A project

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Master of Construction Project and Cost Management

(MSc-CPCM)

Towards Sustainable Technologies in Reusing of Wastewater in Construction Industry: Challenges and Opportunities

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ABSTRACT

Reuse of treated wastewater is an important alternative in areas where freshwater shortages are lacking, or the cost of desalination water is extremely high. Wastewater is used all over the world for irrigation, yet the actual role in reusing wastewater in construction remains an ill-considered topic. Studies have revealed the economic, environmental, and social benefits of reusing wastewater.

The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage. The main aim of this research is to explore the environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. Thus, this study may open new opportunities for investment and utilization of wastewater.

The research methodology is designed in a triangular design method, where data (quantity and quality) were collected and analyzed with the aim of providing comprehensive information and finding new solutions to address the search problem. The purpose of using triangulation design is to compare and analyze qualitative and quantitative data to reach a common and effective solution.

The results of the survey were studied and discussed in order to cover all the main research objectives. The research results indicate that the reuse of wastewater is feasible but needs to be studied thoroughly in terms of cost and environmental impact. The results indicate that wastewater treatment plants in Muscat (Oman) are highly efficient and can be used in the field of construction. However, wastewater exploitation may pose significant challenges as Oman's infrastructure is not fully complemented by the presence of some sites dependent on sewage tankers. The results showed that there are no risks in the exploitation of treated wastewater in the field of construction.

The reuse of treated sewage will help achieve environmental, economic and social sustainability.

Keywords: Wastewater, environmental, economic benefits, investment, triangular design method, infrastructure.

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1 September 2021

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LIST OF ABBREVIATIONS

Circular economy	CE
Haya Water	HW
Station treatment plants	STPs
Membrane Bioreactor Technology	MBR
Cost of construction	C_c
Technical construction cost	C_{tk}
Expenditure costs	S_g
Profit	U_c
Labor	S_a
Materials	M
Transport	N_t
World Health Organization	WHO
Treated wastewater	TWW
Geographic information system	GIS
Remote sensing	RS
Recycled aggregate concrete	RAC
Compressive strength	CS
Sugar factories	SF
Service stations plant	SS
Fertilizer factories	FF
Potable water	PW
Domestic sewerage water	DS
Textile factory	TF
Split tensile strength	STS
Water absorption	WA
Chloride penetration	CP
Incinerated sewage sludge ash	ISSA
Waste treatment sludge	WTS
Water treatment residuals	WTRs
California Bearing ratio	CBR

European Union	EU
Sewage treatment plants	STP
Gulf Cooperation Council	GCC
Lifecycle assessment	LCA
Municipal sewage sludge	MSS
Technical cost modelling	TCM
Wastewater treatment	WWT
Supplementary cementitious materials	SCMs
Lightweight aggregates	LWAs
Silica	SiO_2
Aluminium oxide	Al_2O_3
Calcium oxide	CaO
Ferric oxide	Fe_2O_3

CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION

Constructions consumes a huge amount of water throughout the project cycle. With the development of the need to drain high amounts of groundwater and desalination in the world, the reuse of wastewater will be an important measure in solving the problems of lack of water resources and finding sustainable ways of water resources. Different techniques can be used in the reuse of treated wastewater while providing health and environmental safety, ensuring that risks not affect the ecosystem by following the obligations and laws specified by regulations in any country.

The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage in general and Haya in particular. Oman Wastewater Services Company (Haya company) is responsible for managing Oman's wastewater treatment sector.

The study aims to evaluate different disposal options of treated wastewater and sludge in terms of visibility in environment, cost, and various construction applications. Well waste management may help developing countries such as Oman to develop its economy. In addition, the feasibility of sanitation in construction projects and the challenges and opportunities that make reused wastewater sustainable need to be assessed. Cost and energy efficiency verification for reuse of wastewater treatment is required. Technologies need to be developed for assessing and reducing risks towards sustainable use of wastewater in construction projects.

The study requires assistance from environment authority, Haya company, construction sector and perhaps Oman Cement Company. Currently, the retreated water from Haya is used for irrigation and sometimes in dust suppression. The sludge is processed to make fertilizer (KALA). Thus, this study may open new opportunities for investment and utilization. The study also focuses on utilization of sewage sludge in cement manufacturing process or as a supplementary cementitious material (SCM) due to its chemical similarity with Portland cement produced by Oman Cement Company. In addition, the study of the use of Sewage sludge in paving roads and the use of treated water in concrete is necessary. Oman needs to find new ways to reuse treated wastewater waste. However, wastewater exploitation must be environmentally, economically feasible and socially acceptable. This study may help assess challenges and create opportunities to get rid of excess treated water and sludge in different respects for an easy decision-making model using multi-standard methods.

1.2 AIM & OBJECTIVES

The main aim is to obtain environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. The research have been objectives identified to achieve the research main goal and can be described as follows:

1.2.1 Objective 1:

Evaluating the potential and the effectiveness of reusing the treated domestic wastewater in Oman's construction industry.

Research Questions:

1.2.1.1 How effective is wastewater treatment and reuse in the Sultanate of Oman in the construction industry?

1.2.1.2 What are the processes of wastewater treatment used in the Sultanate of Oman?

1.2.1.3 What are the processes that should be selected that can reduce costs in wastewater treatment and investment in construction industries?

1.2.2 Objective 2:

Assessing the challenges and opportunities of managing and reusing wastewater in construction.

Research Questions:

1.2.2.1 What are the most efficient and effective ways to manage treated wastewater?

1.2.2.2 What are the wastewater reusing options?

1.2.3 objective 3:

Investigating sustainable techniques in implementing and analyzing risk assessment of sewage by-products that impact to the environment, the economy, and the society.

Research Questions:

1.2.3.1 How can management of treated wastewater provide sustainability in a developing country like Oman?

1.2.3.2 What are the main risks of using treated wastewater that affect sustainability in the construction sector?

1.2.3.3 How can the risks of using treated wastewater be identified and assessed in construction projects?

1.3 SCOPE OF THE STUDY

This study focuses on finding solutions to find sewage disposal options in an environmentally friendly, cost-effective and socially acceptable way to achieve sustainability. Managing the reuse of treated sewage and its derivatives in the construction industry may help increase investment and boost Oman's economy. In addition, this study will help overcome obstacles and challenges to find new ways that will have a positive impact on increasing economic growth, particularly in large and small projects in Oman.

1.4 SIGNIFICANCE OF RESEARCH

The reuse of treated wastewater in Oman will reduce the pressure on the use of groundwater and desalinated water due to alarming conditions in the scarcity of groundwater. The application of wastewater reuse technology has a positive economic impact, so the treated water derivatives can be exploited in the manufacture of different materials. This study may open up new opportunities for investment and benefit by studying the reuse of sewage sludge in road paving and other uses and the use of treated water in concrete. In addition, finding environmentally friendly, cost-effective and socially acceptable disposal options for getting rid of sewage sludge and treated wastewater is critical to sustainable development. Also, a comprehensive study of risk assessment, reduction and ways to develop different reuses of wastewater in construction projects have a lot of benefits in protect environment.

1.5 Chapters Organization

Figure 1 shows the chapters of the research and content of each part.

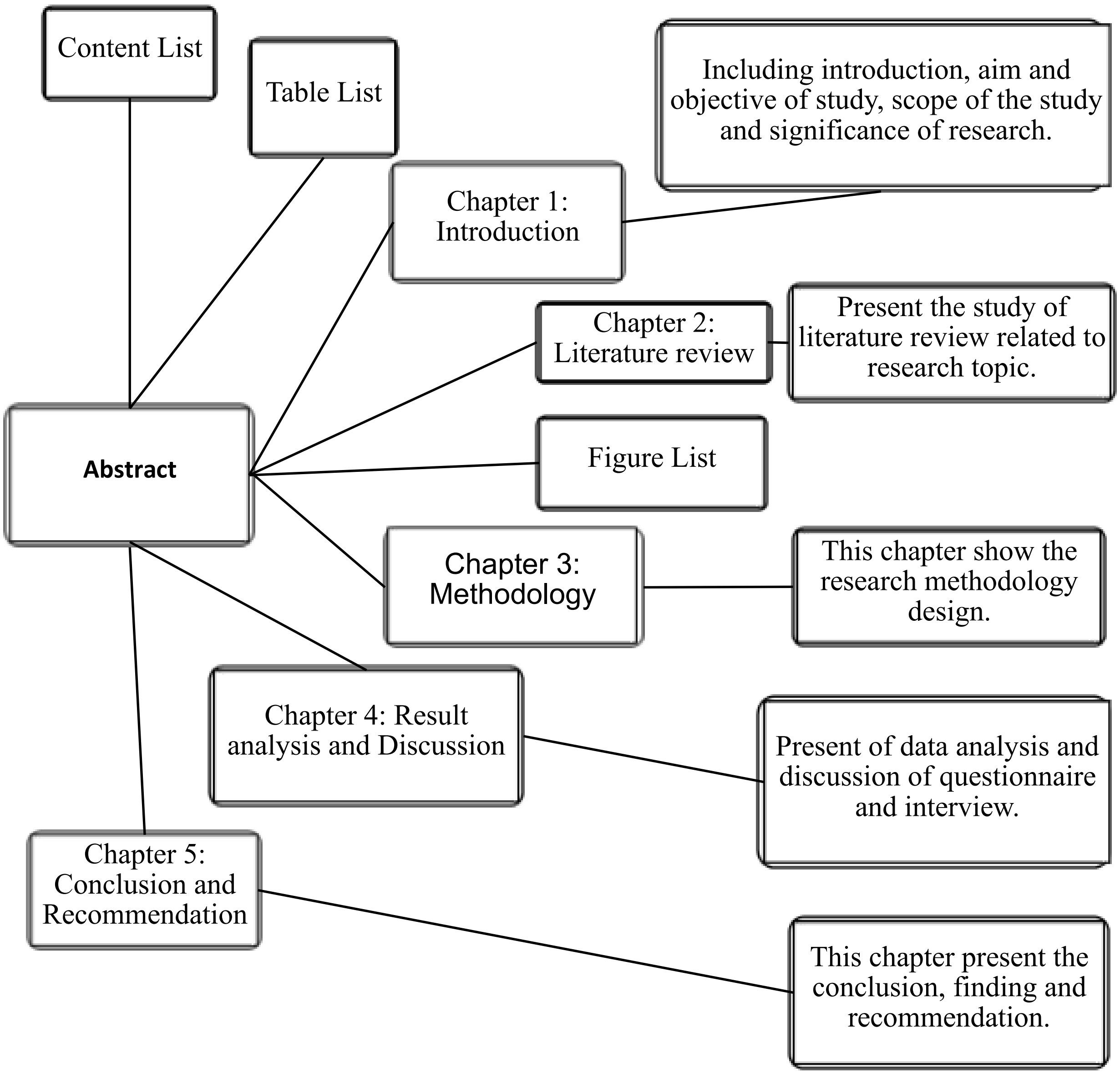

Figure 1: Chapters Structure

CHAPTER 2: LITERATURE REVIEW

2.1. INTRODUCTION

This part of the research provides a comprehensive review of the literature of previous research studies related to sustainable techniques, challenges and opportunities in wastewater reuse in the construction industry. The review is divided into six parts: (1) wastewater treatment infrastructure in Oman, (2) initial investment assessment of wastewater treatment plans, (3) wastewater reuse options, (4) Challenges and opportunities for wastewater management and reuse using circular economy (CE), (5) sustainable wastewater reuse technique, and (6) assessment of the risk of treated wastewater.

2.2 INFRASTRUCTURE OF WASTEWATER TRETMENT IN THE SULTANTE OF OMAN

Oman is considered one of the arid or semi-arid areas among the countries in the Middle East that suffer from water shortages where, the proportion of groundwater and surface water is about 87% (Aleisa and Al-Zubari 2017).

However, as a result of population growth and economic growth in Oman, demand for water resources will increase, leading to a deficit in the amount of water balance during the period 2000-2020. In order to meet the challenges and create opportunities to overcome the water deficit, the government's strategy focuses on increasing and improving different sources of water, increasing the number of wastewater plants, protecting the environment and finding ways to increase wastewater disposal activities. Oman has made progress in infrastructure through the implementation of the successive five-year plan, which began in 1976. Projects have been implemented to manage integrated water resources aimed at increasing the production of desalinated water and increasing production capacity at wastewater treatment plants (Jaffar Abdul Khaliq et al. 2017).

The government is implementing comprehensive strategic plans in the sanitation project that will cover all provinces of Oman at a cost of RO 1.1 billion, which will cover all provinces of Oman. The plan focuses on studying population forecasts, increasing water demand, estimating the amount of processed liquid waste production, and sludge generation (Text 2017).

2.2.1 Wastewater Management in The Sultanate of Oman

Oman Wastewater Services Company or Haya Water (HW) is the organization responsible for wastewater management in Oman. The Company was established by Ministerial Decision No. 31/2002 on 17 December 2002 to manage the treatment and collection of wastewaters. The management and operation of station treatment plants (STPs) belonged to the municipality of Muscat, but now all wastewater treatment plants belong to Haya company. The company follows the disposal of treated wastewater in accordance with the conditions of the Ministry of Environment, which prescribe the disposal of hazardous waste in an environmentally friendly manner and the use of modern wastewater treatment systems. In addition, the company is responsible for the construction and operation of the solids exploitation project for the sludge fertilizer (Baawain et al. 2020).

2.2.2 Process of Wastewater Treatment in the Sultanate of Oman

Wastewater treatment plants reduce the proportion of solid particles, organic matter, pathogenic bacteria, and substances that have a high impact on the environment such as nitrogen and phosphorus. Wastewater treatment plants are operating at different stages of treatment such as primary, secondary, and advanced (tertiary) stages(Mohammed et al. 2018).

The initial stage is called mechanical during which solid wastes are removed from wastewater. After treatment in the initial stage, wastewater is transmitted to the secondary stage, through which certain organisms are added to wastewater to break down organic matter and convert it into carbon dioxide and water. The advanced phase of wastewater treatment has the aim of removing the remaining materials that may exist after secondary treatment. Chlorine is added as the last disinfectant for wastewater(see Figure 2) (Mohammed et al. 2018). Increasing the proportion of untreated wastewater can cause significant damage and degradation to the environment. Wastewater odors from wastewater treatment plants may cause foul odors to spread in the air, affecting the comfort of people living nearby (Alsaidi, Dudin, and Jedidi 2021).

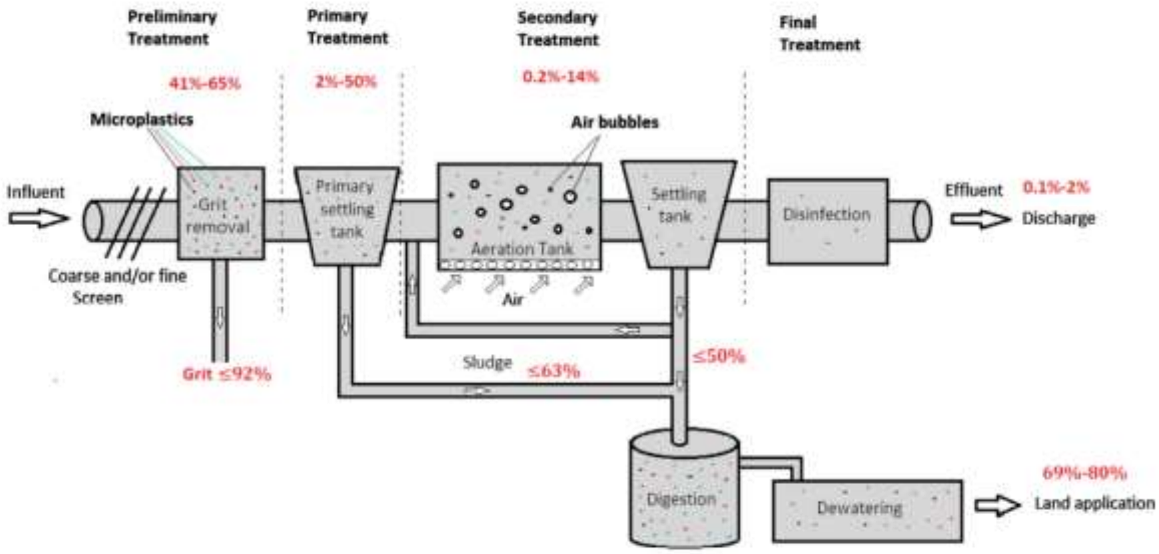

Figure 2**:STAGES OF WASTEWATER TREATMENT (Bakaraki Turan, Sari Erkan, and Onkal Engin 2021)**

Al-Ansab STP absorbs about 55,000 cubic meters/day and is part of the Muscat Wastewater Treatment Scheme project, which serves the second largest population area in Muscat province. Treatment of wastewater is carried out at the plant using Membrane Bioreactor Technology (MBR). The plant has six main wastewater treatment units: mechanical processing, secondary treatment, treated liquid waste storage plant, sludge separation plant, odor control system station, storage unit and chemical doses (Of et al. 2015).

A high percentage of wastewater is treated in Oman, but it is only used in agriculture. A comprehensive study is needed to explore the possibilities of using wastewater for multiple uses to support the economy.

2.2.3 The Wastewater Reuse Quality & Standards in Oman

The quality of treated sewage is controlled for reuse in Oman according to the Ministerial Decision 145/93 dated 13th June 1993 for the protection of the environment in Oman. This is including treated wastewater to be discharged into the environment or reused for irrigation purposes as shown in Table 1.

Table 1:Standards and Quality for wastewater reuse and discharge (Ministry of Regional Municipalities and Environment 1993)

PARAMETER	STANDARDS	
	A	**B**
Biochemical Oxygen Demand (BOD) (5d at 20˚C)	15	20
Chemical Oxygen Demand (COD)	150	200
Suspended Solids (SS)	15	30
Total Dissolved Solids (TDS)	1500	2000
Electrical Conductivity (EC) (micro S. / cm)	2000	2700
Sodium Absorption Ratio (SAR) (The effect of Sodium on soil absorption)	10	10
pH (within range)	6-9	6-9
Aluminum (AI)	5	5
Arsenic (As)	0.100	0.100
Barium (Ba)	1	2
Beryllium (Be)	0.100	0.300
Boron (B)	0.500	1
Cadmium (Cd)	0.010	0.010
Chloride (CI)	650	650
Chromium (Cr)	0.050	0.050
Cobalt (Co)	0.050	0.050
Copper (Cu)	0.500	1
Cyanide (CN)	0.050	0.100
Fluoride (F)	1	2
Iron (Fe)	1	5
Lead (Pb)	0.100	0.200

Lithium (Li)	0.070	0.070
Magnesium (Mg)	150	150
Manganese (Mn)	0.100	0.500
Mercury (Hg)	0.001	0.001
Molybdenum (Mo)	0.010	0.050
Nickel (Ni)	0.100	0.100
Ammoniacal (N)	5	10
Nitrate (NO_3)	50	50
Organic (N)	5	10
Oil and Grease (total extractable)	0.500	0.500
Phenols	0.001	0.002
Phosphorus (P)	30	30
Selenium (Se)	0.020	0.020
Silver (Ag)	0.010	0.010
Sodium (Na)	200	300
Sulfate (SO_4)	400	400
Sulfide (S)	0.100	0.100
Vanadium (V)	0.100	0.100
Zinc (Zn)	5	5
Fecal Coliform Bacteria (per 100ml)	200	1000
Viable Nematode Ova (per liter)	<1	<1

Table 2 show the types of reuse for irrigation purposes and any others reuse

applications which are used in Oman. The enactment of laws in reuse of wastewater treatment is in order to solve the problem of pollution caused by wastewater and the means of security for its use and management in different sectors.

