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Reinforced concrete deterioration caused by contaminated construction water: An overview

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ABSTRACT

Over the years, there were cases of building failures in most developing countries of the world that have led to the loss of lives and property. Yet, most investigations conducted on the causes of building failures have suggested poor design, inadequate supervision, and the use of inferior materials as the factors responsible for the failures. However, not so much emphasis has been placed on concrete mixing water as a contributing factor to the failures. Therefore, this review summarizes the effect of the type and composition of mixing water on the properties of concrete. Different sources of water that can be used to mix concrete were explored, alongside with the effect on fresh and hardened properties of concrete. The fresh properties of concrete, such as setting time and slump, were examined, while the hardened properties focused on the strength and durability of the concrete. A brief statement on the available regulation and standards for mixing water was also reported. This review shows the viability of using water from different sources, such as wastewater, to mix concrete successfully. However, the treatment of some types of water might be required to ensure that excellent strength and durability properties are achieved while preventing any threat to human life and the environment. Area for future research was also suggested, which, among other procedures, could help proffer solutions to the challenge of building failures in developing countries.

1. Introduction

Concrete is the most used building material in the world, with over 7 billion cubic meters produced annually. Also, it is the second most-consumed material in the world after water [1]. Concrete is typically made up of a binder, water, and aggregate. From all these materials, water is an essential component, as it serves as a reactant to the hydration reaction, and also provides workability of the mix. Therefore, it is germane to ensure that the water used to mix concrete does not possess characteristics that can alter the desired concrete performance.

The concrete industry is one of the sectors that consume a higher quantity of freshwater [2]. Approximately 1 billion cubic meters of water is used annually to mix concrete. Besides the use of water for mixing concrete, it is also utilized for cleaning the aggregates

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before concrete casting [3]. Also, a considerable amount of water is used to clean the equipment used for mixing, transporting, and placing concrete. Finally, water is also used for curing concrete [4].

Based on standards, water with a meager percentage of impurities, such as that suitable for drinking, is optimum for mixing concrete [5]. However, in the developing countries where availability of potable water is a significant challenge, the concrete constructors having limited resources to perform water treatment tend to utilize any available water source for the production of concrete. However, this practice may be detrimental to the performance of such concrete that is produced since mixing water can affect factors such as hydration mechanism, porosity, mineralogical, and strength properties in concrete[6–9].

The presence of impurities in the mixing water might alter the resulting hydration reaction, which could lead to the deterioration of concrete properties [10], as such, the basic rule used for the suitability of water used for mixing concrete is "if it is suitable for drinking, it is good for mixing concrete." However, in most cases, it is not possible to use drinking water for mixing concrete. This is a result of the high demand for freshwater for human consumption and also a limited supply of freshwater in some communities. Therefore, other available water sources are used to make concrete. Although there are regulations guiding the suitability of waters for mixing concrete, yet water that is not suitable for drinking and also having impurities (such as sea and wastewaters) have been used for producing concrete [5,11]. But the impurities present in wastewater sources can undermine the properties of the concrete [12]. The assessment of water suitability for concrete is based on the regulations available in some parts of the world, which provide limitations on the number of impurities allowed for water to be used in concrete. Some of the parameters used to determine the suitability of mixing water are total suspended solids (TSS), biological oxygen demand (BOD), chlorine and sulfate residue, total dissolved solids (TDS), total organic, and chemical oxygen demand (COD).

Interestingly, wastewater usage for mixing concrete is gaining huge attention all over the world, since it helps to solve the related challenges to wastewater disposal from different industrial processes. In developed countries such as the United Kingdom, China, and Spain, wastewater is treated for use in mixing concrete, and such concretes are found to give similar characteristics as those made with fresh water. However, the use of raw wastewater in concrete is strongly discouraged because it provides inferior properties [13]. Memon et al. [14] reported that a binary blend of cement and fly ash mixed with water containing salts of sodium, calcium, magnesium, potassium has no significant effect on the mechanical properties of concrete. It was also established that the use of sludge water for mixing concrete caused a reduction in the slump and strength of concrete [15].

Treated wastewater (resulting from sources such as household, industries, and commercial buildings) has been used totally or as partial replacement of freshwater during concrete mixing. The use of treated water to mix concrete has been reported to give similar strength to those made with freshwater [16]. However, the treatment requirement varies from primary to tertiary treatment. The use of mixing water that has undergone tertiary treatment has no adverse effect on the properties of concrete. However, the use of mixing water, which was treated by primary and secondary methods, can negate the properties of concrete. A decrease in strength up to 10% was reported for concrete made with water from primary wastewater treatment [17]. An earlier study also reported 9% decrease in compressive strength when raw sewage water was used as mixing water [18], but in another study, an increase in compressive strength of the concrete was observed when treated effluent was used [19].

