



Assessing Qualities of Different Sources of Water for Mixing Concrete

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Authors' contributions

This work was carried out in collaboration among all authors. Author PPY designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors KAB and WDA managed the analyses of the study. Author WDA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the effects of water sources on concrete properties. A mix ratio of 1:1.5:3 with 0.5w/c was used in mixing the concrete. Water from the Stream, the hand-dug well and the borehole were used for the experiments with pipe borne water serving as the control. Cubes and beams were cast and tested for compression and flexural strengths respectively at 7-day and 28-day curing ages. Chemical and physical properties of the water samples were also tested. The results indicate that the chemical impurities of all the water types were within the limits given in GS 175-1:2009, EN 1008, ASTM C94 and AS 1379. The physical specifications were all satisfactory, except for the stream water. The water sources had no significant effect on the workability of concrete. Effects of efflorescence were not observed on hardened concrete specimens obtained from any of the water sources. Concrete Specimens mixed with water from the hand-dug well had the highest compressive strength.

Keywords: Water; concrete; compressive; flexural; strength.

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1. INTRODUCTION

The use of concrete as a material in construction is very old and till date the most plastic material for constructional works. Beside water, concrete is the most consumed substance with three tones used per person per year in the construction industry. There are many factors that determine the quality of concrete and its strength properties. These include the type of cement used, aggregate quality and grading, the degree of compaction, quality and quantity of water used in concreting, curing method, type of reinforcement used given the sizes, arrangement and spacing [1] and [2].

Water alone as a factor comes with impurities that may interfere with the setting of the cement paste and adversely affect the strength of the concrete. Some solvents in water also cause staining on the surface of concrete as well as lead to corrosion of the reinforcements embedded in the concrete and thereby render the building structure susceptible to decay or eventual failure [1] and [3].

Water for mixing concrete according to Neville [1] must be fit for drinking and good drinking water, according to [4] should be treated. In the developing countries, however, people drink water taken from streams, hand-dug wells and boreholes which most often are not treated. Simply because water from these sources is consumed, builders erroneously presume the sources to be acceptable for mixing concrete. In some arid areas, local drinking water is saline and may contain excessive amounts of chloride, undesirable amount of alkali carbonates and bicarbonates which could all contribute to the alkali-silica reaction [1]. It is not, however, out of place to suggest that some water, not necessarily fit for drinking, could be suitable for concrete production. Water with pH ranging from 6.0 to 8.0 is good for concreting [5]. Natural water that is slightly acidic is harmless, but water containing organic acids may adversely affect the hardening of concrete [1].

The major reason for contractors' failure to use the specified potable water for mixing concrete is the absence or inadequacy of its supply at the project sites. If the report given by [4] that 1.1 billion people in the developing world are without access to safe drinking water is to be considered then one can understand the attitude of builders

in the developing world in failing to use treated water for mixing concrete.

Pursuant of good quality, price and time for the works the Traditional Procurement System as practiced in developing countries like Ghana recommends an open and competitive tender for public funded works and one of the requisite responsibilities for a participating contractor in such a tender is usually to visit the site and assess prevailing conditions including the source and quality of water and if unacceptable, suggest solutions through method statements [6] and [7].

Beyond the tenders and the ambitious method statements usually put together by hired experts leading to subsequent award of contracts, most successful firms, especially the local ones, thereafter seem not to have any interests in complying with quality control measures imposed by the contract conditions. According to Gbenga [8] contractors use any water available to the sites notwithstanding what specifications dictate. Owing to a poor culture of quality control that they have, manifesting in non-compliance with regulations and codes, poor workmanship as well as inadequate supervision, [3] observed that building decay which is caused by water-borne chemical agents, is easily initiated during initial constructional stages and may not be noticed long after handing over and subsequent occupation. Interpreting the procurement act, Act 663 of 2003, [7] stipulated only 6 months as defects liability period and within this period defects such as corrosion of mild steel reinforcements may not be seen for remedy. Thus new buildings in this way may be handed over potentially defective with future useful life potentially shortened.

The aim of this study is to find potential replacement for potable water for concrete production taking into consideration the fact that the item is scarce. This aim has also been considered cognizant of the dangers chemical agents can pose to buildings.