***Table 2: Standers A & B of Application of wastewater reuse* (Ministry of Regional Municipalities and Environment 1993)**

TYPE	A	B
Crops	Vegetables likely to be eaten raw. Fruit likely to be eaten raw and within 2 weeks of any irrigation.	Vegetables to be cooked or processed Fruit if no irrigation within 2 weeks of cropping Fodder, cereal, and seed crops
Grass & Ornamental Areas	Public parks, Hotel Lawns Recreational areas. Areas with public access. Lakes with public contact. (except places which may be used for praying and hand washing)	Pastures. Areas with no public access.
Aquifer Recharge	All controlled aquifer recharge	
Method of Irrigation	Spray or any other method of aerial irrigation not permitted in areas with public access unless with timing control	
Any Other Reuse Applications	Subject to the approval of the Ministry	

There is only one law in accordance with the Law of the Ministry of Environment and Climate Affairs in Oman, which includes the characteristics and quality required for treated wastewater and the conditions for its discharge in the environment and reuse in agriculture. But there is no specific law for the reuse of treated wastewater in the field of construction.

2.2.4 Sludge Management

In the biological phase of wastewater treatment, a large amount of sludge is deposited. The cost of treating sludge is estimated at about 60% of the total cost of operating the wastewater treatment plant. Sludge is used in Oman for agricultural purposes. There are different ways to use sludge, such as turning it into fuel, mixing it with clinker to produce cement and in the manufacture of bricks, but there is no legislation allowing the use of sludge in Oman for construction industry purposes (Baawain, Al-jabri, and Choudri 2015).

The Kala fertilizer project was established by Haya Company in 2010 in Amerat (Muscat) with total area of 60,000 square meters. Kala fertilizer is used for agricultural activities only. Sludge Windrow System is used for manufacturing the Kala fertilizer. The fertilizer is manufactured using Windrow technology and has several stages starting from blending sludge with green waste. After mixing green waste with the sludge, the windrow is formed. Heat-loving fungi are then added for decomposition and pathogens are reduced in the presence of oxygen and burned at 55°C-70°C (Jaffar Abdul Khaliq et al. 2017).

However, Oman lacks strategic plans, guidelines, and measures to implement and prepare projects in wastewater reuse. Sewage treatment needs to be applied in various areas, such as reusing it in the construction industry.

2.3 EVALUATION INITIAL INVESTMENT COST OF WASTEWATER TREATMENT PLANS

Wastewater treatment and reuse is an important part of environment management. Some studies have shown the economic cost of sanitation treatment by cost accounting and management techniques (Jafarinejad 2017). The cost of resources consumed by processing plants, the cost of various activities used in processing of transportation, storage and reuse treatment wastewater are calculated. The actual cost of surface, groundwater and desalination is compared to the cost of wastewater treatment (Ruiz-Rosa, García-Rodríguez, and Mendoza-Jiménez 2016).

The study of wastewater treatment technology is important because wastewater treatment must be selected in accordance with actual local water requirements. Where the treatment methods are considered Biological Phase is the prevailing method of treating wastewater due to the cost and technical efficiency. In addition, choosing the right location for the wastewater treatment plant, the amount of water flow in the receiver and the type of land and its quality are important factors that need to be under consideration in order to achieve sustainability in terms of environmental, economic and urban aspects (Chen et al. 2018).

The cost of building wastewater treatment plant is a key factor to take into account. There are many factors that can affect the plan to build a wastewater treatment plant, so a larger budget value is generally set. Scientific ideas regarding the establishment of the sewage system are designed by developing and evaluating the plant's ability to control pollutants and the project plan for the construction of a treatment plant is designed to have more than 60% of processing plant capacity. The value of construction costs should include the costs of purchasing and installing various pieces of processing equipment required by different operations. This is in addition to the costs of management, pipeline maintenance, repair of equipment and labors cost (Chen et al. 2018).

The costs of civil works and electromechanical equipment for sewage treatment plants should be studied and analyzed. In addition, analysis of management and construction costs depends on the analysis of the cost of construction (C_c), which includes the technical construction cost (C_{tk}), operation and other expenditure costs (S_g) (15% of the construction cost) and profit (**U_c**) (10% of the total value of the construction cost and the general cost of the company) (Acampa, Giustra, and Parisi 2019). Based on independent variables is a linear equation:

$$\mathbf{C_c = C_{tk} + S_g + U_c} \qquad \textbf{Eq. (1)}$$

The cost of technical construction (C_{tk}) includes labor (S_a), materials (M) and transport (N_t) where variable factors depend on the quantities of materials required for construction and time (Acampa, Giustra, and Parisi 2019).

$$\mathbf{C_{tk} = S_a + M + N_t} \qquad \textbf{Eq. (2)}$$

2.3.1 Operating and Maintenance Costs of Sewage Treatment Plants

Operating and maintenance costs include annual fixed costs and variable costs. Annual fixed costs include maintenance costs, electronic equipment, measuring devices, vehicles, staff wages, management costs and contracting service fees with other companies. Variable costs include electricity charges and waste disposal costs (Moral Pajares, Gallego Valero, and Román Sánchez 2019).

A study of the wastewater treatment plant was conducted in Gebze (Turkey) and the annual operating and maintenance cost was found to be 16,900,000 TL per year. Operation cost varies in terms of the size and capacity of the processing plant, terrain characteristics, geographical location, sludge processing type, treatment techniques, power supply, sludge disposal, control, and plant management methods (Turkmenler and Aslan 2017). Table 3 shows the cost of operating and maintenance expenses at the wastewater treatment plant. The highest cost incurred in the plant is for sludge treatment and transport services which is worth 11,000,000 TL/year. In addition, the cost of maintenance, staff and energy represent the highest operating costs at the plant.

Table 3: Annual Operating and Maintenance Costs at the Gebze Sewage Plant (Turkmenler and Aslan 2017)

O&M items	Costs (TL/y)
Personnel services	4,000,000
sludge services (Removal and transportation)	11,000,000
Plant services (maintenance)	1,500,000
Energy services	250,000
Laboratory services	100,000
Measurement services	50,000
Total Cost	16,900,000

Maintenance is an important activity that must be taken into account, it is necessary for operation and can prevent damage that may occur in the future, which may be costly to repair. Maintenance costs include repairing all facilities at the plant such as mechanical, electronic, pumps, etc. Maintenance must be continued at regular intervals at least twice a year. Maintenance costs are calculated from the value and budget of the project (Turkmenler and Aslan 2017).

2.3.2 Revenues from Wastewater Treatment (WWT) Rate

Revenues must cover the costs treated at sewage plants in order to be able to finance treated expenses. The plant can be valued with financial capacity when revenue is equal to or above 100. Financial capacity depends on revenues and wastewater treatment costs, which can be estimated by the equation:

$$\text{Financial capacity} = \frac{\text{Revenues collected}}{\text{Treatment costs}} \times 100 \qquad \text{Eq. (3)}$$

Legislations have been enacted in Spain to impose sanitation fees. These taxes are used to finance, manage, study and protect the environment at sewage treatment plants. These taxes are important for increasing economic growth in order to finance investment, operating costs and maintenance at processing plants. In addition, these taxes are funded to unload, and reuse treated sanitation. The Spanish National Institute of Statistics provided information on sanitation revenue statistics and treatment in different regions of Spain. Statistics included tax amounts for the use and treatment of sanitation, environmental protection, operating and maintenance fees for wastewater treatment plants. The information in Table 4 shows the average values of sanitation revenues in Spain, estimated at 0.72 €/m3 during 2014. The average maximum value was 610,906,000 € in Catalonia. Catalonia's highest revenue was 1,340 (€/m3) and the lowest at Canary Islands was 0.370 (€/m3)(Valero et al. 2018).

Table 4: Average Values for Different Regions of Spain Collected From Wastewater Treatment Plants in 2014 (Valero et al. 2018)

Region	Invoiced Amount (€)	Revenues (€/m^3)	Estimated Revenues (€/m^3)
Andalusia	418,635,000	0.750	0.375
Aragon	73,280,000	0.760	0.380
Asturias	56,517,000	0.720	0.360
Balearic Islands	95.166,000	1.110	0.555
Canary Islands	53,816,000	**0.370**	0.185
Cantabria	36,131,000	0.750	0.375
Castile and Leon	94,668,000	0.410	0.201
Castile-La Mancha	67,524,000	0.460	0.230
Catalonia	**610,906,000**	**1.340**	**0.670**
Valencian Community	328,752,000	0.860	0.430
Estremadura	35,030,000	0.520	**0.173**
Galicia	81,438,000	0.440	0.220

Community of Madrid	311,654,000	0.770	0.385
Murcia	89,750,000	0.890	0.445
Navarre	32,266,000	0.670	0.335
Basque Country	132,930,000	0.910	0.455
La Rioja	13,262,000	0.600	0.300
Ceuta and Melilla	**5,073,000**	0.580	0.290
Maximum	610,906,000	1.340	0.670
Minimum	5,073,000	0.370	0.173
Average Communities	140,933,222	0.720	0.360

2.3.3Technologies Energy Efficient of Wastewater Treatment Plants

Energy consumption depends on the size of the processing plant, and power consumption at treatment plants can be divided into two main parts: direct energy consumption and indirect energy consumption. Direct energy consumption includes electricity for the operation of ventilation blowers and pumps. Indirect energy consumption involves consuming chemicals to remove phosphorus and remove sludge water. The lift sewage pump consumes 10-20% of the total energy consumed to treat wastewater. Representing of 10-25% energy consumption is to treat sludge. It represents 50-70% energy consumption in biological processing. To overcome the challenges of energy consumption at wastewater treatment plants, green energy technologies can be used. Green energy technologies include natural sources such as solar and wind energy (Guo et al. 2019).

The elimination of sludge in the treatment of wastewater is a problem affecting the social environment. Thermal drying techniques are used to reduce the size of sludge for water removal. Solar energy can be used in wastewater treatment because the sun is a renewable energy source. Figure 3 shows the use of solar energy at wastewater treatment plants. Solar heat is collected using a heat complex to raise the temperature to improve processing efficiency. In addition, solar energy is used to dehydrate the sludge and to desalinate the treated water. Photovoltaic cells are used to generate electricity at sewage treatment plants. Solar applications reduce electricity costs to remove pollutants in biological treatment.

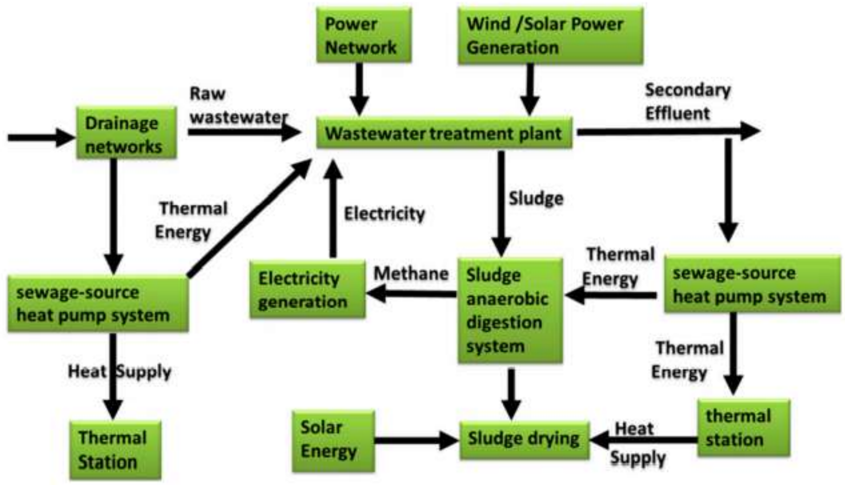

Figure 3: Solar Energy diagram of a wastewater treatment plant **(Guo et al. 2019) .**

Wind turbines can be used at wastewater treatment plants, where wind power is converted into mechanical energy. Wind is a renewable energy that can be used to generate electricity (Guo et al. 2019). The sun and wind are environmentally friendly and pollution-free sources but depend on the weather, making them hard-to-use energy sources.

2.4 THE WASTEWATER REUSING OPTIONS

A study (Akpan, Omole, and Bassey 2020) wastewater reuse was conducted in a civilized area of Canaanland/ Nigeria, which is a city considered located in the economic zone in Africa. The city witnessed rapid development and an increase in the population of about 13,000 people in 2020. A quantitative survey of the city was conducted to study the community's perception of wastewater treatment and reuse. The study targeted random individuals from Canaanland. The questionnaire included specific queries regarding applications for wastewater reuse, such as firefighting, washing (clothing and bathrooms), industrial use, power generation and swimming pools. The results of the survey showed that the reuse of wastewater in Canaanland involves many complexities associated with political, economic, environmental, and social factors (Akpan, Omole, and Bassey 2020).

Figure 4 shows the applications of recycling treated water for industrial uses, agricultural uses and groundwater recharging.

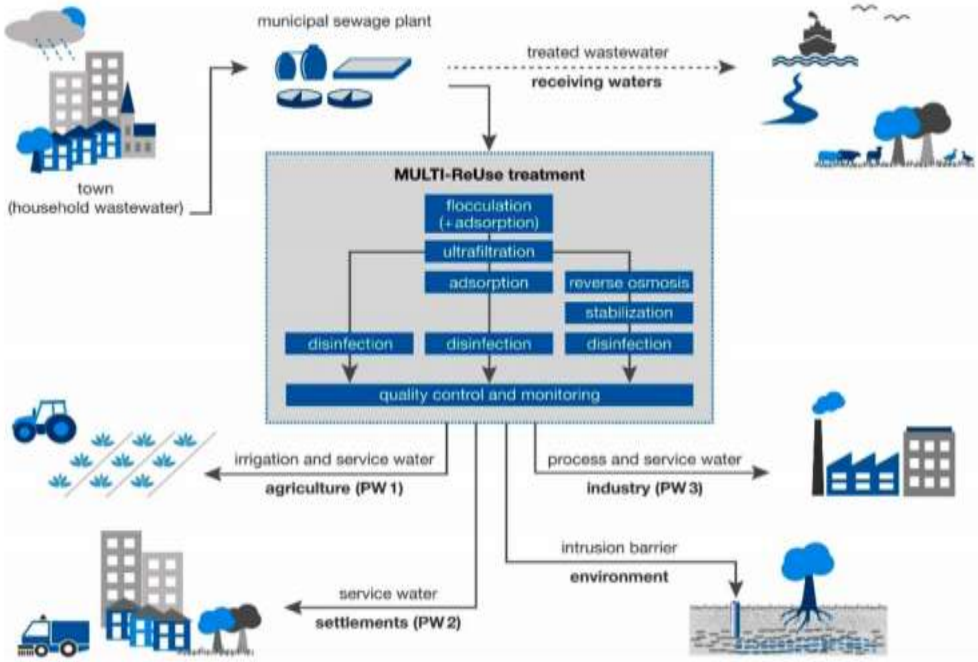

Figure 4: Practical blueprint for versatile processing technologies and applications
(Schramm, Becker, and Fischer 2020)

2.4.1 Urban Reuse of Wastewater Treatment

A wastewater reuse project was implemented in recycling in urban areas in Sweden (Kalmar). Reusing treated wastewater helps to relieve the growing demand for fresh water. Treated wastewater is used in urban areas in different activities. Treated water is used to fight fires, irrigate green flats, irrigate gardens, moisturize sand, feed groundwater and clean toilets (Hogland, Burlakovs, and Jani 2019). However, the technical requirements for reuse of treated wastewater have not been explained and analyzed.

2.4.2 Reuse of Treatment Wastewater in Agricultural

Exhaust water was first reused in Bunzlau (modern Poland) in 1531 and in 1650 it was used in Edinburgh (Scotland) for agricultural purposes, where farms are known as sewage farms. Wastewater based on irrigation and land fertilization has been used to produce useful agricultural crops. Population growth has led to more sewage farms being implemented in order to get rid of increasing amounts of wastewater. At the end of the 18th century sewage farms were applied in both Europe and the United States of America. In the late 19th century the concept of sewage farms was applied in Australia and is still used at the beginning of the 20th century (Angelakis et al. 2018).

In the 19th century, the reuse of wastewater in the world became a concern due to associated risks to health, society, and the environment. The elimination of untreated wastewater has led to the spread of catastrophic water-borne epidemics such as cholera and typhoid fever. In 1973, the World Health Organization (WHO) issued a document on wastewater treatment methods and sanitary conditions for treatment with the aim of proper use of wastewater and liquid waste in agriculture and aquaculture (Jaramillo and Restrepo 2017).

Treated wastewater (TWW) is used around the world to irrigate agricultural crops due to social growth and increased demand for food. TWW is used in France to irrigate agricultural crops where 700 hectares of corn, wheat and beetroot are grown. Also in Australia about 106 million cubic meters of treated sewage for irrigation for cotton and grain crops is used (Leonel and Tonetti 2021).

The plan of Saudi Arabia to target reuse of wastewater reuse is being made: 90% in agriculture, with the current use rate of 540 million cubic meters/yearly and expected in 2035 to increase. Egypt's plan aims to reuse treated wastewater (2,400 million m3/year) in agriculture. Tunisia's long-term objectives have been set by using 25,000 hectares of treated wastewater in crop irrigation and 30 million cubic meters of wastewater in groundwater recharge (Jasim et al. 2016).

2.4.3 Uses of Wastewater in Groundwater Recharge

Groundwater recharge is the process of moving water from the ground surface to the ground where, the water can be from nature through rain or industrial wetlands. Before starting groundwater recharge, the feasibility should be evaluating, and the location should be studied and the availability of adequate water sources should be checked. Treated wastewater can be used to recharge groundwater and is called industrial recharging. Choosing the right sites for the application of industrial nutrition is important, which depends on the analysis of location data and may take a long time. Treated wastewater should be tested before aquifer recharge of underground water. The wastewater has compounds, heavy metals and pathogens which may be harmful for human health. (Ahmadi, Mahdavirad, and Bakhtiari 2017).

A geographic information system (GIS) can be used to studying the location and topography, geology, and hydrology of chosen site. In addition, remote sensing (RS) technology characterized is the rapid provision of spatial and temporal data of the site and a cost-effective tool for studying and monitoring groundwater (Ahmadi, Mahdavirad, and Bakhtiari 2017).

Oman's treated wastewater is of high quality used in irrigation and afforestation. The recharging of industrial groundwater is applied in Salalah, where the total shipping is about 20K cm/day to prevent seawater leakage. The quality of treated water used to ship groundwater is monitored and tested by the Ministry of Agriculture and Fisheries in order to preserve the environment (Aleisa and Al-Zubari 2017).

2.4.4 Treatment of Wastewater to Reused in Power Generation

The sludge from wastewater treatment is an economic source of power generation and electricity supply for the operation of treated plants. In addition, gas is produced through anaerobic digestion of sludge, where bacteria decompose organic matter resulting in the production of methane, hydrogen, acetic acid, nitrogen and phosphorus. Figure 5 shows the steps of anaerobic digestion at wastewater treatment plants.

The amount of methane in biogas is high and can be used to generate electricity by burning sludge. A gas-fired engine is installed in certain places in the sludge treatment department, where electricity is generated by the engine. Electricity generated from biogas can be used to operate pumps and blowers in wastewater treatment plants. In addition, biogas can be invested in power plants and used instead of natural gas to power generators (Guo et al. 2019).