The future demand for concrete is expected to increase due to population growth continually, urbanization, and changing lifestyles [20,21], therefore, a consequential increase in the need for concrete mixing water is also expected. However, some countries in the arid regions are facing a shortage of freshwater, which poses a significant challenge to the production of green concrete. Therefore, this review explores the different types of water used for mixing water and how it affects its fresh and hardened properties. It is anticipated that this review would be a useful reference for contractors to select the best type of water while improving the sustainability of the environment. Also, this review would help researchers to explore other possible sources of mixing water and proffer solutions to the current problems faced with the existing water available for mixing concrete.

1.1. Regulation on mixing water for concrete

To prevent any threat to human life, especially the construction workers, there is a need to follow the existing rules and standards on the suitability of water used for mixing concrete. These regulations also ensure that there is no significant adverse effect on the properties of concrete as a result of the type of mixing water used. The rule sets maximum levels for different chemical and biological parameters that are present in wastewater. One of the kinds of regulation is the one set by the United States Environmental Protection Agency (US EPA) [22]. This regulation limits the quantity of a specific type of materials/chemicals in the treated water to be used as mixing water for concrete, as listed in Table 1. Also, organizations such as Portland Cement Association also set permissible levels of some substances to be present in the water to be used for producing concrete [5].

Table 1
EPA permissible limits for parameters in water used for mixing concrete [22].

Material/chemical	Maximum quantity	Unit
TSS	30	mg/l
BOD_5	30	mg/l
Fecal coliforms	200	CFU/100 ml
Cl_2 residual	1	mg/l

BOD_5 – biological oxygen demand, TSS – total suspended solids.

Standards such as ASTM C94 [23], ASTM C 109 [24], and EN 1008 [25] are also put in place to determine the suitability of water for concrete mixing. ASTM C 109[24] recommends water for mixing concrete as suitable if the mortar made with it gives a 7 days strength not less than the strength of the control samples made with distilled water. Other standards available for mixing water are; ACI 318M [26] and ASTM C1602M [27]. It is, however, important to mention that these standards are only secluded to a particular part of the world (Australia, North America, and Europe). Some studies have suggested limits for certain parameters found in wastewater. For instance, Mehrdadi et al. [28] suggested the limits for COD and BOD for concrete mixing water to be 70 mg/l and 18 mg/l, respectively.

1.2. Reinforced concrete failure – overview

Structural failures have been in history for a very long time. In Babylon (1792–1750 BCE) there was a legal code of conduct stating that any house built by a builder experiences structural failure and causes the death of the inhabitant then the builder would be executed. In the European Middle Ages, due to its partly religious and economic diversity, people regarded structural failure as supernatural causes. The traditional materials used made buckling not a major structural problem and multi storeys structures were uncommon during this age. The construction of domes, arches and vaults in the roman times was consistent and formed a part of the European structure. There is a tendency to make sure important structures do not fail by using materials generously and as a result of that many roman architects survived till to day[29].

In the sixteenth century through to the nineteenth century, technological standard started increasing gradually. Building standards also increased but the sizes were predominantly the same as it was. The major cause of building collapse was poor construction that have always been one major cause as far back in centuries. Although technological changes in buildings were efficient, the various effects of those changes were not checked, thereby causing various collapse in the eighteenth century.

The standard of living have increased over the centuries, technological era causing greater ease of process of constructing buildings. Over the twentieth century into the twenty first century that is the present century, technology have aided in the construction of; better houses, high-rise buildings, aesthetic buildings and various buildings serving various purposes. In this century, buildings can be constructed using computer, in which building loadings are obtained and various risk assessments are made.

In the twenty first century in which there is technological advancement of buildings, numerous cases of structural failures are still being recorded over the years and leaving devastating effects. In the developed countries, structural failures are rare but its major causes are natural disasters. Where as in developing countries, structural failures consistently occurs yearly with various artificially induced causes. These man-made disasters such as; substandard materials, poor supervision, no drainage, nasty construction, structural defect, unqualified professional, over loading, poor quality material, no geotechnical investigation, old age, poor construction, illegal approval, illegal conversion, demolition process, lack of maintenance and numerous others, leads to the loss of large numbers of lives and properties.

2. Types of mixing water

Water is one of the main components of concrete as it helps to activate the binder and provides a workable mix. Mixing water for concrete can be obtained from different sources, and some of these sources includes freshwater, greywater,ground water, concrete wash water, river water, sea water.

