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Authors: Amera Marey Mohammed-Hassanien, Mohamed M. Badawy, Ahmed El-Romy Sherihan Adel

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Utilization of treated water for building construction: A case study in Egypt

Reutilización de agua para la construcción de edificios: un estudio de caso en Egipto

Amera Marey Mohammed-Hassanien[1*] https://orcid.org/0000-0001-5667-4766 Mohamed M. Badawy[2] https://orcid.org/0000-0002-9642-8436 Ahmed El-Romy3 https://orcid.org/0000-0003-4470-0693 Sherihan Adel[4] https://orcid.org/0000-0002-9239-6369

[1]Basic Science Department, The Valley Higher Institute for Engineering and Technology, Al- Obour 11828, Egypt.

[2]Civil Engineering Department, High Institute for Engineering and Technology, Al-Obour (k21 Cairo/Bilbies Road), Egypt.

[3]Civil Engineering Department, The Valley Higher Institute for Engineering and Technology, Al-Obour 11828, Egypt.

[4]Architecture Engineering and Design Department, The Valley Higher Institute for Engineering and Technology, Al- Obour 11828, Egypt.

Corresponding author: Amera Marey Mohammed-Hassanien

e-mail: ameraraafat9@gmail.com

Abstract

Due to rising living standards and population growth, saving fresh water will be a significant problem for the next generation. The Government is indirectly impacted by a significant financial burden due to the current usage of treated wastewater, in all of Egypt's districts. As a case study, Egypt's new administrative capital was chosen, given that it is today one of the most important cities and that its planning was predicated on making it a smart, sustainable city. The goal of the study was to develop methods for replacing potable water in the manufacture of concrete with tertiary-treated wastewater; however, used for concrete mixing or curing after concrete hardening. Property assessments of the fresh and hardened concrete were conducted, to ascertain the best water quality that can be used without compromising the quality or durability of the concrete. ; The results of this paper will serve as a guide for decision-makers looking to decrease costs and increase sustainability by using treated wastewater in making sustainable concrete for buildings, especially in recent decades, rising construction material usage has generated considerable environmental difficulties, particularly in the production of Ordinary Portland cement (OPC).

Keywords: water reclamation; water reuse; sustainable concrete; splitting strength; capital city; compressive strength; slump

Palabras clave: recuperación de agua; reutilización del agua; hormigón sostenible; resistencia a la tracción; ciudad capital; resistencia a la compresión; revenimiento

Resumen

Debido al aumento del nivel de vida y al crecimiento demográfico, el ahorro de agua potable será un problema importante para las próximas generaciones. Los gobiernos se ven indirectamente afectados por la alta carga financiera debido al uso actual de aguas residuales tratadas en todos los distritos de Egipto. Como caso de estudio, se eligió la nueva capital administrativa de Egipto, dado que hoy es una de las ciudades más importantes y que su planificación se basó en convertirla en una ciudad inteligente y sostenible. El objetivo del estudio era desarrollar métodos para reemplazar el agua potable en la fabricación de hormigón con aguas residuales tratadas terciariamente, pero utilizadas para mezclar o curar el hormigón después del endurecimiento. Se realizaron evaluaciones de las propiedades del concreto fresco y endurecido para determinar la mejor calidad del agua que se puede utilizar sin comprometer la calidad o durabilidad del concreto. Los resultados de este documento servirán como guía para tomar decisiones que busquen disminuir costos y aumentar la sustentabilidad mediante el uso de aguas residuales tratadas en la fabricación de concreto sustentable para edificios, especialmente en las últimas décadas, el creciente uso de materiales de construcción ha generado considerables dificultades ambientales, particularmente en la producción de cemento portland ordinario (CPO).