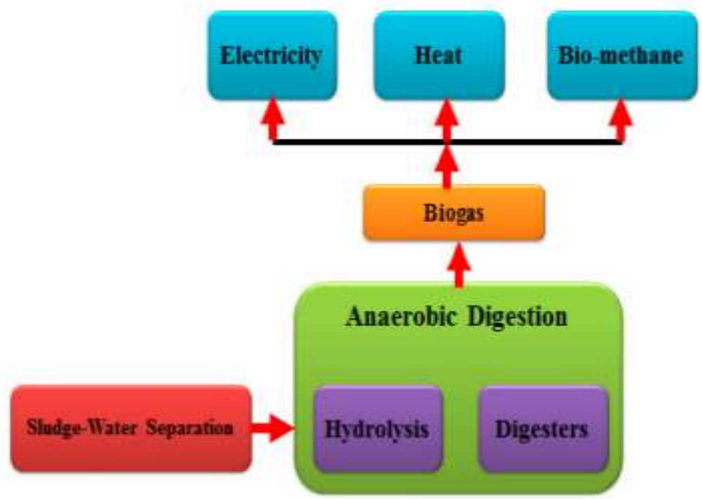

*Figure 5: The steps of anaerobic digestion of sludge in wastewater treatment plant***(Guo et al. 2019)**

2.4.5 Uses of Wastewater in Construction Industry

Rapid urban development and economic growth have led to increase the demand of building materials. The construction industry needs quantities of cement, bricks, and concrete clinker manufacturing, where the manufacture of these materials is highly related to dangerous gas emissions such as carbon dioxide. In addition, natural raw resources are consumed to produce building materials, affecting in human society and the environment. Increased of demand for building materials has led to find an alternative method from available sources and reuse of low-cost and environmentally friendly materials such as waste, treated sewage and industrial products (Pavlík and Záleská 2016).

2.4.6.1 Testing the Strength of Recycled Aggregate Concrete (RAC) by Using Different Types of Recycled Treated Wastewater

Concrete needs high amounts of drinking water by about 1 trillion gallons per year worldwide. In order to balance and provide freshwater use in construction, alternatives to water must be found such as using treated wastewater in ready mix concrete (Raza, Rafique, and Haq 2021).

Did test for Six different samples and using reusable materials. Recycled aggregate concrete (RAC) was used by cracking 1-2-year-old armed concrete with compressive strength (CS) rate of 30-45 MP and Portland cement (Grade 43) was used as a concrete bond material. In addition, water has been used from various sources such as sewage water from sugar factories (SF), wastewater from service stations plant (SS), wastewater from fertilizer factories (FF) and potable water (PW), domestic sewerage water (DS) and sewage water from textile factory (TF). The study aims to exploit wastewater in the field of construction, achieve mechanical performance and strength of concrete by using reusable materials to achieve sustainability (Raza, Rafique, and Haq 2021).

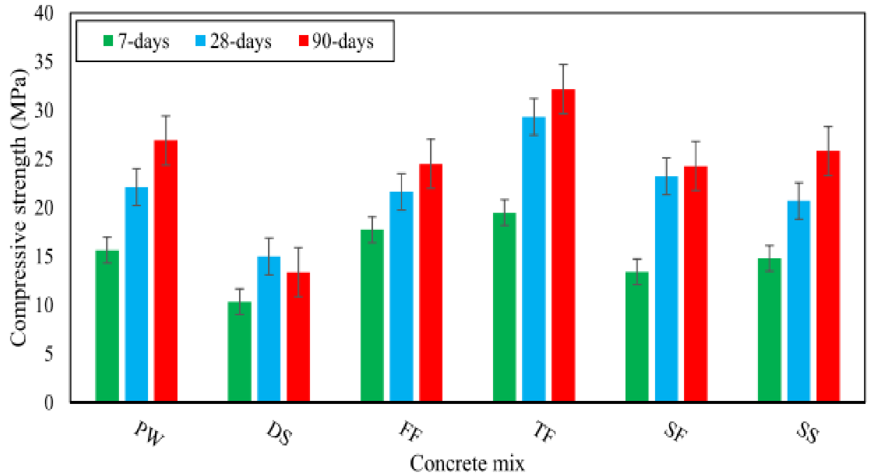

Figure 6: Compressive Strength of RAC During 7-28-90 Days **(Raza, Rafique, and Haq 2021)**

The chart above shows the results of the examination of the six RAC samples where, CS was measured in 7, 28 and 90 days. The results showed the wastewater from textile factories (TF) to produce RAC has a high capacity for concrete compressive strength (CS) at a rate of 32.2 MPa which is 19% higher than the use of drinkable water in concrete. The results showed that DS received the lowest value in CS due to increased sample absorption of water due to domestic sewage containing a high percentage of organic impurities.

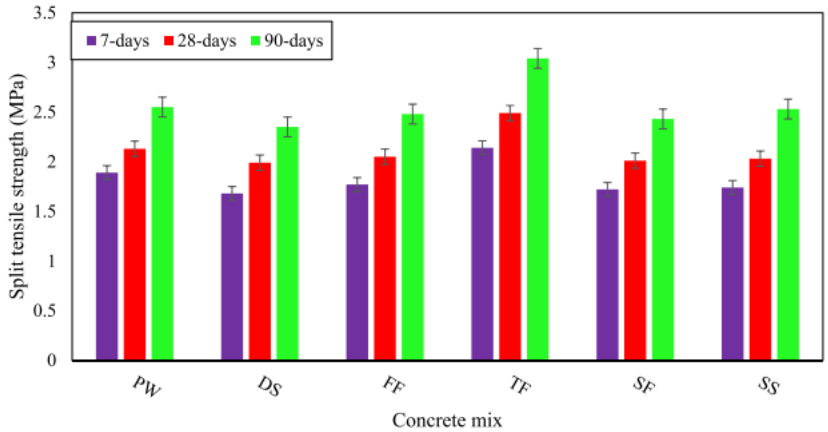

Figure 7: Split Tensile Strength (STS) of RAC During 7-28-90 Days**(Raza, Rafique, and Haq 2021)**

Figure 7 shows that RAC use in the concrete mixture has the ability to tighten STS and that its capacity increases in more than 90 days by 3.04 MPa with an average of about 16% higher than PW. The reason is that RAC ability to withstand tensile strength is increased because it contains less bicarbonate than other types of samples. High concentration of bicarbonate reduces the tension resistance to concrete. Laboratory results showed that DS mixed in the concrete mixture has the lowest value for tensile resistance compared to the PW blend.

Concrete samples that were used in exhaust water were studied and tested from different sources. Samples were examined and monitored by check compressive strength (CS), split tensile strength (STS), water absorption (WA), chloride penetration (CP), sulphuric acid and ANOVA test. The study showed that wastewater after treatment and study can be used for concrete instead of drinking water, achieving economic and environmental sustainability (Raza, Rafique, and Haq 2021). This study may help to exploit wastewater from factories to exploit in ready mix concrete industry which, helping to reduce the use of groundwater and preserve the environment.

2.4.6.2 Use of Sewage Sludge in the Fabrication of Cement

Large amounts of sewage sludge are produced during wastewater treatment. Approximately 1.85 million tons of sewage sludge are produced in Germany, 1.14 million tons in the UK and more than 12 million tons in China (Chang et al. 2020). In order to deal with the high quantities of sewage sludge, the Hong Kong government (China) in 2015 built the largest sewage sludge incinerator in world. About 90% of sludge can be reduced after burning but it is necessary to dispose of incinerated sewage sludge ash (ISSA) in landfill due to the lack of sludge recycling techniques. Thus, getting rid of sludge has become an urgent issue facing the countries of the world and must be disposed of properly and environmentally friendly (Zhou, Y. et al. 2020).

Sewage sludge contains a metal and chemical compound similar to clay and cement because of contains SiO_2, Fe_2O_3, Al_2O_3 and CaO. The dewatered sewage sludge is mixed with lime by burning at 1000-1400°C for at least four hours in the oven for the purpose of producing similar to cement material (Clinker). Incinerated sewage sludge ash (ISSA) can be an alternative material of 5%-15% of the raw materials of the cement industry. To ensure environmental security and safety requirements, the amount of sewage sludge added to cement production should not exceed 15% of the total weight of raw materials (Chang et al. 2020).

A test was conducted in samples of OPC/lime were mixed with different proportions of sewage sludge (ISSA) as shown in Table 5. The table shows that 10%, 20% and 30% OPC/lime of ISSA weight have been added to meet the strength requirements and to activate ISSA pozzolanic activity. The amount of water was added by 0.38 to the samples in order to obtain a standardized blend.

Table 5: The proportions of OPC/lime binder with ISSA samples**(Zhou, G. et al. 2020)**

Sample ID	**ratio of OPC/lime to ISSA**	**Equivalent % replacement**	**water to binder (w/b) ratio**	**Water (g)**	**OPC/lime (g)**	**ISSA (g)**
ISSA (only)	**0**	**0**	**0.38**	**190**	**0**	**500**
OPC-ISSA (10%)	**0.1**	**9.1%**	**0.38**	**209**	**50**	**500**
OPC-ISSA (20%)	**0.2**	**16.7%**	**0.38**	**228**	**100**	**500**
OPC-ISSA (30%)	**0.3**	**23.1%**	**0.38**	**247**	**150**	**500**
lime-ISSA (10%)	**0.1**	**9.1%**	**0.38**	**209**	**50**	**500**

lime-ISSA (20%)	**0.2**	**16.7%**	**0.38**	**228**	**100**	**500**
lime-ISSA (30%)	**0.3**	**23.1%**	**0.38**	**247**	**150**	**500**

A pure ISSA sample cannot withstand Compressive strength. The OPC-ISSA blending sample increases its strength over time and due to increased pozzolanic activity leading to OPC hydration. The sample mixed with lime may lead to increased expansion of the sample, which negatively affects the tolerance of pressure force (Zhou, Y. et al. 2020). The use of SSA as a raw material is a cement component but needs further study and analysis.

2.4.6.3 Using of Sewage Sludge into Clay Bricks

Clay is a building material that is not available large quantities in the world and the increased use of clay has an impact on the environment, which stimulates the creation of alternative ways to develop sustainable building materials. Waste treatment sludge (WTS) chemical composition indicates a similar ratio to the composition of natural clay where WTS can be used instead of clay to manufacture ceramic and other building materials (Erdogmus et al. 2021).

Figure 8: The Study Region of Clay Bricks in Campos dos Goytacazes (Brazil) **(Areias et al. 2020)**

Various samples of clay and sewage sludge were collected from the sewage plants in Campos see Figure 8. The clay samples and sewage sludge were dried in a stove at a temperature of 60°C. Five samples mixed with sewage sludge were prepared in different proportions 0, 2.5, 10 and 15% by weight of sewage sludge. The samples were burned at temperatures of 850°C and 950°C. An analysis was made of linear shrink age, sample absorption of water and compression strength. The temperature of 850°C and 950°C is sufficient to burn sewage sludge and eliminate pathogens. In addition, sludge burning helps to save 40% of the burning energy due to the presence of organic substances that help increase ignition (Areias et al. 2020).

The cost of producing bricks of (9 × 9 × 19 cm) was studied and analyzed using treated sewage sludge and natural clay. This study has shown that the cost of bricks from sewage sludge is 16% lower than the cost of concrete bricks and 20% of the cost of clay bricks that are burned at high temperatures (Areias et al. 2020). The study needs to find ways to develop an industry sustainable bricking by using wastewater treatment products to reach 100% of the weight of sludge without blending to conserve natural resources.

2.4.6.4 Reusing of Water treatment Residuals in Layer of Roads Construction

Cost-effective construction techniques have played an important technique of reduce costs by finding an alternative material from reusing waste materials in construction field. However, the sewage water treatment has been interested in studying of reuse in various construction techniques in order to reduce cost such as construction of subgrade layers of pavements (Nazir et al. 2020).

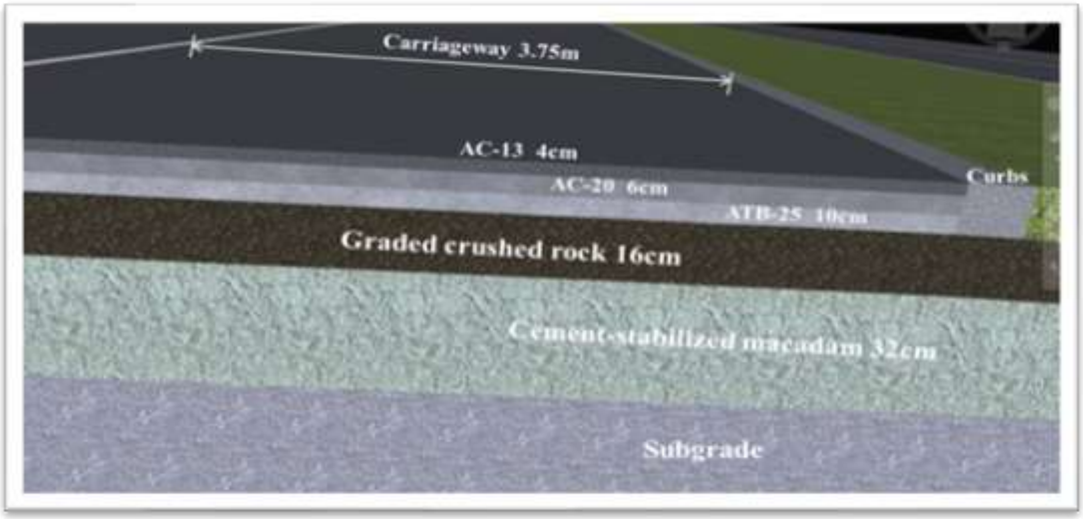

Figure 9: Pavement Cross Section **(Tang et al. 2020)**

As shown in Figure 9, the flexible pavement consists of four basic layers, subgrade, subbase, base course, and surface layer. However, subgrade layer of the pavement is foundation for a road structure and support any load in the surface layer so, should focus on the calculation of strength and CBR of soil when designing foundation of road structure (Nazir et al. 2020).

A study was conducted to determine the use of water treatment residuals (WTRs) as an alternative layer to the road base layer. Soil samples were collected from Burj al-Arab in Alexandria (Egypt), tested, and mixed with 0%, 4%, 8%, 12% and 16% of WTRs weight. Geotechnical measurements were made including WTRs particle size measurement, individual odometer testing and California Bearing ratio (CBR). The study showed that 10% of WTRs weight mixed with soil can be used into a subgrade layer of pavement, so this percentage does not affect in the value of CBR. Moreover, WTRs contains metal cations and organic materials that can interact and form a bonding material which can increasing the subgrade strength. WTRs can help to reduce the cost of road construction and improve soil the prevent of erosion potential by 24.7% in the future (Nazir et al. 2020).

According to experiment of (Abed et al. 2018) in treated sewage water and pine water (desalination of seawater in Sharjah) and used in a 365.8 cm road base layer. The actual cost of treated sewage water and desalination water has been estimated. Estimates show that treated wastewater usually costs less than the cost of production of desalination water by four times. The reuse of treated sewage water has a positive economic impact as it reduces the cost of building the basic layers of the road by up to 68%.

The reuse of waste materials has an important role to play in reducing cost and applying them in Oman's construction industry will be instrumental in increasing the opportunities for optimal investment of wastewater pollutants.

2.5 THE CHALLENGES & OPPORTUNITIES OF MANAGING & REUSING WASTEWATER USING A CIRCULAR ECONOMY (CE)

Circular Economy (CE) is a sustainable development system in where, the strategy focused on the wastewater management, derivatives, recovery of raw materials from sewage, then reuse waste and recycling. Ensuring water savings and reducing pollution is important for sustainable development. The challenge of reusing wastewater as an alternative source of undrinkable water and restoring resources such as various elements and energy from wastewater-based waste is to rethink how resources can be used to create a sustainable economy free of waste and harmful emissions (Smol, Adam, and Preisner 2020).

The European Union (EU) has considering developing plans for sustainability for some key aspects of wastewater management. The EU policy aims to achieve a zero-waste strategy, promote innovation, improve market conditions and use safe and cost-effective treatment sewage. The European Commission confirms the application of the circular economy (CE) by wastewater management. The possibilities for financing investments in the sewage sector have been studied where, the exploitation of waste from sewage and sludge is an important source of extraction of vital raw materials (Smol, Adam, and Preisner 2020).

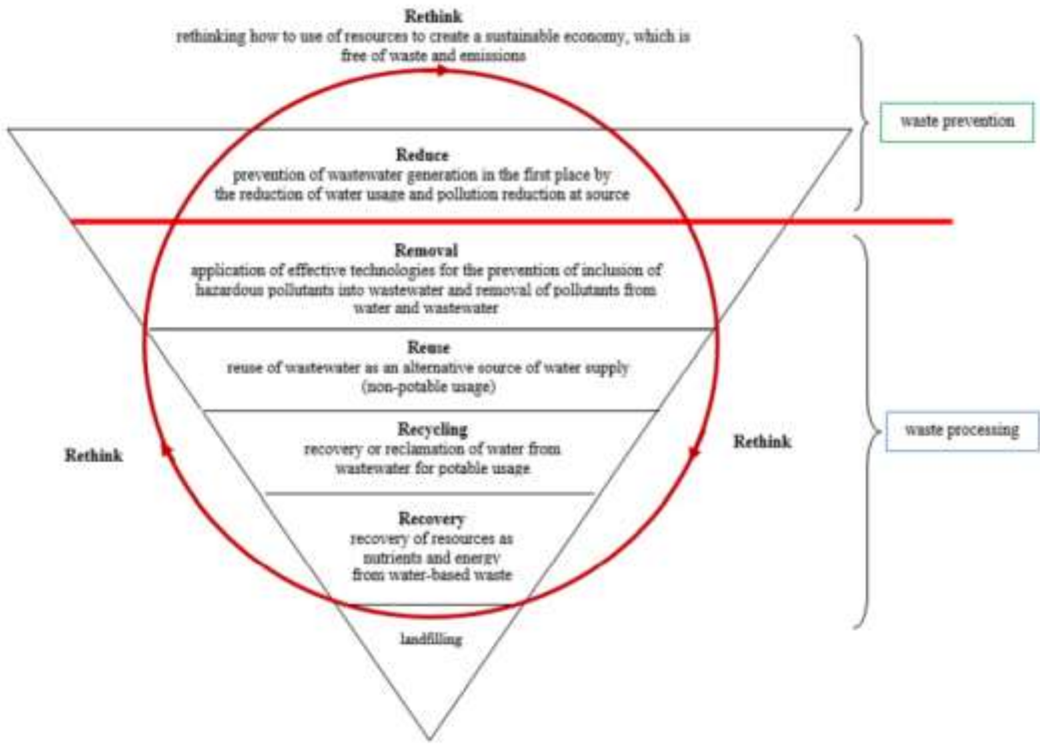

Figure 10: The Circular Economy (CE) Model Framework in the Wastewater Sector **(Smol, Adam, and Preisner 2020)**

Figure 10 shows the typical circular economy framework (CE) in the sewage sector, where it is divided into several sections. The CE model framework includes reducing wastewater generation by reducing freshwater use and reducing pollution through planning and designing strategies to develop water saving habits and maintain environmental quality. Reducing water consumption has benefits in reducing the cost of desalination of seawater, reducing a person's freshwater use costs, reducing the cost of extending water supply systems and facilities, and the cost of constructed of sewage treatment plants (STP). Reclamation or removal is the second phase in CE framework model where it is associated with highly effective techniques for removing all pollutants in sewage. Treatment is carried out in accordance with EU wastewater treatment regulations. In addition, by safe method of treated sewage which is disposed of to preserve the environment and the resulting increase in greenhouse gas emissions and hazardous impurities that have an impact on human health. Reuse treated sewage is an important alternative water and has benefit to environmental, economic, and social sustainability. Water recycling is the reuse of treated sewage for drinking and for other purposes. Water recycling is an expensive method and preferably only for sewage that cannot be reused or reduced. The recovery of recoverable materials in sewage is the fifth option in the proposed circular economy structure. Inorganic substances such as phosphorus (P) and nitrogen can be recovered for reuse. Rethinking is the most important option in the CE application where, should think about how to reuse wastewater in order to achieve sustainability. In addition, achieving the CE framework goal is environment zero waste and hazardous emissions.