Fresh water is suitable for human consumption (such as for cooking and drinking). Though this type of water might contain suspended solids, it is ideal for making concrete when the quantity of the suspended solids is relatively low. However, freshwater may be unsuitable for mixing concrete if it contains a high amount of potassium and sodium [11]. High potassium and sodium content in the mixing water would increase the overall available potassium/sodium, thereby causing an alkali-aggregate reaction when reactive aggregates are used to make concrete [30,31]. Grey water are the types of water obtained from household sources such as showers, bathtubs, and washing machines. However, greywater does not include the water from the toilet (water closet and urinals) and kitchen (sinks and dishwasher). Greywater is mostly used for mixing concrete after it has undergone treatment, as some of the impurities might pose a health threat to humans [32]. But the use of raw greywater for concrete mixing may deter its properties. Ground water is another source of water, but different in that it accumulates underground [33]. For instance, ground water can be found between spaces of loose particles of dirt and rock, and rock cracks and crevices. Generally, the amount of groun water varies with the types of rocks and dirt.

Concrete wash water **is** resulting water from the washing of concrete drums. Approximately 150–300 gallons of water is required to wash inside of a concrete drum [34]. This wastewater from concrete washing has a very high pH, which is between 11 and 12 [35]. The high pH is as a result of high limestone content in the solution. Also, the washing water contains dissolved solids from admixtures and cement used and chemicals as a result of the hydration of cement [36]. The Portland Cement Association sets a limit of 2000 mg/l for total suspended solids (TSS) to be present in the mixing water obtained from washing concrete mixer. This is to prevent interaction between the suspended solids and the new mix, which might alter the properties of the concrete. In addition, washing water contains high alkali and total solids due to the presence of cement and aggregates, respectively [15].

River water, comprising of water from rivers, vary considerably depending on the geology path of the river. Water from rivers is generally used for mixing concrete. However, care has to be taken when there are a large number of contaminants in the water, which mostly result from human activities.

Seawater is used for mixing concrete in developing communities. However, seawater contains a high amount of salts compared to river water, as it was reported that about 88% of its chemical constituents are sodium chloride [37]. The main composition of

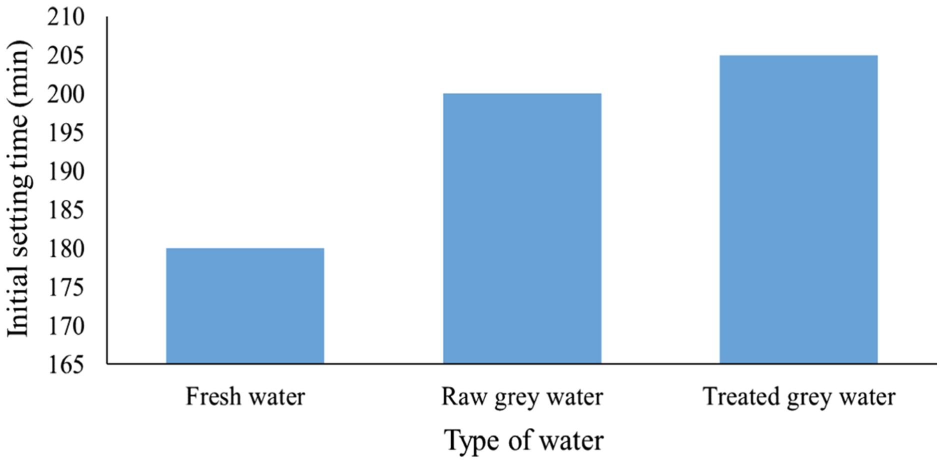

Fig. 1. Effect of treated and untreated greywater type on setting time of cement paste (data from [39]).

seawater is ions of calcium, chloride, magnesium, potassium, and sodium [37], and the pH value ranges from 7.4 to 8.4 [38]. Generally, water having a high amount of salt could be detrimental to concrete lifespan, as corrosion may set in and reduce the quality of the concrete.

3. Influence of the type of water on properties of concrete

Different reactions take place in constituent materials during concrete mixing, which are directly impactful on the physical and morphological changes in the matrix. The effect of various type of mixing water on the properties of concrete are as follows;

3.1. Initial setting time of cement paste

The presence of impurities in mixing water can alter the setting time of cement paste. In other words, the presence of contaminants in concrete mixing water can increase the setting time of the fresh mix. The delay in setting time is attributable to inhibition of the water reaction with cement caused by the impurities. However, in a study by Ghrair et al. [39], they reported a longer setting time for treated greywater compared to the untreated one as presented in Fig. 1.

