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Total Dissolved Solids in Water in Makurdi along Benue Valley-Nigeria: Effects on Potability and Compressive Strengths of Solid Concrete

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Abstract Potable water is a scarce resource in many parts of the world. Also, construction works in modern-day buildings need strength to withstand various loads – and concrete's versatility makes it an ideal material where strength is of importance. Water is a crucial binder in concrete making. A laboratory-controlled experimental approach was used to determine the effect of Total Dissolved Solids (TDS) in the water on the compressive strength of solid concretes in Makurdi and its metropolis. A concrete mix ratio of 1:2:3 was used for the experiment. Water samples were collected from rivers (uphill and downhill of River Benue) and wells in Wurukum, Wadata, High Level and North Bank areas of Makurdi and their TDS measured, using a digital TDS meter. Concrete cubes of uniform dimensions were cast with water from each water source and cured for 28 days. We found out that compressive strengths increased with time and peaked around the 28th day. The mass per litre of the dissolved solids does not appear to affect the compressive strength in a linear pattern, pointing to the nature of the dissolved solids as being responsible for the differences in the compressive strengths. Further study is recommended.

Keywords: *concrete, compressive strength, dissolved solids, water*

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1. Introduction

The problem of potable water is severe in many parts of the world. In many villages in Nigeria, and perhaps, Africa, many people rely on natural water bodies like lakes and rivers for their daily water needs. For this reason, many of the people journey long distances to the locations of the water daily, but access to the water is not the only problem, the potability of it is also an issue. Though many parameters determine water potability, the focus of this study is on the dissolved solids in water. According to the World Health Organization, no standard guideline has been produced as an acceptable total dissolved solids (TDS) limit for drinking water; however, a TDS value between 80 to 600 mg/L has been recommended for palatability [1,2]. The TDS in water is a measure of foreign substances (organic or inorganic) in water small enough to pass through a 2 micrometre filtration pores.

Also, in the study of the strength of materials, the compressive strength is the maximum strength that, under a gradually applied load, a given material would sustain without fracture; it is a material's capacity to withstand loads tending to reduce its size [3]. A testing machine can be used to measure the applied load and deformation that may result from the applied load. Different materials react differently when under a load, some deform permanently, and others do not. Unlike the tensional forces that tend to extend a material, compressive forces tend to shorten a material [4]. Integral reinforcement steel gives concrete assemblies great strength in bonding to resist tension [5].

Compressive strength is a crucial property in the design of structures. Often, additives and reinforcements (such as rebar) are included in the mixture to achieve the desired physical properties of the finished material [6]. In a compression test, linearity exists where a material follows Hooke's law. In this region, the material deforms elastically under stress. By its basic definition, the uniaxial (true) stress is given by equation 1.

$$\partial = \frac{F}{A} \quad (1)$$

Where: F= load applied
A= area (m^2)
σ= stress.

Furthermore, water properties (in terms of quality and quantity) for concrete production and curing may have effects on the compressive strength of the concretes. Concrete's quality depends on the mixture of its two components: aggregates and adhesive. Chemical reactions that take place between the aggregates and the paste may affect concrete's strength and settling time [7]. Cement is a primary ingredient in making concrete [8].

Several factors can cause structural failures; some of which include using cheap construction materials as against the standard ones, improper soil analysis or lack of it, which helps to decide the type of foundation, improper concrete mix ratios and, as well as the quality of water used. In this study, we aim to appreciate the effect the dissolved solids have on the compressive strength of solid concretes produced in Makurdi metropolis. In doing this, only a dimension and mix ratio were considered.

2. Materials and Method

A controlled laboratory experiment was used for this study. The water sample collection follows the recommendation by the United States Environmental Protection Agency [1]. Clean containers were used to collect the water from the various sources, then airtight and transported to the laboratory for TDS test and for making solid concretes.

2.1. Study Location

Makurdi is in the middle belt (or north-central part) of Nigeria. It is the capital of Benue State, a State popularly called "the food basket" because of the volume of agricultural activities there, especially for tubers and cereal production. Most of the inhabitants of these locations are farmers. Figure 1, below, shows the exact locations of the wells and water sources – for sample collections.

