JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Experimental Investigation on Mechanical Properties of Concrete Using Different Sources of Water for Mixing and Curing Concrete the Case of Jimma Town

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

By

Nejiya Sefa Mohe

August 2021

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DECLARATION

I, hereby declare that this thesis entitled: "Experimental Investigation on Mechanical Properties of Concrete Using Different Sources of Water for Mixing and Curing Concrete the Case of Jimma Town" is my original work and has not been presented by any other person for an award of a degree in this or other universities, and all sources of material used for thesis have been well acknowledged.

Nejiya Sefa Mohe Date……August 31……. Signature ……………..

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ABSTRACT

Concrete strength depends on the quality of concrete-making materials selection. The concrete-making materials selection should satisfy the requirement stated in the standards. Mixing and curing water is one of the materials used and should be suitable for making concrete. The quality of water is important because impurities can affect the strength of concrete and lead to corrosion of reinforcement. The usage of potable water is getting more intense with the study area (Jimma town) which can lead to a reduction in potable water consumption. Hence, different sources of water can be used as a substitute for concrete mixing and curing purposes. In this study, water samples were collected from different water sources (potable water, river water, deep well water, and rainwater), and their chemical properties were conducted based on standard lab procedures to identify the constituents. The concrete strength of C-25 was prepared using the identified water sources, and testing was done for 7 and 28 days. Tests were conducted on cement setting time, workability of concrete, compressive, splitting tensile, and flexural strength of concrete. According to laboratory test results, the impurities observed in the identify water sources were within the specified limit as per the ASTM C1602. The initial and final setting time of cement using each water source showed an insignificant deviation from the control (potable water) and all are within the specified limit as per ASTM C 94. The water sources had no significant effect on the workability of concrete the range of slump all is (0-25). The compressive strength test results on the 28-days mark showed that the potable water has more strength with 29.5 MPa followed by river water with 28.8 MPa, deep well water with 26.86 MPa, and rainwater 24.69 MPa for the mixing part, in the curing part river water with 27.09 MPa, deep well water with 26.12 MPa, and rainwater with 25.4 MPa. The same source of water used both mixing and curing parts, river water with 26.6 MPa, deep well water with 25.7 MPa, and rainwater with 22.97 MPa. The results showed that the compressive, splitting tensile, and flexural strength of concrete mixing and curing with potable and river water at 28 days had been more strength compared with deep well and rainwater. Potable water and river water was relatively good for mixing and curing concrete around Jimma town.

Keywords*: Concrete strength, Curing water, Impurities, Mixing water, Water source.*

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ACRONYMS

ASTM	American Society for testing and material
ACI	American Concrete Institute
C -20/25	Concrete having 25 MPa Compressive Strength for cube
FM	Fineness modulus
m^3	Cubic meter
MPa	Mega Pascal
mm	millimetre
%	Percentage
PPC	Portland pozzolana cement
SSD	Saturated surface dry
W/C	Water cement ratio
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Concrete is a widely applicable construction material throughout the world. This is also true in the case of Ethiopia. Many reasons are for wider applicability of construction material; among those reasons, the majors are most durable construction materials, strong, performing well during its service life, availability, comparative cost-effectiveness, flexibility for the desired shape, comparatively less skilled manpower requirement, fire, and corrosion resistance, environmentally friendly, etc. Concrete is a composite construction material made up of water, cement, aggregates (fine and coarse), and sometimes extra materials called admixtures. Generally, concrete finds its use in virtually all Civil Engineering works. Concrete is the most widely used material in the world next to water[1].

Concrete is a mixture of cement, sand, coarse aggregate, and water in a certain proportion, and thus different concrete strengths obtain by altering the mixing proportions of these ingredients. Making good quality concrete that satisfies both strength and durability requirements needs great care starting from ingredient selection. The ingredients selected will be fulfilling the requirements state in the standards. Water is one of the ingredients use and should be suitable for making and curing concrete [2].

Water is an important ingredient of concrete. Part of mixing water is utilized in the hydration of cement and the balanced water is required for imparting workability to concrete. Thus, the quantity and quality of water are required to be looked into very carefully. The strength and durability of concrete are reduced due to the presence of chemical impurities in water. Most of the specifications recommended the use of potable water for making concrete. A practical solution would be tests for the time of set and strength of concrete between the water under consideration and the water of proven quality [3].

In construction sites where potable water supply is inaccessible water is used either from shallow wells, rain, ponds, or rivers. When these natural sources contain significant amounts of suspended particles such as silt, organic impurities, and algae additional testing is necessary. The presence of impurities in water for concrete mixing and curing leads to decreasing structural properties of concrete such as strength and durability to a larger extent [4].

Water quality can significantly vary from one source to another depending on geographical location and season. Hence, the water used for mixing and curing concrete on construction sites should be tested to avoid structural defects, especially where large-scale constructions take place.

In general, the selection of suitable water from different sources for concrete mixing and curing is important to produce quality concrete with adequate compressive strength, split tensile strength, and flexural strength. Thus, other sources besides potable water to make concrete should be checked for their suitability. The present study checked the compressive strength, splitting tensile strength, and flexural strength of concrete with different sources of water used for mixing and curing concrete.

1.2. Statement of the Problem

The quality of water affects the properties of concrete and it is important because impurities in it may interfere with the setting of cement, affect the strength of concrete, and may lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered.

Impurities found in mixing and curing water have an adverse effect on the properties of concrete and thereby render the building structure susceptible to decay or eventual failure. 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 [5].

Concrete construction uses mixing and curing water sources that are distinct depending on the availability, suitability, and location of construction sites. Jimma town has different sources of water such as potable water, river water, rainwater, and deep well water. Water from these different sources has its constituents and properties.

In the standard code provided, drinking (potable) water is recommended for concrete making. However, potable water supply is not easily available in some construction sites due to the shortage of water in the town. Even though the recommended water for concrete construction is potable, some projects utilize sources other than the potable water supply and yet it is not common to test the quality of water. As a result, it is significant to study the effect of the water from different sources because different concentrations of impurities could be found due to environmental exposures. Meanwhile, in Jimma, researches have not been conducted on the effects of impurities found in mixing and curing water for construction purposes. This study aims to identify the different sources of water for making concrete in Jimma town and examine the impurities in the identified water sources. Also, the study aims at conducting laboratory tests for cement setting time, workability, compressive strength, splitting tensile strength, and flexure strength of concrete using river water, deep well water, and rainwater, the potable water used as the reference.

1.3. Research Question

The research has answered the following research questions.

1. What type of chemical properties are found in the identified water sources?
2. What are the effect of the identified water sources on the cement setting time and workability of concrete?
3. What is the effect of different sources of water for compressive strength, splitting tensile strength, and flexure strength on concrete?

1.4. Objectives of the Study

1.4.1. General Objective

The main objective of the study is the experimental investigation on mechanical properties of concrete using different sources of water for mixing and curing for C-25 grade of concrete as practice in Jimma town.

1.4.2. Specific Objective

1. To determine the chemical properties found in the identified water sources.
2. To investigate the effect of the identified water sources on the cement setting time and workability of concrete.
3. To assess the effect of different sources of water for compressive strength, splitting tensile strength, and flexure strength on concrete.

1.5. Significance of the Study

The significance of this research is to find a potential replacement for potable water for concrete production taking into consideration the fact that the item is scarce. To reduce potable water consumption, different sources of water are used as a substitute in concrete mixing and curing. Therefore, use the sources of water and developing the culture of testing water sources should be adopted in this study to avoid structural failure and wastage. Water is one of the essential constituents of concrete, hence it is important to establish the effect of both quantity and quality of mixing and curing water on the strength and other properties of concrete.

This study will help the technical specification and guidance document providers to prepare a detailed document for such different sources of water used for making concrete around Jimma town. Moreover, other researchers will use the findings as a reference for further study.

1.6. Scope and Limitation of the Study

The aim of the study covers the investigation of the common source of mixing and curing water used in Jimma town. This research works the following structural consideration: -

- The experimental investigation was focusing on 25 MPa concrete grade produced with different sources of mixing and curing water such as potable water, rainwater, river water, and deep well water, the potable water used as a reference.
- Different sources of water collected in the source tested the water impurities, and fresh and hardened properties of concrete such as workability, setting time of cement, compressive strength, splitting tensile strength, and flexural strength were determined after the curing ages of 7 and 28 days in the study.
- The PPC-32.5R cement type was used because of the wide availability and usability of this type of cement in the study area.
- This study used a 0.53 water-cement ratio and C-25 grade of concrete.

The limitation of the study, water samples were not investigated for seasonal changes of constituents and the characteristic of geographical locations due to budget and time limitations. The water parameters were studied in this study during the dry season.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1. General

Concrete, is the most commonly used structural material and it consists essentially of mixing water, cement, aggregates (fine and coarse), and sometimes extra materials called admixtures. Generally, concrete finds its use in virtually all Civil Engineering works. Concrete is a widely used material in the world after the water. Cement concrete is a major building material used abundantly in the construction industry. It is used in all parts of the building like foundations, superstructures, and roofs [4].

Concrete structures are built to withstand a variety of loads and may be exposed to many different environments such as exposure to seawater, deicing salts, sulfate-bearing soils, abrasion, and cyclic wetting and drying. The materials and proportions used to produce concrete will depend on the loads it is required to carry and the environment to which it will be exposed. Properly designed and built concrete structures are strong and durable throughout their service life. Furthermore, concrete is an excellent building material because it can be formed into a wide variety of shapes, colors, and textures for use in an unlimited number of applications [6].

Aggregates occupy about 65to 80 percent of the volume of concrete. The paste which is formed from cement and water constitutes 20 to 40 percent of the total volume. Concrete is one of the most frequently used building materials. Its usage worldwide, ton for ton. The quality of the concrete is greatly depending upon the quality of the paste, which in turn, is dependent upon the ratio of water to cement content used. To get quality concrete due to attention should be paid to choosing the constituents, mixing them in correct proportions, correctly mixing the concrete, and finally in using it properly followed by proper curing[7].

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength-giving cement gel, the quantity and quality of water are required to be looked into very carefully. It has been discussed enough about the quantity of mixing water but so far the quality of water has not been discussed. In practice, very often great control on properties of cement and aggregate is exercised but the control on the quality of water is often neglected. Since the quality of water affects the strength, we must go into the purity and quality of water [8].

In general, the permanency of concrete is affected by 5 factors [1].

- Design:- type regarding materials, conditions, then proportions over the materials, diagram about the concrete mixing or depth regarding the figured cowl over reinforcing steel.
- Construction practices:- mixing, delivery, unloading, consolidation, finishing, and curing conditions.
- Properties of hardened concrete:- compressive strength, permeability.
- Environmental exposure conditions:- sulfate attack, freeze-thaw, alkali-silica reaction.
- Load conditions: kind on load, assign duration, stutterer then deep regarding the crack

2.2. Constituents of concrete

Concrete is a mixture of Portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water with or without admixture. The constituent materials must be proportioned correctly, and the concrete must then be mixed, placed, and cured properly. Also, there must be careful quality control of every part of the concrete-making process[6].

2.2.1. Cement

The cement properties that are most significant in decisive curing requirements are strength gain, time of setting, and fineness. The period of mandatory curing of a concrete structure is sometimes directly linked to the strength-gain rate of the cementitious materials[9].

Cement is the most important ingredient of concrete acts as a binding material having both adhesive and cohesive properties. Cement binds the coarse and fine aggregate by filling the voids and chemically reacting with water. A compound of Cement: The raw materials of cement on burning are converted into silicate, aluminates, and ferrite of calcium. Properties of the compound: The compound present in cement each has its properties and activities at the time of reaction when we mix the water in cement.

- Tricalcium Silicate-It hydrates rapidly and generates more heat of hydration
- Dicalcium silicate- It hydrates slowly and generates less heat of hydration. It is responsible for the ultimate strength of cement.
- Tricalcium Aluminate-It reacts fast with water and generates a large amount of heat of hydration.it causes the initial setting of cement.

- Tetra calcium alumino ferrite- It reacts slowly with water and generates little heat of hydration [7][10].

Table 2. 1: Compound of Cement (7).

Name of Compound	Chemical Formula	Abbreviation	Percentage	Literature
Tricalcium silicate	$3caO.SiO_2$	C_3S	40-55	Alite
Dicalcium silicate	$2caO.SiO_2$	C_2S	15-30	Belite
Tricalcium aluminate	$3caO.Al_2O_3$	C_3A	8-10	Celite
Tetra calcium alumino ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	13-17	Felite

i. The consistency of standard paste

For the determination of the initial setting time, the final setting time, and for Le Chatelier soundness tests, a neat cement paste of a standard consistency has to be used. Therefore, it is necessary to determine for any given cement the water content which will produce a paste of standard consistency. Consistency is determined by the Vicat apparatus, which measures the depth of penetration of a 10 mm diameter plunger under its weight. When the depth of penetration reaches a certain value, the water content required gives the standard consistency of between 26 and 33 [10].

ii. Initial and Final Setting Time: The most important physical property of cement is Setting Time. When the water is mixed with cement to make a cement paste or concrete.it becomes gradually less plastic and finally becomes a hard mass. This test covers the determination of the time of Setting of cement using the Vicat needles. Setting means the change from a fluid to a rigid state. The setting time is divided into two types: - initial and final setting time.

- The initial setting time of cement is between the addition of water and the instant cement paste starts to lose its plasticity. It is the time required for a cement paste to stiffen considerably represented by the 1mm needle penetration of 25 mm.
- Time of final set: the time required for the cement to harden to a point where it can sustain some load (Represented by no penetration of Vicat needle)[11][7].

Initial setting time a minimum time of 45 min for cement of strength classes 52.5 N and 62.5 N whereas 60 minutes applies to strength classes of 32.5 N and R and 42.5 N and R. British Standards prescribe the final setting time as a maximum of 10 hours for Portland cement, which is the same as that of the American Standards. The initial and final setting times are approximately related: final time (min.) = 90 + 1.2 [initial time (min.)][10].

Mostly used cement in Ethiopia: In Ethiopia, OPC and PPC are the two most widely used cement types.

iii. Ordinary Portland Cement

Ordinary Portland (Type-I) cement is suitable for general concrete construction when there is no sulfate in the soil and is made from 95% to 100% of the standard Portland cement clinker and from 0% to 5% of non-cementations material. In consequence, modern cement has a higher 28-day strength than in the past, but the later gain in strength is smaller. A practical consequence of this is that we can no longer expect ‘improvement with age’. This is an important point to remember since construction specifications are usually related to the 28 days’ strength of concrete. Ordinary Portland (Type I) cement is an excellent general cement is the cement most widely used[10].

iv. Portland Pozzolana Cement

These cements are made by blending pozzolans with Portland cement. Pozzolan is described as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and the presence of moisture, chemically react with lime (liberated by hydrating Portland cement) at ordinary temperatures to form compounds possessing cementitious properties. As a rule, Portland-pozzolan cements gain strength slowly and therefore require curing over a comparatively long period, but the long-term strength is high. If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing a cementitious compound. It also reduces the heat of hydration since its reaction is slower than that of OPC, which implies that it has a slower rate of strength than OPC [10].

2.2.2. Hydration of Cement

Hydration of Cement: The chemical reaction between cement and water is known as hydration of Cement. The reaction takes place between active components of cement and water. The new compound of hydrated calcium aluminate, hydrated calcium silicate, and calcium hydro-oxide are formed. The calcium silicate breaks down to form di-calcium silicate C_2S and releases the excess lime as $Ca(OH)_2$[7].

- $C_3S + H_2O \rightarrow$ Hydrated Calcium Silicate + $Ca(OH)_2$
- $C_2S + H_2O \rightarrow$ Hydrated Calcium Silicate + $Ca(OH)_2$

2.2.3. Aggregates

Concrete is the versatile and most popular construction material in the world. It is produced by mixing fine and coarse aggregates, cement, water, and additives in a certain prescribed proportion. Aggregates are known to be particles of rock or equivalent which, when brought together in a bound or unbound condition, form part or whole of an engineering or building structure. Aggregates, both fine and coarse, take about 65-75% by volume of concrete and are important ingredients in concrete production. The parent materials of aggregates are derived mainly from volcanic activity[6][12].

Aggregates are separated into two classifications: coarse aggregates, and fine aggregates. The No. 4 sieve generally determines the difference between coarse aggregate and fine aggregate for most highway construction work[13].

I. Fine Aggregate

The particle that passes through a 4.75 mm sieve and retains on 0.075 mm sieve is known as fine aggregate. The voids between the coarse aggregate are filled up by fine aggregate. It reduces the cost of the concrete and increases the Workability of concrete. The main characteristic of fine aggregate which affects the properties of concrete is Bulking. The phenomenon of increase in sand volume due to the increase of moisture content i.e. called Bulking of sand. The main causes of bulking of sand are the moisture content in the sand makes thin films around sand particles. Hence, each particle exerts pressure. Thus they move away from each other causing increasing in volume. The bulking of the aggregate is dependent on two factors: The fineness of the aggregates and Percentage moisture content. A fully saturated fine aggregate does not show any bulking. Thus when the sand contains sufficient moisture 12-

20%, it occupies the same volume as when it was dry. The percentage of bulking is inversely proportional to the size of the fine aggregates. Hence, the finer the sand more is bulking[7].

I. Coarse Aggregate

The particles that are retained on the 4.75 mm sieve are called coarse aggregate. The use of the largest maximum size of coarse aggregate permits a reduction in cement and water requirements. Using aggregates larger than the maximum size of coarse aggregates permitted can result in interlock and form arches or obstructions within a concrete form. That allows the area below to become avoid, or at best, to become filled with finer particles of sand and cement only and results in a weakened area. The size of aggregate shall depend upon the type of work and the reinforcement. And size should be less than the distance between two consecutive steel bars in RCC. The main characteristic of fine aggregate which affects the properties of concrete is the Crushing strength of Aggregate. The Crushing strength of Aggregate defines as the resistance of an aggregate to the compressive load. The Compressive strength of concrete is depending on the strength of aggregate[7].

The different sizes commonly known as 01,02, 03, and 04 are stockpiled separately. Size 02 means aggregates having a maximum aggregate size of 20mm, while 01, 03, 04 has a maximum aggregates size of 10, 30, 40 mm respectively. This method enables to classify aggregates based on their maximum aggregate size and enable engineers to suggest unique mix proportion to arrive at the required concrete quality production.

