Production of Concrete Using Diverted Rainwater First Flush

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Abstract. Rainwater harvesting is a primordial practice gaining acceptance for its fundamental quality. The most stimulating aspect of rainwater harvesting is the methods of capture, storage, and use of this natural resource. Pollutants are accumulated on the roof during dry weather and then washed off at the beginning of a rain event. This contaminated volume of water at the initial stage of a rainfall is known as “first flush”. This study involves the applied use of this foul water as an alternative to potable water in concrete making and compared its performance with the conventional potable water. Water quality tests of diverted rainwater to find out its impact on the prepared concrete and on the usual mix design procedure for preparing concrete are also shown here. After analysing the result, it is established that concrete production can be done in a more environmentally sound way regarding the use of water resources. Construction sector consumes a high volume of water resources. If we can divert the initial dirty water of rainfall events, collect and store it properly, it can be an alternative to the potable water that is being used to produce concrete, maintaining the quality of the concrete.

1. Introduction
Potable water is a precious and scarce commodity in both developing and developed countries. Due to increase in population and rapid industrialization, huge volume of limited potable water is being consumed at a faster rate. In the north and south region of Bangladesh, there is severe drinking water problem. In those areas, rainwater is basically the main source of potable water. In the mid region (i.e. Dhaka city) enough water is available. This makes people in this region uninterested in rainwater harvesting. So, a huge volume of water is wasted every year which could have been used for a lot of purposes. Bangladesh National Building Code (BNBC), in its last edition, makes rooftop rainwater harvesting mandatory for each building. Also, to collect better quality rainwater for drinking or cooking purpose, BNBC recommends collecting that water after the first flush. In this research, that diverted water of first flush is used to produce concrete. A huge volume of water is used in construction purposes and that water is mostly of the time extracted from groundwater. If the diverted first flush water can be stored, using that in construction purpose may save a huge amount of water from being extracted, therefore saving groundwater. As rainwater is considered potable, concrete produced using it should give similar strength as the concrete made with potable water gives. But surely during the first few minutes of a rainfall, the water carries more contamination which may affect the concrete. Hence, this research emphasizes a detailed study to use diverted rainwater from first flush in concrete production referring to the existing broad standards available in various codes of mixing water for concrete.

2. Review of literature
"If you can drink it, you can make concrete with it.” However, water that would not pass drinking water standards can also make good quality concrete. Water used for concrete should be reasonably clean and free of oil, acid, alkali, organic matter or other deleterious substances [1]. Potable water is suitable as
mixing water for cement concrete, plain cement concrete for road construction and other applications, since its chemical composition is known and well regulated. Rainwater quality is quite close to potable water. But the diverted first flush water contains more contaminations which might affect the concrete. Water is considered suitable if it neither changes the setting time by 30 minutes nor reduces the strength by greater than 20% when compared with the setting time and strength of specimens prepared by using potable water [2]. The 7- and 28-days’ strengths of specimens prepared with unknown water should be at least 90% of those obtained with specimens prepared with potable water. But the reduction in compressive strength up to 20% can be acceptable [3].

2.1. Banngladesh National Building Code (BNBC) regarding first flush [4]
According to BNBC (2015), before storing initial rainwater, just after starting raining, shall be drained out for a period as the first washings from the roof or terrace catchments contain more undesirable materials. The recommended time periods are mentioned below.

Table 1. Recommended first flush diversion duration for various regions in Bangladesh (BNBC 2015).

| Location                  | Time |
|---------------------------|------|
| Dhaka metropolitan area   | 20 min |
| Sylhet                    | 15 min |
| Chittagong                | 15 min |
| Other urban areas         | 15 min |

As this study was conducted in Dhaka City, rainwater of first twenty (20) minutes of two (2) rainfall events were collected for concrete production.

2.2. Effect of quality of water in concrete mix
Effect of unknown water samples on setting time and compressive strength of mortar and concrete is studied. Bicarbonates, chlorides and sulfates of calcium and magnesium are found from ground water, lakes and rivers. Higher concentrations of these affect the formation of strength of concrete. Little or no calcium ions can be obtained from both soft water and pure water sourcing from rain or from melting of snow and ice and condensation of fog or water vapor respectively. Hydrolysis or dissolution of the calcium-containing products of these type of waters occur when it come in contact with Portland cement paste [5]. However, in the case of flowing water (natural or treated polluted water from industries) or seepage under pressure, dilution of the contact solution will take place, thus providing the condition for continuous hydrolysis. Calcium hydroxide is the most susceptible to hydrolysis in hydrated Portland cement pastes because of its relatively high solubility in pure water (1230 mg/l). When most of the calcium hydroxide has been leached away and the other cementitious constituents are exposed to chemical decomposition, the hydrolysis of the cement paste continues. In the end, the strength loss from Portland cement pastes by leaching of lime, leaves behind silica and alumina gels with little or no strength [6].