2.2. Materials

Concrete is a mixture of cement, aggregates (fine and coarse) and water. We obtained the water samples from wells in Wurukum, Wadata, Hight Level and North Bank areas of Makurdi plus water samples collected from River Benue (at the uphill and downhill points). The river is a significant discharge point of many illegal households and industrial waste disposal in Makurdi. The water from the two points of River Benue was collected at New Bridge (uphill) and in Wadata (downhill) - these are the two major points of the River Benue where concrete builders usually get water to make concretes too. The materials for the experiment are as listed in Table 1, including their purpose.

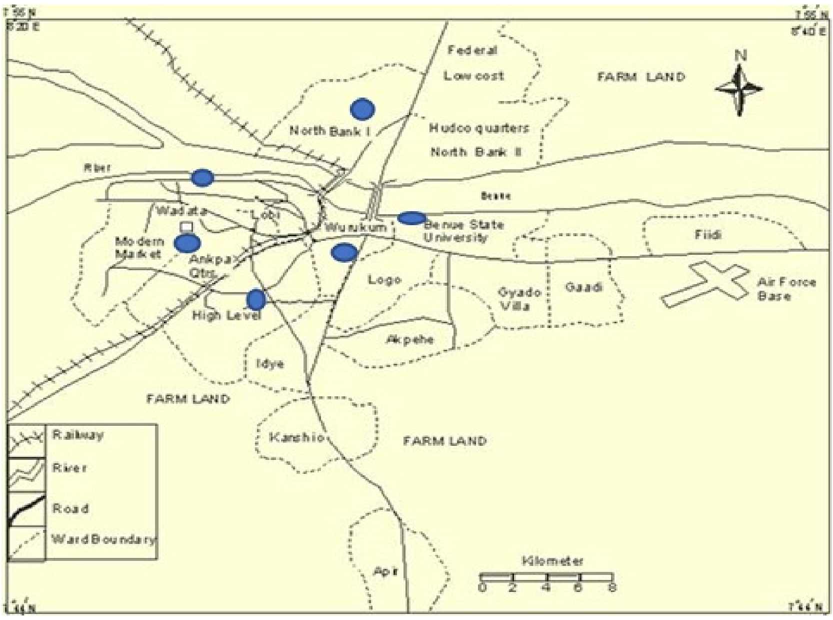

Figure 1. Map of Makurdi Town showing study areas

Table 1. Experimental materials and their use/properties

Materials	Use/properties
Cement	Fundamental material in concrete, specific gravity = 3.15, unit weight = 1440 kg/m^3
Fine Aggregates	Fundamental concrete material, max. size = 5 mm
Coarse Aggregates	Fundamental concrete material, max. size = 18 mm
Water	Reacts chemically with the other constituents to bind the constituents of the concrete, pH = 7.0, density = 1000 kg/m^3
Moulds size (150x150x150) mm	Used to mould the concrete into the desired shape
Hand Trowel	Was used to mix the concrete's constituents
Head pan	Was used to transport the concrete into the moulds
Airtight Gallons (25 litres)	Used to transport water to the experiment area from the different water sources
Compression testing machine	Used to test for the compressive strength of each concrete cube in the laboratory
Shovel	Was used to transfer the mixed concrete into the pans and moulds
Compaction Stick	Used to compact the concrete during casting

2.3. Procedure

At the first stage, water samples were collected from six locations, and their total dissolved solids were measured. We used a digital TDS meter for sample measurement. The TDS meter works on the basis that electrical conductivity of water is directly related to the concentration of dissolved solids in water. Readings were repeated thrice for each sample, and the mean values were determined. The purpose of the TDS test is to ascertain the quantity of dissolved solids present in the various water sources. In the second stage, concretes were mixed manually using a mix design ratio of 1:2:3 and a water-cement ratio of 0.5. The mix proportion was calculated using the standard method.

Before the casting, however, the mix continued until there was a uniform distribution of the materials and the mass was uniform in colour and consistency. The concrete was mixed adequately with equal water volume except that the source of each water was different. The concretes were cast within the hour of mixing to keep its compaction strength. The filling of the concrete into the mould was done in three layers, with each layer followed by adequate compaction. In each of the layers, the cubes were compacted 25 times respectively, as required by the standard procedure. Eight (8) concrete cubes were cast for each of the six different water sources. The curing process took 28 days, after which, the compressive strength test was carried out. The metallic concrete cube's dimension was 150×150×150 mm. Figure 2 shows the water samples in the laboratory, ready for TDS test, with the compression testing machine.