I. Introduction

Egypt Government places a significant emphasis on the subject of water in terms of protecting its water resources and effective management, which has been translated into numerous, thorough, and detailed legal agreements with the nations of the Nile River, requiring them to fully comply with the agreements [1]-[3]. With population expansion and changing consumption patterns, the usage of natural resources grows dramatically. Due to rising demand, drought, groundwater depletion, and contamination, settlements face problems with their water supplies. By generating new sources of high-quality water supplies, water reclamation, recycling, and reuse might be a strategy to overcome some challenges with water resources. Water scarcity affects up to 1 million people annually and is a persistent water catastrophe [4]. Water scarcity impacts large rural and urban populations, as well as the environment and agriculture. Due to the limited supply of water, especially in arid and semiarid regions, water consumption must be reasonable. Reusing water is among the best ways to conserve it. According to recent water reuse studies, replacing treated wastewater with irrigation water and industrial use water is the best water reuse strategy that is both commercially viable and generally accepted [5],[6]. Although there have only been a few studies on the subject, Farid H. Abed undertook one to study the replacement of fresh water using brackish groundwater and oily production waters in base course layers in sustainable pavement construction [7], [8].

Complex systems that comprise sewers, chambers, pumping stations, maintenance holes, and wastewater treatment facilities make up modern wastewater management networks [9]. Sewage water is primarily derived from residential sources, and it is primarily composed of water, with 0.1 percent of soluble, suspended, and settable organic and inorganic materials. Thus, sewage water is cleaned in a sewage treatment facility before being released into an inland river. Currently, rivers receive the treated effluent from sewage treatment plants. This treated effluent can also be considered as a potential source of water for particular applications with sufficient water quality control [M. Maeda et al. [10]]. In wealthy nations, sewage treatment plants treated effluent has been successfully applied to agriculture and industries [11], [12]. One of the current options to use in building such projects and many other works is to use treated water and wastewater, which is regarded as a non-conventional water resource. According to estimates, this water resource contributes 70 million cubic meters (MCM) [per year], which, if used sustainably and responsibly, may be a reliable source of water (American Public Health Association [13]).

Cement, lime, polymers, and other bonding agents, as well as fine and coarse aggregates, water, and other ingredients, come together intimately to form concrete. The dry mixture of aggregates and bonding agents forms a plastic mass when water is introduced, which is then simple to shape and sculpt into the required shape]. Around 7% of the world's total carbon dioxide (CO2) is produced by this cement [14]. Cement Concrete (CC) has varying properties based on its constituents, which include relative and exact amounts of water. As a result, it is the most important building and architectural material in the world because of its formative ability to change its components, site preparation procedure, and curing process. In the same context, the components are made up of four major ingredients: water, Portland cement, aggregates, and air, comprising two parts (aggregates and paste). Aggregates are classified as fine or coarse and make up 60 to 80 percent of concrete. The paste is made up of cement water and entrained air and typically accounts for 20% to 40% of the total composite amount [15]. Due to the necessity for high temperatures during the cement production process, there is also a significant energy requirement, which raises the overall cost of production [16], [17]. Concrete production rates have been continuously rising in recent years due to development, and they will do so in the years to come [18], [19], and [20]. The phrase "green concrete" (GC) refers to concrete that has reached the plastic stage; Many long-term properties of GC essentially replace those of CC.; For example, it is defined as concrete that contains recycled materials as one of its components, or concrete whose manufacturing method is environmentally friendly and provides great performance throughout the life cycle of a building [21], [22]. Moreover, due to their ability to use innovative technology and alternative ecologically friendly materials, GC materials play an important role in decreasing the environmental impact of construction activities [23], [24]. As a result, GC has the ability to achieve both the environmental and economic goals of long-term development. Tests must be conducted on concrete in its plastic and stiff states to determine its workability, segregation, bleeding, hardness, strength, durability, and permeability [25]. In concrete plants, water is used extensively for various purposes, including manufacturing concrete and cleaning patios, washing concrete mixer trucks, and sprinkling aggregates with water to lessen dust [26].

Regarding water utilization, using wastewater instead of potable water can make concrete production more environmentally friendly. Water is used in significant amounts in the building and public works industries, particularly in the production of concrete [27]. In fact, concrete ranks second in terms of global usage only to water (10 billion m^3/year, or 1.5 m^3/person) [28].150 liter of mixing water is used to manufacture one cubic meter of concrete [29]. For washing concrete pumps, equipment, aggregates, curing concrete, and ready-to-use concrete, enormous amounts of drinking water are required [30], [31]. As a result, the study of the life cycle analysis of building materials is significantly impacted by the consumption of water resources. It is critical to decrease fresh water consumption in all industries, especially the building sector, as water becomes more limited [32]. The construction of 1 m^3 of concrete (with a cement: sand: gravel ratio of 1:1.08:1.96 and water: cement ratio of 0.44) may use more than 220 L of water because water consumption is dependent on the ratio of water to cement [33]. In the case of the presence of hydroxides and carbonates as well as the enhanced particle concentration, concrete mixed with wastewater exhibits high pH values, between 11 and 12, and high alkalinity [34]. Due to these features, the effluent must be treated before being disposed of, whether in water or soil. It is important to eliminate impurities impairing the concrete's setting time, construction, and durability. These impurities can interfere with cement hydration reactions and the synthesis of its components in the water used to mix the concrete.