2.2.4. Admixture

An admixture is defined as a material other than water, aggregates, and cement that are used in concrete as an ingredient and added to the batch immediately before or during mixing. The major reasons for using admixtures are: to reduce the cost of concrete construction, to achieve certain properties in concrete more effectively than by other means, to maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions to overcome certain emergencies during concrete operations. Despite these considerations, it should be borne in mind that no admixture of any type or amount can be considered a substitute for good concreting practice. The effectiveness of an admixture depends upon factors such as type, brand, and amount of cementing materials; water content; aggregate shape, gradation, and proportions; mixing time; slump; and temperature of the concrete. The amount of admixture recommended by the manufacturer or the optimum amount determined by laboratory tests should be used. Some admixtures are; Plasticizers, Superplasticizers, Retarders and Retarding Plasticizers, Accelerators and Accelerating Plasticizers, Air-entraining Admixtures, Pozzolanic or Mineral Admixtures, Damp-proofing and Waterproofing Admixtures, Gas forming Admixtures, Air-detraining Admixtures and Workability Admixtures[14][6].

2.2.5. Water

Water is defined as “a liquid without color, smell or taste that falls as rain is in lakes, rivers, seas, and is used for drinking, washing, etc.”. It is a very slightly compressible liquid oxide of hydrogen, represented as H_2O, which appears bluish in thick layers. Water freezes at 0^0C and boils at 100^0C. Water exists in the form of solid as ice, in the form of liquid as water, or a gaseous form as vapor. Water is one component for making concrete and is involved in its whole life. It is used to mix and cure concrete where suitability should be considered.

The use of concrete as a material in construction is very old and to date, the most plastic material for construction works. Besides water, concrete is the most consumed substance with three tones used per person per year in the construction industry. Many factors 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. 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 the 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[5].

2.3. The Role of Water in Concrete

The quality of water in the mix plays a vital role in the strength of the concrete. Potable water can be used in concrete without any testing or qualification. The water of questionable suitability, including non-potable water or water from concrete production operations, can be used in concrete if it is qualified for use by the requirements stated[15].

Water is an important ingredient of concrete without which concrete cannot be manufactured. Water in the concrete making is used for mixing, washing aggregate, and curing. It is important to know that too much water reduces the strength of concrete and too little water reduces the workability of concrete[7].

The quality of the water is important because impurities in it may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface, and may also lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered. A clear distinction must be made between the effects of mixing water and the attack on hardened concrete by aggressive waters because some of the latter types may be harmless or even beneficial when used in a mixing[10].

Testing of water plays an important role in controlling the quality of cement concrete work. Systematic testing of the water helps to achieve higher efficiency of cement concrete and greater assurance of the performance regarding both strength and durability. Water is susceptible to being changed due to physical, chemical, or biological reactions which may take place at the time of sampling and analyzing. Hence it is necessary to test the water before being used for cement concrete production[16].

2.3.1. Water for Mixing

Water is an important ingredient of concrete. Part of mixing water is utilized in the hydration of cement and the balanced water is required for imparting workability to concrete. Thus the quantity and quality of water are required to be looked into very carefully. The strength and durability of concrete are reduced due to the presence of chemical impurities in water. Most of the specifications recommended the use of potable water for making concrete. A practical solution would be tested for a time of set and strength of concrete between the water under consideration and the water of proven quality [3].

Water approved for drinking is generally satisfactory for usage in concrete production, but there are exceptional cases, for instance, in some arid areas, where local drinking water is saline and may contain an excessive amount of chloride, an undesirable amount of alkali carbonates, and bicarbonates, which could contribute to the alkali-silica reaction. However, some water that is not for drinking may be fitted or suitable for concrete production. opined that water with a pH range of 6.5 to 8.5 is good for concreting [1].

The principal considerations on the quality of mixing water are related to performance in fresh as well as harden states. The quality of the water plays an important role in the preparation of concrete. Impurities in water may interfere with the setting of the cement and may adversely affect the strength and durability of the concrete also. The chemical constituents present in water may actively participate in the chemical reactions and thus affect the setting, hardening, and strength development of concrete. In addition to that, health issues related to the safe handling of such water must be considered. The suitability of water can be identified from past service records or tested to performance limits such as setting times and compressive strength and durability tests. Limits are specified for mixing water with their constituents such as total alkalis, chloride sulfate, etc. Biological treatment and pathogen reductions are also ensured safety in the handling of reclaimed water and saline water[16].

The construction industry appears to be responsible for the consumption of a huge amount of fresh water. Approximately 150 lit water is required for $1m^3$ of concrete without considering other applications of water in the concrete industry[17].

The mixing of water that is fit for drinking purposes is fit for concreting, but about 97 percent of water is held in the oceans, while only 3 percent is freshwater. In that the freshwater, only 1 percent is easily available as ground or surface water, the remains are stored in icecaps. Water is used for domestic and industrial purposes from surface water bodies and underground water surfaces. The concrete industry has a serious impact on the environment concerning the consumption of water. Therefore, need to find an alternative source of fresh water in the concrete industry. The ultimate and last option will be treating the wastewater and this treated wastewater is used for drinking purposes. So use this treated wastewater in the construction industry and save the freshwater[18].

2.3.2. Water for Curing

Curing is the name given to the process used for promoting the hydration of the cement. It controls temperature and moisture movement from and into the concrete. Curing allows continuous hydration and strength gain. Once curing stops strength gain of the concrete also stops. Proper moisture conditions are critical because the hydration of the cement virtually ceases. The rate and extent of moisture loss from concrete during cement hydration are controlled by curing. The hydration of cement takes time, days, and even weeks rather than hours. If the water applied for curing is insufficient, the hydration in the cement paste will not proceed and the resulting concrete may not possess the desired strength and impermeability. Additionally, durability problems may arise due to the entrance of deleterious agents caused by the continuous pore structure formed on the near surface. More overdue to early drying, micro-cracks, or shrinkage cracks would develop on the surface of the concrete[19].

Application of Unclean water for curing results in quality problems on the concrete. Suitable Water for making concrete should also be used for curing purposes. Waters containing impurities that leading to stains is intolerable. When concrete is subjected to prolonged wetting, even a very low concentration of iron and organic matter may cause staining

To obtain good quality concrete, the placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening. Curing is the name given to procedures used for promoting the hydration of cement, and thus, the development of strength of concrete, the curing procedures being control of the temperature and the moisture movement from and into the concrete. The latter affects not only strength but also durability[10].

The strength development and durability of concrete can be influenced by the quality of water used for curing the concrete. The quality of water used in curing concrete plays an avital role in the compressive strength of the concrete[20].

The purity of the water used for curing and the curing process: this curing process develops physical and chemical properties. Among other qualities are:- mechanical strength, low moisture permeability, and chemical and volumetric stability[2].

2.4. Source of Water

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. 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[21].

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

When considering water quality in concrete production, it is important to account for all sources of water in the mixture. By far, the greatest volume of mixing water in the concrete is from batch water which may be from either a municipal water supply, a municipal reclaimed water supply, site-sourced water, or water from concrete production operations. Municipal water supply systems get their water from a variety of locations including; aquifers, lakes and rivers, and the sea through desalination. The water is then, in most cases; purified, disinfected through chlorination, and sometimes fluoridated, before use as drinking water. Many large concrete paving projects and remote construction sites use site source water either from shallow wells, ponds, or rivers. These natural sources of water are typically not a concern. When they contain significant amounts of suspended particles such as silt and contain organic impurities and algae, additional testing is warranted[6].

2.5. Function of water in Concrete

The water serves the following purpose:

- Wet the surface of aggregates to develop adhesion because the cement pastes adhere quickly and satisfactorily to the wet surface of the aggregates than to a dry surface.
- To prepare a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position and
- Water is also needed for the hydration of the cementing materials to set and harden during the period of curing[22].

2.6. Tests on Concrete making water

The mean compressive strength at 7 days of the concrete or mortar specimens, prepared with the water, shall be at least 90 % of the mean compressive strength of corresponding specimens prepared with potable water. The ASTM C1602/C1602M requirement for the time of set, deviation from control, from 1:00minute, not more than for initial setting time and 1:30minute, not more than for final setting time. Whether or not staining will occur due to impurities in the curing water cannot be determined based on chemical analysis and should be checked by a performance test involving simulated wetting and evaporation [23].

2.7. Impure Water

A great number of impurities can be found in water and from these impurities, one that is mostly found and influence the quality of normal concrete are chlorides, sulfate, iron salts, inorganic salts mainly found in seawater, acid water, alkaline water, wash water, industrial wastewater, and organic impurities like Sugar, silt or suspended particles, oils, algae [6].

Impurities in water may interfere with the setting of the cement, adversely affect the strength of the concrete or cause staining of its surface, and also lead to corrosion of the reinforcement. The presence of chlorides in reinforced concrete can lead to steel corrosion and reduced concrete strength. Currently, there are no special tests developed to determine the suitability of mixing water except compressive tests. The strength of the concrete made with water in question should be compared with the strength of concrete made with water to known suitability [1].

ASTM C1602 allows the use of potable water without testing and includes methods for qualifying nonpotable sources of water with consideration of effects on setting time and strength. Testing frequencies are established to ensure continued monitoring of water quality.

2.7.1. Common Impurities

Some impurities can be found in different forms in water used for making concrete and the effects on the quality of normal concrete.

1) **Sulfate**

An excessive amount of sulfates in soil or water can attack and destroy concrete that is not properly designed. Sulfates (calcium sulfate, sodium sulfate, and magnesium sulfate) can attack concrete by reacting with hydrated compounds in the hardened cement paste. These reactions can induce sufficient pressure to disrupt the cement paste, disintegrating the concrete (loss of paste cohesion and strength). Sometimes the expansion of concrete may cause serious structural problems, such as the displacement of building walls due to horizontal thrust by an expanding slab[24].

A similar reaction takes place when hardened concrete is exposed to sulfates from external sources. Solid salts do not attack concrete but, when present in solution, they can react with sulfates of hydrated cement paste. The strength of the solution is expressed as a concentration, for instance, as the number of parts by mass of sulfur trioxide (SO), per million parts of water (ppm) that is, mg per liter[23].

2) **Chloride**

Total chloride or acid-soluble chloride in concrete depends on the chloride content in concrete mix ingredients. The precise amount of chloride that is contributed by each element of the concrete mix compositions is hard to be defined because the chloride contents in aggregate and in concrete mixture as a whole are not equally distributed. The total chloride by weight of cement contributed by all mix ingredients was measured experimentally based on different concentrations of chloride ions in mixing water which were 250 ppm, 750 ppm, and 1250 ppm[25].

Concern over a high chloride content in mixing water is chiefly due to the possible adverse effect of chloride ions on the corrosion of reinforcing steel or prestressing strands [26].

A high dissolved solids content of water is sometimes due to high content of sodium chloride or sodium sulfate. Both can be tolerated in rather quantities. The concentration of 20,000ppm of sodium chloride is generally tolerable in concrete that will be dry in service and has a low potential for corrosive reactions[6].

3) Salts

Natural ground waters rarely contain more than 20 ppm to 30 ppm of iron. Iron salts in concentration up to 40,000 ppm do not usually affect concrete strengths adversely. The potential for straining should be evaluated. Salts of manganese, tin, zinc, copper, and lead in mixing water can cause a significant reduction in strength. These, salts of zinc, copper, and lead are the most active. Generally, the concentration of these salts up to 500ppm can be tolerated in mixing water. Another salt that may be detrimental to concrete is sodium sulfide even the presence of 100ppm needs testing[26].

4) Alkali Carbonate and Bicarbonate

Carbonates and bicarbonates of sodium and potassium have different effects on the setting times of different types of cement. Sodium carbonate can cause very rapid setting, bicarbonates can either accelerate or retard the set. In large concentrations, these salts can materially reduce concrete strength. When the sum of the dissolved salts exceeds 1000 ppm[6].

5) Alkaline Waters

Potassium hydroxide in concentrations up to 1.2% by mass of cement has little effect on the concrete strength developed by some cement, but the same concentration, when used with other cement, may substantially reduce the 28-day strength. Waters with sodium hydroxide concentrations of 0.5% by mass of cement do not greatly affect concrete strength provided a quick set is not induced. Higher concentrations, however, may reduce concrete strength[6].

6) Silt or Suspended Particles

Higher amounts might not affect strength but may influence other properties of some concrete mixtures. Before use, muddy or cloudy water should be passed through settling basins or otherwise clarified to reduce the amount of silt and clay added to the mixture by way of the mixed water. About 2000 ppm of suspended clay or fine rock particles can be tolerated in mixing water. When cement fines are returned to the concrete in reused wash water, 50,000 ppm can be tolerated. Water containing less than 2000 parts per million (ppm) of total dissolved solids is generally satisfactory for use in concrete. Water containing more than 2000 ppm of dis- solved solids should be tested for its effect on strength and time of set[6].

7) Organic Impurities

the effect of organic substances on the setting time of portland cement or the ultimate strength of concrete is a problem of considerable complexity. Such substances, like surface loams, can be found in natural waters. Highly colored waters, waters with a noticeable odor, or those in which green or brown algae are visible should be regarded with suspicion and tested accordingly. Organic impurities are often of a humus nature containing tannates or tannic acid[6].

8) Algae

Algae in water lead to lower strengths either by influencing cement hydration or by causing a large amount of air to be entrained in the concrete. Water containing algae is unsuitable for concrete because the algae can cause an excessive reduction in strength. Algae may also be present on aggregates, in which case the bond between the aggregate and cement paste is reduced[6].

9) Other Common Salts

Magnesium sulfate and magnesium chloride can be present in high concentrations without harmful effects on strength. Good strengths have been obtained using water with concentrations of up to 40,000 ppm of magnesium chloride. Concentrations of magnesium sulfate should be less than 25,000 ppm. Carbonates of calcium and magnesium are not very soluble in water and are seldom found in sufficient concentration to affect the strength of concrete. Bicarbonates of calcium and magnesium are present in some municipal waters. Concentrations up to 400 ppm of bicarbonate in these forms are not considered harmful[26].

2.7.2. Acceptable Limit of Impurities

Acceptance criteria for water to be used in concrete are given in ASTM C1602/C1602M and [27] standard specifications for mixing water used in the production of hydraulic cement concrete.

Potable water is permitted to be used as mixing water in concrete without testing for conformance with the requirements. Mixing water that is wholly or partially composed of sources of water that are non-potable or from concrete production operations is permitted to be used in any proportions to the limits qualified to meet the requirements in table 2.1. The acceptable limit in the concrete depends primarily upon the type of structure and the environment to which it is exposed during its service life. Some impurities may have little effect on strength and setting time, yet adversely affect durability and other properties. Therefore, certain optional limits on chlorides, sulfates, alkalis, and solids in the mixing water may be set, or appropriate tests can be performed to determine the effect the impurity has on various properties as shown in Table 2.2[15].

Table 2.2: Optional chemical limits for combined mixing water [15].

Chemical or Type of construction	Maximum concentration, ppm*	Test method
Chloride, as Cl		ASTM C114
Pre-stressed concrete or concrete in bridge decks	500**	
Other reinforced concrete in moist environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms	1000**	
Sulfate, as SO_4	3000	ASTM C114
Alkalies, as (Na_2O +0.658 K_2O)	600	ASTM C114
Total solids by mass	50,000	ASTM C1603

*ppm is an abbreviation for parts per million.

**The requirements for concrete in ACI 318 shall govern when the manufacturer can demonstrate that these limits for mixing water can be exceeded. For conditions allowing the use of calcium chloride (CaCl2) accelerator as an admixture, the chloride limitation is permitted to be waived by the purchaser(ASTM C1602)

Water containing more than 2000 ppm of dissolved solids should be tested for its effect on strength and time of set as shown in Table 2.3[15].

Table 2.3: Concrete Performance Requirements for Mixing Water[15].

	Limits	Test Method
Compressive strength, a minimum percentage of control at 7 days	90	ASTM C31, C39
Time of set, deviation from control, hr: min	From 1:00 earlier to 1:30 later	ASTM C403

*Comparisons must be based on fixed proportions of a concrete mix design representative of questionable water supply and a control mix using100% potable water.

Curing water should generally satisfy the requirements for mixing water. As a rule, water that contains less than 1000 PPM and potable water that contains inorganic solids over 2000 PPM are specified for many projects[6].

Curing is essential if the concrete is to perform the intended function over the design life of the structure. The water used for this purpose should not be more than about 5°C cooler than the concrete Surface. Spraying warm concrete with cold water may give rise to „thermal shock" that may cause or contribute to cracking. Alternate wetting and drying of the concrete must also is avoided as this causes volume changes that may also contribute to surface crazing and cracking[28].

Water fit for making concrete can be used for curing. Waters containing impurities and leading to stains are objectionable. When concrete is subjected to prolonged wetting, even a very low concentration of organic matter may cause staining [29].

2.8. Effect of Impure Water

The impurities in water affect setting time, compressive strength, causes efflorescence, staining, corrosion of reinforcement, volume instability, and reduces durability. It is important to use water that has less amount of undesirable impurities in mixing water for concrete. Hence, it is important to use water that is suitable for mixing and curing concrete at a site because impurities can weaken the strength and decrease durability[6].

The relation between the different sources of water, depending on the constituents, and properties of concrete such as setting time of cement, compressive strength, split tensile strength, and flexural strength of concrete is presented in comparison with other studies.

2.8.1. Influence on Setting Time

The initial and final setting time of cement is utterly affected by the quality of water in mixing concrete. The high level of impurities in wastewater contributes to the higher setting time of the cement which in turn reduces the strength[30].

2.8.2. Influence on Workability of Concrete

A slump cone was filled in three layers of equal volume. Each layer was rodded 25 times with tamping. The cone was lifted upright after leveling the concrete at the top of the cone. The slump cone was then set next to the concrete and the difference in height between the slump cone and the original center of the specimen was recorded[31].

A slump test was conducted to determine the workability of concrete. the slump result obtained, the source of water (Borehole, Rain, Waste, Well) Water- cement ratio are 0.6, The slump test results ranged from 60 mm – 66 mm in mixing concrete doesn't affect the workability of concrete [30].

2.8.3. Influence on Compressive Strength

The compressive strength of concrete i.e. Ultimate strength of concrete is defined as the load to which causes failure of the specimen divided by the area of the cross-section in uniaxial compression, under a given rate of loading. The compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. [8].