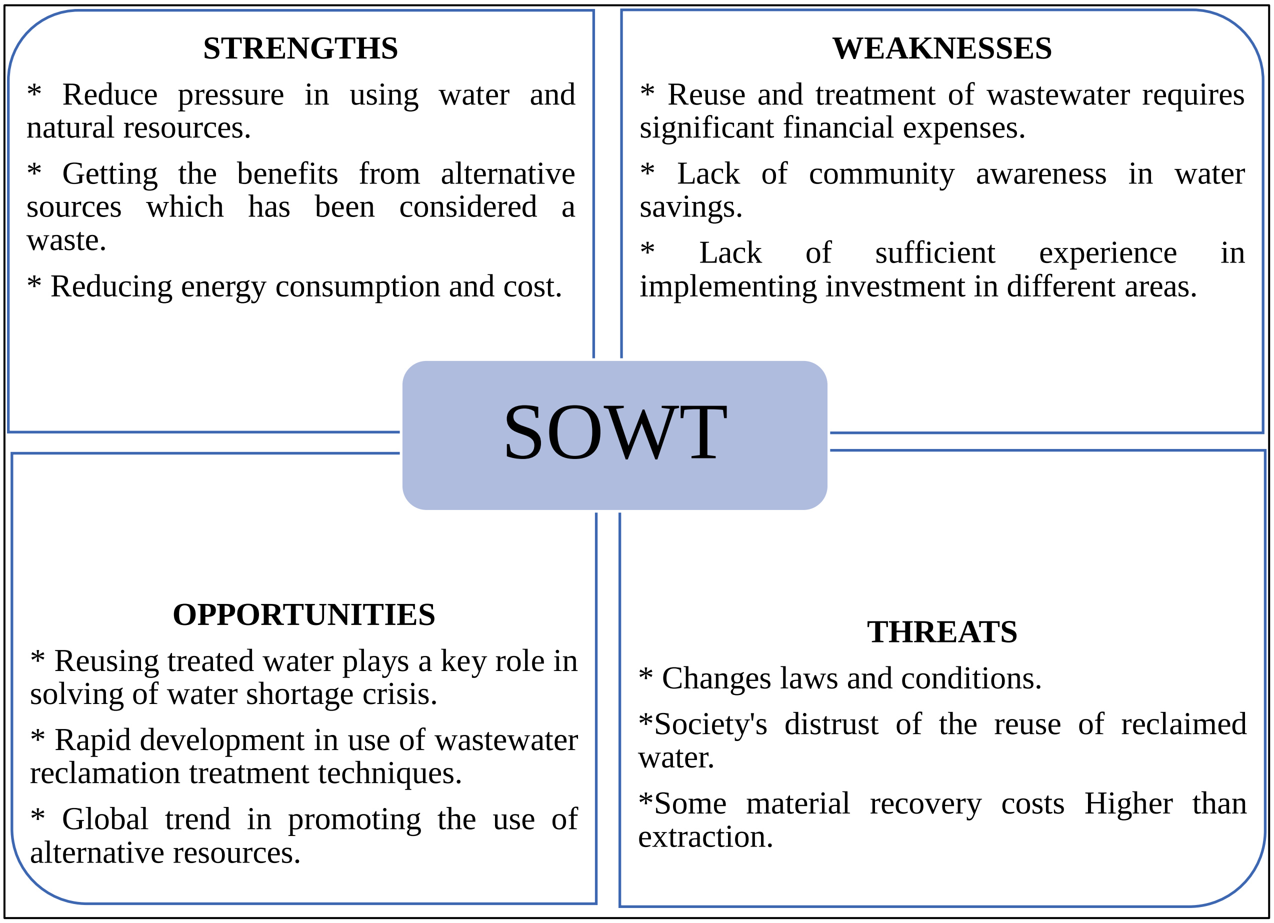

Figure 11: SWOT analysis of circular economy implementation

Figure 11 concludes SWOT's analysis in the implementation of the circular economy. It illustrates the strengths, weakness, opportunities, and threats in use of the circular economy in the sanitation sector. Weaknesses must be addressed by looking for a new investment opportunity to reduce the burden on operating and maintenance costs at sewage plants. Rapid development and technical growth in the world are expected to play an active role in promoting environmentally friendly processes and methods. Environmental management and economic planning for the exploitation of treated pollutants and wastewater for various purposes should be an important topic that must be dealt with properly.

2.5.1 The Lost Opportunity of Reusing Wastewater Treatment in the Gulf Cooperation Council (GCC)

The reuse of treated wastewater in the GCC countries is still in first level where, the treated wastewater is exploited in agriculture and fertilizers. In addition, the proportion of treated water flowing into the sea that has not been exploited is higher than the proportion of reuse wastewater. The amount of sewage produced in the GCC countries about 2.853 billion cubic meters/year. Sewage contains a wide range of pathogens such as viruses, and bacteria. Samples were collected and analyzed from the shores of the GCC using microbiological analysis techniques. The results of the analysis indicate that pollution is transmitted by wind along the Gulf coast, affecting marine ecosystems in the Waters of the Gulf Sea (Aleisa and Al-Zubari 2017).

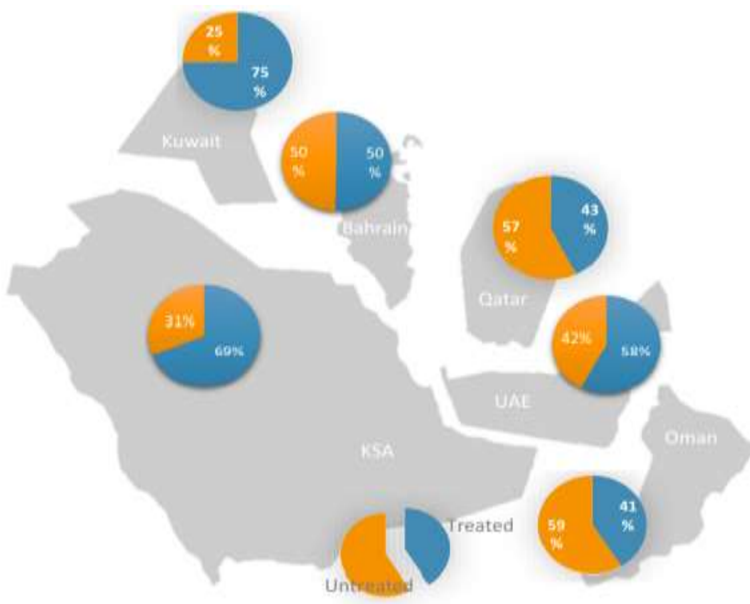

Figure 12: Ration of treated and untreated wastewater in GCC(**Aleisa and Al-Zubari 2017**)

Table 12 shows the proportion of treated wastewater and the proportion of untreated wastewater in the GCC. The ratios vary from country to country, where the graph shows that Kuwait has the highest rate of wastewater treatment, with 75% of total wastewater treated. Saudi Arabia has second rate with 69%, followed by the UAE with 58%. The disparity in ratios is due to the fact because to the cost of sewage treatment services is relatively high and sewage treatment plants facilities have little or no capacity for treatment, affecting treated wastewater properties. In addition, a large number of areas use transport trucks that are not connected with sewage treatment plants. These trucks often contain a high percentage of wastewater from factories and workshops of cars discharged into the sea or deserts instead of wastewater treatment plants (Aleisa and Al-Zubari 2017).

The reusable wastewater treated in the GCC is limited to no more than 43% of the total treated wastewater. Treated wastewater is used to irrigate green spaces, produce fertilizers and some industrial activities. Oman is the only GCC country which is limited of use wastewater treatment to re-inject aquifers. In addition, Kuwait uses treated wastewater to irrigate agricultural crops. The main obstacles facing the GCC countries to the use of treated wastewater are religious, social, and intellectual inaccuracies and lack of infrastructure in the distribution of sewage systems. Accordingly, it is recommended that GCC increase to use of the treated wastewater for extinguishing fires and increase industrial and recreational uses such as artificial lakes (Aleisa and Al-Zubari 2017). The paper did not provide a detailed explanation of new uses of wastewater and new technologies applied in other countries such as The United States and Europe. in addition, the paper did not provide a detail of analysis of the opportunities that can be used to solve the problem of the inability of the Gulf Council countries to increase the supply of the sewage system and how to solve the problem of treatment of all sewage water in GCC.

2.6 A SUSTAINABLE TECHNIQUE FOR REUSE WASTEWATER

Urbanization and economic development in China have led to an increase in the amount of wastewater and sewage sludge that needs to be treated. Waste is an increasing problem that needs to be disposed of in an environmentally friendly, socially acceptable, cost-effective manner and achieving sustainable development (Zhou, G. et al. 2020).

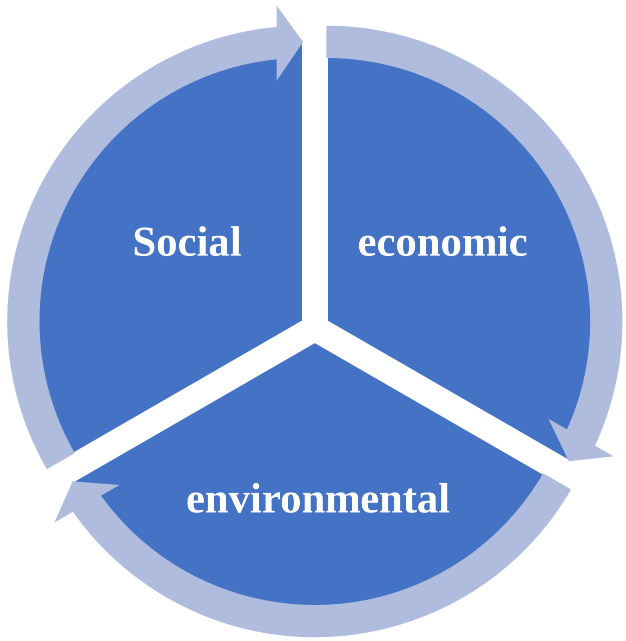

Figure 13: Sustainable Factors of Reuse Wastewater

Environmental: Sewage treatment plants consume high levels of resources and energy to treat wastewater. After treatment, drainage and sludge residues are discharged and a high amount of toxic gases and sludge are generated, thus creating a severe burden on the environment (Zhang and Ma 2020). Environmental impact is assessed by evaluating biological, chemical, thermal, and chemical sludge treatment methods. The pollution rate is determined using lifecycle assessment (LCA), where helps to detect environmental impacts during the sludge treatment life cycle (Teoh and Li 2020).

The study showed that recycling resources and energy use gases emitted from sludge processing is the best option for municipal sewage sludge (MSS) management as it has helped reduce environmental emissions. When sludge is used as building materials, environmental impacts are lower than landfilling (Zhou, G. et al. 2020). Many studies ((Teoh and Li 2020), (Baawain et al. 2020), (Zhang and Ma 2020)) shows that replacing of cement materials with sewage and treated sludge to improve sustainability and reduce the impact of pollutants on the environment.

Economic: Technical cost modelling (TCM) is used to verify economic performance in wastewater recycling. Where the economic profits are assessed by dividing costs and interest into three parts:

operating costs, investment costs and interest. six treatment methods were selected, including construction cost, daily operating costs and transportation (Zhou, G. et al. 2020).

***Table 6: Results of Economic Analysis of Various Municipal Sewage Sludge Processing Techniques* (Zhou, G. et al. 2020)**

	Units	**Landfill**	**Incineration**	**Disposal in cement kilns**	**Pyrolysis**	**Land application**	**Use as building materials**
Operation cost	(¥/t)	227.60	881.83	203.32	639.24	301.34	**19415.35**
Investment cost	(¥/t)	31.00	96.78	28.24	48.80	55.00	**61.63**
Income	(¥/t)	0.00	870.83	100.00	695.00	560.25	**19500.00**
Total cost	(¥/t)	**258.60**	107.78	131.56	-6.96	-203.91	-23.02

Table 6 shows the results of economic analysis of different methods of MSS treatment. The results showed that the use of MSS processing in land applications (fertilizers) and building materials has greater economic benefits than costs due to raw material replacement and energy recovery. However, the results show that the operating costs were higher than the investment costs. Cement kilns require lower investment costs due to the availability of equipment. While the requiring pyrolysis, incineration, building materials and land application needs to build production equipment, which makes the percentage of investment costs higher.

Social is the main category and stakeholders in the wastewater treatment system. where the stakeholders are workers, employees, community, consumers, and participants. Six different techniques have been selected to eliminate sewage sludge so that the disposal method is environmentally friendly, less cost and socially acceptable for sustainable development. Scenario 1, solid waste is disposed of in landfills where sludge is dried to remove water by using lime. For Scenario 2, burning is used in sludge treatment to reduce dangerous properties. Scenario 3, sludge is disposed of by cement kilns where sludge is burned at high temperatures for produce ash which is use in the manufacture of cement clinker. Scenario 4, thermal decay of sludge is used by heat under anaerobic conditions resulting in bio coal and yielding pyrolysis oil. Scenario 5, sludge is used as an organic fertilizer (earth application) and is treated by anaerobic analysis by bacteria. Scenario 6, sludge is used in the manufacture of building materials (Zhou, G. et al. 2020).

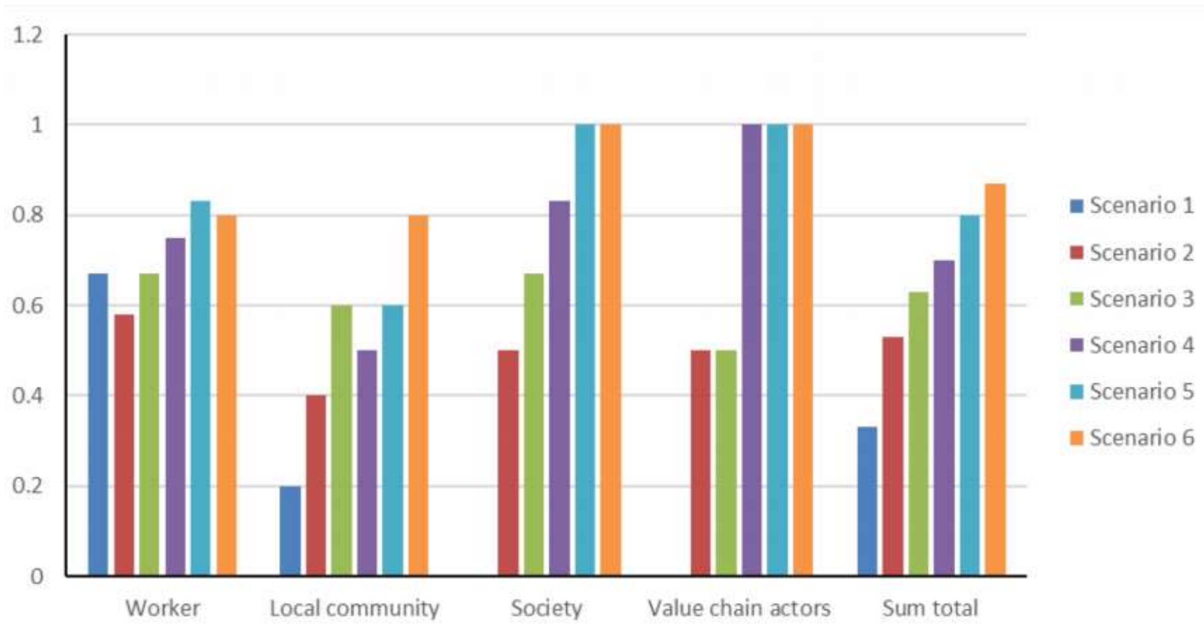

Figure 14 : Chart for Social Impacts in The Six Scenarios **(Zhou, G. et al. 2020)**

Figure 14 presents the social effects of different types of treatment. The graph showed that the use of sludge to make building materials has a beneficial effect and does not affect the surrounding environment. Landfills are the worst in terms of their impact on society as stakeholders. For actors, the treatment of sludge by thermal decay, fertilizer and building materials is the best effect and reduces the consumption of raw materials. Safety disputes and protests against landfills and living conditions using the sludge in earth application and building materials has the best social performance.

Managing and reusing treated wastewater is an important role in the integrated management of the water resource, where can achieve sustainability and secure future water needs. Social, environmental, and economic aspects must be considered for sustainability.

2.7 RISK ASSESSMENT OF TREATED SEWAGE WATER

Treatment of sewage water has an active role to develop a strategy for water management to reduce water shortage around the world. However, there are concerns in the quality of treated water that may cause risks to humans, animals, plants, and the environment. Risk assessment is a combination of possibilities and consequences that may cause adverse risks in reusing wastewater for various purposes (Analouei, Taheriyoun, and Safavi 2020).

There are a range of risks in reuse wastewater , preferably PESTLE analysis which refers to the study of Political, Environmental, Social, Technological, Legal and Economic to make easier to identify risks in the projects of reuse wastewater (Furlong et al. 2017).

Table 7: Risk Factor of Reuse Wastewater Using PESTLE Analysis.

	Risk	Control
Political	1. Change in the GCC Policy to overcome the water depletion issue in the groundwater reservoir, some countries have stopped supporting the water expenses. (Amery and Cahan 2017).	1. Take steps to increase wastewater efficiency. 2. Raise awareness of the community in finding alternative ways to utilize treated wastewater and not only focus on public spaces such as parks and green areas (Analouei, Taheriyoun, and Safavi 2020).
Environmental	1. In some methods of treatments, Some pollutants might not be eliminated completely and they may produce other pollutants (Zhou, G. et al. 2020). 2. The accumulation of heavy metals in the soil can be an environmental problem (Alayish and Çelik 2021).	1. Life cycle assessment (LCA) technology helps to minimize the overall impact of pollutants in sludge (Zhou, G. et al. 2020). 2. Assessing performance, improving design and cost analysis at wastewater treatment plants is important to

	3. The dangerous effects of sewage on the environment is that wastewater is not properly treated (Abbasi, Ahmadi, and Naseri 2021).	control the risk and protect the human and environment. (Abbasi, Ahmadi, and Naseri 2021). 3. Setting standards and foundations for water management, reclamation and reuse by government officials to ensure quality and wastewater safety (Beveridge, Moss, and Naumann 2017).
Social	1. Lack of acceptance by society in reuse of treatment wastewater where, a psychological and cultural problem (Beveridge, Moss, and Naumann 2017). 2. Institutional obstacles due to lack of awareness and the imposition of cooperation between responsible institutions in wastewater treatment management and lacking in regulatory guidelines (Beveridge, Moss, and Naumann 2017).	1. Concern about wastewater use decreases as awareness and promotion campaigns increases to promote the benefits of wastewater reuse increase (Beveridge, Moss, and Naumann 2017).
Technological	1. Malfunction or interruption in the equipment responsible for wastewater treatment at the plant (Łój-Pilch and Zakrzewska 2020).	1. The operation of the treatment plant should be monitored continuously, regular maintenance of equipment and technical services, monitor changes introduced and training of staff in dealing with sudden

		malfunctions at the station (Łój-Pilch and Zakrzewska 2020). 2. The plant must be equipped with electrical a generator in case of a malfunction (Łój-Pilch and Zakrzewska 2020).
Legal	1. Amendments and changes in the laws and conditions addressed (Marković et al. 2021). 2. Lack of compatibility between investor regulations from foreign countries with the state regulations in which they are operated (Marković et al. 2021).	1.The integrated and coordinated approach to planning and developing the treated wastewater reuse law is instrumental in achieving optimal solutions strategies (Liao et al. 2021).
Economic	1. Funding for wastewater reuse projects requires support to recover operating and maintenance costs (Furlong et al. 2017).	1. Finding different way to dispose wastewater in an environmentally friendly way, cost-effective manner and acceptance of social (Zhou, G. et al. 2020). 2. Develop models of repairs and maintenance costs to finance wastewater treatment plants that can be borne by real estate developers and customers in order to provide wastewater treatment service (Furlong et al. 2017). 3. Charging municipal fees can help reduce maintenance and operation costs at treatment

		plants (Amery and Cahan 2017).

