete mixes utilizing various sources of water;
3. To study the applicability and future goals of using non-fresh or wastewater in the construction industry;
4. To study the impact of changing material combinations and the level of wastewater utilization in the construction industry.

2. Materials and Methods

The detailed methodological framework for the development and strength analysis of developed concrete [4,5,7,10] using different water resources is given in Figure 1.

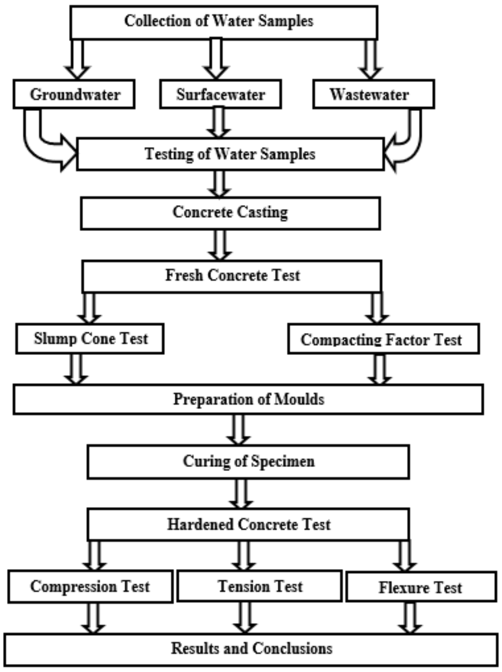

Figure 1. Methodological framework.

As per the established concept of concrete development and strength analysis, the following steps were performed to develop the concrete with help of groundwater, surface water, and wastewater, and later on they were tested according to standard procedures [4,5,7,10].

Step 1: Collection of water samples and testing of chemical and physical properties;
Step 2: Collection of concrete mixing materials;
Step 3: Deciding the mix ratio and mix design (Mix D-1 (1:2:4) and Mix D-2 (1:1.5:3));
Step 4: Developing the concrete samples with each type of water samples;
Step 5: Testing fresh properties of concrete samples;
Step 6: Testing hardened mechanical properties (compression, tensile, and flexural) with reference to different curing day conditions;

Step 7: Final decision making and discussion of results.

2.1. Basic Materials

2.1.1. Cement

The cement used in this study was ordinary Portland cement (OPC) of 53 grades, which was purchased from Maple Leaf Cement Company. This cement is the most widely used type in the construction industry in Pakistan.

2.1.2. Fine Aggregates

Fine aggregates or fine sand was taken from the Chenab River, which is widely used and easily available in the Multan region.

2.1.3. Coarse Aggregates

Coarse aggregates were procured, as shown in Figure 2, from a nearby crusher in the Sakhi-Sarwar area, which are typically the same materials as those used in normal concrete mixtures. The gradation test conducted on aggregates showed that they met the specifications requirements.

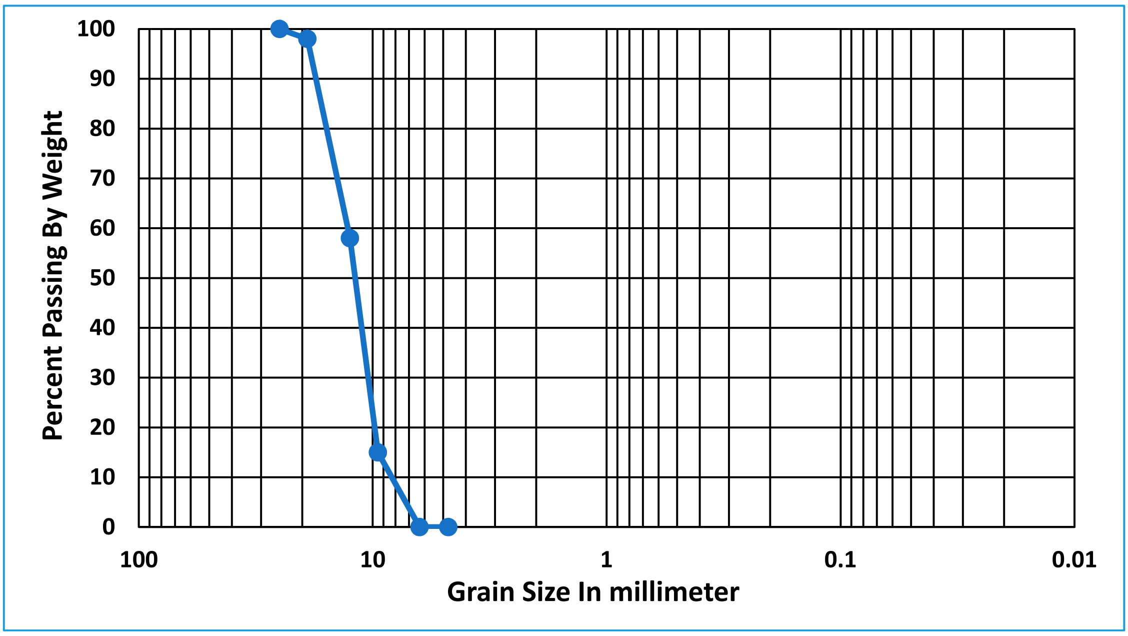

Figure 2. Gradation curve of aggregates.