The concrete cubes (moulds) were lubricated before introducing the mixed, hence reducing the friction between the concrete and the cubes. All the concrete cubes were cured by total immersion in water, with the same water quality used for mixing the constituents of the concrete. The curing environment was the same for each of the samples. Concrete specimens after immersions were kept aside for drying until they were ready for testing.

Figure 2. Water samples ready for (TDS) test (left) and Compression Testing Machine (right)

For each test, the cubes were placed in the loading apparatus, and once the specimen reached its critical load, the load indicator needle on the machine recorded the exact point of failure. During the hydration period, the weights of the concrete cubes were taken on day 1, 7, 14, 21 and 28 of the curing. A total of 48 (eight cubes for each water source) concrete cubes were cast, with each of the six water bodies having three moulds.

3. Result

Table 2 shows the mean result of the Total Dissolved Solids (TDS) in parts per million (ppm) for the various water sources. Table 3 shows the summary of the concrete weights on Day 1, 7, 14, 21 and 28. The weight taking days were chosen arbitrarily to enable recognise the difference in weight; to know the total amount of weight gained by each cube at the end of the curing period. Table 4 shows the compressive strength test values as recorded. Figure 3 is the clustered column chart showing the compressive strength test results with their respective TDS.

Table 2. Total Dissolved Solids (TDS) Test

Water Source	Mean Total Dissolved Solids (ppm)
River Benue (New Bridge, Uphill)	118
River Benue (Wadata-End, Downhill)	119
Wurukum Wells	47
Wadata Wells	633
High-Level Wells	119
North Bank Wells	52

Table 3. Comparing the weights of concrete cubes (kg) at day 1, 7, 14, 21 and 28

Water Source	Mean Weight (Kg) Day 1	Mean Weight (Kg) Day 7	Mean Weight (Kg) Day 14	Mean Weight (Kg) Day 21	Mean Weight (Kg) Day 28	% weight gained
River Benue (New Bridge, Uphill)	7.97	8.31	8.39	8.50	8.56	7.4
River Benue (Wadata-End, Downhill)	8.50	8.74	8.82	8.90	8.95	5.3
Wurukum Wells	8.21	8.29	8.38	8.44	8.50	3.5
Wadata Wells	9.34	9.39	9.49	9.57	9.62	3.0
High-Level Wells	9.54	9.59	9.66	9.73	9.78	2.5
North Bank Wells	7.90	7.98	8.08	8.14	8.20	3.8

4. Discussion of Results

A TDS test value up to 600 ppm has been recommended to ensure palatability of drinking water [2]. Drinking water is fit for concrete making [9] by default. Therefore, we can estimate that all water sources studied in Makurdi, met the minimum requirement for total dissolved solids in water for drinking (except for Wadata water wells) and concrete making.

Table 4. Compressive strength test results on the 28th day of curing

Water Source	Mean Total Dissolved Solids (ppm)	Failure loads (KN)	Mean Compressive Strengths (N/mm^2)
River Benue (New Bridge, Uphill)	118	305	14.9
River Benue (Wadata-End, Downhill)	119	340	17.6
Wurukum Wells	47	280	12.2
Wadata Wells	633	300	14.3
High-Level Wells	119	850	25.1
North Bank Wells	52	800	21.3

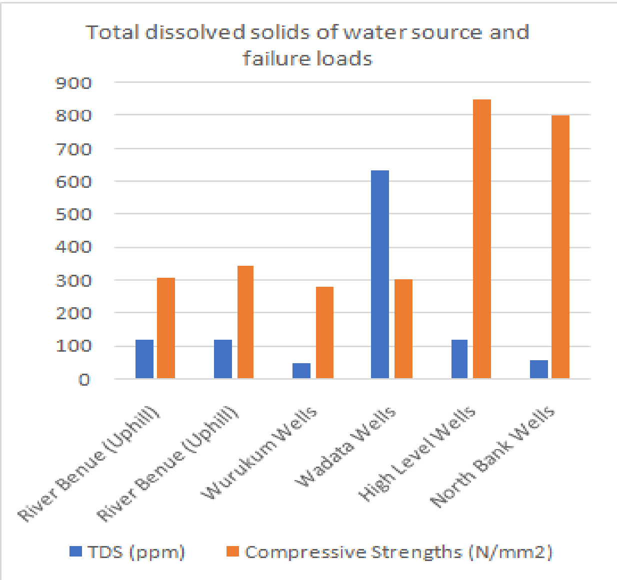

Figure 3. A clustered chart column chart showing the total dissolved solids in water and respective concrete's failure loads (KN).