The development's environmental impact can be reduced by using water wisely throughout the process. It is important to use as little water as possible when building a structure, and disposing of old and contaminated water properly will help minimize the environmental impact of construction. Design and construction methods used in sustainable architecture avoid or reduce the damaging effects that the construction sector has on the environment [35]. Most well-known sustainability initiatives strongly emphasize on energy efficiency and the environment, water quality and resources, site selection and development, indoor environmental quality, and material quality and resources. Getting closer to better sustainability is difficult because of the aforementioned complicated interrelationships [36]. In this context, this study aims to use treated wastewater (TW) instead of potable water to produce concrete for Egypt's new administrative capital city and to explore ways to save the nation with vast quantities of clean water, especially in light of the current water crisis [37]. This work set out to find ways to partially or entirely substitute tertiary-treated wastewater for potable water in the production of concrete. Property evaluations of the freshly laid and cured concrete were implemented in order to determine the best water quality that may be used without sacrificing the quality or longevity of concrete.

II. Materials and methods

From the sewage treatment plant at The Valley Higher Institute for Engineering and Technology, Al- Obour, Egypt, samples of reclaimed wastewater (TWW) were taken and chemically examined according to The Egyptian Code for the Design and Implementation of Concrete Structures 2017. The analysis was completed in the Central Laboratory (the Water and Soil Analysis Unit), at the Desert Research Center (DRC). Furthermore, potable water (PW) was evaluated for comparison purposes. Also, this section describes the experimental work performed through this study, beginning with the used materials, specimen details, measurement devices, test setup, and specimen grouping. All materials used to manufacture concrete were also examined. Ordinary locally available concrete constituent materials have been used to manufacture the test specimens. All specimens are made from one concrete mix with the proportion shown in Table 1. The target standard 28-day compressive cube strength f_{cu} = 40 MPa, and according to the equivalent compressive cylinder strength $f_c^{'}$ = is 32 MPa. The results of testing cubes have satisfied the target strength. Data of Egypt's new administrative capital city Projects 2022 were taken from the Engineering Authority of the Armed Forces, which are displayed in Tables 7 and 8**.**

Table 1. Mix design proportion (Average Strength= 40 MPa)

Material	Dolomite	Sand	Cement	Water
Mix Proportion (Kg/m^3)	1120	585	500	200

Four groups of 60 concrete standard cubes and 24 standard cylinders were cast. Each group consists of 15 cubes divided into 3 cubes that were tested after 7, 28, 90, 180, and 365 days. A direct tensile split test was conducted directly on 24 standard cylinders after 7 and 28 days for the four groups, each reading representing the average value of 3 specimens. The first group was cast with fresh normal water, and cured with fresh normal water as a control specimen. The second group was cast with fresh water but cured with treated water. The third group was cast with treated water but cured with fresh water. Finally, the fourth group was cast and cured with treated water. Table 2 describes tested cube specimens for each group, while Table 3 represents the chemical characteristics of concrete mixing water according to ECP 203/2018 to show the quality of water use; additionally, Tables 4 and 5 refer to the physical and chemical characteristics of treated wastewater, and Table 6 reports the standard requirements for Potable Water according to World Health Organization.