Concrete is affected by the effluents that are expelled out from the sewerage works, sugar and the fertilizer industry, paint, gas works, and textile industries. Various tests have shown that the usage of water or structure that are constructed near to a water body with the excessive amount of salts (dissolved salts) tend to decrease the compressive strength of the concrete by an amount of 10 to 30 percent. This decrease is the strength of concrete compared with that obtained by the concrete using distilled water. The high content of chlorides in water tends to show surface efflorescence, dampness persistently and makes the reinforcement steel prone to corrosion[32].

The effect of different qualities of water on concrete compressive strength. The concrete mix of M20 grade with a water-cement ratio of 0.5 was investigated. Water samples, such as tap water, wastewater, well water, bore well water & mineral water (packed drinking water) were collected from various sources at a college campus and were used to cast 150mm concrete cubes. The cured cubes were crushed on 7 & 28 days for compressive strength estimation. The results showed that the compressive strength of the concrete cubes made with mineral water, tap water, well water, wastewater increased with days & not having much variation in their compressive strength[8].

The study was an attempt to study the possibility of recycling wastewater for concrete production/curing as well as determining the influence of wastewater on the compressive strength of concrete. Waste-water samples from four different sources/effluents; abattoir (A), vegetable-processing (B), industrial (C), and domestic (D) were collected and tested/analyzed in terms of their physicochemical properties. 'pure' water (E) was also collected from a water treatment plant to serve as a control in the experiment. The five water samples (A - E) were used in the mixing/production and curing of concrete cubes. Using 150 x 150 mm molds, fifteen concrete cubes were cast (three from each water sample) and cured for 28 days each. The cubes were subjected to crushing and the loads obtained were used in calculating their compressive strength. Results show values of 13.6 N/mm^2 for concrete A; 19.33 N/mm^2 for B; 24.53 N/mm^2 for C; 15.73 N/mm^2 for D and 26.67 N/mm^2 for E. Comparison of the results shows closeness for samples C and E. This is probably explained by the fact that the industrial effluent was treated to a large extent before disposal[33].

Compressive strength of concrete by using treated domestic wastewater as mixing and curing of concrete. Average compressive strength results of M20 grade concrete cast by using Tap water as mixing and curing water for Mix M1 & treated domestic wastewater as mixing and curing water for Mix M2. Discussion of results covers, M20 grade concrete at the age of 7days the average compressive strength for all the 2 mixes is nearly the same. At the age of 14 days marginal increase in compressive strength is observed in the case of mix M1 but in the case of mix M2 compressive strength remains the same as that of 7 days and at 28 days curing age decrease in compressive strength was observed. This decrease in compressive strength may be due to the use of treated domestic wastewater for mixing and curing[34].

2.8.4. Influence on Split Tensile Strength

The splitting test, a concrete cylinder (or, less commonly, cube) of the type used in compressive strength testing, is placed, with its axis horizontal, between platens of a testing machine, and the load is increased until failure takes place by splitting in the plane containing the vertical diameter of the specimen [23].

According to researchers[4], concluded the following results, Potable water suits the requirements of water to be used for construction activity increases the Compressive, Flexural, and Split tensile strength of concrete compared to other sources of water. It is observed that there is an increase of 14.89 % in the Split tensile strength of potable water concrete when compared to concrete prepared with sewage water.

2.8.5. Influence on Flexure Strength

In the flexure test, the theoretical maximum tensile stress reached in the bottom fiber of a test beam is known as the modulus of rupture, which is relevant to the design of highway and airfield pavements. The value of the modulus of rupture depends on the dimensions of the beam and, above all, on the arrangement of loading. The preferred size of the beam is 150 x 150 x 750mm (6 x 6 x 30 in.) but, when the maximum size of aggregate is less than 25 mm (1 in.), 100 x 100 x 500 mm (4 x 4 x 20 in.) beams may be used [23].

According to researchers[4], concluded the following results, It is observed that there is an increase of 11.12% in Flexural strength of potable water concrete when compared to concrete prepared with the sewage water.

CHAPTER THREE

MATERIALS AND RESEARCH METHODOLOGY

3.1. Study Area

The study area for assessing mixing and curing water sources applicable for concrete construction works at Jimma Institute of Technology Laboratory room and site observation at building construction sites found in Jimma Town. Which is located 335 km by road southwest of Addis Ababa. Its geographical coordinates are approximately $7^0$41'N latitude and 36^0 50'E longitude. The town is found in an area of average altitude, of about 5400ft (1780 m) above sea level. It is a special zone of the Oromia Region and is surrounded by Jimma Zone

3.2. Research Design

In this research work, the experimental research type with a comparative approach was used. The proportion of all constituents (amount of aggregates, amount of cement, and amount of water) was kept constant in all the mixes. The right combination of cement, fine aggregate, coarse aggregate, and water for C-25 grade concrete was arrived at using the ACI mix design method. Finally, different experiments were carried out on the properties of concrete with various mixing and curing water. The sources of mixing and curing water were variable in the concrete mixes. Experimental results of fresh and hardened concrete properties at different mixing and curing water (river water, deep well water, rainwater, and potable water) were compared to reference concrete specimens (Control potable water). A total of 180 concrete samples were cast and tested on the 7^{th} and 28^{th} days curing for compressive strength, splitting tensile strength, and flexural strength.

3.3. Study Variables

3.3.1. Dependent Variables

- Chemical properties of water
- Setting time of cement
- Workability
- Compressive strength
- Split tensile strength
- Flexural strength

In this research, the following parameters are kept constant

- Properties of concrete ingredients except water
- Water-cement ratio (w/c)

3.3.2. Independent Variables

- Sources of water for mixing of concrete
- Sources of water for curing of concrete

3.4. Sources of Data

The sources of data for this study were collected from both primary and secondary data sources to get precise and accurate information that makes the final findings more reliable.

3.4.1. Primary Data Sources

The primary data for this research were the results obtained from experimental (laboratory experiment) investigation. These experimental were include fresh and hardened properties of concrete using a different source of water for mixing and curing.

3.4.2. Secondary Data Sources

The secondary data for this research were obtained from the works of literature, which are related to concrete mixing water, curing water, and other related books, published or unpublished concrete-related data, and standard documents to support the research.

3.5.Population and Sampling Method

3.5.1. Study Population

The total number of populations considered in the study was the number of beams, cubes, and cylinders used for experiment work with a different source of mixing and curing water. the sampling procedure was taken according to ASTM, and related standards.

3.5.2. Sample Size

The sampling size of this research was taken from different sources of water using for concrete mixing and curing. For concrete experimental tests, the samples were based on the types of test requirements available and standards. A total number of 60 concrete cubic specimens of standard size 150mm using four sources of water were cast and tested for compressive strength at the ages of 7 and 28 days used four sources of water curing, 60 concrete cylindrical specimens of standard size 100 mm diameter and 200 mm length were tested for splitting tensile strength at the age of 7 and 28 days, and 60 concrete flexural specimens of standard size (100×100×500) were tested using the identified sources of water and 7 and 28 curing age.

Table 3.1: Sample size for mixing and curing water

No	Mixing water	Curing water	Compressive test		Split tensile test		Flexural test	
			7 day	28 day	7 day	28 day	7 day	28 day
1	Potable	Potable Control	3	3	3	3	3	3
		Rain	3	3	3	3	3	3
		Ground	3	3	3	3	3	3
		River	3	3	3	3	3	3
2	Rain water	Potable	3	3	3	3	3	3
		Rain water	3	3	3	3	3	3
3	Ground water	Potable	3	3	3	3	3	3
		Ground	3	3	3	3	3	3
4	River water	Potable	3	3	3	3	3	3
		River water	3	3	3	3	3	3
5	Total		30	30	30	30	30	30
Total 180 sample								

3.6. Data Collection Procedure

It is necessary to sort data into a different group to make it suitable for the comparison of results. All specimens could be coded before starting experimentation and a quality control check is mandatory for completeness and consistency of the data. A literature search involved a thorough review of current practices and previous research in the area of this study. the data collect first at Jimma Town which source of water is more available in the construction industry, which source of water is more used in concrete mixing and curing purposes, and concrete mixing material this means which type of cement, sand, and aggregate more used. Second, literature searches with published and unpublished related data.

Quantitative data collection from laboratory property of concrete strength test results. For the properties of compressive strength, split tensile and flexural strength tests are Carrie out and the data could be collected as follows by using data collection format as shown in Table 3.2.

Table 3.2: Data collection format

No	Dimensions			Area (mm^2)	Failure load (KN)	Compressive strength (MPa)
	L	W	H			
1						
2						
3						

Figure 3.1: Collecting different water sources

3.7. Data Presentation and Analysis

3.7.1. Data Presentation

In this study, the data presented used tables, graphs, and charts. These tables, graphs, and charts were containing a different source of water and concrete material for each alternative were presented. Tables, graphs, and charts were used to determine the data collected from the laboratory test.

3.7.2. Data Analysis

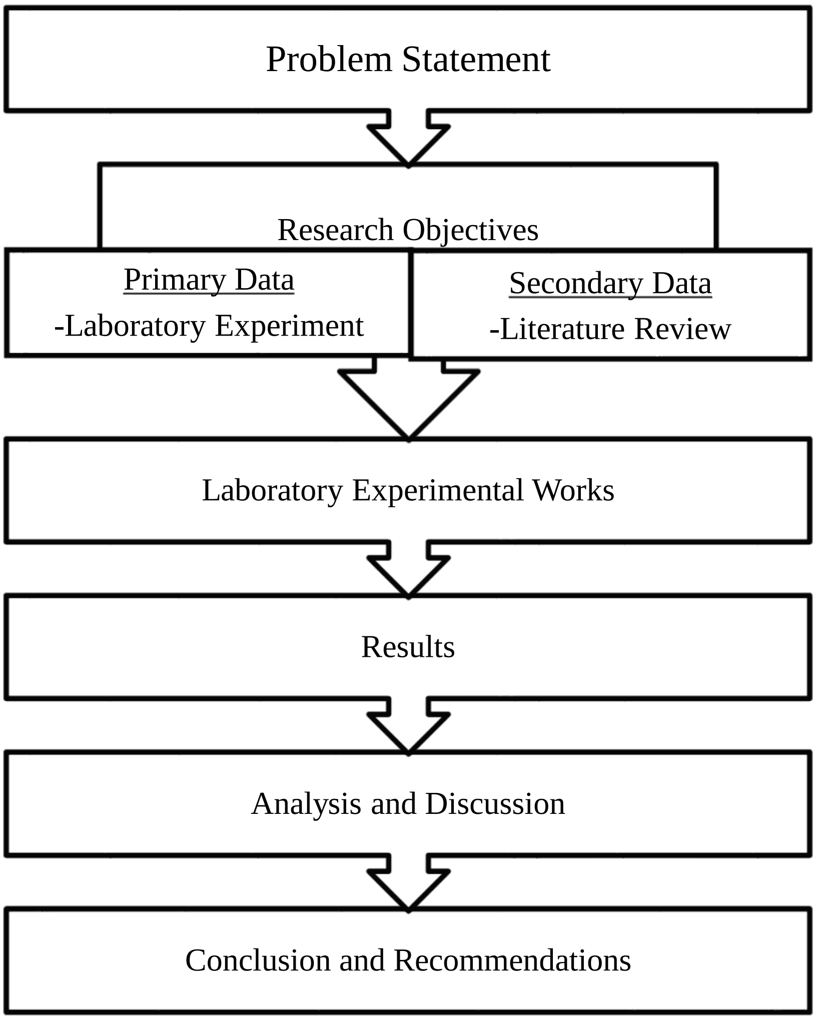


Figure 3.2: Flow chart of data analysis method

3.8. Experimental Procedure

The study methodology leads to accomplishing the research objectives. The first activity in this research field observations and reviewed literature related to the research from different sources like - textbooks, research papers, journals, magazines, the internet, etc. Then, laboratory experiments were carried out. So, to obtain the final results, first concrete making materials preparation and testing were performed. Then, based on the tested results concrete making material proportioning has been executed and mix-design is prepared for C-25 Concrete grade. Concrete sample preparations are taken in similar characteristics. Then, the prepared fresh concrete samples were tested by used a different source of water, and concrete cubes are cast to identify the effect of water source on compressive strength, split tensile strength, and flexural strength of concrete with used a different source of water curing check at the age of 7 and 28days. the results were obtained from the experiment are discussed and presented in Tables, charts, and graphs.

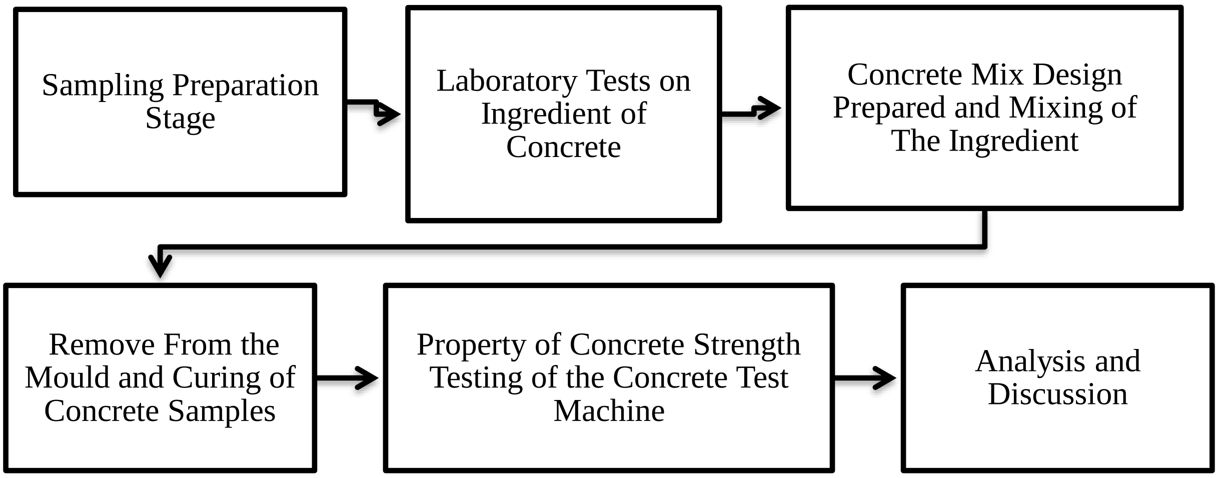


Figure 3.3: Flow chart of laboratory experimental works procedure

3.9. Materials Used

The feature of various materials used in the experimental investigations is as the following. The detail of material properties is summarized in Appendix 1.

3.9.1. Cement

The cement type used for the study was Portland pozzolana cement (PPC) with a grade of 32.5R and manufactured by the Dangote cement factory the physical properties of cement as shown in Table 3.3. The analysis of the initial and final setting time of cement used as per [35] and the cement test procedures used[36].

Table 3.3: Physical properties of PPC cement

Physical Properties of PPC Cement		Average value	Recommended value as per[36] .
Specific gravity		2.9	-
Residue(%) on 75 µm		4.82	-
Consistency		33%	26%-33%
Setting Time (minutes)	Initial	170	Not less than 45minutes
	Final	297	Not more than 10 hours
Compressive Strength(MPa)	7 day	18.52	-
	28 day	29.5	-

3.9.2. Coarse Aggregates

The coarse aggregates (Figure 3.5) with a nominal maximum size of 20 mm. In figure 3.5(a) shows coarse aggregate was air-dried before batching the concrete mix were used and figure 3.5(b) shows 10kg coarse aggregate weigh for sieve analysis. The physical properties of coarse aggregate used are summarized in Table 3.4.

(a) (b) (c)

Figure 3. 4: (a) Air drying (b)Weigh aggregate and (c) Sieve analysis of coarse aggregate

Table 3.4: Physical properties of coarse aggregate used

No	Properties	Coarse Aggregate	Recommended value per[37].
1	Fineness Modulus (FM)	3.9	-
2	Nominal Maximum size of fine aggregate (mm)	20	9.5 to 37.5
3	Moisture content, (%)	0.75	0 to 2
4	Specific gravity, (SSD basis)	2.65	2.3 to 2.9
5	Unit weight, (kg/m^3)	1717	1280 to 1920
6	Water absorption capacity, (%)	0.6	0.4 to 4

3.9.3. Sand

The sand used natural river sand (Chewaka sand) with a nominal maximum size of 4.75 mm. Figure 3.5(a) shows fine aggregate was air-dried before batching the concrete mix. The physical properties of the fine aggregate used are summarized in Table 3.4. In Figure 3.6b 2kg sand sample weight for sieve analysis. It was carried out on representative samples per ASTM

[38]. The analysis of water absorption and bulk specific gravity, saturated surface dry(SSD) used as per ASTM [39].

Table 3.5: Physical properties of fine aggregate used

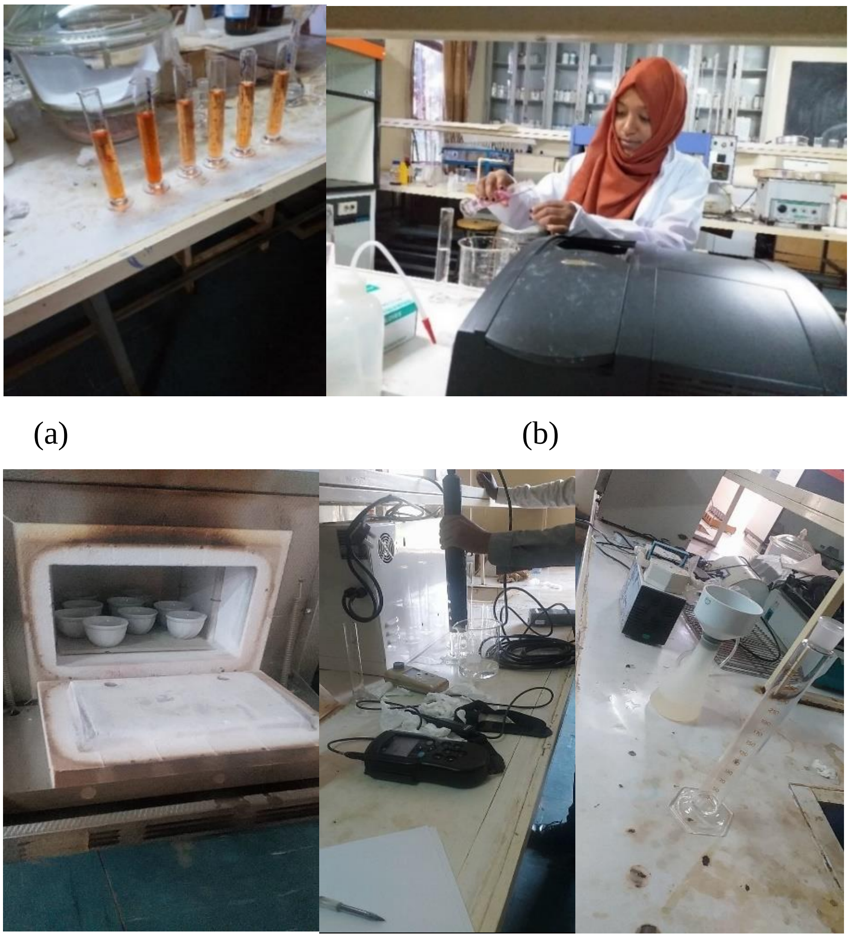
No	Properties	Fine Aggregate	Recommended value as per[37]
1	Fineness Modulus (FM)	2.3	2.0 to 3.3
2	Nominal Maximum size of fine aggregate, (mm)	4.75	4.75mm to 150µm
3	Silt content, (%)	3.5	Not exceeds 6
4	Moisture content, (%)	0.6	0 to 10
5	Specific gravity, (SSD basis)	2.44	2.3 to 2.9
6	Unit weight, (kg/m^3)	1604	-
7	Water absorption capacity,(%)	1.2	0.4 to 4

(a) (b) (c)

Figure 3.5: (a) Air drying sand (b) 2kg weigh sand and (c) Sieve analysis of sand.