Table 7 shows an analysis of the risk factors for reuse of wastewater using PESTLE analysis. Political factors and laws can have an impact on treated sewage. In addition, assessing the wastewater life cycle can help reduce the overall impact of pollutants on the environment. Cost analysis at wastewater treatment plants is important for risk control, human protection, and the environment. The community's lack of acceptance of the reuse of treated sewage and lack of awareness of the risks that can highly affect wastewater reclamation and exploitation. However, the technological malfunction or interruption in the equipment responsible for wastewater treatment at the plant has effect in quality of treated wastewater.

There are risk factors that may affect the development and reuse of wastewater treatment in varies countries. Economic development can helps promote the construction of sewage plants. However, countries with abundant water resources have less inclination to reuse sewage than countries with shortages of groundwater, which have a high enhancement for wastewater treatment and reuse. Community confidence , religious beliefs , the level of education and income can affect in accepting water re-use (Liao et al. 2021). Studies are needed to assess the risks of wastewater use in construction as environmental problems have not yet been proven.

2.8 CHAPTER SUMMARY

The LR review aims to achieve a study of research objectives, focusing research on the study of wastewater treatment plants, the cost and reuse of wastewater, opportunities, challenges and risks of wastewater reuse in construction.

The study was analyses and verified the effectiveness of wastewater treatment and reuse in Oman's construction and infrastructure. In addition, wastewater treatment and sludge management were analyzed in Oman. However, the cost of wastewater treatment in Oman has not been completed due to limited sources in this area.

To estimate the cost, a study was conducted to evaluate the initial investment of wastewater treatment plans (WWT), the operating and maintenance costs of wastewater treatment plants, WWT revenues, and the analysis of energy saving techniques for wastewater treatment plants.

The study included options for reuse of wastewater in urban, agriculture, recharge of groundwater and wastewater treatment for reuse in power generation. In addition, a comprehensive review of literature in the reuse of wastewater treatment in building materials has been studied.

Sustainable techniques for treated wastewater reuse plans, challenges and opportunities for managing and opportunity for wastewater treatment in the GCC have been studied. Wastewater was analyzed and reused using circular economy (CE) and SWOT analysis.

The study contained risk assessment factors that could affect the development of wastewater treatment, the use of treated water and technologies that achieve environmental, economic and social sustainability.

CHAPTER 3: RESEARCH METHOLODOLOGY

3.1 INTRODUCTION

The main objective of this chapter is to study the methodology of research. The research included a study of research methodology, research design, research methods type (quantitative and qualitative), data collection methods, sample size calculation and research limitation.

3.2 RESEARCH METHOLODOLOGY

Research methodology is an important part of the research paper where it helps to solve a particular problem in research systematically. Where the data analysis is prepared to prepare accurate and complete reports for the search (Ragab and Arisha 2017).

The study focuses on the problem of rapid economic development, urban growth and urbanization in Oman, which is the cause of increased generation and discharge of sewage and the need to benefit from wastewater in the field of construction, which is the main pillar of infrastructure. In addition to exploring the environmental and economic benefits in order to reduce the storage of treated sewage, affect the environment, exploit the construction industry and achieve sustainability.

The data were collected using quantitative surveying by distributing the questionnaire regarding the reuse of treated sewage in the construction field. In addition, the research including qualitative research method by conducting interviews in order to reach the collection of information and data on the reuse of treated water in Oman. The study relied on the collection of cultures on the idea of using treated wastewater in the field of construction to achieve sustainability.

3.3 RESEARCH DESIGN

This paper is based on a review of research literature as a keyway to gain an in-depth understanding of the research objectives. In addition, the research methods should include the use of techniques that help study research with an understanding methodology using data collection and analysis tools. Data analysis is a key aspect of research prepare and should include accurate information and reports and provide clear insights into the data.

The research is designed to integrate quantitative and qualitative methodologies called mixed-method research. The mixed search design is divided into four main types as shown in figure 15 : Triangulation Design, Embedded Design, Explanatory Design and Exploratory Design. The first stage of study identification of problem and the second phase is choosing the type of design and the third stage discuss the results for reach an appropriate solution that addresses the problem.

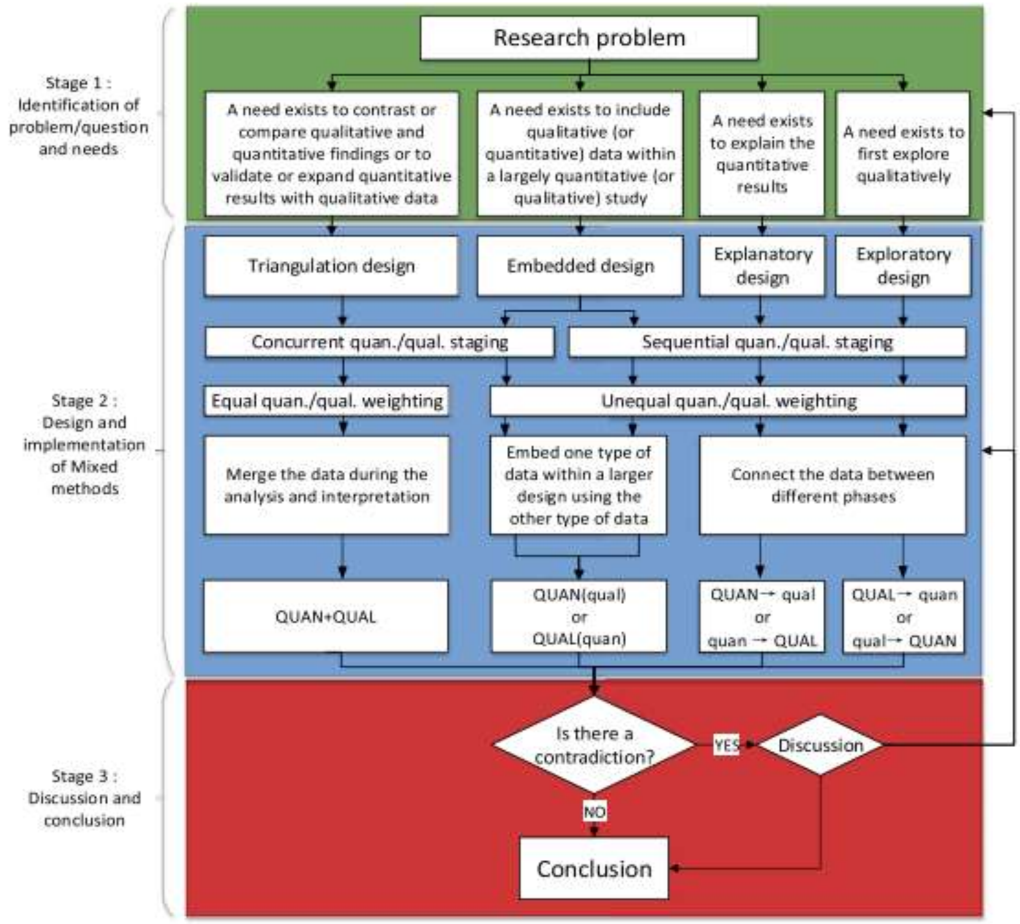

Figure 15 : The Framework of Mixed Methods Research **(Zou et al. 2018)**

The research was designed in a triangulation design method, where data (quantity and quality) are collected and analyzed with the aim of providing comprehensive information and finding new solutions to address the problem. The purpose of using triangulation design is to compare and analyze qualitative and quantitative data to reach a common and effective solution.

3.4 RESEARCH QUESTION

Drafting research question (RQ) is the key to making decisions about the design of research and type of data to be collected and analyzed. Where research question aims to identifies the basic elements of the logic of research and study (Jory 2021).

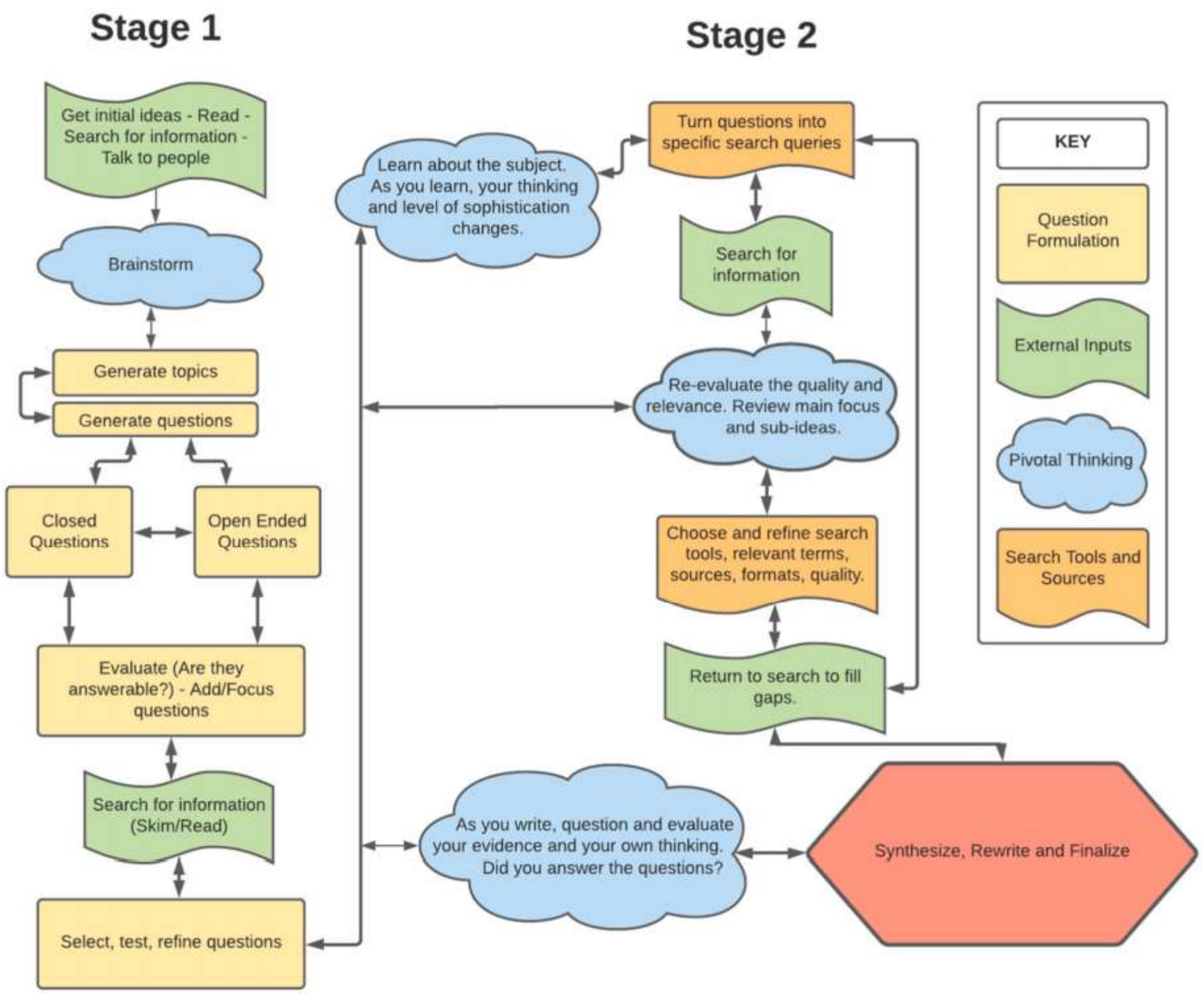

Figure 16: Question Formulation **(Scharf and Dera 2021)**

Figure 16 shows the form of the wording of the question in the research where, it is divided into two stages. In the first stage, the researcher should acquire sufficient information and knowledge of the topics of research, discussion with others and work of the brainstorming plan. Then, the researcher identifies questions related to the research. In the second stage, the researcher focuses on using different methods of questions and developing the level of understanding of the research topic using different techniques to continuously improve questions, collect information and then analyze questions.

Some questions that need to be answered and analyzed on the subject of research:

1. How can investigate the effectiveness of wastewater treatment and reuse in the Sultanate of Oman in the construction industry?
2. What processes should be selected that can reduce costs in wastewater treatment and investment in construction industries?
3. What are the most efficient and effective ways to manage treated wastewater?
4. How can management of treated wastewater to provides sustainability in a developing country like Oman?
5. What are the main risks of using treated wastewater that affect sustainability in the construction sector?

3.5 DATA COLLECTION

The data collected in research based on primary sources such as questionnaires, interviews, and the secondary source like scientific papers, books. The references recorded and documented properly for sufficient quantity and quality of References ensured. Recent papers are considered and preferred more than the old a research. Interviews with experienced Researchers in research field. However, the situation of coved-19 limits the face-to-face interviews. The communication with researchers by sent emails was safer.

3.5.1 The Qualitative Approach (Interview)

Qualitative research is based on studying objects in their natural environments that may include words instead of numbers or descriptive and be in the form of a text description. Where data are studied and analyzed by meanings that people list and quantification is not used (Zou et al. 2018).

An interview is a discussion between two or more parties whose face to face or through use of social media techniques. the aim of discussions is providing deep, clear and comprehensive insights into the subject matter of the research. Interview data is analyzed and collected using qualitative techniques to analyze text and convert into data (Jory 2021). Interviews design conducted with sanitation specialists Oman Wastewater Services Company (Haya Company), Muscat Municipality, Ministry of Housing and Urban Planning, Environment Authority, Ministry of Interior, Oman Environmental Holding Company and other institutions specializing in the same field.

Table 8: Organizations Responsibility roles in Management of Wastewater in Oman

Number	Organization	Responsibility Roles
1	Oman Wastewater Services Company (Haya Company)	Responsible for managing, developing, operating and maintaining sanitation facilities in all provinces in Oman except Dhofar province.
2	Muscat Municipality	Follow-up of sewage management in Oman
3	Ministry of Housing and Urban Planning	Allocating possible lands of liquid waste dumping
4	Environment Authority	Evaluating the environmental impact of the projects
5	Ministry of Agricultural and Fish Wealth and Water Resources	Responsible for developing policies, plans in agricultural sectors and water resources sectors
6	Oman Environmental Holding Company	manage of different waste and recycling
7	Parsons Global Consulting	An international consulting company located in Muscat is instrumental in infrastructure projects, design plans and construction management

Table 8 show the list of organization are involved directly to wastewater management however some organizations have indirect role such as Building Materials Companies and Research Center Organization.

3.5.2 The Qualitative Approach (Questionnaire)

Questionnaire is a general title which is aimed to collecting quantifiable data and includes types of questions (open or closed) where, the data are digital or descriptive and analyzed using statistical techniques.

Questionnaire will be distributed to the general public and stored online using a database (Google Drive) that contains different questions and is divided into four main sections as it shown in table below. After the distribution of the questionnaire, the data will be collected to analyze and examine through the use of statistical software (PSPP).

Table 9: Questionnaire Sections

Questionnaire Sections	Items
Part 1: Personal and general information	8
Part 2: The effectiveness of reusing wastewater and analysis of cost and energy in Oman for construction purposes	9
Part 3: Challenges and Opportunities of Wastewater and sludge management in Oman	7
Part 4: Implementation of sustainable techniques and risk assessment of sewage.	8

3.6 THE STUDY AREA

Muscat province area has 309,500 Km^2, 158,918 buildings and a population of 542,523. Muscat's governor has five states: Boushar, Al-Seeb, Mutrah, Al-Amirat and Muscat (NCSI 2020).

The study was conducted in Muscat because it has the highest population in Oman and wastewater treating facilities compared to other governorates. In addition, Muscat has infrastructure, urbanization, and industrial development.

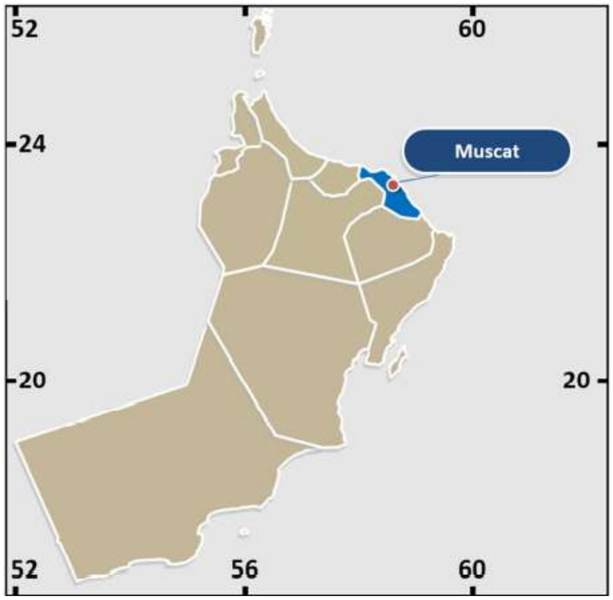

Figure 17: Location Map of Muscat **(Akpan, Omole, and Bassey 2020)**

3.7 THE SAMPLE SIZE

The sample size is the random sample that represents a number of individuals taken from the population as a whole to conduct survey for the study. Sample size is very important for evaluating the study and obtaining accurate statistical results for a successful study (van Rijnsoever 2017). For calculating sample size of survey, the equation below is required:

$$\text{Sample Size} = \frac{\frac{Z^2 \times P(1-P)}{e^2}}{1+\left(\frac{Z^2 \times P(1-P)}{e^2 N}\right)} \qquad \textbf{Eq. (4)}$$

N = population size where, e = Margin of error (percentage in decimal form) and z = z-score (number of standard deviations a given proportion is away from the mean) (SurveyMonkey 2021).

To find z-score use table 3.3:

Table 10 : Desired Confidence Level for finding Z-score **(SurveyMonkey 2021)**

Desired confidence level	Z-score
80%	1.28
85%	1.44
90%	1.65

95%	**1.96**
99%	2.58

Total Population in Muscat is 542,523 (NCSI 2020).

Input: N = 542,523, Z = 1.96, P = 50% = 0.5, e = 5% = 0.05

$$\text{Sample Size} = \frac{\frac{(1.96)^2 \times 0.5(1-0.5)}{(.05)^2}}{1+\left(\frac{(1.96)^2 \times 0.5(1-0.5)}{(0.05)^2 \times 542{,}523}\right)} = 224.905 \approx \quad 225 \text{ Questionnaire required} \qquad \textbf{Eq. (4)}$$

The questionnaire will be distributed to 225 for the survey as the result of calculated sample size.

3.8 THE PILOT STUDY

The pilot study is a first-step in protocol of research where, it is a mini-study to test the design of the research which helps to have accurate plans, easy adaptation and high quality of results (Donald 2018). The study (Turner-Bowker et al. 2018) indicates that the size of the samples used in interviews that reach saturation is between 5 and 10 interviews.

The topic of research was discussed with the supervisor and operations engineer of Haya company for the initial evaluation of the research. According to the pilot study of the current research, twenty questionnaires were distributed and six interviews with specialized persons were conducted. The resulted data were analyzed using SPSS software. The results showed that the community accepted 50% acceptance of the reuse of wastewater in the field of construction. While the interviews were analyzed using six samples, Oman was found to be highly efficient in wastewater treatment but needed financial support to complete the infrastructure.

Table 11: Reliability Statistics (SPSS Software)

Cronbach's Alpha	Cronbach's Alpha (Standardize Items)	Number of Items
0.5	0.81	32

Table 11 show the reliability statistics of quantitative survey by using SPSS software. SPSS software was relied upon to determine the reliability rate (Cronbach's Alpha) for determine the error rate in random measurement.

3.9 Respondents for Qualitative Method

Respondents of qualitative research were identified to participate in a study according to their relationship in the field of sanitation. The corresponding questions were designed according to the main objectives of the research and the opinions of the specialists in the field of research were taken from different organizations. The qualitative research was conducted by sending e-mails because the status quo cannot be conducted face-to-face interviews. Table 12 shows the organizations involved in the qualitative research.