The study has taken a cue from the recommendations made by McCarthy [9] that water with a Total Dissolved Solid (TDS) of less than 6% could be used in the production of concrete with acceptable strength and durability. Other motivations in choosing the objective for this work come from the Utilization of treated effluent water samples, water from lakes,

washout water and sea water for concrete production [2] and [10].

This study sought to investigate the physical and chemical parameters of water from different water sources, which are mostly used in the production of concrete in Ghana. Compressive and flexural strengths and workability properties of concrete from these water sources namely; the Stream, the Hand-dug well, Bore-hole and the Tap were also investigated. [11] Have studied the effect of Magnesium chloride ($MgCl_2$) on ordinary Portland cement concrete. The ordinary Portland cement concrete was produced with $MgCl_2$ dosage of 200, 500, 1000, 1500 and 2000 mg/L and deionised water was used in concrete mix M20 and M50. In addition to this, control specimens were prepared with deionized water without $MgCl_2$ for comparison. The compressive and tensile strengths were evaluated for 28 and 90 days. The results show that, as the $MgCl_2$ concentration increases, the compressive strength increases and tensile strength decreases.

2. MATERIALS AND METHODS

A. Materials

Cement: Ordinary Portland cement produced from GHACEM, Ghana, with strength of grade 42R conforming to BS EN 197-1:2000 [12] was used for the experiment.

Aggregates: The sand was air dried and sieved using BS 5mm sieve to separate any foreign materials such as roots, stones etc. that might have adverse effect on the performance of the concrete. In addition, a silt test was performed in accordance with [13] on the sand to ascertain the silt content.

Crushed Granite Rock of maximum size of 10mm was used as coarse aggregate.

Water Samples: Water was taken from the following four water sources: tap as control, stream, hand-dug well and borehole. A Completely Randomized Design with four treatments was used for the study.

B. Testing Methods and Procedures

Mixing and casting of concrete: A basic concrete mix ratio of 1:1.5:3.1 (cement: sand: crushed granite rock) with w/c ratio of 0.5, with a targeted strength of 30 MPa, used. The mixing of

concrete was done using $1m^3$ hand fed concrete mixer. In all, four batches of concrete were cast. For each batch 10 cubes of side 150 mm (5 for compression and 5 for water absorption) and 5 beams of cross section area of $150 \times 150 \text{ mm}^2$ and length 300mm (for flexural strength) were formed for testing. The tests were conducted in accordance with [14] for compression for flexural. The concrete specimens were cured in water for 28 days under ambient conditions.

Water Samples Analysis: These water samples from the four water sources namely; the Stream, the Hand-dug well, Bore-hole and the Tap were taken to laboratory for analysis. The parameters monitored were the presence of chloride (Cl^-), pH, magnesium (Mg^{2+}), iron (Fe^{2+}), copper (Cu^+), nitrate (NO_3^-), sulphate (O_4S^{2-}), Total Dissolved Solids (TDS), zinc (Zn^{2+}), carbonates (CO_3^-), bicarbonate (HCO_3^-), fluoride (F_2^-), calcium (Ca^{2+}) and other qualities in terms of alkalinity ($MgOH$) and salinity ($MgCl$). The monitored parameters were determined in line with laid down standard of Ghana water quality guideline by Ghana Standard Board [15].

Concrete Slump Test: The slump test was performed in accordance with [16] A slump cone was filled in three layers of equal volume. Each layer was rodded 25 times with a tamping rod of length 600mm long and 16mm diameter with a hemispherical tip. The cone was lifted upright after leveling the concrete at the top of cone. The slump cone was then set next to the concrete and the difference in height between the slump cone and the original centre of the specimen was recorded.

Visual Inspection of Hardened Specimens: All the specimens after curing were arranged on a platform and carefully observed. The purpose of the observation was to determine the colouration resulting from chemical composition of water samples. The findings were recorded in the next section. A Completely Randomized Design was used for the study.

Compressive Strength test: These tests were in accordance with [17] on Cubes at the 7th and the 28th days of curing. All cured cubes were placed with the cast faces in contact with the platens of digital compressive testing machine. An incremental load was applied to every cube until failure and the maximum compressive stress recorded.

Flexural strength test: The determination of the flexural strength was done using the digital

flexural strength machine manufactured by Controls Milano, Italy. The beam was subjected to incremental loading in till failure, accordance with BS 1881-118: 1983 [18]. The maximum tensile stress was recorded.