2.1.4. Mixing Water

Water was taken from three different sources. Groundwater or tap water was taken 250 feet below the land surface, surface water was taken from the canal known as Naubahar Canal (connected to the Chenab River-Source: precipitation) in Multan, while the wastewater was taken from the effluent of the National Fertilizer Company Multan, Pakistan. Water tests analysis as shown in Table 1, included bicarbonates, conductivity, hardness, total dissolved solids (T.D.S), total suspended solids (T.S.S), dissolved oxygen, pH, biochemical oxygen demand, and chemical oxygen demand.

Table 1. Chemical properties of water samples.

Parameters	Units	Maximum Allowable Limit	Ground Water	Surface Water	Wastewater
pH	N/A	6.8–8.5 WHO	7.4	7.3	6.5
T.D.S	mg/L	1000 WHO	899	1010	1007
T.S.S	mg/L	150 EPA	52	75	155
Turbidity	NTU	10 WHO	0.97	8.7	112
Bicarbonates	mg/L	1000 WHO	330	200	600
Conductivity	micro-S/cm	1000	1450	1630	1632
Hardness	mg/L	100 WHO	360	270	280
D.O	mg/L	4–7 EPA	6.3	6.1	4.7
C.O.D	mg/L	150 EPA	18	55	257
B.O.D	mg/L	80 EPA	12	37	179

Note: Limit for drinking water (errors and omissions excepted) WHO [19], EPA [20].

After analysis, the wastewater ranged beyond safe drinking water because the total dissolved solids (T.D.S), total suspended solids (T.S.S), turbidity, hardness, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) values were beyond the safe limit. The disposal and treatment of such wastewater is also a wastewater management issue. Thus, if a successful alternative for utilizing such wastewater with potable water in concrete development is attained, drinking water/ground water consumption can be saved, which is a major resource for human life.

2.2. Mix Design and Sample Preparation

Two mix design proportions were used for the preparation of concrete based on a cement, sand, and aggregate combination. These proportions were M-I (1:2:4) and M-II (1:1.5:3). The water–cement ratio was kept constant at 0.60 for both the design proportions. It should be noted that only one water sample was used at a time while preparing the concrete, and there was no intermixing among the other water samples in any case or in any design ratio. The constituents were weighted in a separate tray and then the materials were mixed in a concrete mixer, as per the American Society for Testing and Materials (ASTM C192-98). The general blending time was around 5–7 min, after which the concrete mix was then compacted, utilizing a vibrating table. The slump test was carried out to determine its workability and to later compare the effect of the water sample on the workability of the concrete. Furthermore, the compacting factor test was also performed to check the workability of the prepared concrete. The specimens were demoulded after 24 h, cured in water, and then tested at room temperature at the required time. To determine the compressive strength and tensile strength, 36 150 mm diameter × 300 mm long cylinders were prepared for each mix design (two mix design ratios were taken, i.e., M-1 (1:2:4) and M-II (1:1.5:3), in the casting process). In addition, to determine the flexural strength (modulus of rupture) for each mix, 36 100 mm × 100 mm × 500 mm prisms or beams were cast. So, a total of 216 samples (72 (comp strength-cylinder) + 72 (tensile strength-cylinder) + 72 (flexural strength-beams)) were developed. All these samples were tested after 7, 14, and 28 days of curing.

2.3. Mechanical Testing Procedure

After curing, the following tests were carried out on the concrete specimens:

- A compressive strength test was carried out at 7, 14, 21, and 28 days according to the ASTM C39, with a loading rate of 2.5 kN/s;
- The splitting cylinder tensile test was carried out at 7, 14, 21 and 28 days to the ASTM C496-96, with an increasing loading rate of 2 kN/s;
- A three-point loaded, flexure strength test of a beam was carried out according to the ASTM C78-94, with a loading rate of 0.2 kN/s.

3. Results

3.1. Analysis of Fresh Properties of Concrete

The slump and the compacting factor test results are given in Table 2 below. The results show that the slump obtained from wastewater and surface water for both the mix proportions was a true slump, while that of the tap or groundwater was a shear slump. On the other hand, the compacting factor test results were in the permissible range, i.e., 0.7–0.95. The values are represented in Table 2.

Table 2. Properties of fresh concrete developed with different water resources.

	Mix Ratio	Slump Value (mm)	Compaction Factor
Groundwater	M-I (1:2:4)	132.2	0.93
	M-II (1:1.5:3)	102.3	0.85
Wastewater	M-I (1:2:4)	39	0.79
	M-II (1:1.5:3)	29.5	0.72
Surface water	M-I (1:2:4)	25.5	0.81
	M-II (1:1.5:3)	50.8	0.88

3.2. Analysis of Mechanical Properties of Concrete

The mechanical properties of concrete consist of three major parameters, i.e., compressive strength, tensile strength, and flexural strength. All the properties of the concrete samples were developed using ground, surface, and wastewater for both the design mix proportions, as shown in Table 3. These results were obtained at 7, 14, 21, and 28 days of curing and the testing machine used is shown in Figure 3.