The cause of the longer setting time for the sample with treated greywater could be due to the presence of dissolved salts, which tends to delay the hydration process. The initial setting time of cement paste has been reported to extend due to the presence of salts in treated water [3]. Besides, the presence of more salt in treated greywater compared to raw greywater would increase the setting time. Also, the increase in the ratio of water has been found to increase the setting time of cement paste [11]. However, in a study conducted by Ghorab et al. [40], it was reported that both the initial and final setting times were lesser when river water (from the Nile), groundwater, and seawater were used for mixing concrete than tap water concrete. Fig. 2 shows the effect of tap, river, groundwater, and seawater on setting times of cement paste. As can be seen, the use of seawater gave the shortest initial and final setting time. This could be attributed to the high percentage of salt in seawater.

Sodium chloride by 1.5% of the mass of the cement paste was detected in samples made with seawater, while other types of water

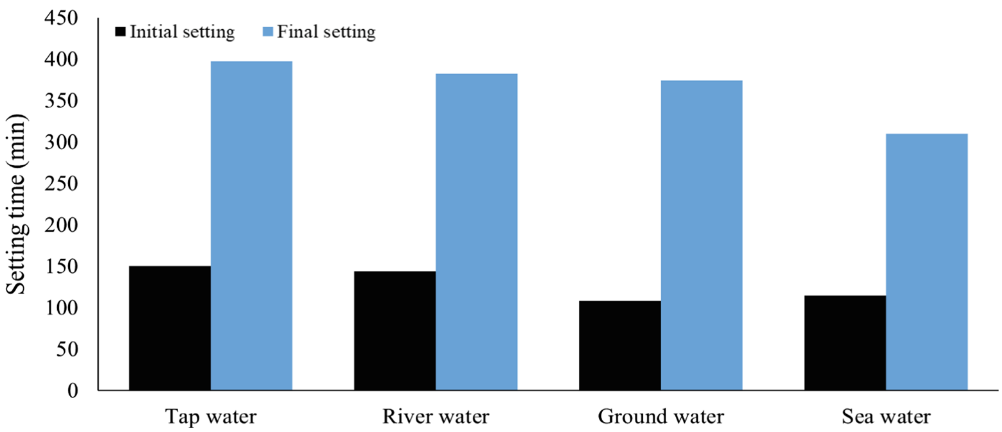

Fig. 2. Effect of tap, river, ground and sea water on setting times of cement paste (adapted from [40]).

gave an average of 0.25% [40]. The presence of a high concentration of lead in water, which is unable to react with calcium oxide in cement may increase the setting time of the cement paste. Also, the set times are also extended when there is magnesium hydroxide in the mixing water [41]. There are certain compounds such as carbonate and bicarbonates of potassium and sodium in mixing water, which, when present in concrete, can alter the setting time. The presence of sodium carbonates in a concrete mix reduces the time taken for the concrete to set. Whereas, the presence of bicarbonates in a concrete mix either increases or reduces the setting time of the concrete. Also, Asadollahfardi et al. [2] reported that the use of wastewater for making cement paste increases the setting time. The extension of the setting time by wastewater has been attributed to the presence of impurities, which delay the setting process. In a related study, Wegian [38] reported that the use of seawater for mixing concrete accelerated setting time. Also, the presence of calcium sulfate in mixing water has been found to increase the setting time. However, the rate of increase is reduced when a higher concentration of calcium sulfate is present in the mixing water [42].

Moreover, it was reported that mixing water with high pH increases the setting time of paste drastically. The higher the alkalinity, the more accelerated the setting times. This accelerated setting time has been attributed to the formation of gyrolite [42]. The presence of sulphuric acid or hydrochloric acid has been found to decrease the initial and final setting time of paste [43]. Thus, at about 300 mg/L concentration of the acid, a more significant shortening of the initial setting time could occur.

3.2. Effect on workability (slump)

Slump test is generally used to determine the workability of a concrete mixture. There is common notion in concreting, which infers that "the higher the slump of a cementitious paste, the more workable it is." The properties of the mixing water can influence the slump property of concrete. Using greywater to mix concrete can lead to a decrease in the slump, this is due to the presence of dissolved solids in the water that also increase the overall solids in the mixture [39]. The slump of concrete decreases when greywater is used to mix concrete [3]. Also, Al-Ghusain and Terro [17] reported that there was an increase in the slump when different wastewater with different treatment levels were used in mixing concrete. However, Asadollahfardi et al. [2] found no significant effect on slump when treated wastewater was used to make concrete. This non-consistent result in slump could be as a result of the drastic reduction of impurities in the wastewater after treatment. The use of concrete wash water does not have any significant effect on the slump [44]. Ismail and Hashmi [45] used resin wastewater to produce concrete. Their study indicated a decrease in the slump of mixtures with resin waste compared to mixtures made using freshwater.