Table 12 : The Organizations Involved in the Qualitative Research

No	Organization Name	Date of Corresponding by Email	Responded Date
1	Oman Wastewater Services Company (Haya Company)	4/8/2021	11/8/2021
2	Oman Environmental Holding Company	8/8/2021	No Respond
3	Environment Authority	9/8/2021	11/8/2021
4	Muna Noor Group	8/8/2021	8/8/2021
5	Oman Cement Company	8/8/2021	9/8/2021
6	Diwan Royal Court/ Office for Conservation Environment	8/8/2021	8/8/2021
7	Environment Engineering Services	8/8/2021	8/8/2021
8	Sultan Qaboos University	11/8/2021	No Respond

3.10 Respondents for Quantitative Method

The questionnaire was distributed by using Google Drive. Questionnaire contains 32 questions divided into four sections: personal and general information, the effectiveness of reusing wastewater and analysis of cost and energy in Oman for construction purposes, challenges and opportunities of wastewater and sludge management in Oman, implementation of sustainable techniques and risk assessment of sewage. In addition, the questions were written in Both Arabic and English for easy understanding by all participants. The questionnaire was distributed to people living in Muscat.

Table 13 shows the total sample size 225 but the total respondent of questionnaire is 193 where, the rate of respondent is 85.8%.

Table 13: Respondent Rate in Questionnaire

Study Area	Sample Size	Questionnaire Respondent Receive	Respondent Rate
Muscat	225	193	85.8%

3.11 DATA ANALYSIS IN QUALITATIVE & QUANTITATIVE METHOD

3.11.1 Qualitative Data Analysis Method

Interview data was collected and analyzed by thematic analysis to ensure the quality of the data. Thematic analysis focuses on seven practices as it shown in figure 18 for order to complete qualitative analysis and organizing the data (Lester, Cho, and Lochmiller 2020).

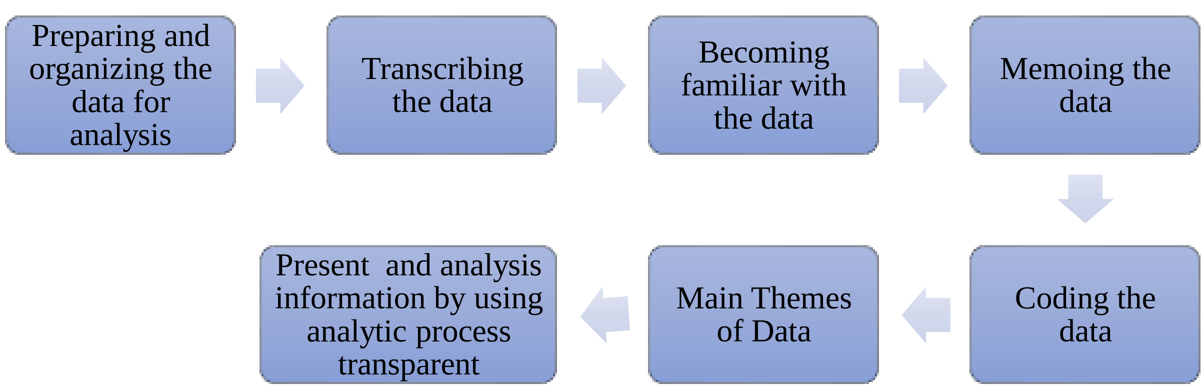

Figure 18 : Thematic Analysis Process

3.11.2 Quantitative Data Analysis Method

Statistical data analyses were performed in the questionnaire with the of help of SPSS Version 23. In addition, a data analysis was carried out using the descriptive statistic method, showing frequencies and percentages. Data was sorted and displayed through graphs, numbering questionnaires, and systematically arranging statistics.

3.12 LIMITATIONS

One of the limitations related to the research several problems and can be developed as an experimental study aimed at laying the foundation for a future research study. First, it is difficult to obtain sufficient information about Oman in terms of sewage and treatment costs. Secondly, the sample size was 225 and the number of participants was 193, as it was difficult to reach enough participants. Third, the research includes interviews with sanitation professionals who have had difficulty accessing them because of the precautions to be taken in the crisis of the outbreak of the Covid-19 epidemic.

3.13 SUMMARY

The design of the research methodology was based on the integration of quantitative and qualitative methodologies and is called the mixed research method. The data were collected through the use of primary sources such as questionnaires, interviews and secondary sources such as research literature study. The research study site in Muscat, where the questionnaire and interviews were distributed, and the data were analyzed using different techniques for analysis. The research methodology has been studied in order to achieve the main research objectives.

CHAPTER 4: RESULT ANALYSIS & DISCUSSION

4.1 INTRODUCTION

This chapter presents the analysis of data collected from the questionnaire and interviews. The questionnaire contains of 32 questions divided into four sections. SPSS Software and Crosstabs analysis was used for quantitative data analysis.

while the interview questions contain of 12 questions divided into two parts. Interview data was collected and analyzed by objective analysis to ensure the quality of the data.

4.2 QUANTITATIVE RESEARCH FINDING: QUESTIONNAIRE ANALYSIS

In this section, the questionnaire was distributed to 193 participants and aims to understand the public's views on their acceptance of the reuse of treated sewage water. The questionnaire is designed in four sections. The questionnaire was reviewed by a sanitation specialist. The data was analyzed by using SPSS software and Microsoft Excel. Descriptive statistical analysis procedures were applied, containing graphs of frequencies, percentages, and statistical relationships.

4.2.1: Part 1: Personal Information

In this part contains of eight different personal questions. Table 14 shows the descriptive statistics of personal information. For more details see the appendix C part 1.

Table 14 : Descriptive Statistics of Personal Information (P1)

Descriptive Statistics						
Questions Number	**Variable**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
P_1.1	Gender	193	1.73	0.44	1	2
P_1.2	Age	193	2.33	0.86	1	4
P_1.3	Years of Work Experience	193	3.19	1.41	1	5
P_1.4	Work organization	193	2.07	1.28	1	4
P_1.5	Occupation	193	3.7	1.99	1	6
P_1.6	Education level	193	2.66	0.9	1	5

P_1.7	Knowledge of wastewater treatment	193	1.84	0.84	1	3
P_1.8	Uses of wastewater	193	2.92	1.93	1	5

Table 15 : Gender Analysis

Gender					
P_1.1	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Male	1	52	26.94	26.94	26.94
Female	2	141	73.06	73.06	100
Total		193	100	100	

According to the descriptive analysis of a survey, the results showed that the number of participants was 193, and the highest frequency of participants was female with 141, compared to 52 males as shown in Table 15.

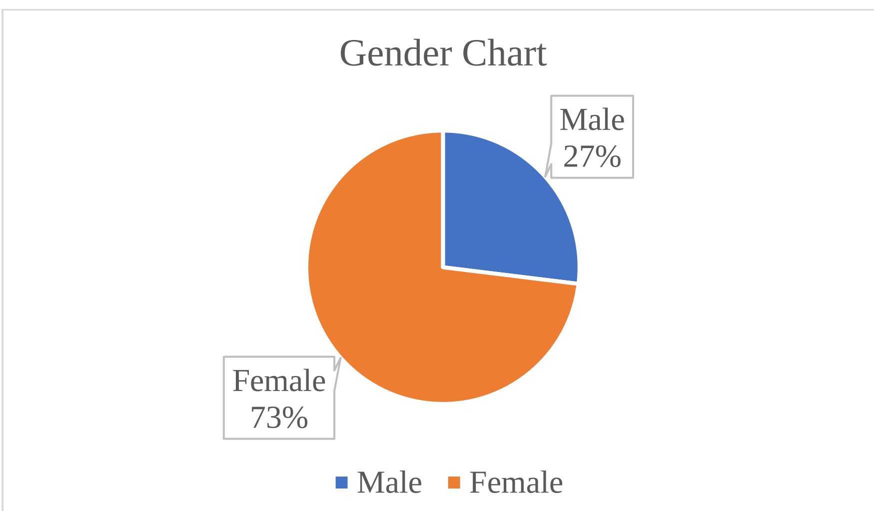

Figure 19 : Gender Analysis Chart

Figure 19 shows gender respondent’s analysis, where the percentage of male 27% with 52 sample number and female 73% with 141 sample number.

Table 16: Age Analysis

Age					
P_1.2	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
18-25	1	34	17.62	17.62	17.62
26-35	2	77	39.9	39.9	57.51
36-45	3	67	34.72	34.72	92.23
Above 46	4	15	7.77	7.77	100
Total		193	100	100	

Table 16 show, the age analysis where, the number of participants reached 77 participants aged 26-35 years, 67 participants aged 36-45, 34 participants aged 18-25 and 15 participants over the age of 45.

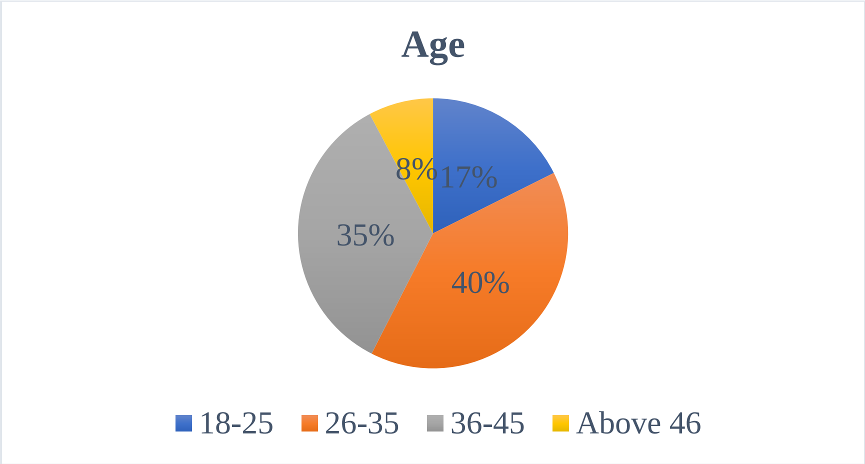

Figure 20: Age Analysis

According to figure 20 shows the highest age of Participants within range from 26 to 35 with percentage 40%. The lowest number of Participants above 46 with percentage 8%.

Table 17: Years of Work Experience Data Analysis

Years of Work Experience

P1.3	Value	Frequency	Percent	Valid Percent	Cum Percent
1-5	1	30	15.54	15.54	15.54
6-10	2	32	16.58	16.58	32.12
11-20	3	57	29.53	29.53	61.66
More than 20	4	19	9.84	9.84	71.5
None	5	55	28.5	28.5	100
Total		193	100	100	

According to Table 17, the largest number of participants reached 11-20 years of work experience and the lowest number of participate more than 20 years of work experience.

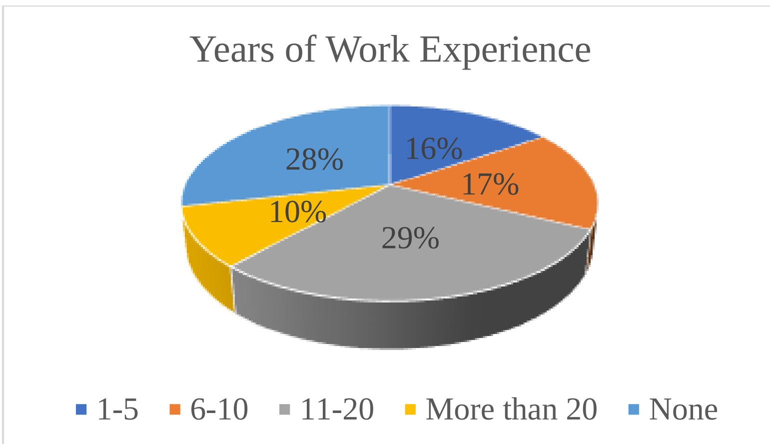

Figure 21 : Chart of Years of Work Experience

According to figure 21 the height's years of work experience with percentage 29% a range from 11 to 20. The lowest experience work percentage more than 20 years with 10%.

Table 18 : Showing Analyzing Type of organizations

Organization					
P1.4	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Government sector	1	102	52.85	52.85	52.85

Private company	2	25	12.95	12.95	65.8
Government company	3	16	8.29	8.29	74.09
Other	4	50	25.91	25.91	100
Total		193	100	100	

According to the analysis of the type of organization, the results showed that 102 participants from government institutions, 25 from private companies and 16 from government company as it shown in Table 18.

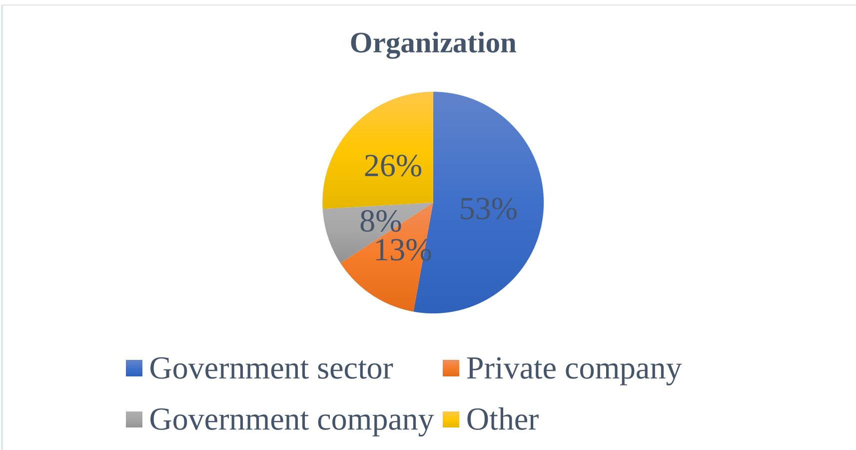

Figure 22: Pie Chart Showing Analyzing Type of organizations

Around of 53% of respondent work in government sector compare with private company 13% and government company around 8%. About 26% of participants does not work.

Table 19: Profession of Participants

Occupation					
P_1.5	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Engineer	1	56	29.02	29.02	29.02
Doctor	2	2	1.04	1.04	30.05
Teacher	3	18	9.33	9.33	39.38
Employee	4	41	21.24	21.24	60.62
Student	5	20	10.36	10.36	70.98

Other	6	56	29.02	29.02	100
Total		193	100	100	

According to Table 19, the results of the analysis of the participants' specialties showed 56 engineers, 56 other disciplines that were not mentioned, 41 employees, 20 students, 18 teachers and 2 doctors.

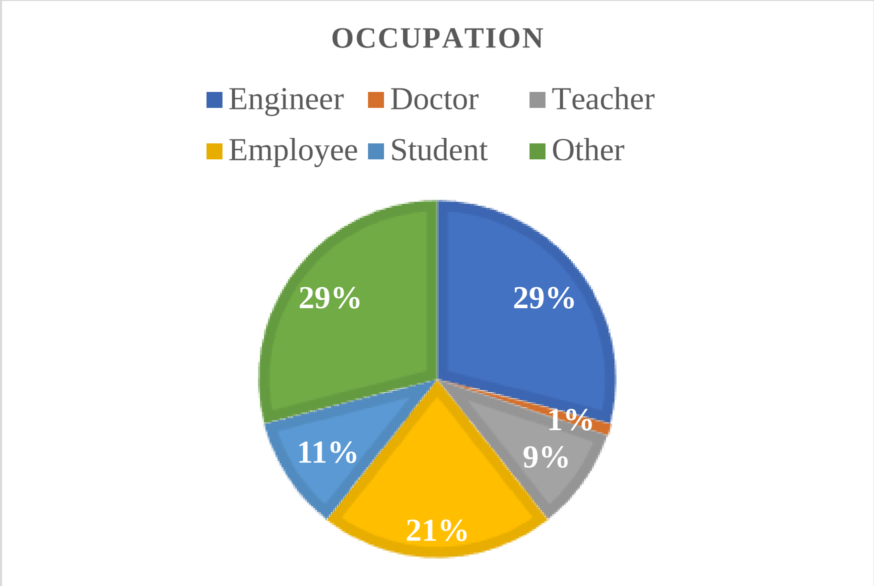

Figure 23: Profession of Participants

According to pie chart above, 29% of the participants in the profession are engineers and do not work compared to 21% employees and 11% students. The lowest participation are doctors by 1%.

Table 20: Level of Education

Education					
P_1.6	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
General Education Diploma	1	23	11.92	11.92	11.92
Diploma	2	51	26.42	26.42	38.34
Bachelor	3	88	45.6	45.6	83.94
Master	4	30	15.54	15.54	99.48
Ph.D.	5	1	0.52	0.52	100

Total	193	100	100	

According to Table 20, the highest number of participants was 88 at the Bachelor level and the lowest at 1 of her Ph.D. level.

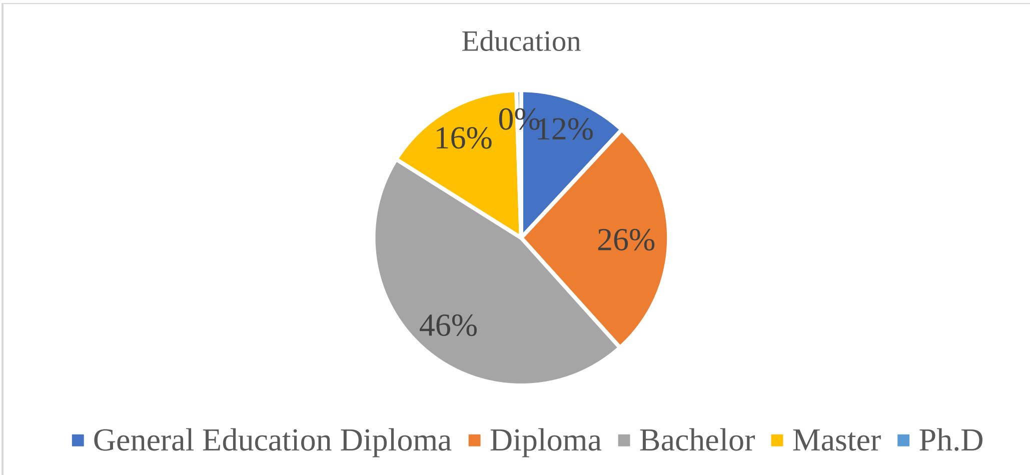

Figure 24: Level of Education

Figure 24 shows that most participants have a 46% bachelor's degree. According to table 18 data 26% diploma, 16% master, 12% general education diploma, 0.52% Ph.D.

Table 21: Knowledge of Wastewater Treatment in the Sultanate of Oman

Knowledge					
P1.7	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Yes	1	85	44	44	44
No	2	54	27.98	27.98	72.02
Maybe	3	54	27.98	27.98	100
Total		193	100	100	

According to Table 21, the results show that 85 participants with knowledge of wastewater treatment in Oman and 54 participants who had no knowledge of wastewater treatment. while 54 participants maybe have little information in WWT in Oman.

Figure 25: Knowledge of Wastewater Treatment in the Sultanate of Oman

Knowledge of participants of wastewater treatment in Oman is shown in Figure 25. About 44% of respondents said yes, and the rest 27.98% had no knowledge and probably had simple knowledge.

Table 22: Uses of Wastewater

Uses of Wastewater and Sludge Treated in Oman					
P_1.8	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
In the irrigation of green areas	1	87	45.08	45.08	45.08
Making fertilizers	2	17	8.1	8.1	53.89
In irrigating agricultural crops	3	1	0.52	0.52	54.4
Recharge of groundwater	4	0	0	0	0
All of the above	5	88	45.6	45.6	100
Total		193	100	100	

According to the analysis, the uses of sewage and sludge in Oman were answered by 88 participants all of the above, 87 participants for the irrigation of green areas, 17 participants in making fertilizers and one participant selected in irrigating agricultural crops as it shown in Table 22.