Table 2. Uses of Potable water and waste-treated water for Tested Groups

Group no.	Casting Water	Curing Water
1	Potable Water	Potable Water
2	Waste Treated Water	Potable Water
3	Potable Water	Waste Treated Water
4	Waste Treated Water	Waste Treated Water

Table 3. Representation of the chemical characteristics of concrete mixing water according to **ECP 203/2018.** [38]

Parameter	Results
pH	7
TDS gm/L	2.00
Chloride gm/L	0.50
Sulfate gm/L	0.30
Carbonate and Bicarbonate gm/L	1.00
Sodium Sulfide gm/L	0.10
Organic Substances gm/L	0.20
Inorganic Substances (Clay and suspended particles) gm/L	2.00

Table 4. Physical and Chemical characteristics of treated wastewater (TWW)

Parameter	Results
pH	6.1

Electrical conductivity (EC) µS/cm	394
Total dissolved solids (TDS) mg/L	241
Calcium mg/L	29
Magnesium mg/L	17.7
Sodium mg/L	20
Potassium mg/L	11
Carbonate mg/L	0
Bicarbonate mg/L	230
Sulfate mg/L	10
Chloride mg/L	38.3

Table 5. Representation of the analysis of Heavy metals in treated wastewater

ement	**Ag**	**Al**	**Ni**	**B_1**	**B_2**	**Ba**	**Mn**	**Ca_1**	**Ca_2**	**Cd**	**Sb**	**Co**	**Mg**
its	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**Cts/S**	**ppm**	**pp**
erage	-0.368	0.4744	0.0388	- 0.2428	0.1702	0.0485	0.0448	20.75	34.90	0.0016	zero	-0.027	13.
ddev	0.0820	0.4618	0.0574	0.8133	0.1148	0.0126	0.0554	18.76	2.34	0.0284	zero	0.0981	0.9
RSD	223.0	97.36	147.8	334.9	67.41	25.92	123.6	90.42	6.702	1772	zero	361.7	7.0
1	0.0309	0.3645	-0.044	- 0.7124	0.1040	0.0462	0.0931	3.768	35.45	0.0327	z 5.733	-0.082	13.
2	- 0.0132	0.0774	0.1040	- 0.7124	0.3027	0.0621	0.0572	40.89	36.92	-0.05	z 5.467	0.1079	14.
3	- 0.1280	0.9812	0.0169	- 0.7124	0.1040	0.0373	- 0.0157	17.59	32.34	-0.0229	z 4.463	0.0554	12.
ement	**Cr**	**Cu**	**Si**	**Sn**	**Sr**	**Ti**	**Zn**	**Mo**	**Fe_1**	**Fe_2**	**V**	**Pb**	
its	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**Cts/S**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	
erage	- 0.2832	0.1730	1.819	35.83	0.3922	Zero	0.0213	0.0386	- 0.406	0.426	-0.139	0.0660	
ddev	0.3192	0.4862	0.073	8.35	0.0355	Zero	0.0327	0.0921	0.729	0.297	0.0442	0.670	
RSD	112.7	281.1	3.988	23.32	9.058	Zero	153.6	238.7	179.4	69.85	318.4	0.1016	
1	0.0236	- 0.1709	1.807	27.30	0.4079	z 23.40	- 0.0107	0.1400	- 0.418	0.234	-0.361	-0.463	
2	- 0.6135	0.7292	1.897	36.17	0.417	z 23.20	0.0547	0.0155	0.328	0.7690.819	-0.426	0.8199	

3	-0.2596	-0.0394	1.753	44.00	0.3515	z 22.50	0.0198	-0.039	-1.13	0.270	-0.370	-0.158	

Table 6. Standard Requirements for Potable Water

	ECP203 of potable water	**World Health Organization** [39]
T. D. S	500 mg/L	1000 mg/L
T. S. S	-	-
pH	6.5-8.5	6.5-8.5
COD	-	-
BOD	-	-

Table 7. Case Study: New Administrative Capital City (Cairo- [Egypt])