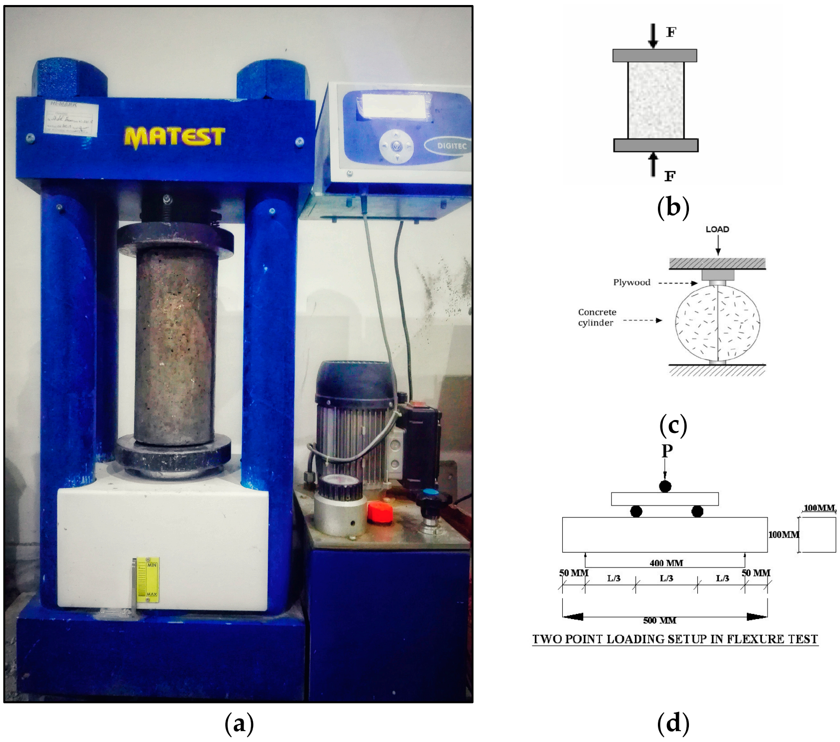

Figure 3. (**a**) Compression machine, (**b**) compressive strength, (**c**) split tensile, (**d**) flexural strength test mechanism.

The results clearly show that the compressive strength of the concrete cylinders increased at 28 days for both the concrete mix designs. Moreover, the compressive strength of wastewater for both the mix design proportions was greater than the cylinders made by surface and groundwater. The compressive strength of wastewater at 28 days was 20.02 MPa for the mix design ratio M-I (1:2:4). Furthermore, the compressive strength of concrete of mix proportion M-II (1:1.5:3) of wastewater at 28 days was also greater than the other two, at 21.85 MPa. Split tensile strength (MPa) was also observed to be increasing, as it increased from 1.35 MPa to 2.10 MPa for Mix Design-I, and from 1.49 MPa to 2.29 MPa for Mix Design-II, when using wastewater in comparison to groundwater. Figures 4–8 display the graphical representation of the given data. In the graphs, M1 refers to mix design ratio 1:2:4, and M2 mix design ratio 1:1.5:3.

Table 3. Detailed range of concrete properties after testing.

Variable	Description	Mean	SD	Min	Q1	Med	Q3	Max
CS	Compressive Strength (MPa)	17.171	2.815	9.93	15.731	17.105	18.885	24.13
TS	Tensile Strength (MPa)	1.5762	0.4974	0.43	1.2563	1.5425	1.9175	3.105
FS	Flexural Strength (MPa)	2.885	0.6751	1.07	2.4425	2.8675	3.1325	5.67
Days	Curing Days (7, 14, 21, 28)	-	7.881	7	-	-	-	28
WT	Water Type (1-GW, 2-WW, 3-SW)	-	-	1	-	-	-	3
WAT	Water (L)	20	2.014	18	18	20	22	22
CEM	Cement (kg)	32	4.028	28	28	32	36	36
SND	Sand (kg)	55	1.007	54	54	55	56	56
AGG	Aggregate (kg)	110	2.01	108	108	110	112	112
Ph	Ph Value	7.0667	0.4056	6.5	6.5	7.3	7.4	7.4
TUR	Turbidity (NTU)	40.56	50.97	0.97	0.97	8.7	112	112
HARD	Hardness (mg/L)	303.33	40.56	270	270	280	360	360
N	No. of Samples (36 for each mix)	72(CS-Cylinder) + 72(TS-Cylinder) + 72(FS-Beams) = 216 No.						

Note: SD—Standard deviation, Min—minimum, Max—maximum, Q1–Q3—quartile range, Med—median. 72 Samples = (3 Samples for each × 3 Water Types × 4 Curing Conditions = 36 × 2 Types of Mix Design).

The bar chart in Figure 4 illustrates the impact of groundwater, wastewater, and surface water on the compressive strength of concrete (mix ratio 1:2:4) at a 7 to 28 days interval. It can be seen that the overall trend of compressive strength increased with the use of wastewater and surface water. However, the overall strength gain by incorporating wastewater was larger than with surface water.