3.9.4. Water

Mixing and curing water was taken from four different water sources. Tap(potable) water taken from Jimma Institute of Technology construction laboratory room, River water taken from Aweitu river, which is from bisects the center of the city and kito which flows at the western end, rainwater from Jimma town, and deep well water taken from Biriy deep well water, which around Jimma Institute of Technology. A water test was carried out at Jimma university's main campus in the environmental laboratory room. Water parameters were studied in this study: - Temp(0^c), PH, Salinity(mg/l), TDS (mg/l), TSS (mg/l), Alkalinity(mg/l), Sulfate (mg/l), Turbidity(NTU), Hardness(mg/l), Chloride(mg/l), Iron, Manganese, Nitrate, e. conductivity(ns/cm).



(a) (b)

(c) (d) (e)

Figure 3.6: (a) Iron, (b) Manganese, (c) Sulfate (d) pH, Tc, and Salinity (e) TDS test of water sources

3.10. Mix Designing and Proportioning

Construction materials such as cement, sand, and coarse aggregate for concrete specimens were prepared. The ratio of proportions for Class C-25 was 1:1.8:3.1, Mix design for A specified compressive strength of 25 MPa is expected to be proportioned. a slump between 20-100 mm and nominal maximum aggregate size of 20mm was made using the ACI 211.1 mix design table procedure. The detailed mix design procedures for C-25 grade concrete as per ACI Method are discussed in appendix 2. For all the mixes, a mixing Cement: a fine aggregate: the coarse aggregate ratio of 1:1.8:3.1 was used, the total concrete mixing ingredients amount from Table 3.6.

Table 3.6: Mix design material used in laboratory

No	Source of water	Ingredients	Quantity (kg/m^3)	Ratio	Volume(m^3)
1	Potable water	Cement	96.5	1	0.394
		Sand	173.7	1.8	
		Gravel	299.1	3.1	
		Water	51.14	0.53	
2	River water	Cement	48.25	1	0.197
		Sand	86.85	1.8	
		Gravel	149.56	3.1	
		Water	25.57	0.53	
3	Deep well water	Cement	48.25	1	0.197
		Sand	86.85	1.8	
		Gravel	149.56	3.1	
		Water	25.57	0.53	
4	Rainwater	Cement	48.25	1	0.197
		Sand	86.85	1.8	
		Gravel	149.56	3.1	
		Water	25.57	0.53	

3.11. Mixing, Casting and Curing of Concrete

3.11.1 Mixing

Concrete materials were prepared and mixed with the identified water sources. Figure 3.8 shows the mixing of concrete materials. All ingredients of concrete were measured by weighing, immediately after batching of ingredients to started mixing. Before adding ingredients into the mixer, the interior part of the mixer was cleaned and moistened with some water. Before starting rotation of the mixer, the coarse aggregate and some of the mixing water were added. After starting the mixer, the coarse aggregate, fine aggregate, cement, and water were added. After all, ingredients are in the mixer, the concrete was mixed for 3 minutes followed by a 2minute rest, followed by a 2-minute final mixing. To eliminate segregation, the mixed concrete was deposited in the clean, damp mixing pan and remixed bay shovel until it appears to be uniform. The ingredients were mixed for a total of six minutes[40].

Figure 3.7: Mixing of concrete ingredients

Table 3. 7: Source of water used in laboratory maxing concrete ingredients

No	Source of water	Total No of specimens	For compressive test	For tensile test	For flexural test
1	Control(potable water)	72	24	24	24
2	Rainwater	36	12	12	12
3	Deep well water	36	12	12	12
4	River water	36	12	12	12

3.11.2 Casting

Before casting, cubical, flexural, and cylindrical molds were prepared by cleaning and oiling to easily demolding the concrete specimens shown in Figure 3.9(a). The concrete mixtures were cast in molds in three layers and consolidated using a tamping rod. Each layer was tamped 25 times with a standard 16mmdiameter and a 600 mm long steel rod is shown in Figure 3.9(b). After each layer was rodded, the outsides of the molds were lightly tapped 10 times with the mallet to close any holes left by rodding and to release any larger air bubbles that may have been trapped shown in Figure 3.9(c). In all, the test samples included 150mm concrete cubes, 100×100×500mm concrete flexural, and 100×200mm concrete cylindrical specimens prepared for the compressive, flexural, and splitting strength tests respectively. All the experiments were done used different sources of water. The concrete sample was removed from their mold after 24 hours. A total of 180 specimens were prepared for the tests 7 and 28 days.

(a) (b) (c)

Figure 3.8: (a) Cleaning the mold (b) Compacting and (c) Leveling the top surface of cubes

3.11.3 Curing

After the mixing operation had been completed a total of 180 specimens in which 60 cube specimens for a compression test, 60 beam specimens for flexure test, and 60 cylinder specimens for split tensile tests were prepared, and curing tanks which had different water sources, for 72 specimens were curing by potable water show in the Figure 3.10(d), 36 specimens were curing by rainwater show in the Figure 3.10(c), 36 specimens were curing by deep well water show in the Figure 3.10(b), and 36 specimens were curing by river water show in the Figure 3.10(a) for 7 and 28-day tests.

Figure 3.9: Curing of sample

3.12. Properties of Concrete Test

3.12.1. Workability

A slump test was adopted to determine the workability of fresh concrete as per[41]

Slump test procedures

- Place the cone on a smooth, flat, and clean surface
- To fill the mold with 3 layers of concrete approximately the same for each thickness.
- Compact of each layer by tamping 25 times with the standard steel rod shown in Figure 3.11(a)
- Level the top surface of the concrete with a trowel
- Lift the cone slowly vertically to allow concrete to subside
- Measure the difference in level between the height of the mold and that of the highest point of the subsided concrete this difference in height in mm was taken as slump of the concrete show in Figure 3.11(b).

(a) (b)

Figure 3.10: (a) Compact and (b) Measuring the slump height

3.12.2. Setting Time of Cement Paste

Initial and final setting times were determined by the Vicat apparatus, which measures the resistance of cement paste of a standard consistency to the penetration of a needle. This test was performed as per ASTM [35]. This study setting time was tested both manually and automatically show in Figure 3.12(a).

(a) (b)

Figure 3.11: (a) Setting times tested both manually and automatic and (b) Penetration depth measurement

3.12.3. Compressive Strength

Compressive strength test was carried out per ASTM Standard[42] 150mm cubes were used throughout the test program.it is the most common test conducted on hardened concrete. The cubic specimens were tested after the curing age of 7 and 28 days using an Automatic compression testing machine which has a capacity of 2000KN. Three samples were tested for each age date, for each curing condition and the average result was reported, those procedures shown in Figure 3.13.

(a) (b) (c) (d)

Figure 3.12: (a)After curing (b) Weighting the cube (c) Cube test and (d) Result display

The compressive strength is given by

$$\mathbf{f_c} = \frac{\mathbf{P}}{\mathbf{bd}} = \frac{\mathbf{P}}{\mathbf{150 \times 150}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

where $\mathbf{f_c}$ = Compressive stress

P = Failure load

B = d = Width

3.12.4.Splitting Tensile Strength

Splitting tensile strength was carried on the cylindrical specimens with the size of 100mm diameter and length 200mm after the curing age 7 and 28 days. The standard cylindrical concrete sample was placed horizontally between the applied loading surfaces of the compression testing machine. Strips of poly wood were placed between the specimen and the loading surfaces to ensure the uniform distribution of the applied load show in Figure 3.14.

$$f_t = \frac{\mathbf{2P}}{\boldsymbol{\pi}\mathbf{DL}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

where f_t = Tensile stress

D = Diameter of cylinder

L = Length of cylinder

(a) (b)

Figure 3.13: (a) weighting the cylinder sample and (b) tensile test on the compressive machine

3.12.5. Flexural Strength

Flexural strength is the measure of an unreinforced concrete beam or slab to resist failure in bending**.** In this study beams of 100×100×500 mm were used for the flexural strength test. the specimens were placed on the flexural testing machine support by measuring d distance of 10cm from the two edges of the beam. And then, the loads were applied to the beam at two points. These two points loads have a distance of 10cm between them and it was applied on the specimens gradually until the specimens were crushed as seen in Figure 3.15. then by taking the failure load the flexural stress can be calculated by using the two-point load method or modules of rupture formula.

Two-point load formula

$$\text{Flexural stress} = \frac{\boldsymbol{Mc}}{\boldsymbol{I}} \quad \ldots\ldots 3.3$$

Where $M = \frac{pl}{3}$ but $p = \frac{P}{2}$,

$I = \frac{bd^3}{12}$, $c = \frac{d}{2}$

P = Total applied load on the beam

$$\text{Modulus of rapture formula, } f_r = \frac{\boldsymbol{pl}}{\boldsymbol{bd^2}} \quad \ldots\ldots 3.4$$

(a) (b)

Figure 3.14: (a) Measuring flexural support distance and (b) Flexure test

3.12.6. Compressive Stress-Strain Relation for Different Sources of Water

The stress-strain curves are drawn by selecting a better graph from potable water, river water, deep well water, and rainwater used both mixing and curing of concretes comparison with control (potable water). The strain at each point of compressive stress was determined by using a displacement gauge which was attached to the compressive strength test machine before applying the load to the cube specimen. The deformation (Δh) of specimens was recorded from the gauge for each load increment and the strain was calculated by dividing deformation by the height of the cube specimen (h). the stress was calculated using the load which was taken with the respective gauge reading change in the compressive testing machine during the test undergo. The stress is calculated by

$$\boldsymbol{\sigma} = \frac{\mathbf{P}}{\mathbf{A}} \qquad \text{……3.5}$$

Where σ = stress with respective load

P = Applied load

A = Area of a cube

The strain was also calculated for the change in height of the cube obtained from the gauge reading during the load was applied to the cube divided by the original height of the sample.

$$\boldsymbol{\varepsilon} = \frac{\Delta \boldsymbol{h}}{\boldsymbol{h}} \qquad \text{……3.6}$$

Where ε = Strain for each change in length

Δh = change in height of the cube

h = original height of the cube

CHAPTER FOUR

RESULTS AND DISCUSSIONS

The objective of this study was to investigate the mechanical properties of concrete using potable water, river water, deep well water, and rainwater for mixing and curing concrete. The experimental program was planned to investigate the effect of water sources for mixing and curing on the strength of concrete at 7 and 28 days. This study includes the determination of the chemical properties of water, setting time of cement, workability of concrete, compressive strength, splitting tensile strength, and flexural strength of concrete the total of 180 specimens were made and cured by using potable water, river water, deep well water, and rainwater.

4.1. Water Test Result

Samples taken from four water sources were collected then tested for impurities. The samples from potable water, river water, rainwater, and deep well water, and test result as shown in Table 4.1. The water test conducted on the constituents portrays a result that is within the limits specified [15].

The results of the four water samples investigated showed that the pH values ranged from 6.4-6.75 the values fell within the range permitted by WHO(6.5-8.5) except for rainwater which had a pH of 6.4. All the identify water sources parameters were within the permissible limit of the WHO standard except for iron and manganese.

The comparison of each water source from Table 4.1 results indicated that:-

- The salinity, TDS, and e.conductivity contents of rainwater and deep well water are more compared with potable and river water.
- In rainwater, the sulfate and turbidity values are more compared with the other identified water sources.
- The alkalinity and pH value of rainwater is less compared with the other identified water sources.
- Deep well water has more amount chloride value compare to others.
- River water more amount of pH value compared with the other identified water sources.

Table 4.1: Chemical examination of water samples

Water parameters	Water sources				Requirement value	
	Potable water	Deep well water	Rain Water	River water	As per [15]	As per[43]
Temp(0^c)	24.5	24.7	24.4	24.8		NA
pH	6.6	6.5	6.4	6.75		6.5-8.5
Salinity(mg/l)	50	100	90	60		NA
TDS(mg/l)	114	240	150	116		500
TSS(mg/l)	17.2	16.8	17.2	36.4		NA
Alkalinity(mg/l)	58	32	30	62	600	200
Sulfate (mg/l)	3	6	15	7	3000	100
Turbidity(NTU)	4.73	3.83	10.42	4.48		5
Hardness(mg/l)	50	82	40	42		150
Chloride(mg/l)	2.5	27.5	8.75	3.75		250
Iron	0.9	0.95	0.85	2.75		0.3
Manganese	0.2	0.17	0.05	1.6		0.2
Nitrate	2.485	1.232	1.214	0.76		50

4.2. Test Results of Setting Time of Cement

This study used Dangote PPC (32.5R) Cement. The initial and final setting time is recorded by preparing cement paste using the identified water source and tested by used the Vicat apparatus the results as shown in Table: 4.2 and the detailed setting time results are listed in Appendix 1.

Table 4.2: Result of setting time of cement

No	Mixing Water Source	Consistency (%)	Initial Setting Time(min)	Final Setting Time(min)
1	River Water	33	168	295
2	Potable Water	33	170	297
3	Deep Well Water	33	183	313
4	Rain Water	33	193	325

The result shows that the consistency of all water sources was the same value of 33% and the initial and final setting times made with rainwater was a high value compared with the other identified water sources. The observed differences in the initial setting time compared with potable water were approximately -2 min river water,+13 min for deep well water, and +23 min for rainwater.

The observed differences in the final setting time compared with potable water were about -2 min river water, +16 min for deep well water, and +28 min for rainwater.

The setting time of deep well water and rainwater is more than the potable water and river water. The case may potable water and river water contained more alkalinity and pH values compared with deep well and rainwater. The results indicate the setting time of cement increase with the alkalinity decrease. Alkalinity is acceleration or retardation of the setting time of cement.

As Per [15] specified a questionable water source should not have more than 60minutes of initial setting time and 90 minutes of final setting time compared with the control (potable water). In this study, the difference of setting time from the control is within the specified limit as shown in Table 4.3.

Table 4.3: Deviation of setting time from the control

Test Item	Water Source Deviation From The Potable Water				ASTM C1602
	Potable Water	River Water	Deep Well Water	Rain Water	
Initial Setting Time(Min)	0	2	13	23	< 60
Final Setting Time(Min)	0	2	16	28	< 90

4.3. Test Results of Concrete Workability

The slump test results ranged from 10-25mm with the tap water having more value of 25mm, followed by rain and river water have 15mm and 13mm slump value respectively, the deep well water having a 10mm slump value. All the values fell within class 0-25mm slump value.

Table 4.4: Slump test result

Water Sample	Slump(mm)	Water- Cement Ratio
Tap water	25	0.53
Rainwater	15	0.53
River water	13	0.53
Deep well water	10	0.53

4.4. Test Results of Concrete Compressive Strength

A different source of water used both mixing and curing of concrete. A total of 60 specimens was used for cube tests on 7 and 28 days. The compressive strength test results of cubes made with potable water, river water, deep well water, and rainwater sources. The compressive strength test results on the 7 and 28 days showed in Table 4.5 concrete cubes cast using potable water attained more strength value of 18.52 MPa and 29.5MPa both 7 and 28 days respectively followed by river water which has 28.8 MPa at 28 days, the deep well water and rainwater 26.86 and 24.69 MPa at 28 days curing by potable water.

Table 4.5: Concrete compressive strength test results for the identified water

No	Mixing water	Curing water	Code	7 days Avg load (KN)	7 days Avg stress (MPa)	28 days Avg load (KN)	28 days Avg stress (MPa)
1	Potable water	Potable (Control)	C	416.6	18.52	663.7	29.5
		River	C1	364.98	16.22	609.4	27.09
		Deep well	C2	402.15	17.94	587.7	26.12
		Rainwater	C3	391.22	17.39	578.63	25.72
2	River water	Potable	M1	405.8	18.03	648.42	28.8
		Riverwater	S1	361.05	16.05	598.4	26.6
3	Deep well water	Potable	M2	414.6	18.43	604.39	26.86
		Deep well	S2	401.9	17.86	578.093	25.7
4	Rain water	Potable	M3	392.42	17.45	555.69	24.69
		Rain water	S3	369.54	16.43	516.73	22.97

The compressive strength test results of cubes made for the different water source deviations on the 7 and 28 days were divided into three-part.

- ✓ The effect of mixing water on concrete compressive strength. This means different sources of water such as potable water, river water, deep well water, and rainwater used for mixing and only potable water used for curing.
- ✓ The effect of curing water on the compressive strength. This means only potable water is used for mixing and different source of water (Potable water, River water, Deep Well water, and Rainwater) are used for curing.
- ✓ The effect of the same source of water used for mixing and curing on the compressive strength of concrete. This means concrete mixing and curing by potable water, river water, deep well water, and rainwater.

4.4.1. The Effect of Mixing Water on the Concrete Compressive Strength.

Table 4.6: 7- day compressive strength test results using identified water for mixing concrete

No	Mixing water	Curing water	Code	7 days Avg stress (MPa)	Control (MPa)	Satisfied From control(%)	ASTM minimum %of control at 7 Days
1	Potable(control)	Potable	C	18.52	18.52	100	≥ 90 of the potable water
2	River water	Potable	M1	18.03	18.52	97.35	
3	Deep well	Potable	M2	18.43	18.52	99.51	
4	Rainwater	Potable	M3	17.45	18.52	94.22	

The compressive strength test result of cubes mixed by different water sources shows deviation on the 7th day and as summarized in Table 4.6. The deviation of average compressive strength test results at 7th day keeping the potable water as a control, all are achieved 90% of the control. As mixing part river water achieved 97.35% of the control, deep well water achieved 99.51% of the control and rainwater achieved 94.22% of the control. The results show that concrete made with different sources of water such as river water, deep well water, and rainwater have on the 7thday compressive strength satisfied 90% of the control.