3.3. Effect on compressive strength

The use of treated greywater for mixing mortar was found to have no detrimental impact on the strength of the mortar [39]. However, the use of raw greywater caused a reduction in the compressive strength of mortar. The impact of natural greywater treated greywater, and freshwater on the compressive strength of mortar is presented in Fig. 3.

The reduction in compressive strength can be attributed to the presence of a large amount of organic materials in raw greywater. As can be seen in Fig. 3, there was no significant difference between the compressive strength of mortars made with freshwater and treated greywater. However, using raw greywater as mixing water caused a significant reduction in compressive strength. Whereas, when similar water types were used for concrete production (Fig. 4), there was no significant difference in compressive strength. Similar observations were also made by Chini and Mbwambo [46]. Consequently, it can be deduced that the property of mixing water does not affect the compressive strength of the concrete.

Some attempts have also been made to replace freshwater with raw greywater [28] partially. However, there was no significant effect of mixing raw greywater and freshwater on the strength of the concrete. As presented in Fig. 5, Ghorab et al. [40] also reported that there was no significant change in the compressive strength of the concrete when different types of water were used to make concrete. The maximum difference in compressive strength observed from the study was 3 MPa. In a related study, Sandrolini and

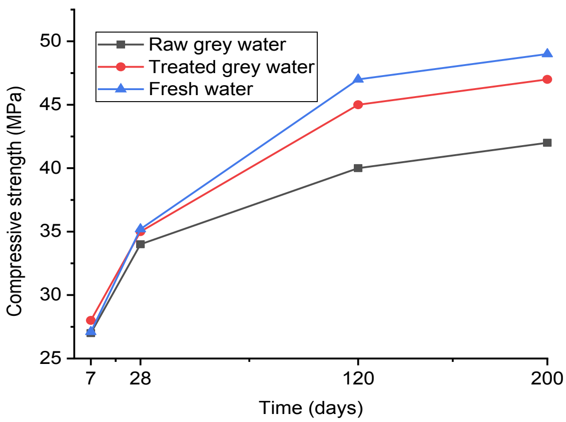

Fig. 3. Effect of water type on the compressive strength of mortar (data from [39]).

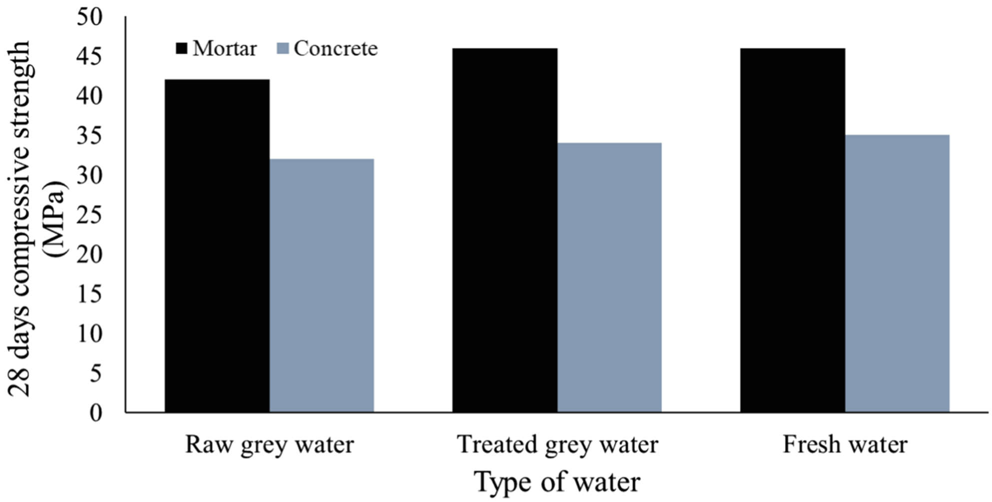

Fig. 4. Effect of water type on the compressive strength of mortar and concrete (data from [39]).