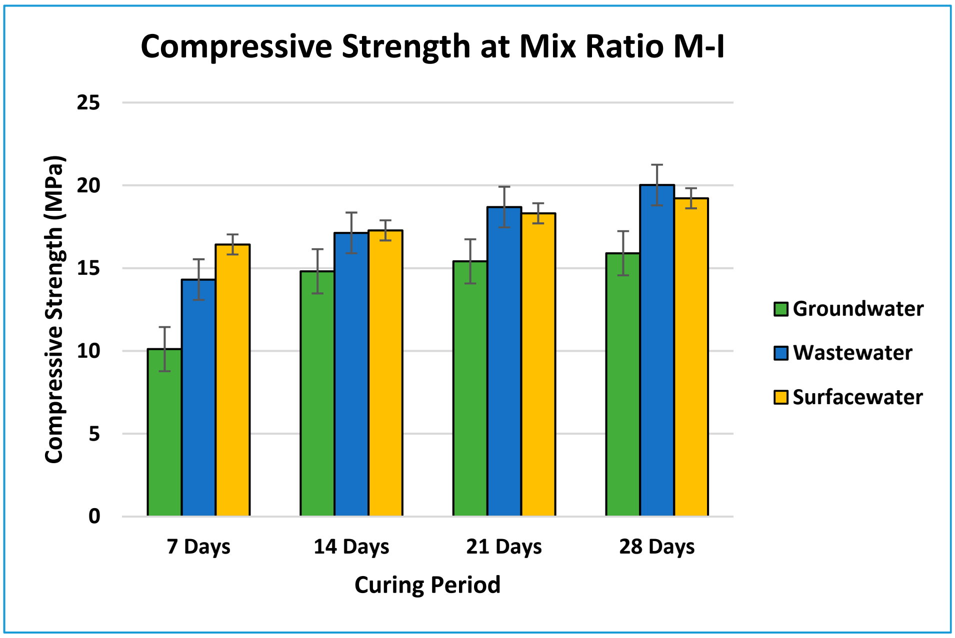

Figure 4. Cylinder compressive strength of concrete for the ratio M-I (1:2:4).

In the following bar chart in Figure 5, the trend of compressive strength of concrete (mix ratio 1:1.5:3) is shown. It is clear from the bar chart that the wastewater added more strength to the concrete than the surface water. Overall, the performance of wastewater and surface water was better than the groundwater.

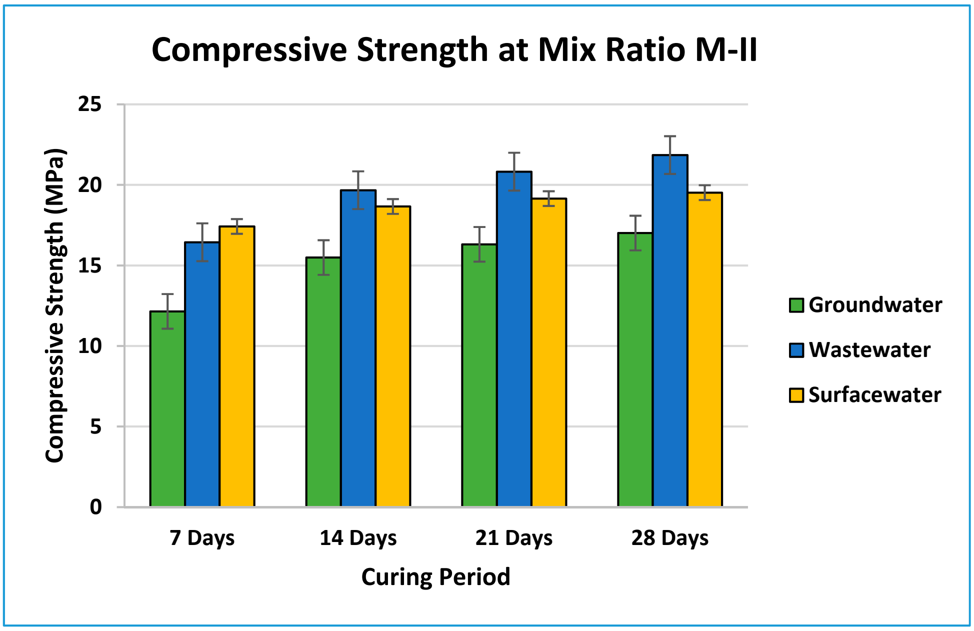

Figure 5. Cylinder compressive strength of concrete for the ratio M-II (1:1.5:3).

The behavior of tensile strength is illustrated in Figure 6, with substantial improvement in the tensile strength of concrete at the mix ratio 1:2:4. It is clear from the graph that the wastewater had the most significant impact on the concrete in tension, as it improved from 1.35 MPa to 2.10 MPa for Mix Design-I and from 1.49 MPa to 2.29 MPa for Mix Design-II when using wastewater, in comparison to groundwater. The overall trend increased for both waste and surface water as compared to groundwater.