The compressive strength test result of cubes mixing with different water sources shows deviation on the 28th day and as summarized in Table 4.7. The deviation of average compressive strength test results at 28th day keeping the potable water as a control, all are achieved 90% of the control but rainwater under 90% of the control.

Table 4.7: 28-day compressive strength test results using identified water for mixing concrete.

No	Mixing water	Curing water	Code	28days Avg stress (MPa)	Control (MPa)	Satisfied from control(%)
1	Potable(control)	Potable	C	29.5	29.5	100
2	River water	Potable	M1	28.8	29.5	97.63
3	Deep well	Potable	M2	26.86	29.5	91.05
4	Rain water	Potable	M3	24.69	29.5	83.69

On the 28th day mixing part river water achieved 97.63% of the control, deep well water achieved 91.05% of the control and rainwater is 83.69 % of the control. On the 28th-day rainwater did not satisfy the requirement. Rainwater on the 7th-day achieved 94.22% of the control but on the 28th day 83.69% of the control or under the minimum compressive strength of C-25 concrete (25MPa). Concrete mixed with rainwater was decreased the compressive strength as the day of curing increased compared with the satisfied value from control. Because from Table 4.1 water tested results indicated the rainwater content more amount of sulfate, and turbidity compared to the other identified water sources in those impurities that may affect the concrete compressive strength, and also the pH value less than 6.5 or under the WHO requirement.

Overall potable water, river water, and deep well water show better compressive strength compared with rainwater.

4.4.2. The Effect of Curing Water Sources on the Concrete Compressive Strength

The compressive strength test result of cubes curing with different water sources shows deviation on the 7th day and as summarized in Table 4.8. The deviation of average compressive strength test results at 7th day keeping the potable water as a control, all are achieved 90% of the control except river water was 87.58%of the control. From curing part river water was 87.58% of the control, deep well water achieved 96.86% of the control and rainwater achieved 93.9% of the control.

Table 4.8: 7th-day compressive strength test results of concrete using identified water for curing

No	Mixing water	Curing water	Code	7 days Avg stress (MPa)	Control (MPa)	Satisfied From control(%)	ASTM minimum %of control at 7 Days
1	Potable (control)	Potable	C	18.52	18.52	100	≥ 90 of the potable water
2	Potable	River water	C1	16.22	18.52	87.58	
3	Potable	Deep well	C2	17.94	18.52	96.86	
4	Potable	Rain water	C3	17.39	18.52	93.9	

The compressive strength test result of cubes curing by different water source show deviation on the 28th day and as summarized in Table 4.9. The deviation of average compressive strength test results at 28th day keeping the potable water as a control, river water 8.17% less than the control, deep well water 12% less than the control, and rainwater 13.9% less than the control.

Table 4.9: 28th-day Compressive strength test results of concrete using identified water for curing

No	Mixing water	Curing water	Code	28 days Avg stress (MPa)	Control (MPa)	Satisfied from control(%)
1	Potable(control)	Potable	C	29.5	29.5	100
2	Potable	River water	C1	27.09	29.5	91.83
3	Potable	Deep well	C2	26.12	29.5	88
4	Potable	Rain water	C3	25.4	29.5	86.1

All are achieved the minimum requirement of C-25 grade of concrete however rainwater and deep well water on the 7th day achieved 93.9% and 96.86 of the control but on the 28th day, less satisfied values compared with the 7 days, which have 86.1% and 88% of the control respectively. However river water on the 28th day more satisfied value compared with the 7th day, 91.83% of control on the 28 days and 87.58% of control on the 7 days. Concrete curing with rainwater and deep well water were decreased the compressive strength as the day of curing increased compared with the satisfied value from control. Because during this study concrete curing by potable water, river water, and deep well water were normal in terms of color and odor however concrete curing by rainwater was seen color and odor changed. The color and odor changed in rainwater it may be due to inorganic material, water change color and odor as a long time may be more affect the concrete strength so water to change color and odor not used as concrete mixing and curing. From Table 4.1 water test results show deep well water contains more amount of salinity, chloride, and TDS compared with the other identify water sources those impurities as a long time may more affect the concrete strength.

4.4.3. The Effect of the Same Water Source used for Mixing and Curing on the Concrete Compressive Strength

The compressive strength test result of cube both mixing and curing used the same water source show deviation on the 7th day and as summarized in Table 4.10. The deviation of average compressive strength test results at 7th day keeping the potable water as a control, deep well water achieved 90% of the control, river water was 86.7%of the control, and rainwater was 88.71%of the control

Table 4.10: 7th-day compressive strength test results of the same water source used both mixing and curing

No	Mixing water	Curing water	Code	7 days Avg stress (MPa)	Control (MPa)	Satisfied from control(%)	ASTM minimum %of control at 7 Days
1	Potable (control)	Potable	C	18.52	18.52	100	≥ 90 of the potable water
2	River	River	S1	16.05	18.52	86.7	
3	Deep well	Deep well	S2	17.86	18.52	96	
4	Rain	Rain	S3	16.43	18.52	88.71	

The compressive strength test result of cube both mixing and curing used the same water source show deviation on the 28 day and as summarized in Table 4.11.

The same sources of water used both mixing and curing concrete, river water was 9.8% lower than the control, deep well water was 13% lower than the control, and rainwater was 23% lower than the control

Table 4.11: 28th-day compressive strength test results of the same water source used both mixing and curing.

No	Mixing water	Curing water	Code	28 days Avg stress (MPa)	Control (Mpa)	Satisfied from control(%)
1	Potable(control)	Potable	C	29.5	29.5	100
2	River	River	S1	26.6	29.5	90.2
3	Deep well	Deep well	S2	25.7	29.5	87
4	Rain	Rain	S3	22.97	29.5	77

Generally, sources of water used for mixing and curing of concrete are good on the 7th-day but for the 28th day, some variations from the control except river water so used source of water for a long time carefully select the source and test the water impurities.

4.5. The Effect of Water Source on Splitting Tensile Strength

A total of 60 specimens were used for splitting tensile tests on 7 and 28 days. The tensile strength test results of cylinders made using potable water, river water, deep well water, and rainwater source for 7 and 28 days are shown in Table 4.12, potable water attained more strength value of 2.43 MPa and 3.7 MPa both 7 and 28 days respectively followed by river water which has 3.4 MPa at 28 days, the deep well water and rainwater 3.32 and 2.91 MPa at 28 days curing by potable water.

Table 4.12: Splitting tensile strength test results in identify water sources

No	Mixing water	Curing water	Code	7 day Avg load (KN)	7 days Avg stress (MPa)	28 day Avg load(KN)	28 days Avg stress (MPa)
1	Potable water	Potable (Control)	C	76.42	2.43	116	3.7
		River	C1	58.7	1.87	105.2	3.35
		Deep well	C2	75.68	2.41	100.84	3.21
		Rain	C3	68.8	2.19	99.9	3.18
2	River water	Potable	M1	68.17	2.17	106.84	3.4
		River	S1	66.9	2.1	101.78	3.24
3	Deep well water	Potable	M2	70.7	2.25	104.3	3.32
		Deep well	S2	68.5	2.18	94.62	3.01
4	Rainwater	Potable	M3	69.12	2.2	91.7	2.91
		Rainwater	S3	59.7	1.9	83.46	2.66

The splitting tensile strength test results are using different water source deviations on the 7 and 28 days show into three parts, mixing effect, curing effect, and the effect of the same water sources used both mixing and curing concrete.

4.5.1. The Effect of Mixing Water on Splitting Tensile Strength

The splitting tensile strength test result of concrete mixed by different water sources shows deviation on the 7 and 28 days as summarized in Table 4.13. The deviation of average splitting tensile strength test results at 7th and 28 days keeping the potable water as a control, river water was 10.7% and 8.11% lower than the control, deep well water was 7.4% and 10.3% lower than the control, and rainwater was 9.5% and 21.35% lower than the control for the 7 and 28 days respectively. Rainwater has less splitting tensile strength compared with the other identified water sources.

Table 4.13: Splitting tensile strength test results at different mixing water sources

Mixing water	Curing water	code	7th day Avg stress (MPa)	Satisfied from control(%)	28th day Avg stress(MPa)	Satisfied from control(%)
Potable(control)	Potable	C	2.43	100	3.7	100
River water	Potable	M1	2.17	89.3	3.4	91.89
Deep well	Potable	M2	2.25	92.6	3.32	89.73
Rainwater	Potable	M3	2.2	90.53	2.91	78.65

4.5.2. The Effect of Curing Water on Splitting Tensile Strength

The splitting tensile strength test result of concrete mixed with potable water and curing with different the identified water sources shows deviation on the 7th and 28 days as summarized in Table 4.14. The deviation of average splitting tensile strength test results at 7th and 28 days keeping the potable water as a control, river water was 23.05% and 9.46% lower than the control, deep well water was 0.8% and 13.24% lower than the control, and rainwater was 9.88% and 14.01% lower than the control for the 7 and 28 days respectively. Rainwater has less splitting tensile strength compared with the other identified water sources.

Table 4.14: Splitting tensile strength test results using different curing water sources

Mixing water	Curing water	Code	7th day Avg stress (MPa)	Satisfied from control(%)	28th day Avg stress(MPa)	Satisfied from control(%)
Potable(control)	Potable	C	2.43	100	3.7	100
Potable	River water	C1	1.87	76.95	3.35	90.54
Potable	Deep well	C2	2.41	99.2	3.21	86.8
Potable	Rainwater	C3	2.19	90.12	3.18	85.9

4.5.3. The Effect of the Same Source of Water used for Mixing and Curing on Splitting Tensile Strength

The splitting tensile strength test result of concrete mixing and curing used the same water source show deviation on the 7 and 28 days as summarized in Table 4.15. The deviation of average splitting tensile strength test results at 7 and 28 days keeping the potable water as a control, river water was 13.58% and 12.44% lower than the control, deep well water was 10.3% and 18.65% lower than the control, and rainwater was 21.81% and 28.1% lower than the control for the 7 and 28 days respectively. Rainwater has less splitting tensile strength compared with the other identified water sources.

Table 4.15: Splitting tensile strength test results using the same water source for mixing and curing

Mixing water	Curing water	Code	7^{th} day Avg stress (MPa)	Satisfied from control(%)	28^{th} day Avg stress(MPa)	Satisfied from control(%)
Potable(control)	Potable	C	2.43	100	3.7	100
River water	River water	S1	2.1	86.42	3.2	87.56
Deep well	Deep well	S2	2.18	89.7	3.01	81.35
Rainwater	Rainwater	S3	1.9	78.19	2.66	71.9

4.6. The Effect of Water Sources on Flexural Strength.

A total of 60 specimens were used for flexural strength tests for 7 and 28 days. The flexural strength test results of plain beams made using potable water, river water, deep well water, and rainwater sources for 7 and 28 days are shown in Table 4.16. The deviation of average flexural strength test results at 7 and 28 days keeping the potable water as a control, river water was 20% and 1.21% lower than the control, deep well water was 4.32% and 11.82% lower than the control, and rainwater was 22.73% and 14.54% lower than the control for the 7 and 28 days respectively.

Table 4.16: Test result of average flexural stresses obtained from 7 and 28 days.

Mixing Water	Curing Water	Code	7 day Avg Load KN	7day Avg Stress (MPa)	Satisfied from Control(%)	28 day Avg Load (KN)	28 day Avg Stress (MPa)	Satisfied from Control(%)
Potable water	Potable	C	17.42	5.23	100	24.065	7.22	100
	River	C1	17.16	5.15	98.47	23.88	7.16	99.23
	Deep Well	C2	13.555	4.06	77.629	23.34	7	96.97
	Rain	C3	13.35	4.005	76.577	21.16	6.35	87.93
River water	Potable	M1	13.945	4.1835	79.99	23.775	7.13	98.79
	River	S1	10.77	3.231	61.778	20.57	6.17	85.46
Deep Well	Potable	M2	16.68	5.004	95.679	21.22	6.37	88.18
	Deep Well	S2	12.795	3.8385	73.394	18.855	5.66	78.35
Rainwater	Potable	M3	13.47	4.041	77.266	20.6	6.17	85.46
	Rain	S3	12.46	3.738	71.472	18.765	5.63	77.98

The results show that for curing part potable water, river water, and deep well water are better results compared with rainwater for both 7 and 28 days. For mixing part potable and river waters better result compared with deep well and rain waters. For the same sources of water used both mixing and curing parts the similar results as the mixing part.

4.7. Stress-Strain Relation of Cubes with Different Sources of Water

In this study, the stress-strain curves draw for each different water source used for mixing and curing parts. The detailed cube stress-strain relation for the 28days test result is listed under Appendix 3.

- ❖ Figures 4.1 and 4.2 show stress-strain curve relation of different water sources used for concrete mixing and only potable water used for concrete curing both 7 and 28 days test results.

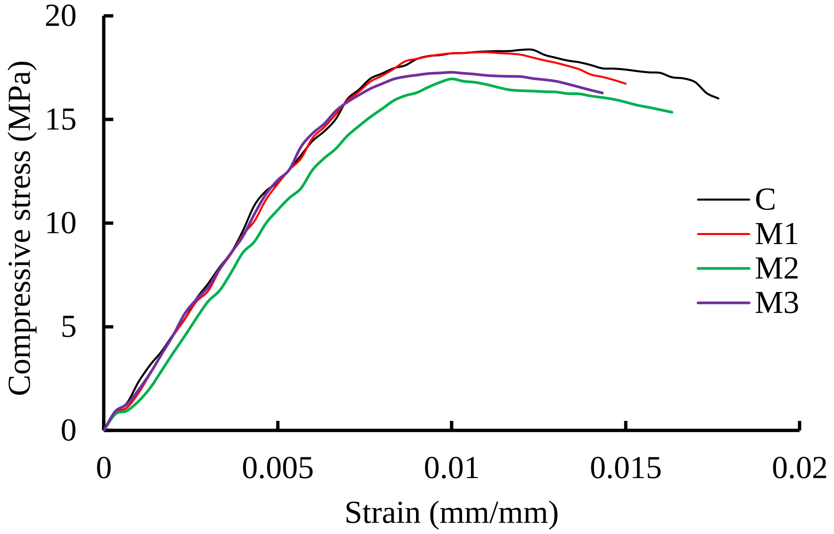


Figure 4.1: 7th-day stress-strain curve of different mixing water

Figures 4.1 and 4.2 show that the 7^{th}-day strain is more compared with the 28^{th}-day strain. The stress and strain of potable water are more compared with river water, deep well water, and rainwater. Deep well water in the 7^{th}-day strain more than river water and rainwater however in the 28-day less than river water and rainwater.

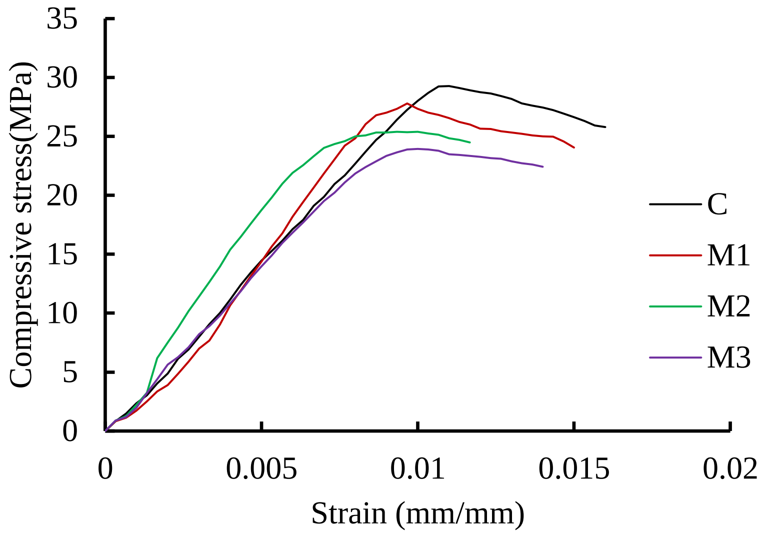


Figure 4.2: 28th-day stress-strain curve of different mixing water

- In Figure 4.3 and 4.4 shows stress-strain relation of different water source used for curing of concrete and only potable water used for mixing both 7 and 28 days test results.

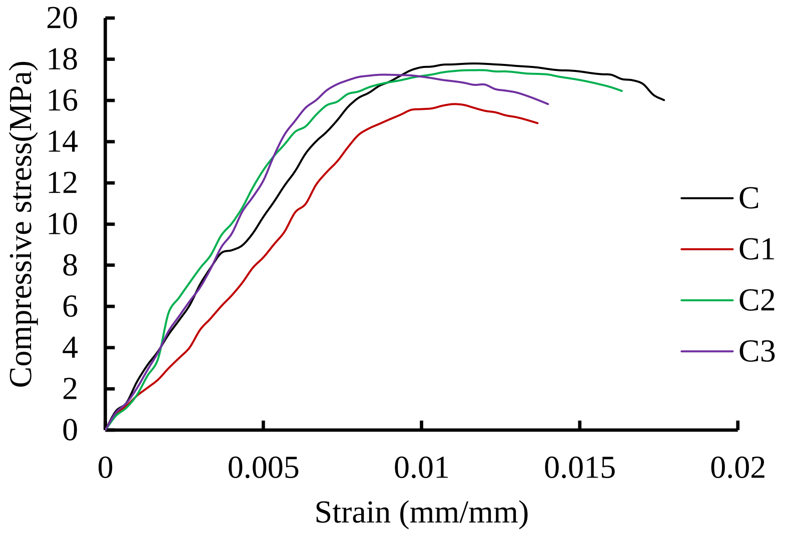


Figure 4.3: 7th-day stress-strain curve of different curing water source

Figures 4.3 and 4.4 shows that the 7th-day strain is more compared with the 28th-day strain, the stress-strain of potable water are more compared with river water, deep well water, and rainwater, river water in the 7th-day strain is less than deep well water and rainwater however in the 28-day strain more than deep well water and rainwater.