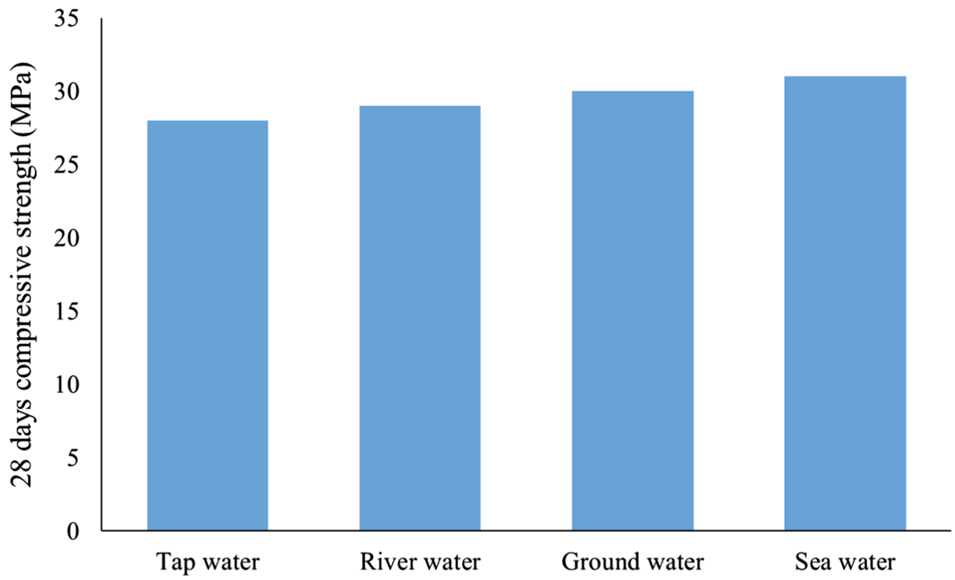

Fig. 5. Effect of tap, river, ground and seawater on concrete strength (data from [48]).

Franzoni [47] reported that there was no loss of strength when raw greywater was used to mix concrete

The presence of a higher quantity of magnesium sulfate in mixing water reduces the compressive strength of the mortar [49]. Also, the presence of magnesium chloride caused a decrease in the early strength of concrete when it reacts with slaked lime [50]. The reduction in early strength could be attributed to the formation of calcium chloride, which affects the hydration reaction between cement and water. Also, the presence of water-insoluble bases such as magnesium hydroxide (brucite) in wastewater causes a reduction in the compressive strength of concrete [41]. Reclaimed wastewater was also used as mixing water at different replacement levels of freshwater [51]. An increase was observed in the early ages; however, no significant difference was observed at later ages. Tay and Yip [52] also found that there was no significant effect on the compressive strength of concrete at later ages when portable water was replaced with reclaimed wastewater. Another report showed that the use of tertiary waste yielded higher strength compared to those made with potable water [53]. In another study, the strength of mortar and concrete produced using wash water was found to be higher than a conventional mix [47]. However, Chatveera et al. [15] reported a decrease in strength for a similar mix. In essence, the reduction in strength could be as a result of high pH or presence of solids, which makes the cementitious matrix porous. In another related study, Asadollahfardi et al. [44] reported that no significant difference in the compressive strength was noticed when concrete wash water was used for concrete mixing. Fig. 6 shows the effect of seawater and freshwater on the compressive strength of concrete.

The use of drinking water for mixing concrete, as recommended in standards, gives higher strength compared to those made with wastewater [2]. This again supports the need to use potable for concrete production. Seawater helps early strength development and

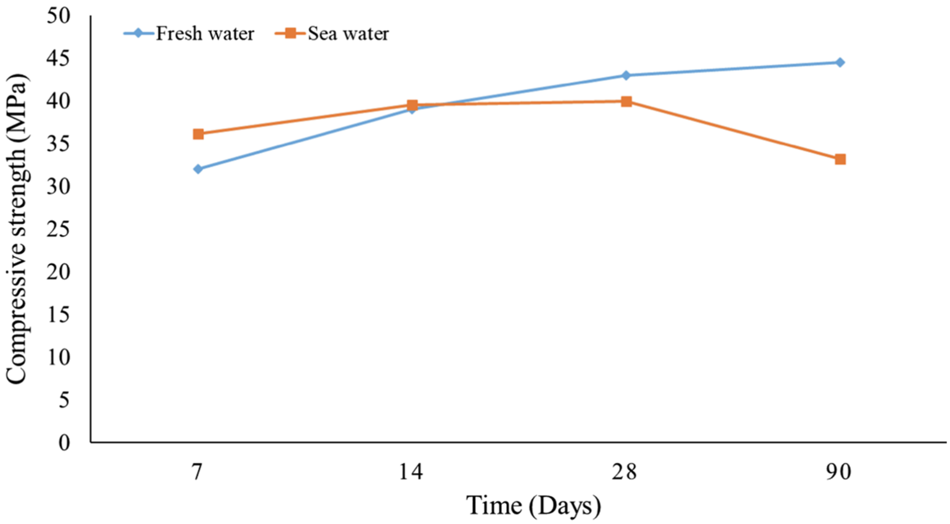

Fig. 6. Effect of seawater and fresh water on the compressive strength of concrete (adapted from [38]).