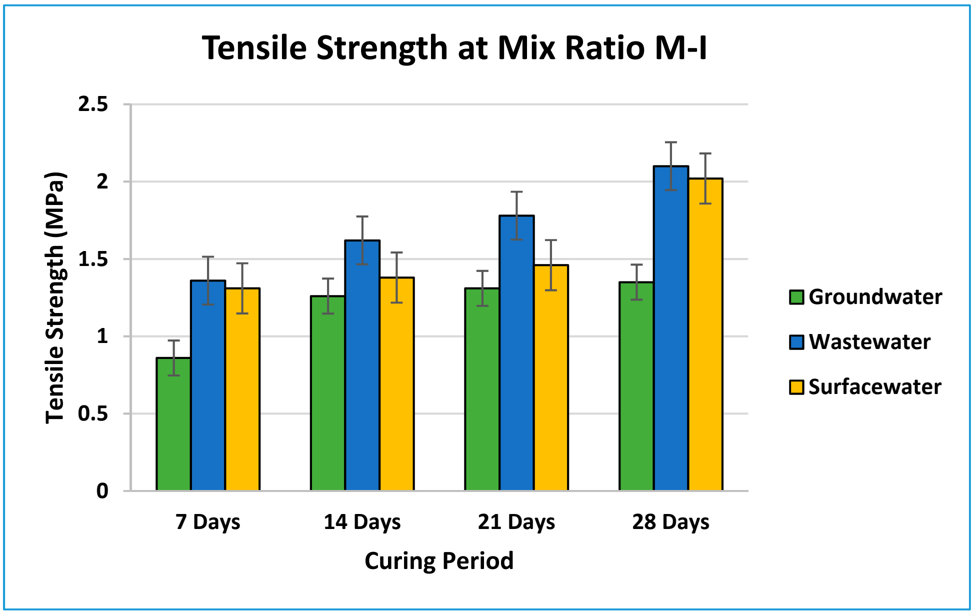

Figure 6. Split tensile strength of concrete for the ratio M-I (1:2:4).

In Figure 7, a bar chart illustrates the effect of the use of wastewater and surface water on the tensile strength of concrete (mix ratio 1:1.5:3). Wastewater had a considerable impact on the tensile strength as compared to surface water, as it improved from 1.49 MPa to 2.29 MPa using wastewater in comparison to groundwater. However, the overall trend for both increased and it improved the tensile strength of concrete as compared to the groundwater.

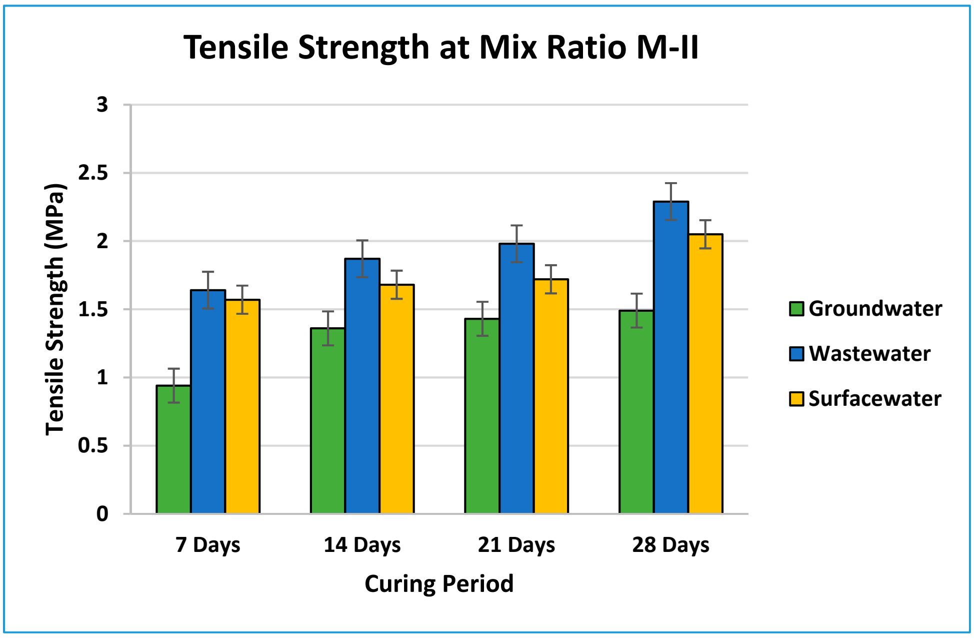

Figure 7. Split tensile strength of concrete for the ratio M-II (1:1.5:3).

In Figure 8, the gain in the flexure strength of concrete (mix ratio 1:2:4) is shown. The flexure strength increased for both wastewater and surface water as compared to groundwater. It is clear that the overall trend for flexure strength was increasing, with a maximum gain by using wastewater. At 28 days the trending increased from 2.79 MPa to 3.13 MPa.