Though the compressive strengths vary, the values were within an acceptable range for their sizes. According to [10], up to about 2000 ppm of dissolved materials in water for concrete mixing would not do any harm to the concrete strength. The authors also posited that reused water from concrete work with up to 50,000 ppm can be used in concrete mixing without problems. It means that all the water samples were suitable for concrete making.

We found out that the compressive strengths of the concrete made from various water sources vary widely (based on the values obtained from the test). Wadata wells with the highest TDS value did not produce the concrete with the highest comprehensive strength. Likewise, Wurukum wells with the lowest TDS did not produce concretes with the highest compressive strength.

The weight of the cubes increases as the curing days increased, reaching its maximum on the 28th day. We expected that the weight of concretes made with water with the highest TDS would produce the most substantial weight (like the Wadata wells). However, concrete casts with the High-level water wells had a mean weight of 9.78 kg (the highest) after the curing period of 28 days. The High-level water wells had a minimal TDS value compared to that of Wadata wells and the other water sources. Concrete cubes from Wadata wells had the highest TDS value of 633 ppm, but this did not translate to increased compressive strength as we have seen from the results.

The cubes cast from North Bank wells had a low TDS, and the results showed a compressive strength of 21.3 N/mm^2. In sharp contrast, the cubes made from Wurukum wells had the lowest TDS, but the compressive strength was low - just 12.2 N/mm^2) when compared with the other water sources (like the North Bank wells with low TDS).

There was no much difference in the value of TDS obtained at two significant points of River Benue, and the compressive strengths of the cubes were about the same too. However, the concrete cubes from the two points of the river gained more weight than the others. It could be attributed to the large sediments in the river, adding to the weight of the constituent materials that made up the concrete. There was no noticeable colour change in any of the concrete cubes either. All the other concrete cubes also gained weights as they aged owing to the hydration effect.

Therefore, we think that the total dissolved solids values have no linear relationship on the weight and compressive strength of the solid concrete cubes. Low TDS in water does not translate to high compressive strengths of the corresponding concrete. Similarly, high TDS does not translate to low compressive strengths either. It means the TDS can have a positive or negative effect on the compressive strength of concrete. It agrees with the study by [7], which concluded that all impurities might not have adverse effects on the properties of concrete; some impurities react such that, the net result may be harmless or may even improve the properties of the concrete.

5. Conclusion and Recommendations

Test results of the investigation carried out on the solid concrete cubes cast with water sourced from six distinct locations within Makurdi metropolis has been presented. The water was sourced from wells in Wurukum, Wadata, High Level and North Bank areas of Makurdi, as well as two points of River Benue. These were cured for 28 days under the same condition and time. The results obtained showed that water obtained from the significant areas of Makurdi has different total dissolved solids in them. For concrete making, all the water sources met the least TDS values required. The TDS values and the compressive strengths of the concretes obtained showed a non-linear pattern between the two factors. In this peculiar observation, high TDS does not indicate high or low compressive strengths of the concrete outputs, and neither does low TDS supports high or low compressive strength of concretes.

Though the water sources were found suitable for concrete making, further study is recommended to find the nature of the dissolved solids in the water sources around

Makurdi and its metropolis, which we believe was the reason for the differences in the compressive strengths. This is because dissolved solids appear to favour compressive strengths of the concretes in some areas of the town but does not translate to strength in other locations. It means that it is the nature of the dissolved solids in water that affects the compressive strengths of concretes in some of the locations and not the quantity of the total dissolved solids in the water used in making the concretes.

For optimum compressive strength, concrete makers in Makurdi metropolis should consider using water from High Level and North Bank areas as the water from these locations produced concretes with the highest compressive strengths. For drinking purpose, water from the Wadata area may require more treatment because of its high TDS, which, if the dissolved solids are from hazardous wastes, could pose serious health problems.

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