C. Data Analysis

Data collected was subjected to one-way ANOVA using the SPSS software version 22. Means were separated at 5% probability level.

3. RESULTS AND DISCUSSION

A. Chemical and Physical Properties

The Chemical concentrations of the water samples were within the potable water limits and specification of water for mixing concrete as per [1,8,14,15,19,20] standards. The pH value of the hand-dug well water sample however was 5.9, a value which is lower than the recommended lower limit of 6.5. The iron (Fe) in the stream water also exceeded the maximum limit by 8.33%.

The normal range of pH for drinking water and water fit for mixing concrete is between 6.0 and 8.5 [1]. The hand-dug well water with a lower pH value thus is likely to cause steel reinforcement bars in the concrete to corrode if used to mix concrete and for that matter can be said to be unsuitable for concrete works.

The Physical Properties of the Water Samples are indicated in Table 1. The four water samples contained substances such as sulphate, alkaline and salt which can be harmful but for their small concentrations which are far below the maximum limit by standard. The colour, taste and odour of the stream water sample were objectionable to the consumer and cannot be said to be conforming to the specification of potable water. The bad odour of the stream water tends to imply that some deleterious materials might have been deposited into it and thereby making it unacceptable for mixing concrete. The study however is reluctant to accept this hasty conclusion due to the assertion of [21] who maintained that the mere detection of unpleasant smell, color and taste of a water source does not mean deleterious substances are present.

Table 1. Chemical parameters of water sample

| Parameters | Stream | Bore-Hole water | Hand-dug Well | Tap water | (GS 175-3:2009) for potable water |
|---|--------|-----------------|---------------|-----------|-----------------------------------|
| PH | 6.6 | 6.9 | 5.9 | 6.5 | 6.5 – 8.5 |
| chloride(Cl ⁻) (mg/l) | 47.0 | 42.0 | 46.0 | 41.0 | 250 |
| Magnesium (Mg ²⁺) (mg/l) | 23.0 | 40.0 | 10.0 | 11.0 | 50 ⁺ |
| Iron (Fe ²⁺)(mg/l) | 0.325 | 0.025 | 0.040 | 0.000 | 0.3 |
| Copper (Cu ⁺) (mg/l) | 0.45 | 0.025 | 0.01 | 0.37 | 2.0 |
| Nitrate (NO ₃ ⁻) (mg/l) | 2.4 | 2.1 | 2.2 | 2.2 | 50 |
| Sulphate (S O ₄) (mg/l) | 9.0 | 1.0 | 3.0 | 41.0 | 250 |
| Total Dissolve Solids (TDS) (mg/l) | 62.3 | 186.0 | 46.5 | 108.5 | 1000 |
| Zinc (Zn ²⁺) (mg/l) | 0.04 | 0.31 | 0.23 | 0.31 | 5.0 ⁺ |
| Akalinity (MgOH) (mg/l) | 52.0 | 220.0 | 20.0 | 55.0 | 1500 ⁺ |
| Salinity (MgCl) (mg/l) | 124.6 | 372.0 | 93.0 | 217.0 | 1600 ⁻ |
| Carbonate (CO ₃ ⁻) (mg/l) | 49.0 | 110.0 | 24.2 | 42.8 | 1000 ^h |
| Bicarbonate (CO ₃ ⁻) ₂ (mg/l) | 2.0 | 40.0 | 6.3 | 7.8 | 1000 ^h |
| Fluoride (F ₂ ⁻)(mg/l) | 0.0 | 0.17 | 0.0 | 0.4 | 1.5 |
| Colour (apparent) | 18 | 4 | 5 | 4 | ≤5Hazen units |
| Taste | Ob | N/O | N/O | N/O | N/O |
| Odour | Ob | N/O | N/O | N/O | N/O |

Except pH all Parameters are in mg/L or ppm, ⁺Limits obtained from WHO's potable water specification ⁺limits obtained from EN 1008 (specification for mixing water), ^hlimits obtained from [22], ⁻ obtained from [23]
Ob- Objectionabl, N/O- Not Objectionable

B. Compressive Strength of Concrete

At the end of the 7-day curing age and the 28-day curing age, cubes from each batch were taken for compressive strength tests. The results of the compressive strength of concrete cubes are recorded in Table 2.