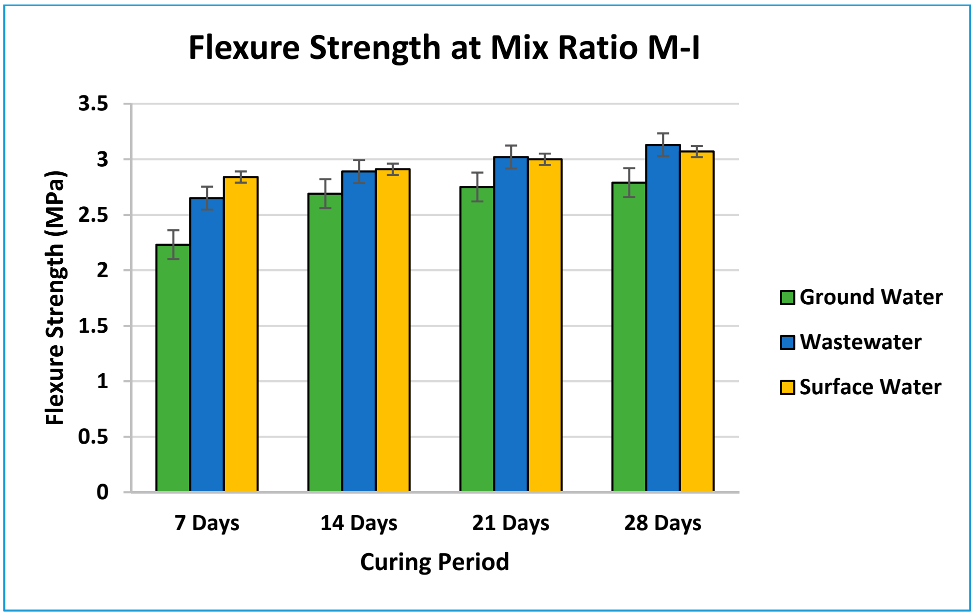

Figure 8. Flexure strength of concrete for the ratio M-I (1:2:4).

The graph below in Figure 9 shows the increasing trend in the flexure strength of concrete (1:1.5:3). The flexure strength of concrete improved from 2.89 MPa to 3.27 MPa and 3.09 MPa with the use of wastewater and surface water, with reference to groundwater. Overall, the strength increasing trend of wastewater was better than for surface water, however, both made a significant improvement in flexure strength.

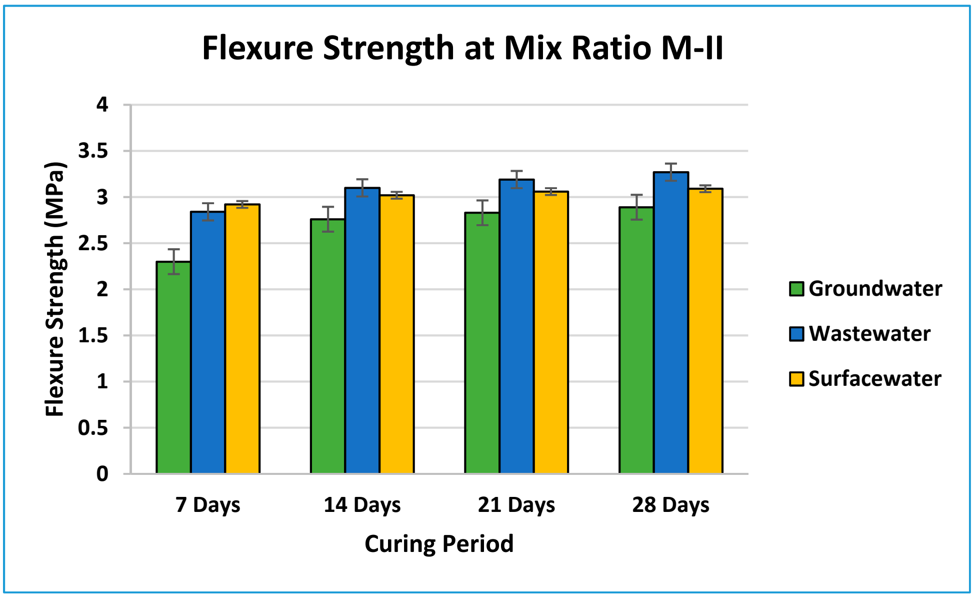

Figure 9. Flexural strength of concrete for the ratio M-II (1:1.5:3).

3.3. Comparative Analysis for the Impact of Water Quality with Respect to Mix Design on Construction Materials

Figure 10 shows the overall behavior of compressive strength for both concrete mix ratios using line graph analysis. It can be seen that the wastewater had the highest impact on concrete compressive strength as compared to the groundwater and surface water.