2.2.1. Effects of total dissolved solids. Experiments show that water containing excessive amount of dissolved salts reduces compressive strength by 10% to 30% of that obtained using potable water. A variety of dissolved salts can cause many problems from slower setting and hardening times to reduced strength. High amounts of sulfate can cause increased crystallization [7].

2.2.2. Effect miscellaneous inorganic salt. Presence of zinc chlorides retards the setting of concrete to such an extent that no strength tests are possible at 2 and 3 days. Calcium chloride is placed in the mixing water to serve as an accelerator in the hardening of the concrete. Persistent dampness and surface efflorescence grounds from large quantities of chlorides present in water (e.g. Sea water) which results in the reduction of concrete strength [7].
2.2.3. **Effects of organic material.** The reduction of the bond between the cement paste and aggregates might result from the blend of organic matter with cement (cement + algae). Moreover, this mixing of organic matter through water will encourage the air entrainment in large quantities, which eventually effect in the reduction of concrete strength [8].

2.2.4. **Effects of total suspended solids.** It is objectionable to introduce large quantities of clay and slit into the concrete which will be implausible to happen if mixing water with high content of suspended solids is allowed to stand in a setting basin before use. High amounts of solids can also increase water demand, increase dry shrinkage, cause efflorescence and affect air-entraining [9].

2.2.5. **Effect of acids and alkalis.** The water that has a pH value of 6-8 is desirable for the concrete construction. In acidic solutions, where the pH is less than 3.5, erosion of the cement matrix will occur. There is a danger of alkali aggregate reaction when the water has a high concentration of sodium or potassium [8].

3. **Methodology**

As this study is a part of the authors’ undergrad thesis work, the study areas were selected near their institution, Military Institute of Science and Technology (MIST) and residential area for the convenience of collection of data.

3.1. **Study area**

For this research, the rainwater has been collected from Banani residential area (old DOHS), Dhaka. Two rainfall events were covered. The water of first twenty minutes of rainfall was collected.

3.2. **Collection of diverted first flush of rainwater**

Rainwater was collected from the roof. The water was stored in a plastic tank. Capacity of the tank was ten (10) liters.

3.3. **Comparison of potable water and first flush water with standards**

Samples of rainwater and potable water were analyzed. Samples were collected on the same day to have traceability possibility and then tested. As rainwater is considered very close to potable water, its parameters were within the allowable limit as mixing water for concrete. The average of the values found in two rainfall events are compared with potable water quality parameters in table 2. As can be seen, according to the results emitted by the laboratory, in both cases the water is suitable for the preparation of a concrete mixture.

| Constituents       | Potable Water | Foul Rainwater | Limits |
|--------------------|---------------|----------------|--------|
| pH                 | 8.18          | 5.97           | ≥5     |
| TSS (mg/L)         | 0             | 44             | 2000   |
| TDS (mg/L)         | 7             | 49.7           | 2000   |
| Turbidity (NTU)    | 3.26          | 35.6           | 200    |
| Alkalinity (mg/L)  | 40            | 7.25           | 500    |
| Zinc (mg/L)        | 0.7           | 0.2            | 500    |
| Chlorides (mg/L)   | 46            | 8              | 1000   |
| Sulfates (mg/L)    | 12            | 5              | 1000   |
| Phosphates (mg/L)  | 0             | 0              | 100    |
| Nitrates(mg/L)     | 0.3           | 4.4            | 500    |
| Manganese (mg/L)   | 0.084         | 0.0023         | 500    |
3.4. Materials
The aggregates were collected from a construction site near MIST. Stone chips and Sylhet sand was chosen as coarse and fine aggregate respectively. The cement used for preparation of concrete is Ordinary Portland cement (OPC).

3.5. ACI mix design procedure
To complete ACI mix design required material information- sieve analyses of both fine aggregate (FA) and coarse aggregates (CA), FM of Fine Aggregate, dry unit weight, specific gravity and absorption capacity, moisture content of aggregates were determined. The process is shown below step by step and the results are shown in table 3.