long-term durability in concrete than in those made with freshwater, but there was a reduction in the strength of the former at later ages [38]. This observation agrees with an earlier study [54]. The high early strength obtained in seawater concrete can be due to the acceleration of cement hydration by the seawater. However, seawater limitation based on reduction in strength of concrete at maturity may be due to defects from impurities in the water that gradually weakens the concrete. Although, this can be overcome by using mineral admixtures like metakaolin in concrete mixed with seawater, which can initiate pozzolanic reactions to render additional strength. Also, the use of mineral admixtures can provide pore refinement and filler effect in the cementitious matrix [55]. Similarly, higher strength was also reported when resin wastewater was used to mix concrete [45]. A summary of the effect of various water types on concrete compressive strength is presented in Table 2.

3.4. Effect on durability

Durability property is an essential requirement for concrete assessment. The durability of concrete can be defined as its ability to resist the detrimental forces in the environment to which it is exposed. As mixing water is an important component of concrete that participates in the chemical reaction, the presence of substances in the mixing water would consequently affect the durability of the concrete.

Some studies indicated that there was no substantial detrimental effect on durability when treated greywater was used for mixing concrete [3,39]. Also, the authors above obtained water absorption values of 1.69, 1.75, and 1.74% for concrete made with raw greywater treated greywater, and freshwater, respectively. Because the constituent materials (except water) and mixing conditions were the same for the concrete, then it could be suggested that raw greywater contained dissolved solids that render some filling effect in the concrete. However, water with a high amount of chloride should be avoided as the chloride ions in it may influence the corrosion of reinforcement bars or prestressing strands [62]. Kucche et al. [12] reported that water that possesses acidic properties tends to be more combative in action. Therefore, the high acidity level of mixing water creates a higher risk of acid attack on concrete.

Generally, the presence of acidic compounds in mixing water does not result in the expansion of the concrete. However, it

Table 2
Effect of various water types on concrete compressive strength.

Type of mixing water	Effect on concrete compressive srength	Source
Tap water	No effect	[56]
Treated industrial wastewater	No effect	[56]
Tap water + equal amount of treated industrial wastewater	No effect	[56]
Tertiary treated wastewater	15% reduction in 28 day compressive strenght	[57]
Secondry treated wastewater	Slight increase in compressive strength	[57]
Wastewater	7% reduction in strenght	[58]
Wastewater	No effect of high strength concrete	[16]
Grey water	no significantly reduction in compressive strength	[59]
Treated domestic wastewater	No significant effect on strength	[18]
Mixer truck wash water	higher compressive strengths up to 7 days	[60]
Industrial waste water	near or higher strength than conventional concrete	[45]
Seawater	higher strength at early age	[61]

dissolves a portion of the cement, thereby reducing its cementitious characteristics that lead to an overall weakening of the concrete. Due to this long-term detrimental effect on concrete, the use of mixing water containing a high amount of acidic compounds should be avoided. When the pH of water used for mixing concrete is below 12.5, it tends to behave aggressively with the concrete [63], because the decrease in the fluid alkalinity will eventually render the cementing material less valid. It is noteworthy that the rate at which the chemical reaction occurs also depends on the concrete permeability. For instance, concrete with low permeability and in contact with the fluid of pH above 6 will cause a slow attack in concrete. The attack on concrete will result in cracking, an increase in permeability, and a decrease in its ability to withstand the load. Addressing the issue of acidity and alkalinity, water with pH in the range of 6.0 to 8.0 is suitable for use in concrete mixing [53]. Besides, the water must be free of impurities or contain very minimal contaminants. When the surface resistivity method was used to test for the durability of concrete, it was found out that both treated water and freshwater give similar resistance [44].

The high amount of sodium chloride in seawater has made it a huge threat to the durability of concrete. Seawater is detrimental to concrete's ability due to its alkalinity reduction of the pore solution and the attack by magnesium sulfate crystallization. In addition, the presence of sulfate salts in concrete can lead to deterioration of the concrete due to sulfate attack [64]. The sulfate attack occurs as a result of the interaction between sulfate salts and calcium hydroxides. Notably, the attack of calcium hydroxide by magnesium sulfate, which produces a soluble magnesium hydroxide that causes damaging effects on the concrete [65]. In addition, the chloride ions that is present in seawater can reduce the alkalinity of concrete pore water leading to depassivation (a mechanism and process of corrosion in concrete and steel). The corrosion of reinforcing steel occurs below a pH of 11. Also, the sodium and potassium ions in seawater could lead to the propagation of alkali-aggregate reaction when reactive aggregates are used. However, the significant threats caused by seawater on the durability of concrete are corrosion of reinforcement and crystallization of salts in the concrete [66]. The crystallization of salts in concrete creates tension within the concrete [67], which might lead to expansion and crack formations. Also, seawater has been found to cause efflorescence and dampness when used in mixing concrete [41]. However, the use of seawater with metakaolin has been found to enhance the durability of the concrete [55]. The enhanced durability is as a result of the immobilization of the chloride ions by the formation of Friedel's salt. Akinkurolere et al. [68] reported that the use of seawater for mixing concrete is not recommended for plain and reinforced concrete exposed to marine environments.