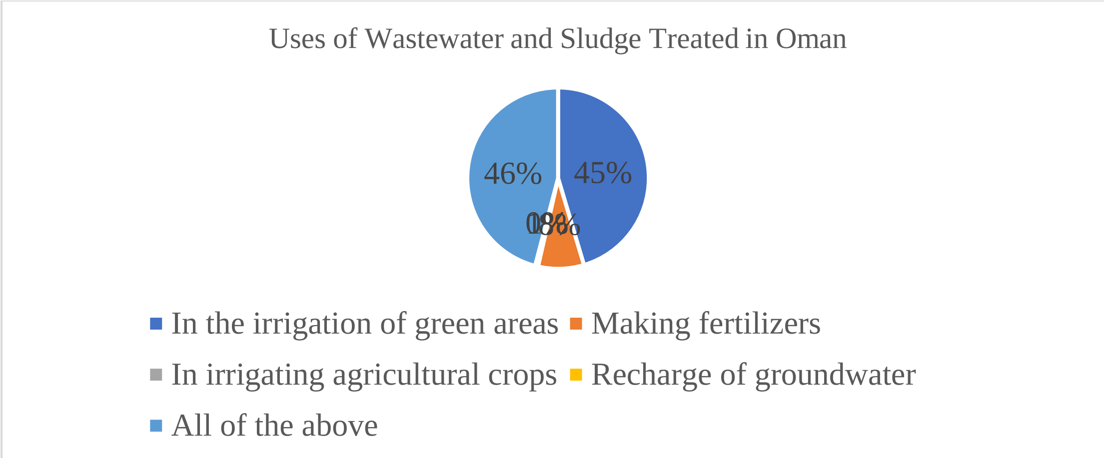

Figure 26: Uses of Wastewater

Figure 26 shows 45.6% of participants believed that Oman used treated sewage to irrigate green areas, agricultural crops, recharge of groundwater and fertilizer industry. While 45.08% of respondents thought that the use of treated sewage was used to irrigate green areas compared to the rest of the participants 8.1% said used in the fertilizer industry and 0.52% in recharge of groundwater.

4.2.2 Part 2: The Effectiveness of Reusing Wastewater in Oman for Construction Purposes

In this section, the questionnaire contains nine questions related to the first objective of the research study as it shown in analysis in Table 23. For more details see the appendix C part 2.

Table 23:Descriptive Statistics of the Effectiveness of Reusing Wastewater in Oman for Construction Purposes

Descriptive Statistics								
	N	**Mean**	**S.E. Mean**	**Std Dev**	**Variance**	**Range**	**Minimum**	**Maximum**
Oman's Infrastructure	193	2.5	0.7	0.97	0.95	4	1	5
The Government Strategic Plans	193	2.31	0.7	1.02	1.05	4	1	5
Treatment Company in Oman can do its	193	2.1	0.7	0.92	0.84	4	1	5

part in wastewater management								
Sewage Taxes	193	2.62	0.08	1.14	1.31	4	1	5
Investing of Treated Wastewater	193	1.68	0.06	0.9	0.81	4	1	5
Solutions of Pollution Resulting from Wastewater	193	1.7	0.07	0.91	0.84	4	1	5
The Exploitation of Treated Wastewater in Construction Field	193	1.79	0.07	0.97	0.94	4	1	5
Using of treated wastewater in mix concrete	193	2.12	0.08	1.06	1.12	4	1	5
Exploitation of solid waste from wastewater treatment in the cement and brick industry	193	2.16	0.08	1.11	1.24	4	1	5

Table 24: Oman’s Infrastructure

Oman's Infrastructure					
P_2.1	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Strongly Agree	1	28	14.51	14.51	14.51
Agree	2	74	38.34	38.34	52.85
Neutral	3	64	33.16	33.16	86.01
Disagree	4	21	10.88	10.88	96.89
Strongly Disagree	5	6	3.11	3.11	100
Total		193	100	100	

According to Table 24, 74 and 64 of participants answered agree and neutral that Oman's infrastructure is efficient in wastewater treatment. While 24 and 21 of participate strongly agree and disagree that Oman's infrastructure is efficient in wastewater treatment.

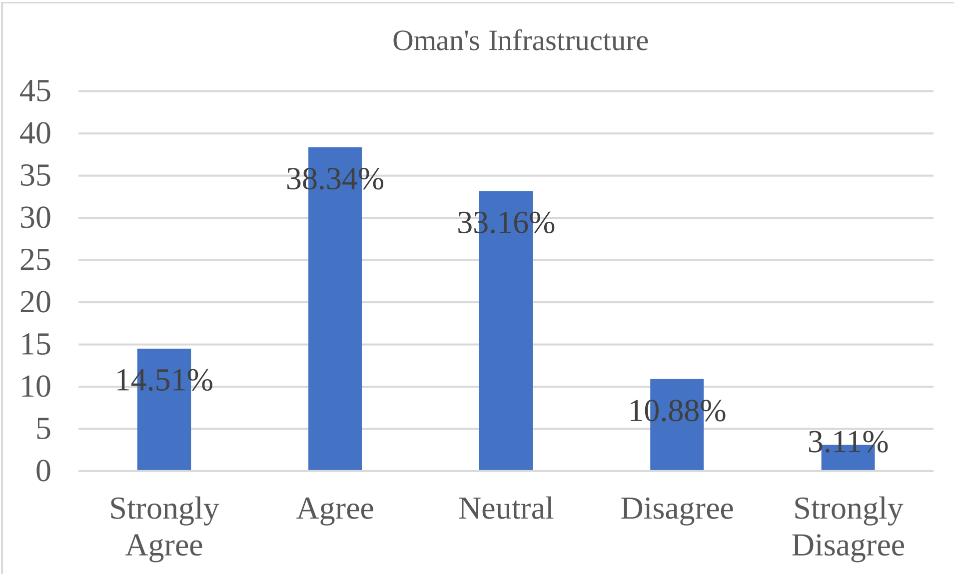

Figure 27: Readiness of Oman's Infrastructure

As shown in the Figure 27, some of participants agree that Oman's infrastructure is efficient in wastewater treatment with 38.34%. The number of neutral participants was 64 with 33.16%, compared to 33.16% of those who strongly agree of Oman's infrastructure as having a high efficiency in wastewater treatment and can be used in construction. However, 10.88% of participates disagree and 3.11 % of them are strongly disagree.

Table 25: Strategic Plans

The Government Strategic Plans					
P_2.2	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Strongly Agree	1	47	24.35	24.35	24.35
Agree	2	67	34.72	34.72	59.07
Neutral	3	58	30.05	30.05	89.12
Disagree	4	15	7.77	7.77	96.89
Strongly Disagree	5	6	3.11	3.11	100
Total		193	100	100	

Table 24 show 67 and 58 of participate answered agree and neutral compare to 47 and 15 disagree that the government will implement comprehensive strategic plans in the sanitation projects.

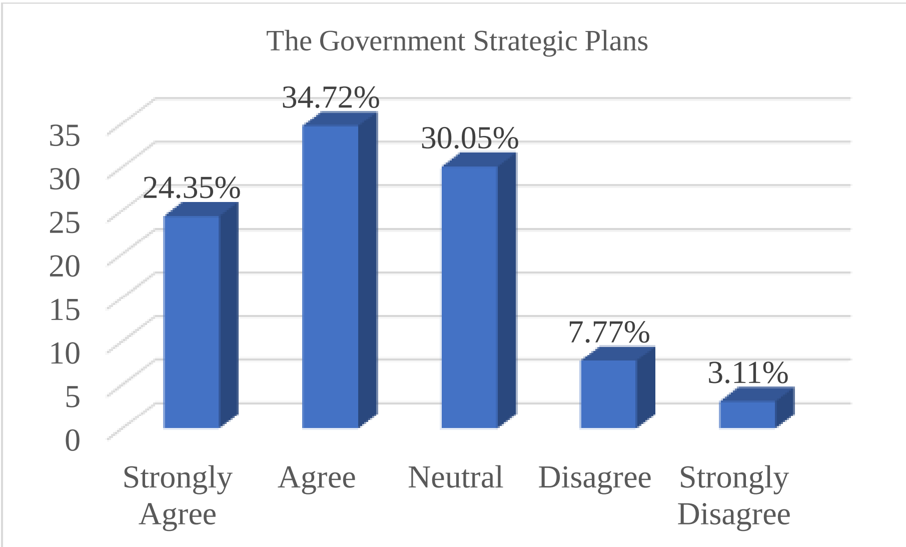

Figure 28: The Government Strategic Plans

According to the Figure 28, more than 55% of participants agree that the government will implement comprehensive strategic plans in the sanitation projects, which will cover all provinces of Oman. While 41% of respondents believe that the government needs to increase and develop of the implementation of strategic plans to include all provinces of Oman.

Table 26: Wastewater Management

Treatment Company in Oman can do its part in wastewater management					
P_2.3	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Strongly Agree	1	52	26.94	26.94	26.94
Agree	2	89	46.11	46.11	73.06
Neutral	3	34	17.62	17.62	90.67
Disagree	4	17	8.81	8.81	99.48
Strongly Disagree	5	1	0.52	0.52	100
Total		193	100	100	

Table 26 show, the highest number of participate is 89 agree and lowest is 1 strongly disagree.

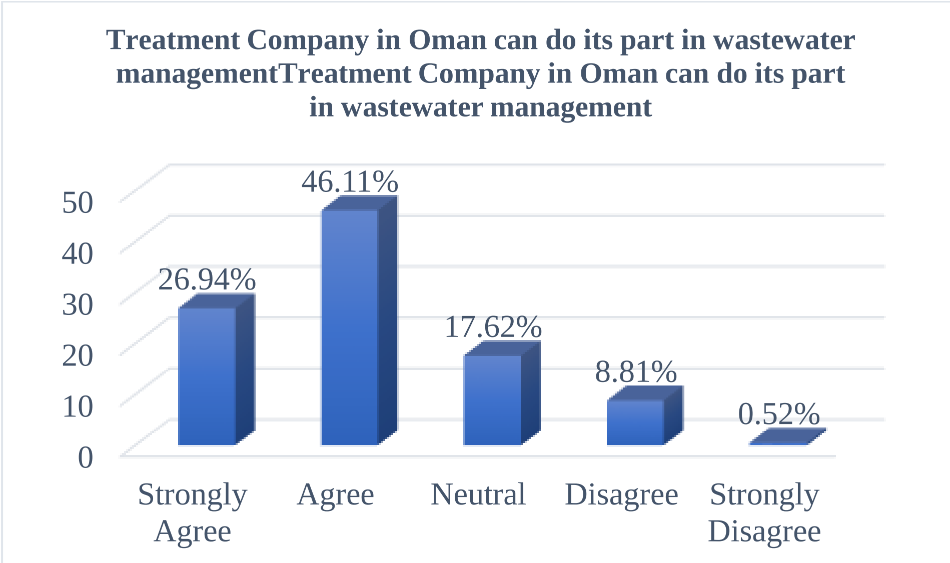

Figure 29: Wastewater Management

Figure 29 showed, more than 60% of the participants' opinion that the treatment company in Oman has a high ability to play its role in wastewater management. More than 30% believe the company needs to be equipped with high processing efficiency.

Table 27: Sewage Taxes

Sewage taxes are paid only by companies and foreigners residing in Oman in order to be used to Operating and Maintenance Costs and protect the environment in sewage treatment plants					
P2.4	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Strongly Agree	1	34	17.62	17.62	17.62
Agree	2	58	30.05	30.05	47.67
Neutral	3	66	34.2	34.2	81.87
Disagree	4	18	9.33	9.33	91.19
Strongly Disagree	5	17	8.81	8.81	100
Total		193	100	100	

According to Table 27, 66 and 58 of participate answered neutral and agree that Sewage taxes are paid only by companies and foreigners residing in Oman in order to be used to Operating and Maintenance Costs and protect the environment in sewage treatment plants.

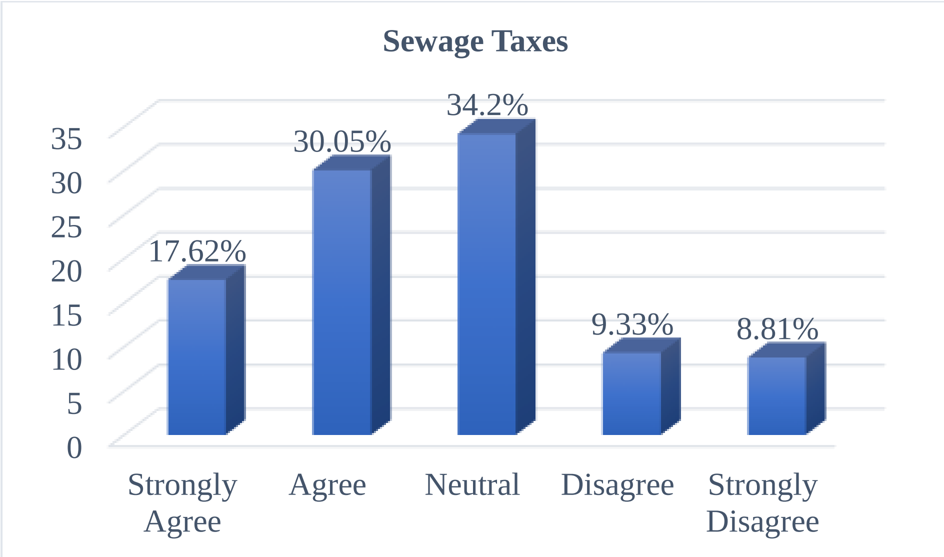

Figure 30: Sewage Taxes

Over 15% of participants disagree to the imposition of sewage taxes by companies and foreigners residing in Oman in order to use them in operating, maintenance and environmental protection costs at wastewater treatment plants. While 45% of participants agree to impose the taxes for contribute to reducing operating and maintenance costs for sewage treatment plants as it shown in Figure 30.

Table 28: Investing of Treated Wastewater in Oman

Investing of Treated Wastewater					
P2.5	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Strongly Agree	1	104	54.89	54.89	53.89
Agree	2	58	30.05	30.05	83.94
Neutral	3	21	10.88	10.88	94.82
Disagree	4	8	4.15	4.15	98.96
Strongly Disagree	5	2	1.04	1.04	100
Total		193	100	100	

The answers of 104 and 58 of participants strongly agreed and agree that wastewater should be invested for different purposes in order to achieve economic and environmental sustainability. This indicates that society accepts the idea of exploiting sewage in the field of construction as shown in Table 28.

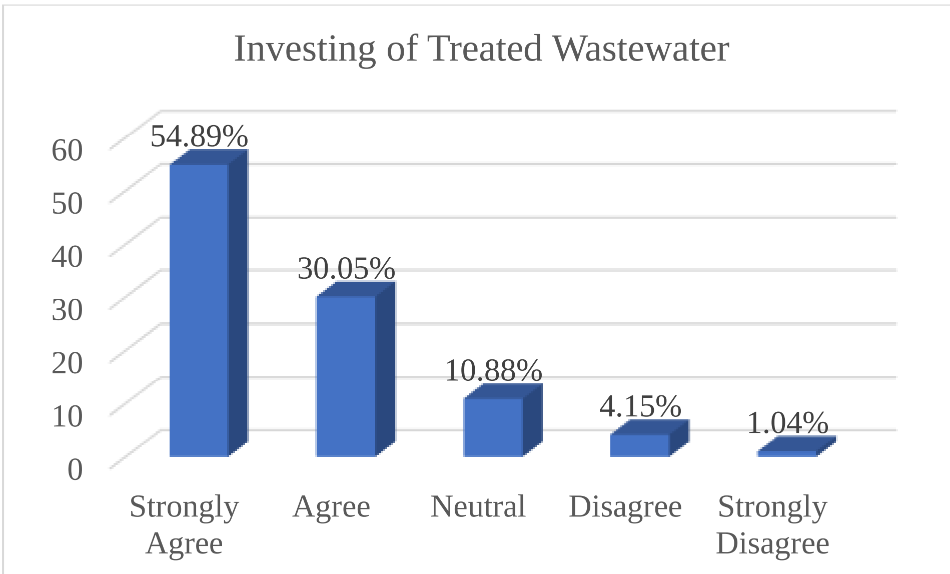

Figure 31:Investing of Treated Wastewater in Oman

As described in the Figure 31, 70% of participants are agree that investing treated wastewater will help to reduce treatment and disposal costs by turning waste into a useful resource and can provide economic and social benefits. While 30% of respondents believe that the investment of treated water has no economic impact.

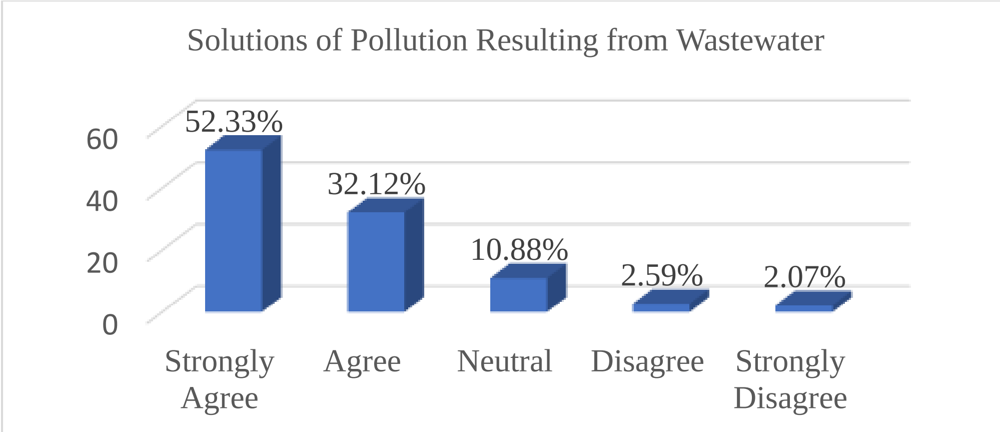

Figure 32: Solutions of Pollution

According to Figure 32, 75% of participants agree on the development of Oman's infrastructure by increasing the number of wastewater treatment plants will be contributed to finding solutions to pollution caused by sewage leakage in the soil. 12% of respondents expect that there are some other solutions could be alternative to wastewater treatment.

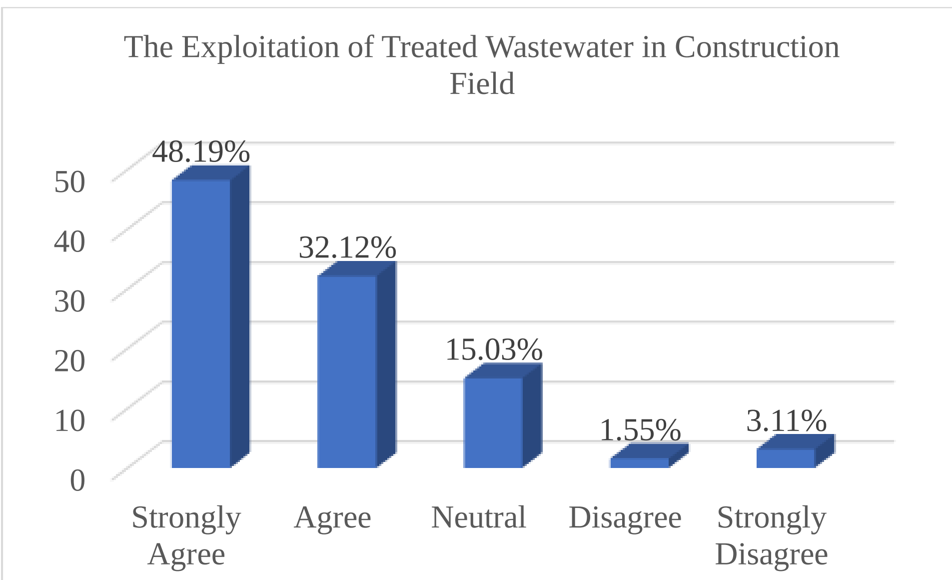

Figure 33: The Exploitation of Treated Wastewater

The results show that most of the participate are support the idea of exploitations exploitation of treated wastewater into the field of construction will contribute to reducing dependence on groundwater and desalination as it shown in Figure 33.