- **Nominal Maximum Size**
  - 5kg of stone was taken;
  - 5% retained on 25mm sieve.

- **Fineness Modulus (FM)**
  - Stone- 5kg based on nominal maximum size; manual sieving was done;
  - Sand- 500g based on nominal maximum size; mechanical sieve shaker was used.

- **Specific gravity & Absorption capacity**
  - 4kg of stone based on nominal maximum size;
  - 500 g of sand based on nominal maximum size.

- **Amount of Water**
  - Water required was determined based on maximum aggregate size and slump size.

- **Choice of Slump**
  - Slump size was determined for construction of non-air entrained mass concrete.

- **Unit Weight**
  - The size of the both fine and coarse sample was approximately 125-200% of the quantity required to fill the measure;
  - 25 strokes were given on each layer.

- **Water Cement Ratio**
  - Based on selected twenty-eight (28) days compressive strength water cement ratio is, w/c = 0.45

- **Amount of Cement**
  - Obtained by dividing amount of water by the water-cement ratio.

- **Amount of FA & CA**
  - Stone weight-dry bulk volume of CA* dry unit weight
  - Sand weight- concrete - (CA + cement+ water) volume

Table 3. Test results of the above-mentioned test of ACI mix design procedure.

| Tests                      | Fine Aggregate (FA) | Coarse Aggregate (CA) |
|----------------------------|---------------------|------------------------|
| Nominal Maximum Size       | 25 mm (1 inch)      |                        |
| Fineness Modulus           | 2.75                | 7.5                    |
| Specific Gravity (OD)      | 2.95                | 2.61                   |
| Specific Gravity (SSD)     | 2.99                | 2.63                   |
| Absorption Capacity        | 1.20%               | 0.80%                  |
| Unit Weight                | 1581.96 kg/m³       | 1476 kg/m³             |
| Choice of Slump            | 20 mm (MIN) & 80 mm (MAX) |
| Water                      | 193 kg              |                        |
| W/C                        | 0.45                |                        |
Tests | Fine Aggregate (FA) | Coarse Aggregate (CA) |
---|---|---|
Cement | 429 kg | |
Sand | 994.8 kg | |
Stone | 832 kg | |

4. Result and analysis

In table 4, the results of the tests are shown to determine the stress resistance compressing concrete mixtures with potable water and diverted rainwater.

| Days | Potable Water (Mpa) | Diverted Flush Water (Mpa) |
|------|---------------------|---------------------------|
| 1    | 9.342               | 7.625                     |
| 3    | 18.796              | 15.972                    |
| 7    | 28.316              | 24.388                    |
| 28   | 41.88               | 35.19                     |

![Compressive Strength](image)

**Figure 1.** Compressive strength comparison of concrete made with potable water and rainwater.

4.1. Strength difference between concrete made with potable and rainwater in percentage

All the tested parameters of both potable and rainwater are within the limits. As a result, all the cylinders (both made with potable and rainwater) obtained the designed strength, which was 4000 psi (27.57 MPa). But almost every cylinder made with rainwater showed a slightly less strength than potable water. The reasons behind this are - though the pH of rainwater was within limit; it was quite lower than potable water; Nitrate content in rainwater was also higher in rainwater but the difference
was very small and also very much within the limits. In potable water, there was a higher amount of chloride present. In the mixing water it serves as an accelerator in the hardening of the concrete. Reacting with chloride in OPC it decreases setting time and increase the flow of concrete mix and strength of the resulting concrete. The compressive strength difference is illustrated in figure 1 and percentage of strength difference is tabulated in table 5.

| Days | % of Strength Reduction |
|------|-------------------------|
| 1    | 12.813                  |
| 3    | 15.024                  |
| 7    | 13.872                  |
| 28   | 15.974                  |

As reduction of strength is always within allowable 20% limit, so flush water is suitable to make concrete.