Building Use type	Project Title	Project Summary
Residential use	The residential district R1	Situated just to the north of the northern Sheikh Zayed axis, at the administrative entrance. The first residential district, R1, has many various residential buildings t constructed. R2, R3, and R8 are the last three residential districts.
	The residential district R2	It is close to the regional and central ring roads, the Cairo-Ain Al-Sukhna road, road, and other roads as. It provides all services inside the administrative capital the requirements of all citizens, including educational, entertainment, religious security, and public services.
Services use	Central bus station	The establishment of A new company to manage the smart transportation system in Administrative Capital, which is situated next to Knowledge City, parallel to the road and the northern axis of M, and includes planning for the establishment of fue stations, projects for the establishment of administrative buildings, as well as a nu recreational facilities.
	The banking district	The Administrative Capital Banks Complex is distinguished by its crucial and pr location within the Administrative Capital since it is close to the financial and district, one of the Administrative Capital's most significant and wel neighborhoods.
Recreational use	The People's Square	It is distinguished by the presence of 32 commercial buildings and 8 lit fountai situated close to the administrative district and the palace.
	Flagpole	It will be the tallest flagpole in the world, standing at 207.8 meters, and is one of Square's most significant features. The Egyptian flag, which is 60 meters wide meters high, will be flown above the sari, which is taller than the Cairo Tower.
Religious use	The mosque of Egypt	The mosque is being built on the highest hill in the Administrative City so that seen from all across the capital. It features the two highest minarets in Egypt, with of 140 metres, and is situated in the center of the government area of the new admin capital.
Educational use	The Military College	A variety of structures and organizations of the Egyptian armed forces, inclu Ministry of Defense, military universities, military hospitals, and service build being built as part of the strategic defense complex in the new administrative capi
Entrances	Gate 5	The Suez Road, the Regional Ring Road, the Ain Sukhna Road, the Axis of Hope Middle Ring Road are the main roadways where the gates are situated. As a resu

		gates were created with the most recent designs and international standards approp a significant and large project like the New Administrative Capital.
	Gate 6	The study's research components (the buildings on which the study is placed) wer to examine the outcomes of the research paper on the multi-use architectural bui terms of service, recreation, religion, and education usage.

Table 8. Egypt's New Administrative Capital City Projects: Engineering Authority of the Armed Forces data 2022

Reinforced concrete quantity (m^3)	**Quantity of water for reinforced concrete (L)**	**Quantity of water for normal concrete (L)**	**Quantity of normal concrete (m^3)**	**project Name**	**No**
1995426	349199550	85206625	486895	Residential district R1	1
1016111.313	177819479.8	40645224.38	232258.425	Residential district R2	2
22751.5	3981512.5	1568175	8961	Gate 5	3
3470	607250	11200	64	Gate 6	4

534746	93580550	21034125	120195	Central bus station	5
6860	1200500	165025	943	Development and expansion of the entrances to the capital	6
502964	88018700	44433550	253906	Banks Complex	7
1920	336000	158375	905	The new works of the people's arena	8
8944	1565200	1158500	6620	Flag column	9
148995	26074125	3383625	19335	Colleges and military institutes	10
5000	875000	52500000	300000	Egypt Mosque	11
117987484	20647809.7	7084962.5	40485.5	People's arena	12
4410175.297	763905677	257349386.9	1470567.925	Total	13

III. Results and discussions

All results for all tested groups are presented in Table 9. A comparison of Compressive strength for four groups is presented in Figure 1. The comparison illustrates that the values of compressive strength decreased when treated water was used for casting or curing concrete. However, the compressive strength of concrete for groups 2, 3, and, 4 decreased by 9%, 11%, and 12%, respectively, compared to control group 1, in which the average of these percentages presented values of compressive strength at different ages for concrete 7, 28, 90, 180 and 365 days, these were discussed in details in Table 8. The tensile splitting strength of the concrete was also compared at 7 and 28 days for the examined four groups, as presented in Figure 2. Procedures for casting and testing of concrete standard cubes and cylinders are presented in Figure 3. Slump and compacting factor testing for fresh concrete were conducted for all groups; it provides good agreement with ECP 203-2018 guiding values for slump ranges from 75 to 125 mm for reinforced concrete sections with steel reinforcement varied from 80 to 150 kg/m^3 and gives compacting factor value greater than 95% for the same reinforced concrete requirements. Figure 4 presents the slump and compacting factor for fresh concrete of group (1). Splitting tensile strength decreased by 10, 17, and 14 %, respectively, for groups 2, 3, and 4, which had good results in agreement compared to the control-tested group. From the failure modes of the standard cubes and cylinders, it is noticeable that some staining appears on a concrete surface, especially in the samples that were poured and treated with treated water, as presented in Figures 5 and 6, respectively. After completion of 7, 28, 90,180, and 365 days of the curing period, two cylinders for each concrete mix group were immersed in water for 24 hours, the concrete specimens were prepared, and initial weights of all cylinders were taken. After completion of every curing stage, weights of all cubes were taken again and registered as the final weight. The amount of water absorption in dried and cured cubes was calculated and compared in Table 10. This test is performed to determine the susceptibility of unsaturated concrete to the penetration of water. It measures the rate of absorption of water and other liquids into unsaturated concrete through capillary suction. Using treated wastewater for casting concrete had the highest percentage of voids (approximately 18%), which gave good agreement results compared to using potable fresh water for concrete casting (approximately 12%), Water mixing was the significant parameter that governed water absorption and void volume of concrete samples as presented in Table 10.