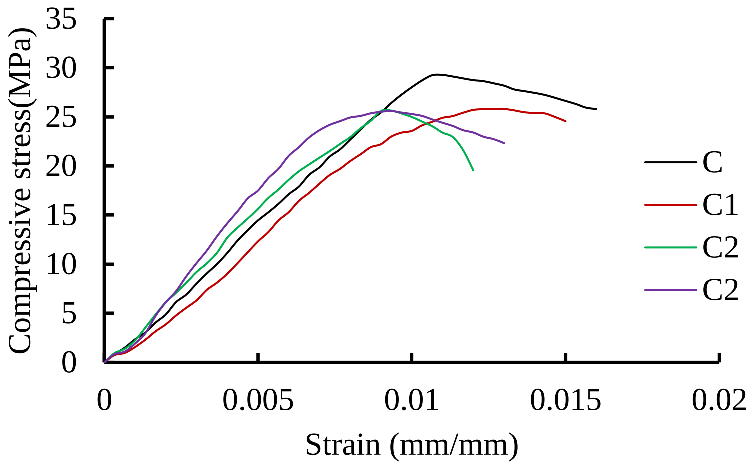


Figure 4.4: 28th-day stress-strain curve of different curing water source

Generally from all the above stress-strain curves, the following observation is drawn

- The date of curing increases the average compressive stress also increases but the strain of concrete decreases. The 7th-day strain is more compared with the 28th-day strain which shows the 28th-day strain is relatively brittle compared with the 7th-day strain.
- The stress and strain of potable water are more compared with the other identified water source on both the 7th and 28-days.
- For all parts of the 28th-day, the stress-strain curve shows deep well water is less strain compared with potable water, river water, and rainwater.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The quality of water is very important to improve concrete strength. Water is continuously important with mixing and curing part of concrete. The concrete strength is excellently achieved by using clean water. This study was assessing the effect of mixing and curing water sources on the properties of concrete. The properties of the concrete test were performed with four different mixings and curing water sources. These water sources show a relative influence on the properties of concrete. Based on the test results the key findings and conclusions drawn from the study are as follows.

- The initial and final setting time of cement tests results in all the identified sources of water are within the limits specified by ASTM C 94. The initial setting time of deep well and rainwater was 13-23min more than from the control and also the final setting time was l6-28min more than from the control.
- From the slump, a result obtained the source of water all the values fell within class 0-25mm slump value then workability may not be affected by the identified sources of water.
- The identify water source test result and analyze the constituents of water sources show the number of impurities found was within the limits stated in ASTM C 1602.
- In the mixing part, results showed that river water and deep well water have 7 and 28-day compressive strength satisfied 90 percent of the reference specimens made with potable, river water achieved 97.63%of the control and deep well water achieved 91.05%of the control but rainwater has 24.69MPa not satisfied the minimum requirement of C-25 grade of concrete(25MPa).
- Concrete mixing and curing in potable water and river water shows good results on the compressive, splitting tensile and flexural strength compared with deep well water and rainwater.
- The effect of different water sources on the compressive, splitting tensile and flexural strength are similar. Hardened concrete properties are affected by water impurity.

Therefore, from the test result, we can note that deep well water and rainwater have more amounts of impurity compared with potable and river water. So in potable and river water was good results compared with deep well water and rainwater.

5.2. Recommendations

Based on the study the following recommendations are forwarded.

- Around the study area (Jimma town), potable water and river water was relatively good for mixing and curing concrete.
- To practice testing mixing and curing water sources needs serious attention selecting suitable water source because water quality varies from one source to another and water impurities may adversely affect the long term strength.
- The study assesses the source of water used for mixing and curing concrete without treatment for further study treatment of mixing and curing water sources to focus on better concrete strength.
- The study focuses C-25 grade of concrete and used 0.53 W/C for further study of the different grades of concrete and different water-cement ratios investigated on concrete strength.
- The study investigated 7 and 28-day concrete strength. For further study, the durability of concrete is made with different mixing and curing water sources.
- From water test results deep well water contains more amount of chloride compared with the identified water sources so, along-term may lead to corrosion so for further study the corrosion effect of different water sources.

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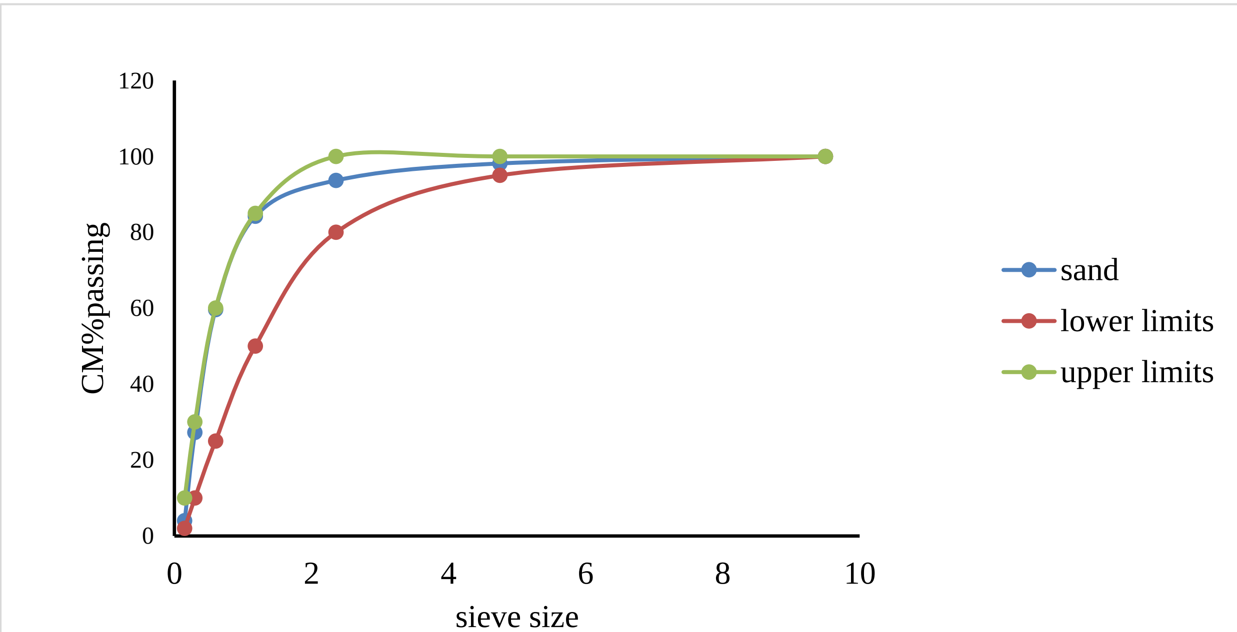
APPENDIX 1

Physical properties of materials

1.1.physical Properties of Sand

Sieve analysis of sand

Sieve Size (mm)	mass retained (gm)			% Retained	%cumulative retain	Cumulative %Passing	ASTM C-33 Limits (%)		Remark
	Trial 1	Trial 2	Avg.				Lower	Upper	
9.5	0	0	0.0	0.00	0	100	100	100	ok.
4.75	36	39	37.3	1.86	2	98	95	100	ok.
2.36	83	96	89.3	4.47	6	94	80	100	ok.
1.18	188	190	189.0	9.45	16	84	50	85	ok.
0.60	500	485	492.5	24.63	40	60	25	60	ok.
0.30	665	630	647.5	32.38	73	27	10	30	ok.
0.15	450	480	465.0	23.25	96	4	2	10	ok.
Pan	78	81	79.5	3.98	100	0	_	_	_
Total	2000	2000	2000	-	233	-	_	_	_
Fineness Modulus(FM)=230/100 =2.33 ~_2.3									



Specific gravity and absorption capacity of sand

Fine aggregate (chewaka Sand)

Description	Sample No		Average
	Trial1	Trial2	
Weight of saturated & surface dry sand (gm)	500	500	
Weight of pycnometer+sample+water (C) (gm)	1854.2	1855.8	
Weight of pycnometer+water (B) (gm)	1560	1560	
Weight of oven dry sand (A) (gm)	494.5	493.5	
Bulk specific gravity=A/(B+500-C)	2.40	2.417	2.41
Bulk specific gravity (sat.sur.dry basis)=500/(B+500-C)	2.430	2.449	2.44
Apparent specific gravity=A/(B+A-C)	2.469	2.496	2.48
Absorption capacity(%)=((500-A)/A)*100	1.1	1.3	1.2

Silt content of Sand

Laboratory method

S.No	Description	Sample	
		Trial 1	Trial 2
1	Air dried mass(g),M1	1000.0	1000.0
2	Oven dried mass(g),M2	964.5	965.0
3	Silt content in %=((M1-M2)/M1)*100	3.6	3.5
	Average	3.5	

The moisture content of Fine Aggregate

S no	Description	Trial 1	Trial 2
1	Weight of original sample ,A,(Kg)	0.5	0.5
2	Oven dried mass ,B,(Kg)	0.4966	0.4976
3	Moisture content in %=((A-B)/B)*100	0.7	0.5
	Average	0.6	

Unit weight Fine Aggregate

Description	Trial 1	Trial 2
Mass of cylinder(kg),A	1.052	1.052
Mass of cylinder and sample(kg),B	9.090	9.050
Mass of sample (kg), C=(B-A)	8.038	7.998
Volume of cylinder(m^3), D	0.005	0.005
Unit weight(kg/m^3)=(C/D)	1608	1600
Average	1604	

1.2.properties of coarse aggregate

Coarse aggregate gradation

Sieve Size (mm)	Mass retained (gm)			% Retained	% cumulative retain	% Passing	ASTM C-33 Limits (%)		Remark
	Trial 1	Trial2	Avg.				Lower	Upper	
37.5	0	0	0.0	0.00	0	100	100	100	ok.
25	410	408	409.0	4.09	4	96	95	100	ok.
19	2353	2289	2321.0	23.21	27	73	-	-	
12.50	4107	4393	4250.0	42.50	70	30	25	60	ok.
9.50	2196	2135	2165.5	21.66	91	9	-	-	
4.75	651	459	555.0	5.55	97	3	0	10	ok.
2.36	276	312	294.0	2.94	100	0	0	5	ok.
pan	7	4	5.5	0.06	100	0	_	_	_
Total	10000	10000	10000				_	_	_

Specific gravity and Absorption capacity of coarse aggregate

S.NO	Description	Trial1	Trial2	Average
1	M_W=Weight in water of saturated aggregate (Kg)	1.240	1.251	
2	M_{SSD}=Weight in air of saturated surface dry(Kg)	2.002	2.003	
3	M_D=Weight in air of oven-dried aggregate(Kg)	1.990	1.991	
4	Specific gravity of gravel	**2.627**	**2.664**	**2.65**
5	absorption capacity (%)	**0.60**	**0.60**	**0.60%**

The moisture content of coarse Aggregate

S. No	Description	Trial 1	Trial 2
1	Weight of original sample ,A (Kg)	2.0	2.0
2	Weight of oven dried sample B ,(Kg)	1.985	1.986
3	Moisture content(%)=(A-B/A)*100	0.8	0.7
	Average	0.75	

Unit weight coarse Aggregate

Description	Trial 1	Trial 2
Mass of cylinder(kg),A	1.6770	1.6770
Mass of cylinder and sample(kg),B	18.848	18.846
Mass of sample (kg), C = (B-A)	17.171	17.169
Volume of cylinder(m^3), D	0.010	0.010
Unit weight(kg/m^3) = (C/D)	1717.1	1716.9
Average	1717	

1.3 Properties of Cement

Normal consistency of PPC Cement mixing by potable water

Trial	weight of cement(gm)	%of water	amount of water added(ml)	W/C ratio	penetration depth(mm)
1	400	30	120	0.3	5
2	400	31	124	0.31	7
3	400	33	132	0.33	10

Normal consistency of PPC Cement mixing by river water

Trial	weight of cement(gm)	%of water	amount of water added(ml)	W/C ratio	penetration depth(mm)
1	400	30	12000	0.3	5
2	400	31	12400	0.31	6
3	400	33	13200	0.33	9.5

Normal consistency of PPC Cement mixing by deep well water

Trial	weight of cement(gm)	%of water	amount of water added(ml)	W/C ratio	penetration depth(mm)
1	400	30	12000	0.3	6
2	400	31	12400	0.31	7.5
3	400	33	13200	0.33	10.5

Normal consistency of PPC Cement mixing by rainwater

Trial	weight of cement(gm)	%of water	amount of water added(ml)	W/C ratio	penetration depth(mm)
1	400	30	12000	0.3	5.5
2	400	31	12400	0.31	8
3	400	33	13200	0.33	11

Setting time of cement

Potable water mixing	
Time (min)	penetration depth(mm)
30	39.1
40	39.3
50	39.8
60	39.6
70	39.5
80	39.8
90	39.5
100	39.4
110	39.3
120	39.2
130	39.1
140	38.6
150	37.1
160	30
170	25
175	20.5
180	19
190	17.5
200	14

River water mixing	
Time (min)	Penetration depth(mm)
30	39.1
40	39.3
50	39.5
60	39.8
70	39.5
80	39.4
90	39.6
100	39.5
110	39.3
120	39.3
130	39.2
140	39.1
150	38.1
160	33.4
168	25
170	20.9
180	12.3

Deep well water mixing	
Time (min)	Penetration depth(mm)
30	39.8
40	39.6
50	39.8
60	39.7
70	39.7
80	39.9
90	39.6
100	39.8
110	39.5
120	39.6
130	39.4
140	39.1
150	39.1
160	39.2
170	37.2
180	28.6
183	25
190	16.3

Rainwater mixing	
Time (min)	penetration depth(mm)
30	39.2
40	39.6
50	39.7
60	39.8
70	39.5
80	39.4
90	39
100	39.3
110	39.5
120	39.4
130	39.3
140	39.2
150	39.3
160	39.2
170	39.1
180	38.2
180	33.5
190	28
193	25
200	17.5
210	10.9

Fineness of cement

Description	PPC cement type
Weight of cement original sample, w(gm)	100
Residue from the sample retained on the 75 µm sieve, R_s	4.82
The fineness of cement expressed as %age passing the sieve $F(\%)=100-[R_S*100/w]$	95.18

APPENDIX 2

. **C -25 Mix Designing and proportioning**

Requirement data

- Cement – Dangote PPC (32.5R) and specific gravity of cement 2.9
- Non-Air entrained concrete type
- Fine aggregate
  - Fineness modulus = 2.3
  - Free surface moisture =0.603%
  - Specific gravity =2.44
  - Absorption capacity =1.2. %
- Coarse aggregate
  - Free surface moisture = 0.75%
  - Bulk Specific gravity of (SSD) = 2.65
  - Absorption capacity = 0.6%
  - Dry- rodded unit weight = 1717kg/m^3
  - Maximum size of aggregate = 20mm
- The desired strength is 25MPa

Step 1: Choice of Slump**:** - The expected slump for workability is selected as between 20 – 100

Step 2: Choice of Maximum aggregate size: - The choice of the maximum size of aggregate size according to ACI should be the largest size possible so long as it is consistent with the dimension of the structure (spacing between side forms, the thickness of the slab, and spacing of the reinforcement bars). For this case, since it is for experiment purposes, I take a maximum size of aggregate 20mm

Step 3: Estimation of the mixing water content and air content: - The quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum aggregate size, the shape, and grading of both coarse and fine aggregate, and the amount of entrained air. The mix is non-air entrained. For the maximum nominal aggregate size of 20mm and slump value the required amount of mixing water is 185 kg/m3, and the air content recommended for extreme exposure conditions is 2%.

Step 4: Selection of water to cement ratio: for the given mix design of non-air-entrained concrete of 25MPa

- The maximum water-cement ratio is 0.5 for durability requirement with the moderate condition of exposure and maximum aggregate size of 20mm
- The maximum water-cement ratio is 0.6 for the strength requirement of 25MPa concrete

strength. Taking the minimum of the two values; the water-cement ratio to be used for the mix design is W/C 0.50.

Step 5: Calculation of cement content: - Based on steps 3 and 4, the required cement content is $\frac{185}{0.5}$ =370kg/m^3 ≥360kg/m^3…………………. ok

Step 6: Estimation of coarse aggregate content: - For the nominal maximum size of 20mm and fines modules of fine aggregate = 2.3 ≈ 2.4. the bulk volume per unit volume of concrete of dry rodded aggregate from ACI Table 11.4 = 0.66

weight of coarse aggregate =0.66*1717 = 1133.22kg/m^3

Step 7: Estimation of fine aggregate content: - The fine aggregate content can be estimated by the weight method or the volume method. Due to its more accuracy for this research purpose the weight method was used. Accordingly, from ACI table 11.9, the first estimate of the density of fresh concrete for 20 mm maximum size of aggregate for non-air entrained concrete is 2355 kg/m^3.

Weight of fine aggregate = 2355-(185+370+1133.22) = 666.78kg/m^3

The mixture has the following estimated quantities of ingredients (proportions of materials) before trial mix per unit volume of concrete.

Ingredients	Cement	Sand	gravel	Water
quantity (kg/m^3)	370	666.8	1133.22	185
Ratio	1	1.8	3.1	0.53
Quantity in KG	50	90.11	153.14	25.00

Step 8: Adjustment for field condition

Fine aggregate has surface moisture of 0.603%.

Weight of fine aggregates = (666.78+0.00603*666.8) kg/m3= 670.8 kg/m^3

Coarse aggregate absorbs 0.6% of water.