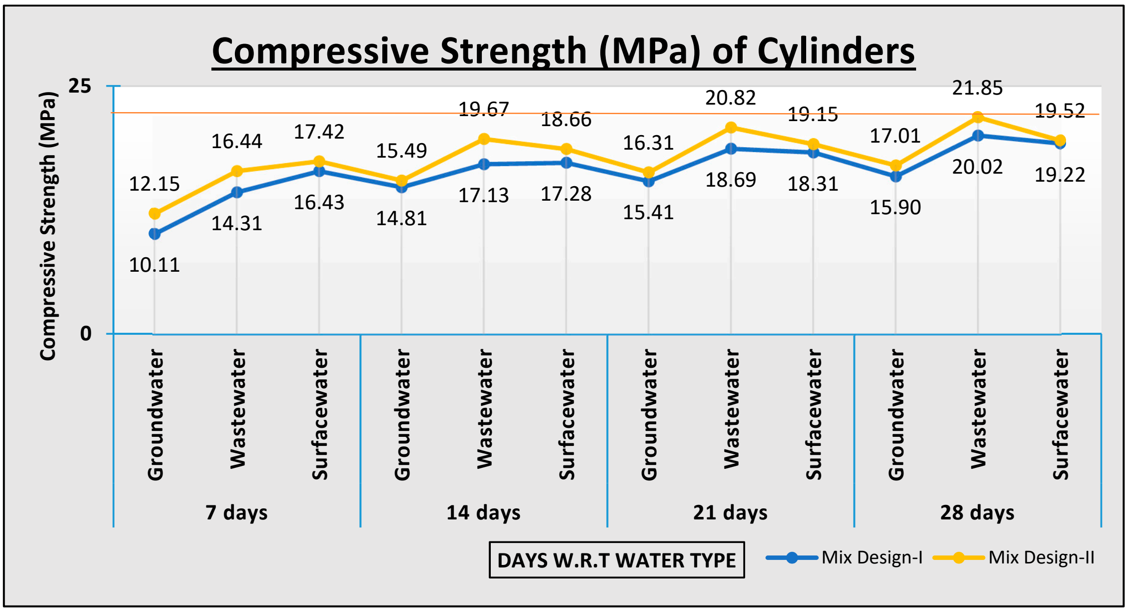

Figure 10. Comparative analysis for the impact of water quality on compressive strength with respect to mix design.

Figure 11 below illustrates the effect of water type on the tensile strength of concrete at a 7 to 28 days interval, with respect to both concrete mix ratios. The overall trend in the graph indicates that the wastewater and surface water improved the tensile strength of concrete when used in both mix ratios, however, the wastewater showed the most significant improvement in tensile strength as compared to the other two types.

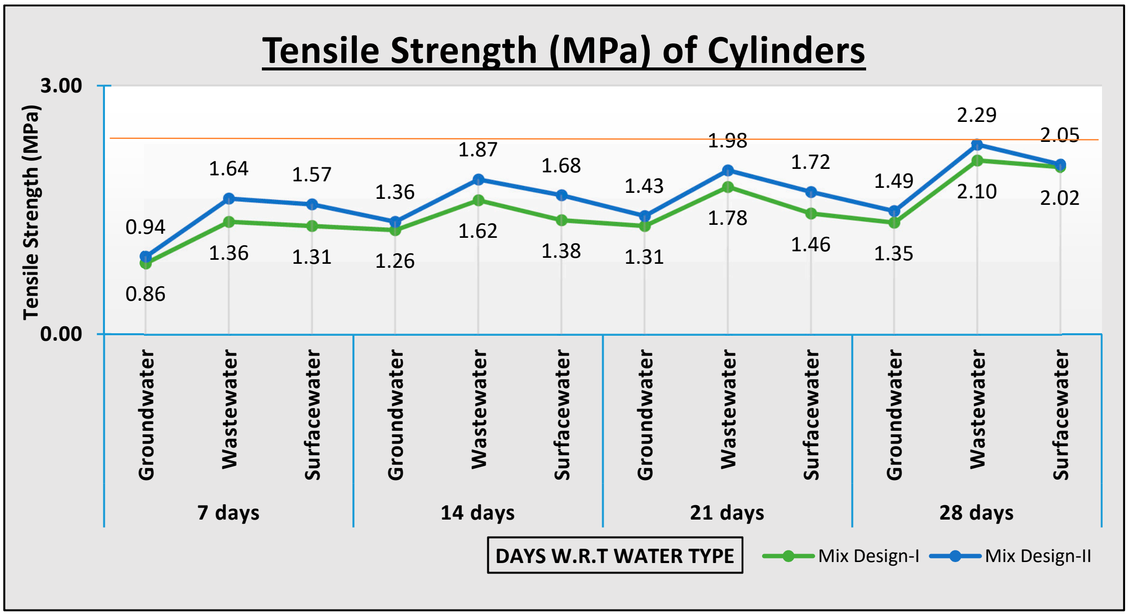

Figure 11. Comparative analysis for the impact of water quality on tensile strength with respect to mix design.

A comparison of the overall improvement in the flexure strength of concrete is illustrated in Figure 12 below. It is clear from the graph that the flexure strength improved when wastewater and surface water were used, as compared to groundwater.