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Table 9. Compressive strength, splitting tensile strength, and slump, and compacting factor for all tested specimens

Group no.	Compressive Strength (MPa)				Splitting Tensile Strength (MPa)			Slump (mm)	Compacting Factor
	7 days	28 days	90 days	180 days	365 days	7 days	28 days		
1	330.37	434.70	512.95	521.70	573.85	11.70	16.70	56	0.98
2	304.10	405.50	470.40	477.90	520.90	10.40	15.20	58	

									0.97
3	291.90	394.50	453.70	460.20	497.10	9.60	13.90	55	0.94
4	283.80	388.90	445.30	451.30	478.40	8.60	12.80	56	0.97

Table 10. The average percentage of Water Absorption and Void Volume of Concrete Samples

Group no. / Age (Days)	**The Volume of Voids (%)**				
	7 days	**28 days**	**90 days**	**180 days**	**365 days**
1,3	9.40	10.70	11.60	13.40	12.00
2,4	12.20	15.23	14.08	17.70	13.77

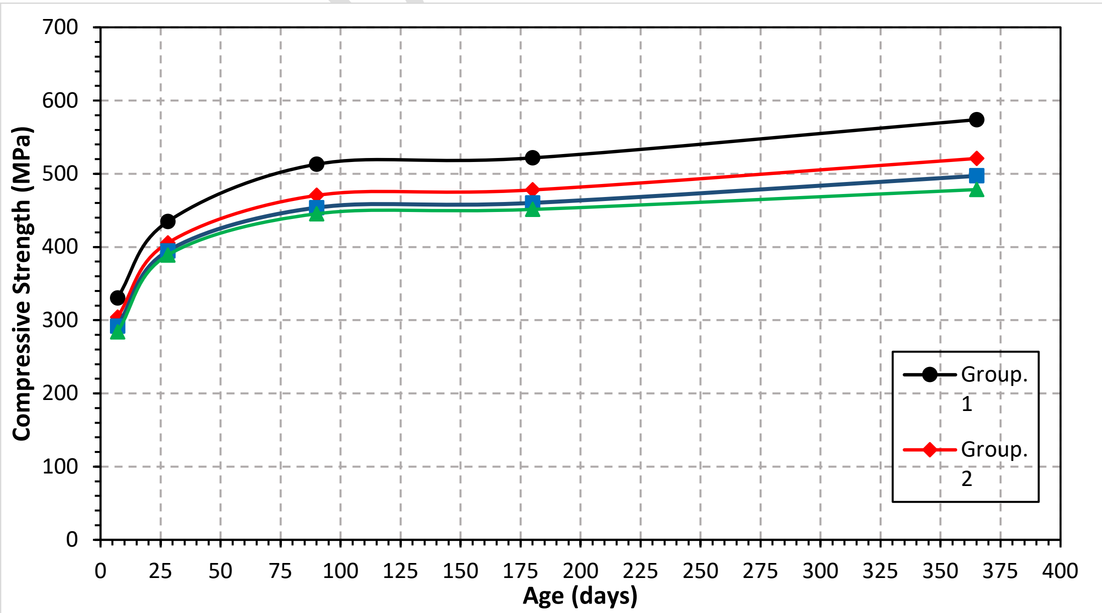

Fig.1. Presented Comparison of Compressive Strength for Tested Four Groups

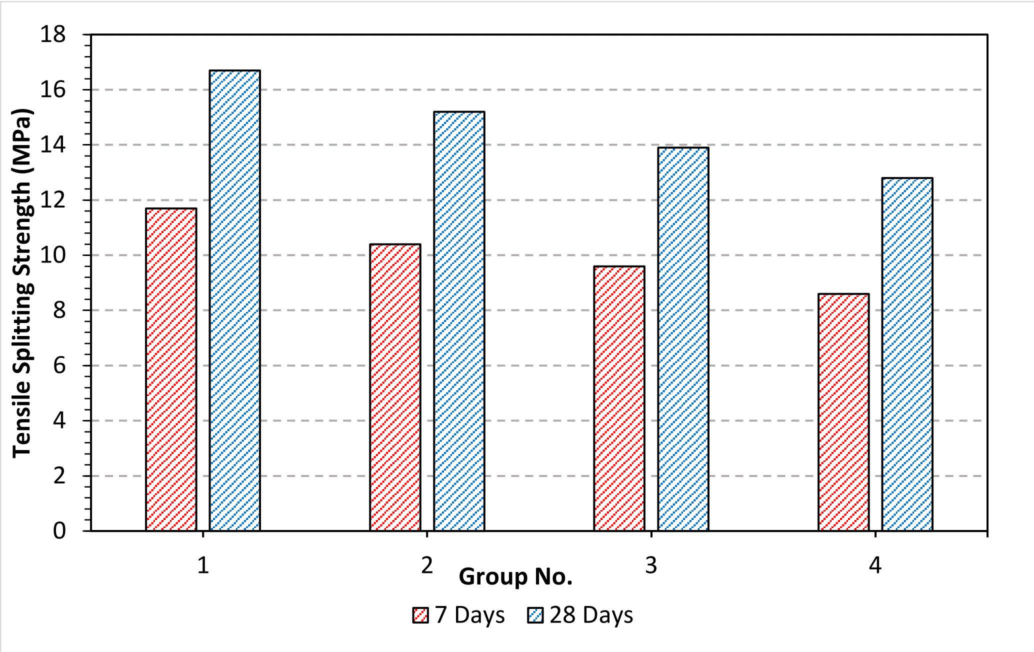

Fig. 2. Presented Comparison of Splitting Tensile Strength for Tested Four Groups

 Preparing Concrete Standard Cubes.	 Concrete Cube during Compressive Strength Testing.	 Preparing Concrete Standard Cylinders.	 Concrete Cylinder during Splitting Tensile Strength Testing.

Fig. 3. Preparing Standard Cubes and Cylinders during Casting and Testing.

	
Slump test	Compacting Factor Test

Fig. 4. Presented Slump and Compacting Factor Tests for Control Specimen

Group.1 Group.2 Group.3 Group.4

Fig. 5. Failure Modes of Standard Cubes for Examined Four Groups at Age 28 days

Group.1	Group.2	Group.3	Group.4

Fig. 6. Failure Modes of Standard Cylinders for Examined Four Groups at 28 days

IV. [Conclusions]

The results obtained from the experimental study of various concrete mixes showed that wastewater had no significant negative effect on the mechanical properties of concrete, so using wastewater will save about 257349.386 m^3 and 763905.677 m^3 for standard and reinforced concrete quantity for the current case study in new administrative