The compressive strength test results obtained from cubes cast using the four different water samples are shown in Table 2. The cubes cast with water from the hand-dug well yielded the highest values of 19.41 N/mm² for the 7-day curing age and 29.85 N/mm² for the 28-day curing age while cubes cast with water from the borehole yielding the lowest values of 17.76 N/mm² for the 7-day curing period and 27.91 N/mm² for the 28-day curing period. The cubes cast with tap water (used as control) produced values of 18.36 N/mm² for the 7-day curing age and 28.54 N/mm² for the 28-day curing age. The cubes obtained, using stream water, yielded 18.40N/mm² and 28.65N/mm² for the 7 and 28 curing ages respectively. All specimens obtained from the four different water samples namely, increased in compressive strength with increase in curing age from the 7th day to the 28th day. In ranking the four water samples in terms of compressive strength that they have produced the tap water which has recommendable water quality placed third.

From Table 1 the alkalinity of hand-dug well, stream and tap (control) water was lower than the borehole sample. This implies that the hydroxide product of the borehole sample concrete would increase, due to the presence of alkaline in the water; therefore delaying hydration hence, low compressive strength. The TDS concentration of hand-dug water is the least. This might have caused less interference with cement active ingredients accounting higher compressive

strength, relatively. The higher the TDS values the lesser the compressive strength of the concrete. This result falls in line with the study of [9] on the use of alternative water sources where the experimented samples obtained compressive strengths higher than the sample of the control water source. On the contrary, the study of [8] on Ogunpa stream in Nigeria showed that the sample of the control (tap water) performed better than the experimented. The conflicting results in these studies might be due to different chemical compositions of those different water samples.

Table 2 stipulates that if the compressive strength is up to 90 percent of the control specimen then the source of water may be accepted for concrete production [14,19,20,24]. The compressive strength of concrete cubes mixed with water samples from the stream, the hand-dug well and the borehole were 100.38%, 104.59% and 97.42% respectively over the control cubes which were mixed with Tap water [25]. The implication here is that all the experimented water are good for mixing concrete.

One factor ANOVA test at a significance level of 5% was also conducted as shown in Table 3 to test if the difference in group means is attributed to chance or error. The F-value = 1.745 shows low variability between the different water sources than variability within each group. The Significance level was 0.235, that is F (3, 8) = 1.745; P>0.05. This indicates that the water samples have no significant influence on the strength of concrete. This result was in line with [9] who in similar study, concluded that water quality does not seriously affect the performance of concrete provided the water lies within the specified limits by standard.

Table 2. Compressive strength of concrete made from different water samples

| Water sample | 7 days | | 28 days | |
|---------------------|---------------------------|-----------|---------------------------|-----------|
| | Mean (N/mm ²) | Std. Dev. | Mean (N/mm ²) | Std. Dev. |
| Tap water (control) | 18.36 | 1.12929 | 28.54 | 0.77208 |
| Stream | 18.40 | 2.16648 | 28.65 | 1.57762 |
| Hand-dug well | 19.41 | 1.11499 | 29.85 | 0.74726 |
| Borehole | 17.76 | 0.62642 | 27.91 | 0.89605 |

Table 3. ANOVA summary of the compressive strength of the four water samples

| Strength | Sum of squares | Df | Mean squares | F | Sig. |
|----------------|----------------|----|--------------|-------|------|
| Between groups | 5.9 | 3 | 1.9 | 1.745 | .235 |
| Within groups | 8.9 | 8 | 1.1 | | |
| Total | 14.8 | 11 | | | |

C. Strength versus Alkalinity and TDS

It could be seen from Table 1 that the water sources used for the study have higher concentration of alkaline and TDS. This study sought to establish the relationships between compressive strength and alkaline on one hand and that with TDS on the other hand.