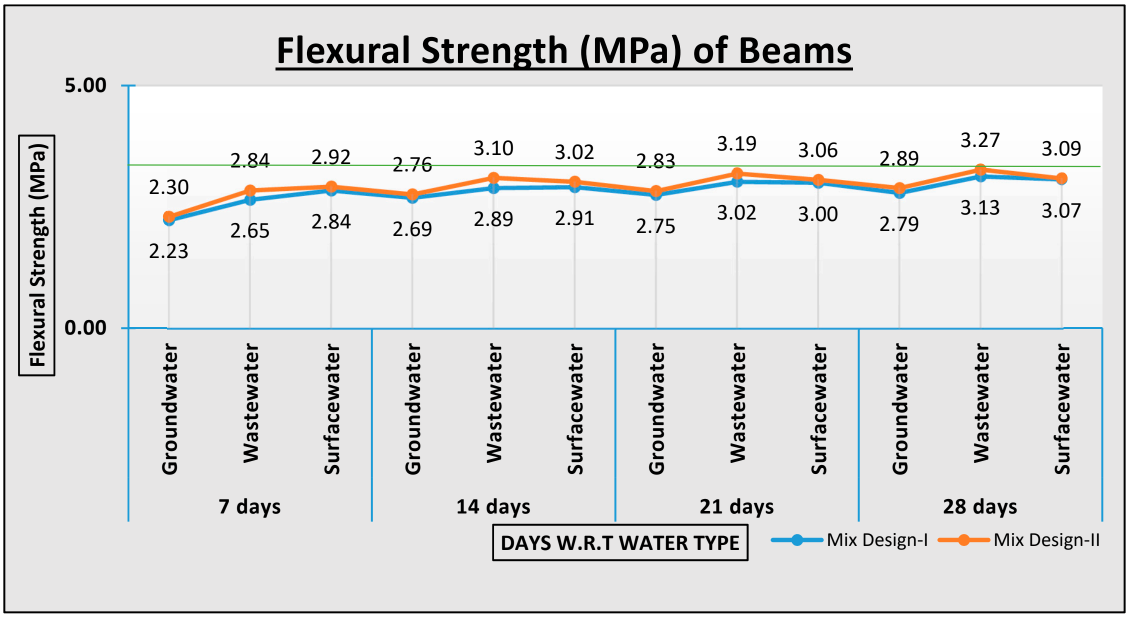

Figure 12. Comparative analysis for the impact of water quality on flexural strength with respect to mix design.

4. Limitations of the Study

The focus of this study was to test the utilization and applicability of untreated wastewater and surface water with reference to groundwater for the development of construction materials. Efficient water resource utilization is one of the key issues around the globe. There may be a discussion on the utilization of such concrete in buildings, because of the environmental impact of odor and fumes, but such concrete can be used as rigid pavement concrete, which can be a beneficial utilization of such concrete. This study is the first phase of such testing, as testing mechanical properties is considered a strong basis of concrete utilization. Further testing related to its health monitoring can be conducted in the future.

5. Conclusions

This study investigated the development of construction materials with the help of different water resources. Water samples were collected from different resources and chemical examination, which was performed on the groundwater, surface water, and wastewater, elaborated the quality of the water. The information shows that all the chemical structures of the wastewater and surface water were a lot higher than those parameters found in groundwater. The results demonstrate that the target objectives have been achieved, such as:

- Construction materials like concrete can be successfully developed with the help of wastewater and surface water, i.e., different water quality resources;
- The mechanical properties of developed concrete from different water resources were tested and analyzed, showing a successful replacement of groundwater with wastewater for concrete development. These properties include compressive strength, tensile strength, and flexural strength;
- The compressive strength of concrete developed using wastewater (20.02 MPa) is better than surface water (19.22 MPa) and groundwater (15.9 MPa) with mix ratio M1, and also using wastewater (21.85 MPa) is better than surface water (19.52 MPa) and groundwater (17.01 MPa) with mix ratio M2;
- The tensile strength of concrete developed using wastewater (2.10 MPa) is better than surface water (2.02 MPa) and groundwater (1.35 MPa) with mix ratio M1 and also using wastewater (2.29 MPa) is better than surface water (2.05 MPa) and groundwater (1.49 MPa) with mix ratio M2;
- The flexural strength of concrete developed using wastewater (3.13 MPa) is better than surface water (3.07 MPa) and groundwater (2.79 MPa) with mix ratio M1 and also using wastewater (3.27 MPa) is better than surface water (3.09 MPa) and groundwater (2.89 MPa) with mix ratio M2;
- The analysis showed that wastewater and surface water can be successfully utilized in the construction industry for the formation of concrete structures, especially rigid pavement construction, which has no issue with the environment and odor-related problems during the applicability of such water resources;
- For the utilization of concrete structures, structural properties change with a change in mix design, and it has also been shown that the successful implementation of wastewater and surface water as mechanical properties has improved even with a change in mix design parameters. Concrete Mix-M-I is usually used for normal single-story structures, whereas Mix Design-M-II is used as a high-strength concrete for multistory buildings and heavy loading structures.

The water samples used in the research process are suitable for the environment, except in the case of wastewater, as it contains more dissolved and suspended solids than that of other two, and therefore it is unsuitable for the environment. The following conclusions are justified by taking into consideration ground, surface, and wastewater on the mechanical properties of concrete. The chemical compositions of wastewater and surface water are different from ground water. So, the suitability of wastewater was established for small construction to large construction projects, like rigid pavement road construction and water-related structures of barrages and dams. It might be concluded from this study that the utilization of wastewater and ground water effectively affects the mechanical properties of concrete. Moreover, the research should be extended to check the conduct of wastewater and surface water on the environmental impact of concrete.

6. Future Recommendations

After the successful compilation of concrete with the help of three different water sources, i.e., groundwater, wastewater, and surface water, it was found that wastewater and surface water can work as replacements for potable/groundwater, even after changing the mix design parameters. For further investigation, research can be directed towards impact analysis of changes in the chemical parameters of water samples on the development of concrete. This can be conducted by changing water resources (i.e., wastewater resources of different chemical properties/sources or from different wastewater treatment plants/sewage plants) and the development of different types of concrete (e.g., normal concrete, high-strength concrete, self-compacted concrete).

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