capital. Slump value had no significant change when using treated water for concrete casting or curing and agreed with the Egyptian code of practice for the design of reinforced concrete structures ECP 203-2018. The findings show that the compressive strengths of concrete groups 1, 2, and 3 decreased by 9%, 10%, and 11%, respectively, in comparison to concrete cast and curing with 100% potable water. Based on the obtained laboratory results for ages 7, 28, 90, 180, and 365 days, wastewater had a minor effect on the compressive strength results of concrete; however, it was used for casting or curing concrete at different ages. Splitting tensile strength had no significant negative impact by using treated water except for specimens cured with treated water. From the paper results, the usage of partially or fully treated water may already have been reported, according to some observations; however, for pouring or curing concrete to save a considerable amount of potable water. The limits of this study are valid for concrete ages up to 365 days. The deficiency in compressive strength values of concrete is related to the number of tested samples and may vary with more samples.

V. **Recommendation**

For further research, it is recommended to:

- Examine more and more specimens from cubes and cylinders at different ages to validate the effect of using wastewater on compressive strength and splitting tensile strength of concrete.
- Examine the flexural strength of concrete through prism specimens to investigate the effect of using treated water, to cast or cure the results.

VI. Declaration of competing interest

I (We) declare that I (we) have no significant competing interests including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

VII. Funding

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VIII. Data availability statement

All procedures were carried out in compliance with the institutional and national research committee's ethical requirements.

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