Weight of coarse aggregate = (1133.22+0.006*1133.22) Kg/m3= 1140 kg/m^3

Adjust the amount of water based on moisture content

the required mixing water = 185-670.8(0.00603-0.012)-1140(0.0075-0.006) = 196.015

Step 9: Final design proportion

Ingredients	Cement	sand	Gravel	Water
quantity (kg/m^3)	370	670.8	1140	196.015
Ratio	1	1.8	3.1	0.53
One bag cement	50	91	154	25

APPENDIX 3

Stress-strain relation for cube test: For the 28^{th}-day cube stress-strain result for control (potable mix potable curing)

ΔH	Load (KN)			Area	Strain	Stress-1	Stress-2	Stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	18	21	18	22500	0.000333	0.8	0.933333	0.8
0.1	34	42	25	22500	0.000667	1.511111	1.866667	1.111111
0.15	55	58	45	22500	0.001	2.444444	2.577778	2
0.2	67	70	68	22500	0.001333	2.977778	3.111111	3.022222
0.25	88	89	96	22500	0.001667	3.911111	3.955556	4.266667
0.3	102	111	116	22500	0.002	4.533333	4.933333	5.155556
0.35	137	139	138	22500	0.002333	6.088889	6.177778	6.133333
0.4	149	159	158	22500	0.002667	6.622222	7.066667	7.022222
0.45	179	188	174	22500	0.003	7.955556	8.355556	7.733333
0.5	199	216	196	22500	0.003333	8.844444	9.6	8.711111
0.55	216	245	215	22500	0.003667	9.6	10.88889	9.555556
0.6	241	267	244	22500	0.004	10.71111	11.86667	10.84444
0.65	271	298	268	22500	0.004333	12.04444	13.24444	11.91111
0.7	295	329	285	22500	0.004667	13.11111	14.62222	12.66667
0.75	315	348	313	22500	0.005	14	15.46667	13.91111
0.8	336	369	326	22500	0.005333	14.93333	16.4	14.48889
0.85	368	381	341	22500	0.005667	16.35556	16.93333	15.15556
0.9	382	408	366	22500	0.006	16.97778	18.13333	16.26667
0.95	402	421	386	22500	0.006333	17.86667	18.71111	17.15556
1	431	452	407	22500	0.006667	19.15556	20.08889	18.08889
1.05	449	472	420	22500	0.007	19.95556	20.97778	18.66667
1.1	469	499	447	22500	0.007333	20.84444	22.17778	19.86667
1.15	478	526	460	22500	0.007667	21.24444	23.37778	20.44444
1.2	496	550	486	22500	0.008	22.04444	24.44444	21.6
1.25	511	575	513	22500	0.008333	22.71111	25.55556	22.8
1.3	532	598	537	22500	0.008667	23.64444	26.57778	23.86667
1.35	557	611	550	22500	0.009	24.75556	27.15556	24.44444
1.4	576	632	575	22500	0.009333	25.6	28.08889	25.55556
1.45	592	649	599	22500	0.009667	26.31111	28.84444	26.62222
1.5	612	658	621	22500	0.01	27.2	29.24444	27.6
1.55	632	667	639	22500	0.010333	28.08889	29.64444	28.4
1.6	649	675	650	22500	0.010667	28.84444	30	28.88889
1.65	647	673	656	22500	0.011	28.75556	29.91111	29.15556
1.7	643	662	660	22500	0.011333	28.57778	29.42222	29.33333
1.75	637	651	664	22500	0.011667	28.31111	28.93333	29.51111
1.8	631	643	666	22500	0.012	28.04444	28.57778	29.6
1.85	627	639	667	22500	0.012333	27.86667	28.4	29.64444

1.9	622	630	666	22500	0.012667	27.64444	28	29.6
1.95	617	622	663	22500	0.013	27.42222	27.64444	29.46667
2	611	605	660	22500	0.013333	27.15556	26.88889	29.33333
2.05	607	600	657	22500	0.013667	26.97778	26.66667	29.2
2.1	601	598	653	22500	0.014	26.71111	26.57778	29.02222
2.15	599	593	646	22500	0.014333	26.62222	26.35556	28.71111
2.2	592	587	639	22500	0.014667	26.31111	26.08889	28.4
2.25	586	581	630	22500	0.015	26.04444	25.82222	28
2.3	579	576	621	22500	0.015333	25.73333	25.6	27.6
2.35	572	571	608	22500	0.015667	25.42222	25.37778	27.02222
2.4	569	568	604	22500	0.016	25.28889	25.24444	26.84444

a) **For potable mix**

River curing

ΔH	Load, KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	22	13	15	22500	0.000333	0.977778	0.577778	0.666667
0.1	32	16	17	22500	0.000667	1.422222	0.711111	0.755556
0.15	54	27	24	22500	0.001	2.4	1.2	1.066667
0.2	95	32	28	22500	0.001333	4.222222	1.422222	1.244444
0.25	139	39	35	22500	0.001667	6.177778	1.733333	1.555556
0.3	171	45	45	22500	0.002	7.6	2	2
0.35	214	52	56	22500	0.002333	9.511111	2.311111	2.488889
0.4	245	62	68	22500	0.002667	10.88889	2.755556	3.022222
0.45	271	77	78	22500	0.003	12.04444	3.422222	3.466667
0.5	312	88	98	22500	0.003333	13.86667	3.911111	4.355556
0.55	338	96	114	22500	0.003667	15.02222	4.266667	5.066667
0.6	364	117	128	22500	0.004	16.17778	5.2	5.688889
0.65	390	138	154	22500	0.004333	17.33333	6.133333	6.844444
0.7	422	149	186	22500	0.004667	18.75556	6.622222	8.266667
0.75	447	169	216	22500	0.005	19.86667	7.511111	9.6
0.8	466	184	245	22500	0.005333	20.71111	8.177778	10.88889
0.85	490	212	274	22500	0.005667	21.77778	9.422222	12.17778
0.9	514	231	288	22500	0.006	22.84444	10.26667	12.8
0.95	533	262	316	22500	0.006333	23.68889	11.64444	14.04444
1	545	291	330	22500	0.006667	24.22222	12.93333	14.66667
1.05	552	320	357	22500	0.007	24.53333	14.22222	15.86667
1.1	556	348	384	22500	0.007333	24.71111	15.46667	17.06667
1.15	559	362	409	22500	0.007667	24.84444	16.08889	18.17778
1.2	560	388	436	22500	0.008	24.88889	17.24444	19.37778
1.25	564	407	459	22500	0.008333	25.06667	18.08889	20.4
1.3	578	429	472	22500	0.008667	25.68889	19.06667	20.97778
1.35	575	443	482	22500	0.009	25.55556	19.68889	21.42222

1.4	570	467	515	22500	0.009333	25.33333	20.75556	22.88889
1.45	572	482	525	22500	0.009667	25.42222	21.42222	23.33333
1.5	568	495	528	22500	0.01	25.24444	22	23.46667
1.55	560	521	548	22500	0.010333	24.88889	23.15556	24.35556
1.6	558	534	562	22500	0.010667	24.8	23.73333	24.97778
1.65	555	558	568	22500	0.011	24.66667	24.8	25.24444
1.7	550	572	571	22500	0.011333	24.44444	25.42222	25.37778
1.75	547	597	572	22500	0.011667	24.31111	26.53333	25.42222
1.8	545	617	573.3	22500	0.012	24.22222	27.42222	25.47956
1.85	542	631	568	22500	0.012333	24.08889	28.04444	25.24444
1.9	539	641	562	22500	0.012667	23.95556	28.48889	24.97778
1.95	536	658	548	22500	0.013	23.82222	29.24444	24.35556
2	533	668	531	22500	0.013333	23.68889	29.68889	23.6
2.05	530	674	515	22500	0.013667	23.55556	29.95556	22.88889
2.1	529	675	510	22500	0.014	23.51111	30	22.66667
2.15	526	677	508	22500	0.014333	23.37778	30.08711	22.57778
2.2	520	660	506	22500	0.014667	23.11111	29.33333	22.48889
2.25	500	658	500	22500	0.015	22.22222	29.24444	22.22222
2.3	490	656	498	22500	0.015333	21.77778	29.15556	22.13333

Deep well curing

ΔH	Load,KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	22	19	22.5	22500	0.000333	0.977778	0.844444	1
0.1	28	25	40.5	22500	0.000667	1.244444	1.111111	1.8
0.15	53	43	54	22500	0.001	2.355556	1.911111	2.4
0.2	85	75	78	22500	0.001333	3.777778	3.333333	3.466667
0.25	112	110	106.5	22500	0.001667	4.977778	4.888889	4.733333
0.3	138	145	130.5	22500	0.002	6.133333	6.444444	5.8
0.35	158	168	151.5	22500	0.002333	7.022222	7.466667	6.733333
0.4	178	189	180	22500	0.002667	7.911111	8.4	8
0.45	198	225	198	22500	0.003	8.8	10	8.8
0.5	210	251	219	22500	0.003333	9.333333	11.15556	9.733333
0.55	238	280	235.5	22500	0.003667	10.57778	12.44444	10.46667
0.6	315	298	244	22500	0.004	14	13.24444	10.84444
0.65	298	330	298	22500	0.004333	13.24444	14.66667	13.24444
0.7	325	353	310.5	22500	0.004667	14.44444	15.68889	13.8
0.75	346	374	336	22500	0.005	15.37778	16.62222	14.93333
0.8	378	396	355.5	22500	0.005333	16.8	17.6	15.8
0.85	398	420	370.5	22500	0.005667	17.68889	18.66667	16.46667
0.9	433	438	384	22500	0.006	19.24444	19.46667	17.06667
0.95	459	453	402	22500	0.006333	20.4	20.13333	17.86667
1	485	459	417	22500	0.006667	21.55556	20.4	18.53333
1.05	511	463	433.5	22500	0.007	22.71111	20.57778	19.26667

1.1	536	468	448.5	22500	0.007333	23.82222	20.8	19.93333
1.15	560	470	471	22500	0.007667	24.88889	20.88889	20.93333
1.2	584	480	484.5	22500	0.008	25.95556	21.33333	21.53333
1.25	607	498	503.5	22500	0.008333	26.97778	22.13333	22.37778
1.3	627	510	523.4	22500	0.008667	27.86667	22.66667	23.26222
1.35	638	525	565.5	22500	0.009	28.35556	23.33333	25.13333
1.4	642.6	555	533	22500	0.009333	28.56044	24.66667	23.68889
1.45	641	540	530	22500	0.009667	28.48889	24	23.55556
1.5	633	532	522	22500	0.01	28.13333	23.64444	23.2
1.55	625	530	500	22500	0.010333	27.77778	23.55556	22.22222
1.6	618	525	480	22500	0.010667	27.46667	23.33333	21.33333
1.65	605	514	460	22500	0.011	26.88889	22.84444	20.44444
1.7	592	504	453	22500	0.011333	26.31111	22.4	20.13333
1.75	550	470	440	22500	0.011667	24.44444	20.88889	19.55556
1.8	500	420	400	22500	0.012	22.22222	18.66667	17.77778

Rain curing

ΔH	Load,KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	15	21	20	22500	0.000333	0.666667	0.933333	0.888889
0.1	25	25	24	22500	0.000667	1.111111	1.111111	1.066667
0.15	53	38	38	22500	0.001	2.355556	1.688889	1.688889
0.2	78	56	65	22500	0.001333	3.466667	2.488889	2.888889
0.25	116	89	114	22500	0.001667	5.155556	3.955556	5.066667
0.3	145	123	145	22500	0.002	6.444444	5.466667	6.444444
0.35	168	153	168	22500	0.002333	7.466667	6.8	7.466667
0.4	212	181	198	22500	0.002667	9.422222	8.044444	8.8
0.45	238	212	232	22500	0.003	10.57778	9.422222	10.31111
0.5	281	231	256	22500	0.003333	12.48889	10.26667	11.37778
0.55	324	254	289	22500	0.003667	14.4	11.28889	12.84444
0.6	351	276	329	22500	0.004	15.6	12.26667	14.62222
0.65	382	300	356	22500	0.004333	16.97778	13.33333	15.82222
0.7	412	331	384	22500	0.004667	18.31111	14.71111	17.06667
0.75	429	355	397	22500	0.005	19.06667	15.77778	17.64444
0.8	455	376	435	22500	0.005333	20.22222	16.71111	19.33333
0.85	480	395	456	22500	0.005667	21.33333	17.55556	20.26667
0.9	516	421	483	22500	0.006	22.93333	18.71111	21.46667
0.95	539	435	506	22500	0.006333	23.95556	19.33333	22.48889
1	559	456	532	22500	0.006667	24.84444	20.26667	23.64444
1.05	571	478	547	22500	0.007	25.37778	21.24444	24.31111
1.1	573	504	556	22500	0.007333	25.46667	22.4	24.71111
1.15	576	521	561	22500	0.007667	25.6	23.15556	24.93333
1.2	577	543	563.4	22500	0.008	25.64444	24.13333	25.03822
1.25	579	553	562	22500	0.008333	25.73333	24.57778	24.97778

1.3	580	573	559	22500	0.008667	25.77778	25.46667	24.84444
1.35	583	582	558	22500	0.009	25.91022	25.86667	24.8
1.4	581	589.6	557	22500	0.009333	25.82222	26.20222	24.75556
1.45	580	585	552	22500	0.009667	25.77778	26	24.53333
1.5	579	582	546	22500	0.01	25.73333	25.86667	24.26667
1.55	576	577	541	22500	0.010333	25.6	25.64444	24.04444
1.6	572	563	535	22500	0.010667	25.42222	25.02222	23.77778
1.65	569	551	527	22500	0.011	25.28889	24.48889	23.42222
1.7	564	543	518	22500	0.011333	25.06667	24.13333	23.02222
1.75	559	526	511	22500	0.011667	24.84444	23.37778	22.71111
1.8	551	520	509	22500	0.012	24.48889	23.11111	22.62222
1.85	544	505	502	22500	0.012333	24.17778	22.44444	22.31111
1.9	539	496	499	22500	0.012667	23.95556	22.04444	22.17778
1.95	533	491	483	22500	0.013	23.68889	21.82222	21.46667

b) For River mixing

Potable curing

ΔH	Load, KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	21	20	15	22500	0.00033	0.93333	0.88889	0.66667
0.1	26	28	23	22500	0.00067	1.15556	1.24444	1.02222
0.15	44	40	33	22500	0.001	1.95556	1.77778	1.46667
0.2	67	56	46	22500	0.00133	2.97778	2.48889	2.04444
0.25	96	69	62	22500	0.00167	4.26667	3.06667	2.75556
0.3	104	89	70	22500	0.002	4.62222	3.95556	3.11111
0.35	126	127	74	22500	0.00233	5.6	5.64444	3.28889
0.4	156	156	86	22500	0.00267	6.93333	6.93333	3.82222
0.45	196	170	107	22500	0.003	8.71111	7.55556	4.75556
0.5	207	188	123	22500	0.00333	9.2	8.35556	5.46667
0.55	225	218	167	22500	0.00367	10	9.68889	7.42222
0.6	258	248	213	22500	0.004	11.4667	11.0222	9.46667
0.65	285	285	234	22500	0.00433	12.6667	12.6667	10.4
0.7	312	315	262	22500	0.00467	13.8667	14	11.6444
0.75	339	342	290	22500	0.005	15.0667	15.2	12.8889
0.8	367	375	316	22500	0.00533	16.3111	16.6667	14.0444
0.85	393	396	343	22500	0.00567	17.4667	17.6	15.2444
0.9	421	436	370	22500	0.006	18.7111	19.3778	16.4444
0.95	458	458	396	22500	0.00633	20.3556	20.3556	17.6
1	486	486	422	22500	0.00667	21.6	21.6	18.7556
1.05	512	517	446	22500	0.007	22.7556	22.9778	19.8222
1.1	538	534	484	22500	0.00733	23.9111	23.7333	21.5111
1.15	550	569	516	22500	0.00767	24.4444	25.2889	22.9333

1.2	575	570	532	22500	0.008	25.5556	25.3333	23.6444
1.25	600	595	563	22500	0.00833	26.6667	26.4444	25.0222
1.3	624	608	576	22500	0.00867	27.7333	27.0222	25.6
1.35	646	595	582	22500	0.009	28.7111	26.4444	25.8667
1.4	667	580	599	22500	0.00933	29.6444	25.7778	26.6222
1.45	682	579	615.21	22500	0.00967	30.3111	25.7333	27.3427
1.5	689	566	590	22500	0.01	30.6222	25.1556	26.2222
1.55	691	557	576	22500	0.01033	30.7111	24.7556	25.6
1.6	692.05	545	573	22500	0.01067	30.7578	24.2222	25.4667
1.65	685	538	570	22500	0.011	30.4444	23.9111	25.3333
1.7	670	535	566	22500	0.01133	29.7778	23.7778	25.1556
1.75	665	530	561	22500	0.01167	29.5556	23.5556	24.9333
1.8	650	525	557	22500	0.012	28.8889	23.3333	24.7556

River curing

ΔH	Load,KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	16	19	20	22500	0.00033	0.71111	0.84444	0.88889
0.1	24	28	24	22500	0.00067	1.06667	1.24444	1.06667
0.15	29	53	48	22500	0.001	1.28889	2.35556	2.13333
0.2	27	86	78	22500	0.00133	1.2	3.82222	3.46667
0.25	36	117	112	22500	0.00167	1.6	5.2	4.97778
0.3	49	132	138	22500	0.002	2.17778	5.86667	6.13333
0.35	63	163	167	22500	0.00233	2.8	7.24444	7.42222
0.4	73	177	195	22500	0.00267	3.24444	7.86667	8.66667
0.45	90	196	219	22500	0.003	4	8.71111	9.73333
0.5	98	211	245	22500	0.00333	4.35556	9.37778	10.8889
0.55	122	239	267	22500	0.00367	5.42222	10.6222	11.8667
0.6	143	249	295	22500	0.004	6.35556	11.0667	13.1111
0.65	168	268	318	22500	0.00433	7.46667	11.9111	14.1333
0.7	217	290	342	22500	0.00467	9.64444	12.8889	15.2
0.75	246	310	353	22500	0.005	10.9333	13.7778	15.6889
0.8	267	337	365	22500	0.00533	11.8667	14.9778	16.2222
0.85	296	352	374	22500	0.00567	13.1556	15.6444	16.6222
0.9	302	377	379	22500	0.006	13.4222	16.7556	16.8444
0.95	327	390	386	22500	0.00633	14.5333	17.3333	17.1556
1	350	403	390	22500	0.00667	15.5556	17.9111	17.3333
1.05	378	429	416	22500	0.007	16.8	19.0667	18.4889
1.1	408	448	429	22500	0.00733	18.1333	19.9111	19.0667
1.15	447	476	436	22500	0.00767	19.8667	21.1556	19.3778
1.2	471	489	447	22500	0.008	20.9333	21.7333	19.8667
1.25	508	513	461	22500	0.00833	22.5778	22.8	20.4889