The relative variation in strength among water samples was partly attributed to the concentration of alkaline and TDS in the samples. From Table 4 increase in alkaline and TDS concentrations resulted in corresponding low compressive strengths. It can be inferred that there exists a negative correlation among concrete strength, alkaline and TDS. In Table 4, the Adjusted $R^2 = 0.72$ indicates that 72% of variation in compressive strength can be explained by the presence of alkaline and TDS in the water samples. The regression equation, (1) imply that, if the alkaline is kept constant and TDS content is increased by 1 mg/l, Compressive strength will decrease by 0.005 N/mm^2 . On the other hand, when TDS remains constant and the alkaline content is increased by 1 mg/l the compressive strength will decrease by 0.11 N/mm^2 .

$$C_s = -0.11\text{Alkaline} - 0.005\text{TDS} + 29.58 \quad (1)$$

D. Flexural Strength

The results of the Flexural strength of concrete samples in the study are shown in Table 5. The

Flexural strength followed the pattern of the compressive strength. The beams cast with water from hand-dug well recorded the highest strength value of 4.46 N/mm^2 whereas those of the borehole specimen recorded the least strength value of 4.18 N/mm^2 and values for beams cast with stream water and tap water (control) were 4.32 N/mm^2 and 4.27 N/mm^2 respectively. In comparing the two strengths (compressive and flexural), there exists a relationship between the two; hence the same factors that influenced the variations in compressive strength can be said to be influencing the flexural strength also.

E. Visual Inspection of Hardened Concrete Specimens

Visual inspection was conducted on the concrete cube specimens to determine if any strange physical appearance could be noticed. Specimens made from tap water (control), water from hand-dug well and borehole water was normal in terms of colour; they had the normal grey colour of a good concrete. However, specimens produced with the stream water were seen to be yellowish. The yellowish colour found on the specimens produced by the use of stream water can be attributed to the colour of the stream water itself. Signs of efflorescence were not noticed on any of the specimens. This may be attributed to the fact that the MgCl content in the various water samples was relatively low considering the reference standard.

Table 4. Strength versus alkalinity and TDS

| Water sample | Concrete's strength(C_s) Nmm^{-2} | Water parameter (ppm) | |
|----------------|---|--------------------------|-------|
| | | NaOH | TDS |
| Stream | 28.65 | 52.0 | 62.3 |
| Hand-dug well | 28.54 | 55.0 | 108.5 |
| Borehole | 27.91 | 220.0 | 186.0 |
| $R^2 = 0.872,$ | | $R^2 \text{ adj} = 0.72$ | |

Table 5. Flexural strength versus water sample

| Water sample | N | 28- day curing age | |
|---------------------|---|--------------------|-----------|
| | | Mean (N/mm^2) | Std. dev. |
| Tap Water (control) | 3 | 4.27 | 0.48539 |
| Stream | 3 | 4.32 | 0.71141 |
| Hand-dug well | 3 | 4.46 | 0.56400 |
| Borehole | 3 | 4.18 | 0.59506 |

4. CONCLUSION

By virtue of the results obtained from this study the conclusion is drawn that water from such sources as the stream, the borehole and the hand-dug well may not be good for drinking due to the odour, taste and colour they may have but they are good for mixing concrete. Considering results obtained by this study, the Compressive and Flexural strengths gained from mixing concrete with the use of water from alternative sources should compete with values obtained when potable water is used. Although these Water samples that were studied did not attain the maximum parameters in terms of specifications for water fit for drinking as well as for mixing concrete they did not show any signs of staining nor efflorescence. The observation was also made that no chemical or physical qualities inherent in these alternative water sources interfered significantly with the attainment of compressive and flexural strengths of the concrete.

5. RECOMMENDATIONS

Based on the results of this study, the following recommendations would be useful:

1. To reduce pressure on tap water which is an essential commodity in the middle and low income countries, governments should make legislation to accept the use of alternative sources of water different from potable water.
2. To do further study about various durability aspects such as long term volume stability.
3. Other sources of water to be accepted should first be assessed through their use in casting concrete samples which subsequently must be crushed for their strength to be ascertained and compared to values of concrete cast with tap water. The Compressive strength of these Concrete samples cast with alternative sources of water must amount to 90% strength of concrete cast with potable water.
4. Stream water which is coloured is not recommended for works which will be finished fare face.
5. Where stream water is to be accepted, tests must be performed on it every time it is taken since stream water quality keeps changing depending on changes in temperature and given the fact that discharges such as municipal sewerage

that are likely to alter its chemistry are likely to be made into the river [24].

6. Where generally alternative sources of water are to be accepted, at contract placement stage relevant clauses should be inserted into the contract conditions which will legally ensure quality control by spelling out what roles the contractor and clerk of works shall play to ensure ethical conduct in the use and management of these alternative sources of water. Contractors' preliminaries should also be enhanced to include the keeping of site laboratories to conduct tests relating to the use of water from other sources different from the treated tap water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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