4.2. Calculation of the number of buildings that can be made with diverted flush water of Dhaka City

Hourly maximum rainfall intensity in Dhaka city is 79.41 mm [10]. So, assuming per minute intensity is \( \frac{79.41}{60} \) = 1.323 mm/minute. Considering the area of Dhaka city is approximately 306.4 sq.km. As BNBC is suggesting diverting the water of first twenty (20) minutes of a rainfall event after a dry period as first flush, the total rainfall received in Dhaka city in these 20 minutes is about \( 306.4 \times 1.323 \times 20 = 8107 \) million liters. Taking BUET as a representative area, from GIS analysis (figure 2) we get that:

- \( \frac{(423488.07-352395.79)}{352395.79} \times 100\% = 20.17\% \) of the total area is roof top area.
- The quantity of rain that can be realistically harvested in 20 minutes works out to be:

\[ (8107 \times 0.2017) = 1635 \text{ million litres} \]

So, the diverted first flush water from Dhaka city is found out to be about 1635 million liters. If decided to use this water to produce concrete:

Approximately, a 2000 sq.ft, one (1) storied building requires 800 bags of cements, each weighing 50 kg [11]. As we assumed w/c ratio to be 0.45, so required water quantity of will be \( (0.45 \times 800 \times 50) \) kg =18000 kg. So, diverted amount of water can be used to build as many as \( 1635 \times 10^6 / (18000 \times 5) \) = 18,166 nos. of 2000 sq. ft five storied concrete buildings.
5. Recommendations
The rainwater used in the present investigation may be had a slight negative effect in the behavior of the concrete from the physical-mechanical point of view as the pH of rainwater was slightly lower. Very low chloride concentration did not allow the rainwater concrete to be hardened as fast as the samples made with potable water. The tests were done with a fixed W/C ratio, which was 0.40. The obtained resistances were in the mix design ranges; however, it is recommended to work with different W/C ratios, in order to observe if there is any change in results. Changed ratio may increase the durability of hardened concrete. Workmanship can also be a reason behind the concrete samples made with rainwater showing a lower strength. The variable studied was rainwater and it should be noted that the behavior of fresh concrete was similar for both mixtures in terms of characteristics such as settlement, workability and surface appearance. It was also found that the color of the concrete did not change, even though the rainwater sample had a darker shade than the potable water sample. In Dhaka city there are zones with different concentrations of particulate and gaseous material. In the present investigation rainwater was collected from one of the less contaminated areas of the city (Banani DOHS). The quality of the air affects the quality of rainwater. So it is recommended to collect water from different sources and make concrete from it to observe if there is any change in the behaviors of the concrete. But from the test results obtained from this research work, it can be said that rainwater can be used to produce concrete.

6. Limitations
To increase the effectiveness of the study more concrete mix should have been used with different water cement ratio to see any change in behavior. Number of test cylinders should have been more. In this study, concrete casting with both rainwater and potable water was done only once. So, if there were any effects of workability, there was no chance to find that out.

7. References
[1] AASHTO T26-79., Standard Method of test for quality of water to be used in concrete.
[2] Mindess, Sidney and Young, J Francis 1981 Concrete. (Englewood Cliffs, N.J.: Prentice-Hall) ISBN 0131671065.
[3] Method for test for water for making concrete. 1980 (London : British standard institute) BS 3148-1980
[4] Bangladesh National Building Code (BNBC) 2015 (Draft) (Ministry of Works).
[5] Mehta, Kumar P and Monteiro, Paulo J M 2001 CONCRETE Microstructure, Properties and Materials. 4th. (McGraw-Hill Education) ISBN-10: 0071797874.
[6] Biczók, Imre 1967 Concrete Corrosion and Concrete Protection. 3rd. (Chemical Pub. Co.).
[7] Sautya, Malay June 01, 2018 Effect of Impurities in Water on Properties of Concrete Civil Engineering. [Online] https://www.civilnoteppt.com/2018/05/effect-of-impurities-in-water-on-and-their-permissible-limits-IS-code.html.
[8] Effect of Water Impurities on Concrete Strength, Durability and Other Properties The Constructor [Online];https://theconstructor.org/concrete/effect-water-impurities-concrete-properties/17123/.
[9] Quality of water in concrete Mix Foundation, Concrete and Earthquake Engineering. [Online] 2009 https://www.civil-engg-world.com/2009/09 qualidade-of-water-in-concrete-mix.html.
[10] Haq, Syed A 2017 Harvesting Rainwater from Buildings. (Springer). 978-3-319-46360-5.
[11] Building Material Requirement for 1000 SQ.FT Construction Area Quora [Online] 2017 https://www.quora.com/I-want-to-build-a-1000-sq-ft-building-How-much-stone-brick-and-cement-is-required.

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