1.3	521	535	486	22500	0.00867	23.1556	23.7778	21.6
1.35	547	556	496	22500	0.009	24.3111	24.7111	22.0444
1.4	569	573	509	22500	0.00933	25.2889	25.4667	22.6222
1.45	589	575.39	523	22500	0.00967	26.1778	25.5729	23.2444
1.5	601	573	537	22500	0.01	26.7111	25.4667	23.8667
1.55	602.42	569	550	22500	0.01033	26.7742	25.2889	24.4444
1.6	600	567	579	22500	0.01067	26.6667	25.2	25.7333
1.65	598	566	588	22500	0.011	26.5778	25.1556	26.1333
1.7	587	556	597	22500	0.01133	26.0889	24.7111	26.5333
1.75	575	549	606	22500	0.01167	25.5556	24.4	26.9333
1.8	569	543	590	22500	0.012	25.2889	24.1333	26.2222
1.85	554	539	591	22500	0.01233	24.6222	23.9556	26.2667
1.9	539	537	585	22500	0.01267	23.9556	23.8667	26
1.95	535	536	580	22500	0.013	23.7778	23.8222	25.7778
2	530	535	576	22500	0.01333	23.5556	23.7778	25.6

c) Deep well mixing

Potable curing

ΔH	Load,KN			Area	Strain	Stress-1	Stress-2	Stress =3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	18	20	21	22500	0.00033	0.8	0.88889	0.93333
0.1	22	32	32	22500	0.00067	0.97778	1.42222	1.42222
0.15	35	55	59	22500	0.001	1.55556	2.44444	2.62222
0.2	56	82	82	22500	0.00133	2.48889	3.64444	3.64444
0.25	86	208	123	22500	0.00167	3.82222	9.24444	5.46667
0.3	117	235	155	22500	0.002	5.2	10.4444	6.88889
0.35	149	260	183	22500	0.00233	6.62222	11.5556	8.13333
0.4	185	290	211	22500	0.00267	8.22222	12.8889	9.37778
0.45	214	318	240	22500	0.003	9.51111	14.1333	10.6667
0.5	242	344	268	22500	0.00333	10.7556	15.2889	11.9111
0.55	270	376	296	22500	0.00367	12	16.7111	13.1556
0.6	311	404	323	22500	0.004	13.8222	17.9556	14.3556
0.65	335	428	350	22500	0.00433	14.8889	19.0222	15.5556
0.7	364	451	375	22500	0.00467	16.1778	20.0444	16.6667
0.75	390	475	401	22500	0.005	17.3333	21.1111	17.8222
0.8	416	496	426	22500	0.00533	18.4889	22.0444	18.9333
0.85	448	516	452	22500	0.00567	19.9111	22.9333	20.0889
0.9	478	525	476	22500	0.006	21.2444	23.3333	21.1556
0.95	494	532	496	22500	0.00633	21.9556	23.6444	22.0444
1	519	533	523	22500	0.00667	23.0667	23.6889	23.2444
1.05	544	534.2	543	22500	0.007	24.1778	23.7422	24.1333
1.1	568	520	556	22500	0.00733	25.2444	23.1111	24.7111

1.15	593	498	570	22500	0.00767	26.3556	22.1333	25.3333
1.2	614	496	577.49	22500	0.008	27.2889	22.0444	25.6662
1.25	633	491	570	22500	0.00833	28.1333	21.8222	25.3333
1.3	654	486	569	22500	0.00867	29.0667	21.6	25.2889
1.35	667	480	563	22500	0.009	29.6444	21.3333	25.0222
1.4	680	476	558	22500	0.00933	30.2222	21.1556	24.8
1.45	688	470	553	22500	0.00967	30.5778	20.8889	24.5778
1.5	696	468	550	22500	0.01	30.9333	20.8	24.4444
1.55	700	460	544	22500	0.01033	31.1111	20.4444	24.1778
1.6	701.49	456	539	22500	0.01067	31.1773	20.2667	23.9556
1.65	696	450	531	22500	0.011	30.9333	20	23.6
1.7	689	448	530	22500	0.01133	30.6222	19.9111	23.5556
1.75	680	445	528	22500	0.01167	30.2222	19.7778	23.4667

Deep well curing

ΔH	Load,KN			Area	Strain	Stress-1	Stress-2	Stress =3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	19	17	20	22500	0.00033	0.84444	0.75556	0.88889
0.1	37	28	29	22500	0.00067	1.64444	1.24444	1.28889
0.15	62	40	53	22500	0.001	2.75556	1.77778	2.35556
0.2	95	51	112	22500	0.00133	4.22222	2.26667	4.97778
0.25	128	59	133	22500	0.00167	5.68889	2.62222	5.91111
0.3	156	65	158	22500	0.002	6.93333	2.88889	7.02222
0.35	179	70	169	22500	0.00233	7.95556	3.11111	7.51111
0.4	216	72	189	22500	0.00267	9.6	3.2	8.4
0.45	248	76	210	22500	0.003	11.0222	3.37778	9.33333
0.5	278	99	229	22500	0.00333	12.3556	4.4	10.1778
0.55	306	115	248	22500	0.00367	13.6	5.11111	11.0222
0.6	320	132	268	22500	0.004	14.2222	5.86667	11.9111
0.65	346	158	290	22500	0.00433	15.3778	7.02222	12.8889
0.7	373	180	312	22500	0.00467	16.5778	8	13.8667
0.75	396	225	335	22500	0.005	17.6	10	14.8889
0.8	425	260	370	22500	0.00533	18.8889	11.5556	16.4444
0.85	438	306	395	22500	0.00567	19.4667	13.6	17.5556
0.9	464	345	419	22500	0.006	20.6222	15.3333	18.6222
0.95	488	380	446	22500	0.00633	21.6889	16.8889	19.8222
1	513	416	470	22500	0.00667	22.8	18.4889	20.8889
1.05	530	443	486	22500	0.007	23.5556	19.6889	21.6
1.1	547	481	504	22500	0.00733	24.3111	21.3778	22.4
1.15	568	518	515	22500	0.00767	25.2444	23.0222	22.8889
1.2	579	544	520.93	22500	0.008	25.7333	24.1778	23.1524
1.25	583	566	512	22500	0.00833	25.9111	25.1556	22.7556

1.3	586	590	504	22500	0.00867	26.0444	26.2222	22.4
1.35	589	604	489	22500	0.009	26.1778	26.8444	21.7333
1.4	594	608	472	22500	0.00933	26.4	27.0222	20.9778
1.45	599	610.86	470	22500	0.00967	26.6222	27.1493	20.8889
1.5	602.49	608	468	22500	0.01	26.7773	27.0222	20.8
1.55	601	601	465	22500	0.01033	26.7111	26.7111	20.6667
1.6	598	596	460	22500	0.01067	26.5778	26.4889	20.4444
1.65	592	580	455	22500	0.011	26.3111	25.7778	20.2222
1.7	574	560	450	22500	0.01133	25.5111	24.8889	20
1.75	566	552	444	22500	0.01167	25.1556	24.5333	19.7333

d) For Rain mixing

Potable curing

ΔH	Load,KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	21	19	19	22500	0.00033	0.93333	0.84444	0.84444
0.1	29	26	25	22500	0.00067	1.28889	1.15556	1.11111
0.15	48	43	43	22500	0.001	2.13333	1.91111	1.91111
0.2	73	77	67	22500	0.00133	3.24444	3.42222	2.97778
0.25	103	108	85	22500	0.00167	4.57778	4.8	3.77778
0.3	127	136	118	22500	0.002	5.64444	6.04444	5.24444
0.35	132	163	128	22500	0.00233	5.86667	7.24444	5.68889
0.4	139	197	143	22500	0.00267	6.17778	8.75556	6.35556
0.45	157	230	167	22500	0.003	6.97778	10.2222	7.42222
0.5	168	255	178	22500	0.00333	7.46667	11.3333	7.91111
0.55	184	283	195	22500	0.00367	8.17778	12.5778	8.66667
0.6	198	311	221	22500	0.004	8.8	13.8222	9.82222
0.65	212	338	251	22500	0.00433	9.42222	15.0222	11.1556
0.7	221	367	288	22500	0.00467	9.82222	16.3111	12.8
0.75	237	398	309	22500	0.005	10.5333	17.6889	13.7333
0.8	248	418	339	22500	0.00533	11.0222	18.5778	15.0667
0.85	268	431	379	22500	0.00567	11.9111	19.1556	16.8444
0.9	281	457	398	22500	0.006	12.4889	20.3111	17.6889
0.95	294	477	423	22500	0.00633	13.0667	21.2	18.8
1	318	494	445	22500	0.00667	14.1333	21.9556	19.7778
1.05	333	518	467	22500	0.007	14.8	23.0222	20.7556
1.1	346	531	489	22500	0.00733	15.3778	23.6	21.7333
1.15	357	553	513	22500	0.00767	15.8667	24.5778	22.8
1.2	375	563	537	22500	0.008	16.6667	25.0222	23.8667
1.25	388	578	546	22500	0.00833	17.2444	25.6889	24.2667
1.3	397	588	559	22500	0.00867	17.6444	26.1333	24.8444
1.35	415	593	568	22500	0.009	18.4444	26.3556	25.2444

1.4	427	597	573	22500	0.00933	18.9778	26.5333	25.4667
1.45	435	598.26	579.62	22500	0.00967	19.3333	26.5893	25.7609
1.5	442	596	578	22500	0.01	19.6444	26.4889	25.6889
1.55	447	591	574	22500	0.01033	19.8667	26.2667	25.5111
1.6	456	578	572	22500	0.01067	20.2667	25.6889	25.4222
1.65	461	556	568	22500	0.011	20.4889	24.7111	25.2444
1.7	467	550	564	22500	0.01133	20.7556	24.4444	25.0667
1.75	474	546	556	22500	0.01167	21.0667	24.2667	24.7111
1.8	483	540	548	22500	0.012	21.4667	24	24.3556
1.85	487	534	542	22500	0.01233	21.6444	23.7333	24.0889
1.9	489.2	530	540	22500	0.01267	21.7422	23.5556	24
1.95	485	523	536	22500	0.013	21.5556	23.2444	23.8222
2	482	521	530	22500	0.01333	21.4222	23.1556	23.5556
2.05	480	520	526	22500	0.01367	21.3333	23.1111	23.3778
2.1	478	516	520	22500	0.014	21.2444	22.9333	23.1111
2.15	474	514	513	22500	0.01433	21.0667	22.8444	22.8
2.2	468	510	512	22500	0.01467	20.8	22.6667	22.7556
2.25	462	505	511	22500	0.015	20.5333	22.4444	22.7111
2.3	457	500	508	22500	0.01533	20.3111	22.2222	22.5778

Rain curing

ΔH	Load,KN			Area	Strain	stress-1	stress-2	stress-3
	1	2	3	mm^2				
0	0	0	0	22500	0	0	0	0
0.05	20	21	20	22500	0.00033	0.88889	0.93333	0.88889
0.1	34	34	65	22500	0.00067	1.51111	1.51111	2.88889
0.15	53	58	86	22500	0.001	2.35556	2.57778	3.82222
0.2	67	87	113	22500	0.00133	2.97778	3.86667	5.02222
0.25	89	123	134	22500	0.00167	3.95556	5.46667	5.95556
0.3	120	60	158	22500	0.002	5.33333	2.66667	7.02222
0.35	137	88	177	22500	0.00233	6.08889	3.91111	7.86667
0.4	153	216	197	22500	0.00267	6.8	9.6	8.75556
0.45	169	243	218	22500	0.003	7.51111	10.8	9.68889
0.5	178	276	243	22500	0.00333	7.91111	12.2667	10.8
0.55	197	311	261	22500	0.00367	8.75556	13.8222	11.6
0.6	214	348	278	22500	0.004	9.51111	15.4667	12.3556
0.65	237	388	295	22500	0.00433	10.5333	17.2444	13.1111
0.7	258	415	314	22500	0.00467	11.4667	18.4444	13.9556
0.75	273	438	329	22500	0.005	12.1333	19.4667	14.6222
0.8	298	463	348	22500	0.00533	13.2444	20.5778	15.4667
0.85	314	490	356	22500	0.00567	13.9556	21.7778	15.8222
0.9	341	524	368	22500	0.006	15.1556	23.2889	16.3556
0.95	354	545	377	22500	0.00633	15.7333	24.2222	16.7556

1	377	558	381	22500	0.00667	16.7556	24.8	16.9333
1.05	392	576	387	22500	0.007	17.4222	25.6	17.2
1.1	404	588	392	22500	0.00733	17.9556	26.1333	17.4222
1.15	425	592.25	395	22500	0.00767	18.8889	26.3222	17.5556
1.2	434	588	398	22500	0.008	19.2889	26.1333	17.6889
1.25	448	571	399	22500	0.00833	19.9111	25.3778	17.7333
1.3	459	551	400	22500	0.00867	20.4	24.4889	17.7778
1.35	467	543	403	22500	0.009	20.7556	24.1333	17.9111
1.4	475	540	407	22500	0.00933	21.1111	24	18.0889
1.45	482	536	413	22500	0.00967	21.4222	23.8222	18.3556
1.5	487	534	417	22500	0.01	21.6444	23.7333	18.5333
1.55	492	530	418	22500	0.01033	21.8667	23.5556	18.5778
1.6	493	526	419	22500	0.01067	21.9111	23.3778	18.6222
1.65	495	520	420	22500	0.011	22	23.1111	18.6667
1.7	496	515	421	22500	0.01133	22.0444	22.8889	18.7111
1.75	498	510	422	22500	0.01167	22.1333	22.6667	18.7556
1.8	499	498	424	22500	0.012	22.1778	22.1333	18.8444
1.85	501.73	495	427	22500	0.01233	22.2991	22	18.9778
1.9	500	492	431	22500	0.01267	22.2222	21.8667	19.1556
1.95	497	490	435	22500	0.013	22.0889	21.7778	19.3333
2	495	488	437	22500	0.01333	22	21.6889	19.4222
2.05	492	485	438	22500	0.01367	21.8667	21.5556	19.4667
2.1	488	480	441	22500	0.014	21.6889	21.3333	19.6
2.15	484	477	443	22500	0.01433	21.5111	21.2	19.6889
2.2	480	470	446	22500	0.01467	21.3333	20.8889	19.8222
2.25	475	463	447	22500	0.015	21.1111	20.5778	19.8667
2.3	472	460	451	22500	0.01533	20.9778	20.4444	20.0444
2.35	468	455	453	22500	0.01567	20.8	20.2222	20.1333
2.4	465	450	455	22500	0.016	20.6667	20	20.2222
2.45	462	446	456.2	22500	0.01633	20.5333	19.8222	20.2756
2.5	460	444	455	22500	0.01667	20.4444	19.7333	20.2222
2.55	452	441	451	22500	0.017	20.0889	19.6	20.0444
2.6	450	437	446	22500	0.01733	20	19.4222	19.8222
2.65	446	436	443	22500	0.01767	19.8222	19.3778	19.6889
2.7	440	434	438	22500	0.018	19.5556	19.2889	19.4667

APPENDIX 4

Photos

The selected image that shows the study process was shown as follows

Figure 4.1: Test different water parameters in the identify water sources

Figure 4.2: Preparing and test concrete ingredients

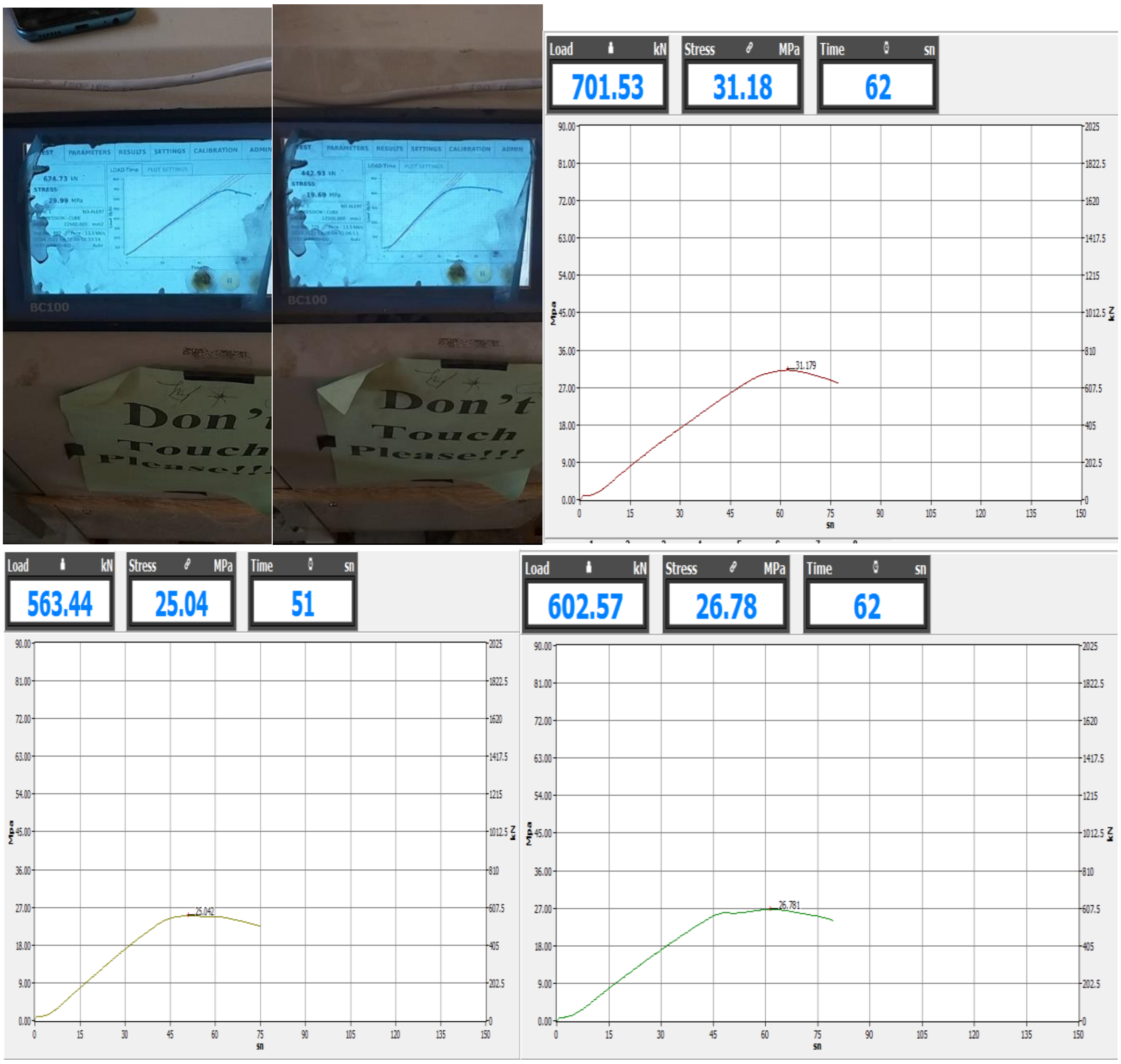


Figure 4.3: Display results