The use of concrete wash water for mixing fresh concrete has been reported to cause drying shrinkage in concrete [15]. From the study mentioned above, the shrinkage of concrete increased with a corresponding increase in the percentage of concrete wash water used. In addition, there was a reduction in the weight of samples made with concrete wash water due to acid attack on the samples.

The presence of calcium sulfate in mixing water could result in higher early strength of concrete [42]. However, the effect is similar to that of seawater, which caused a reduction in the decrease in compressive strength at later ages. The high early-age strength could be attributed to the formation of tricalcium silicates as a result of the reaction between calcium and silicate ions. Whereas the decrease in strength with age has been ascribed to be due to the formation of ettringite in the matrix [42], and the loss in strength could be traced to acidic concentration in mixing water [49]. A significant decrease in the strength of concrete has been observed when the concentration of sulphuric acid and hydrochloric acid are 300 mg/L and 500 mg/L, respectively [49]. In the case of concrete made with car wash water, there was no significant difference in strength [16], and then, the strength increased with the age of curing independent of the ratio of wastewater used.

4. Review summary and suggestion for further studies

There are currently numerous data on the use of different water sources during the production of concrete. The familiar sources include freshwater, greywater, concrete wash water, river water, and seawater. Even though the standards for concrete production recommend potable water for concrete mixing, but there is currently a sustainable approach entailing the treatment of wastewaters in order to ensure their suitability for concrete production. The various effects explored concerning the use of different mixing water sources include slump, setting time, strength, and durability properties.

However, in developing countries where there is inadequate potable water supply in some locations, and without an effective water treatment scheme in place, the building contractors tend to utilize any available water source for concrete mixing. But, in structural concrete, the purity of the water used for concrete production cannot be overlooked, as this influences the hydration phenomenon and overall strength development in concrete. Thus, the causes of building failures that occur in the developing countries may be a factor of inferior concrete technology that pays less attention to intrinsic morphological changes in concrete.

In this study, based on the evaluation of the various effect of concrete mixing water on its properties, it is established that there is alteration in the intrinsic features of concrete due to reaction of water impurities with concrete constituents. It is clear from the review that the following types of water (tap, treated industrial wastewater, and grey water) have no observable effect on concrete strength. Whereas, other waters (tertiary treated wastewater and some other waste waters caused reduction in compressive strength of concrete. It should be noted that concrete mixer waste water and sea water positively influence strength properties of concrete by a noticeable increment.

Given these challenges, there is a need for investigations that will explore the phenomenon of mixing water for concrete in the developing countries, with a major focus on the water types on the fresh properties of concrete. Not so much data is available in open literature regarding setting time, slump and compacting factor of concrete incorporating wastewaters. Moreover, other issues to be resolved include hydration mechanism, mineralogical changes, crack integration, and porosity in concrete that is mixed using the locally sourced waters. There are currently insufficient data on this phenomenon in the available literature.

5. Conclusions

This review has explored the varieties of water sources that are available for mixing concrete. However, there is a notion that water has a significant influence on the strength and durability of concrete based on the rate of hydration and other issues. Hence, care has to be taken when different types of water other than drinking water are used to mix concrete. Based on this review, the following conclusions can be drawn;

- Mixing water should be free of impurities as much as possible. As the concentration or type of the impurity can affect the properties of the mortar/concrete. Greywater should be treated before it is used to mix concrete. In cases where raw greywater is to be used, it should use as a partial replacement of freshwater. The presence of organic materials in raw wastewater would lead to a significant decrease in the strength of the cement paste. However, there is no significant decrease in the compressive strength of the concrete.
- The effect of type of mixing water is more significant on the fresh properties compared to the hardened properties. Though most of the studies reported insensitivity of concrete's strength to the type of water used, however, the durability of concrete is very sensitive to the kind of mixing water. Overall, the use of treated wastewater is a viable substitute for freshwater used for mixing concrete.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.engfailanal.2020.104715.

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