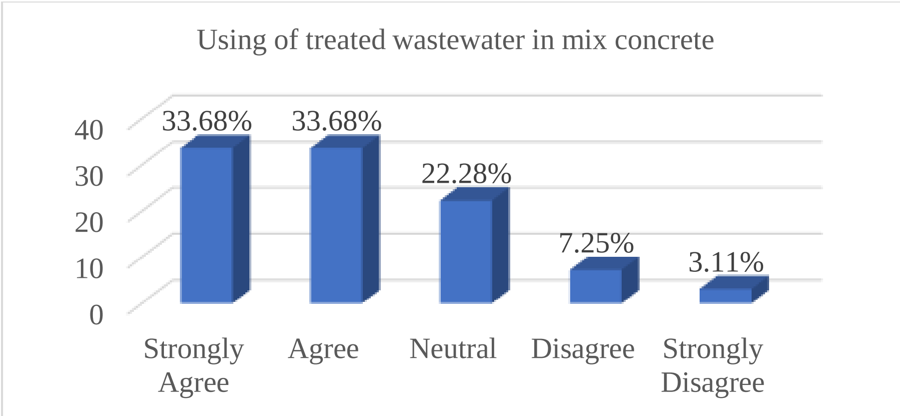

Figure 34: Wastewater Reusing in Mix Concret

As shown in Figure 34, more than 70% of participants encourage the exploitation of wastewater in the concrete mixture. While 10% of participants believe that the use of sewage in concrete mixtures is inappropriate and may cause damage in the future.

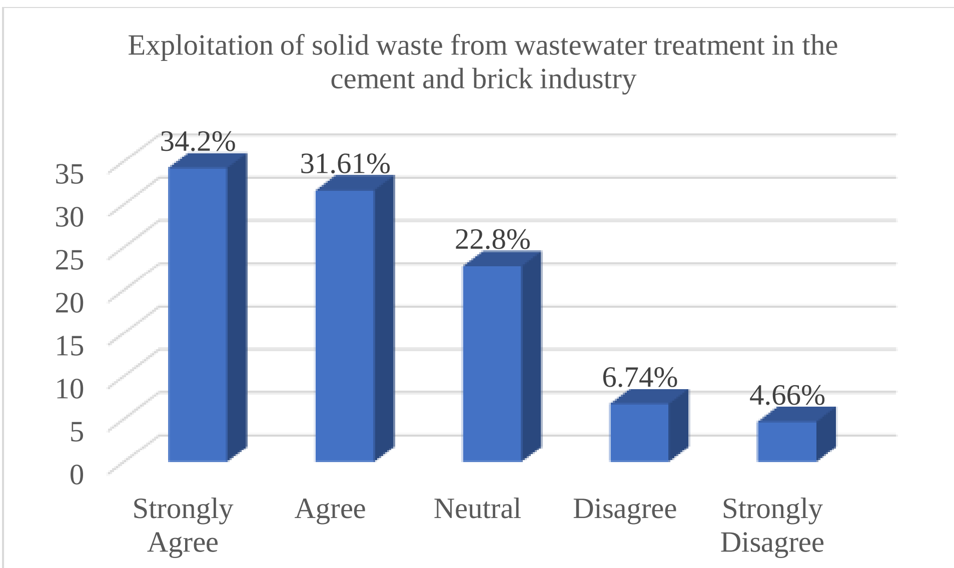

Figure 35: Exploitation of Sludge from Wastewater Treatment in Construction Industry

According to Figure 35, the results showed that more than 65% of participants supported the exploitation of sludge from wastewater treatment in the construction industry, compared to 10% of participants who did not prefer to use sludge in construction.

4.2.3 Part 3: Challenges and Opportunities of Wastewater and Sludge Management in Oman

This section contains 7 questions related to challenges and opportunities in reusing treated wastewater as it shown in descriptive statistics shown in Table 29. For more details see the appendix C part 3.

Table 29: Descriptive Statistics of Challenges and Opportunities of Wastewater and Sludge Management in Oman

Descriptive Statistics								
	N	**Mean**	**S.E. Mean**	**Std Dev**	**Variance**	**Range**	**Minimum**	**Maximum**
Challenges of Reusing Treated Wastewater in Construction Industry in Oman	193	3.52	0.12	1.72	2.97	5	1	6
Major factors for determining the most appropriate wastewater reuse option	193	4.06	0.11	1.52	2.3	5	1	6
The equipment efficient in treatment wastewater	193	2.19	0.06	0.84	0.71	2	1	3
The factors needed to exploit treated wastewater in Oman	193	5	0.13	1.74	3.02	6	1	7
A new law should be formulated by the Environment Authority to cover more application of reusing treated wastewater like construction industry.	193	1.67	0.07	0.95	0.91	4	1	5

Reusing treated wastewater is a relatively low-cost technology compared to alternatives such as desalination, groundwater extraction and transportation.	193	3.19	0.07	0.95	0.9	4	1	5
Circular economy	193	3.43	0.06	0.88	0.77	4	1	5

Table 30:Challenges of Reusing Treated Wastewater

Challenges of Reusing Treated Wastewater in Construction Industry in Oman					
P_3.1	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Environmental Factors	1	41	21.24	21.24	21.24
Social Factors	2	22	11.4	11.4	32.64
Economic Factors	3	31	16.06	16.06	48.7
Religious factors	4	5	2.59	2.59	51.3
All of the Above	5	83	43.01	43.01	94.3
Other	6	11	5.7	5.7	100
Total		193	100	100	

According to table 30, 83 and 41 of the participate answered all the above and environmental factors that Challenges of Reusing Treated Wastewater in Construction Industry in Oman.

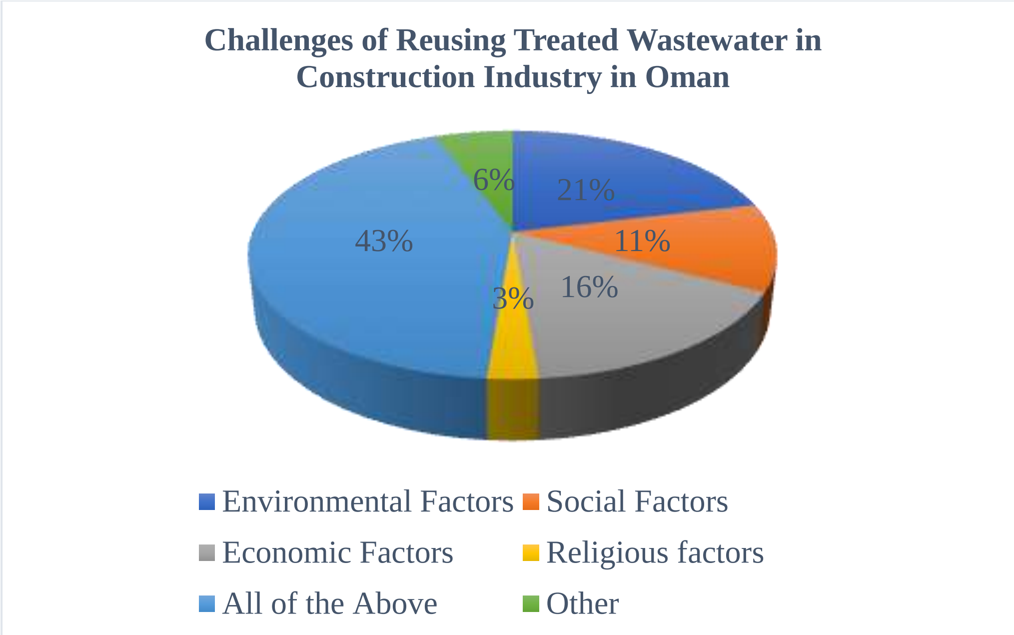

Figure 36: Challenges of Reusing Treated Wastewater

According to Figure 36, 43% of participants agree that the main factors in the challenges of re-using sewage in Oman for construction field are economic, environmental, religious and societal factors. While 21% of participants said the main reason is environmental factors compared to 16% of the participants agree that the cause is for economic factors.

Table 31: Major Factors in Determining Wastewater Reuse Option

Major Factors in Determining the Most Appropriate Wastewater Reuse Option					
P3.2	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Infrastructure Costs	1	19	9.84	9.84	9.84
Total Treatment Costs of Wastewater	2	29	15.03	15.03	24.87
Institutional Constraints	3	8	4.15	4.15	29.02
Operational and Maintenance Costs	4	10	5.18	5.18	34.2
All of the Above	5	120	62.18	62.18	96.37
Other	6	7	3.63	3.63	100

Total	193	100	100	

As described in the Table 31, 120 frequency responses of 62.18% for the main factors in determining the most appropriate wastewater reuse option are all of the above. While 15.03% of respondents believe that the main factor is the total cost of wastewater treatment.

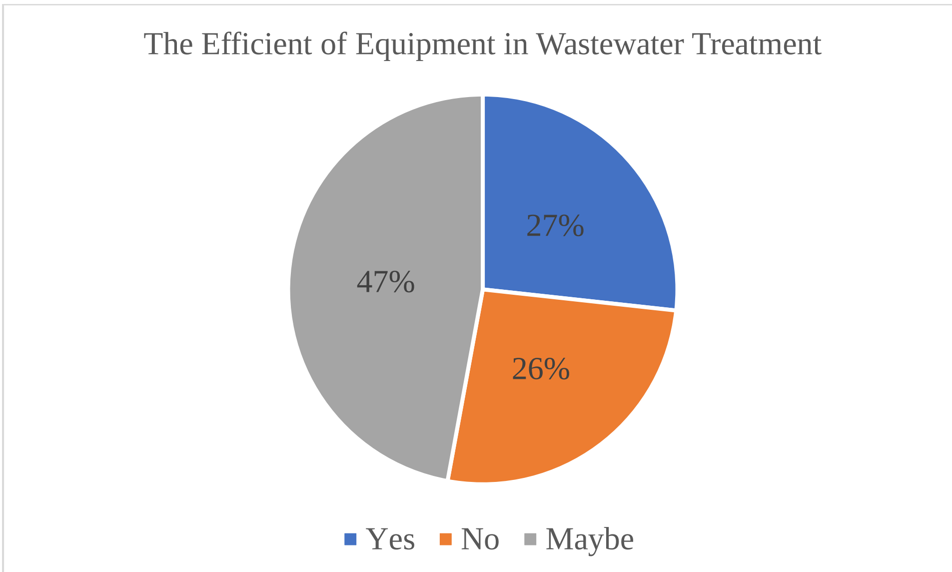

Figure 37: The Efficient of Equipment in Wastewater Treatment

P3.3: According to Figure 37, 47% of participants had no background with wastewater treatment equipment in Oman compared to 27% of respondents who believed that sewage treatment equipment is efficient enough to allow sludge to be reused in the construction materials industry. While 26% of participants agree that sanitation treatment equipment is not highly efficient in processing.

Table 32:The Factors Needed to Exploit treated Wastewater in Oman

The Factors Needed to Exploit treated Wastewater in Oman					
P3.4	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Finance	1	19	9.84	9.84	9.84
Skilled Manpower	2	8	4.15	4.15	13.99

Management Support	3	11	5.7	5.7	19.69
Advanced Processing Equipment	4	13	6.74	6.74	26.42
Improved Operating Efficiency	5	13	6.74	6.74	33.16
All of the Above	6	123	63.73	63.73	96.89
Other	7	7	3.11	3.11	100
Total		193	100	100	

Most participants agree that the factors needed to exploit treated sewage in Oman are finance, skilled manpower, administrative support, advanced treatment equipment, and improved operating efficiency by 64% compared to 10% of participants who believe that financial capacity is a major reason to benefit from the re-exploitation of wastewater as shown in Table 32.

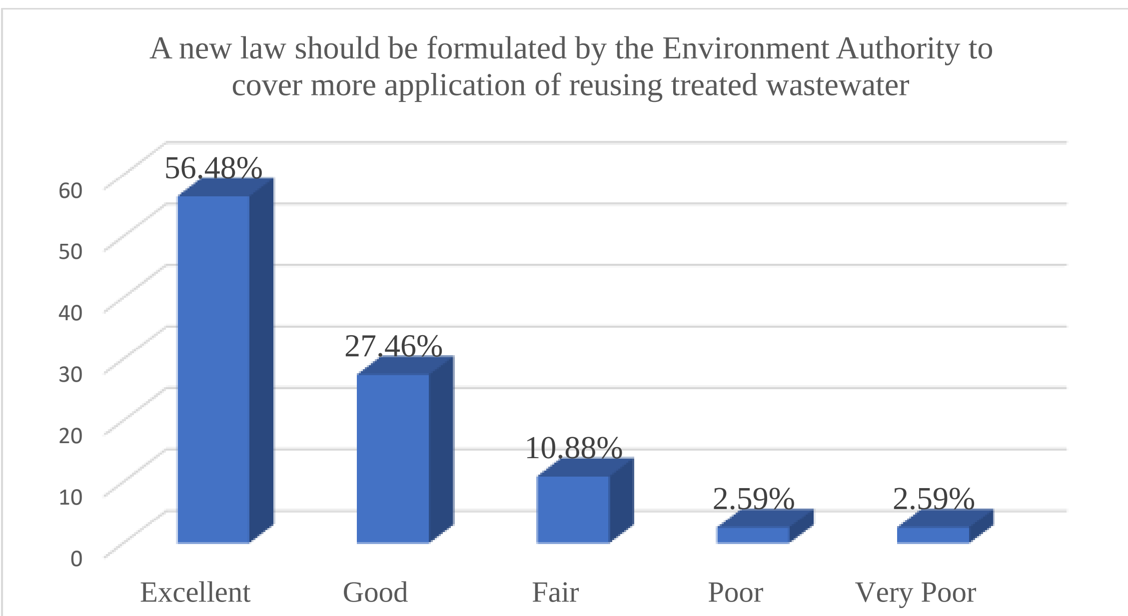

Figure 38:Environment Authority Law in Application of Reusing Treated Wastewater

P3.5: According to the Figure 38, more than 70% of the participants support for change in the regulations of the Environment Authority regarding the requirements for the reuse of sewage in a different field such as in the field of construction. While 14% of respondents believe that the law does not need to change.

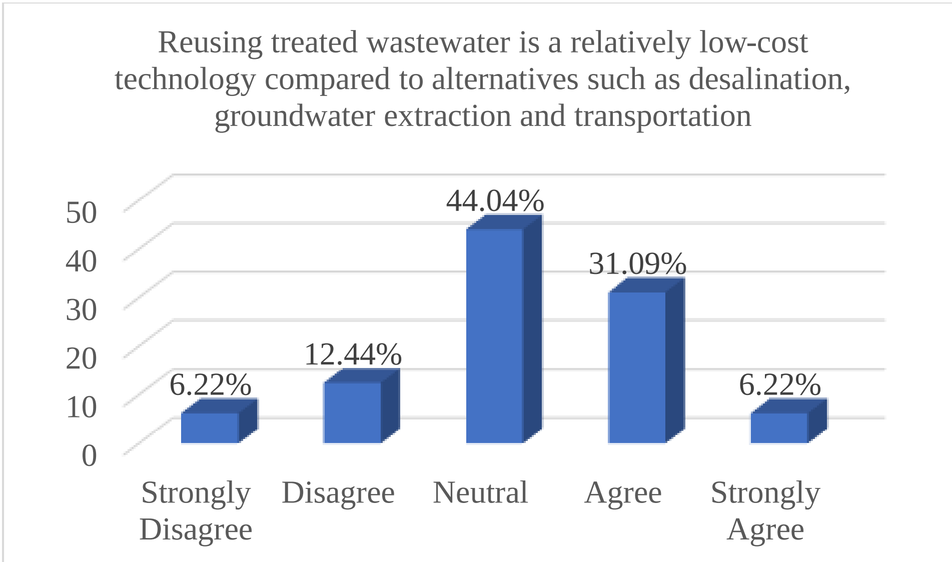

Figure 39: Reusing Treated Wastewater is A relatively Low-cost

P3.6: 44% most of respondents have no knowledge of reusing treated wastewater as a relatively low-cost technique compared to alternatives such as desalination, groundwater extraction and transportation. More than 31% of respondents agree that the cost of using treated wastewater is lower than the cost of using groundwater or desalinated water as it shown in Figure 39.

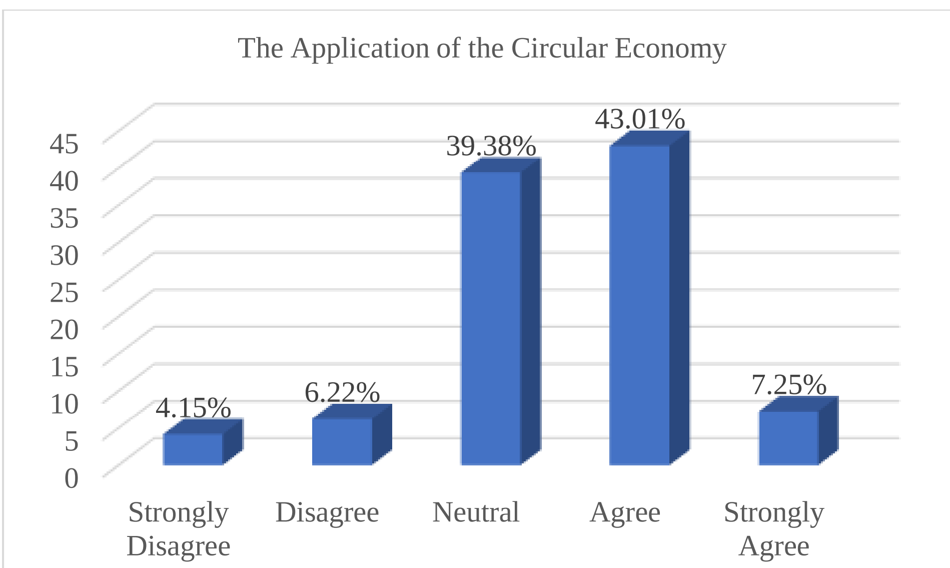

Figure 40: Circular Economy

P3.7: According to Figure 40, 43% of respondents support the application of the circular economy system compared to 39% neutral of participants and 6% of respondents disagree.

4.2.3 Part 4: Implementation of Sustainable Techniques and Risk Assessment of Sewage.

This section contains 8 questions related to Implementation of sustainable techniques and risk assessment of sewage as it shown in Table 33. For more details see the appendix C part 4.

Table 33: Descriptive Statistics of Sustainable Techniques and Risk Assessment of Sewage

Descriptive Statistics								
	N	**Mean**	**S.E. Mean**	**Std Dev**	**Variance**	**Range**	**Minimum**	**Maximum**
Benefits of Water Recycling	193	4.61	0.15	2.07	4.3	6	1	7
Monitoring of the Operation of the Treatment Plant	193	1.61	0.07	0.91	0.82	4	1	5
Covid-19 Will Cause Risks for Wastewater Treatment Plants	193	3.31	0.08	1.08	1.16	4	1	5
Reusing treated wastewater in construction purposes can achieve Sustainability in Oman	193	2.27	0.07	1	0.99	4	1	5
The Expansion of Cities and the Rapid Growth of the Population	193	3.22	0.08	1.05	1.1	4	1	5

Mixing Sewage Sludge with Cement and Clay	193	3.13	0.07	0.93	0.86	4	1	5
Awareness of the Process of Wastewater Treatment Management Process	193	3.94	0.07	0.98	0.96	4	1	5
Economic Risks of Treating Wastewater	193	3.67	0.07	0.92	0.85	4	1	5

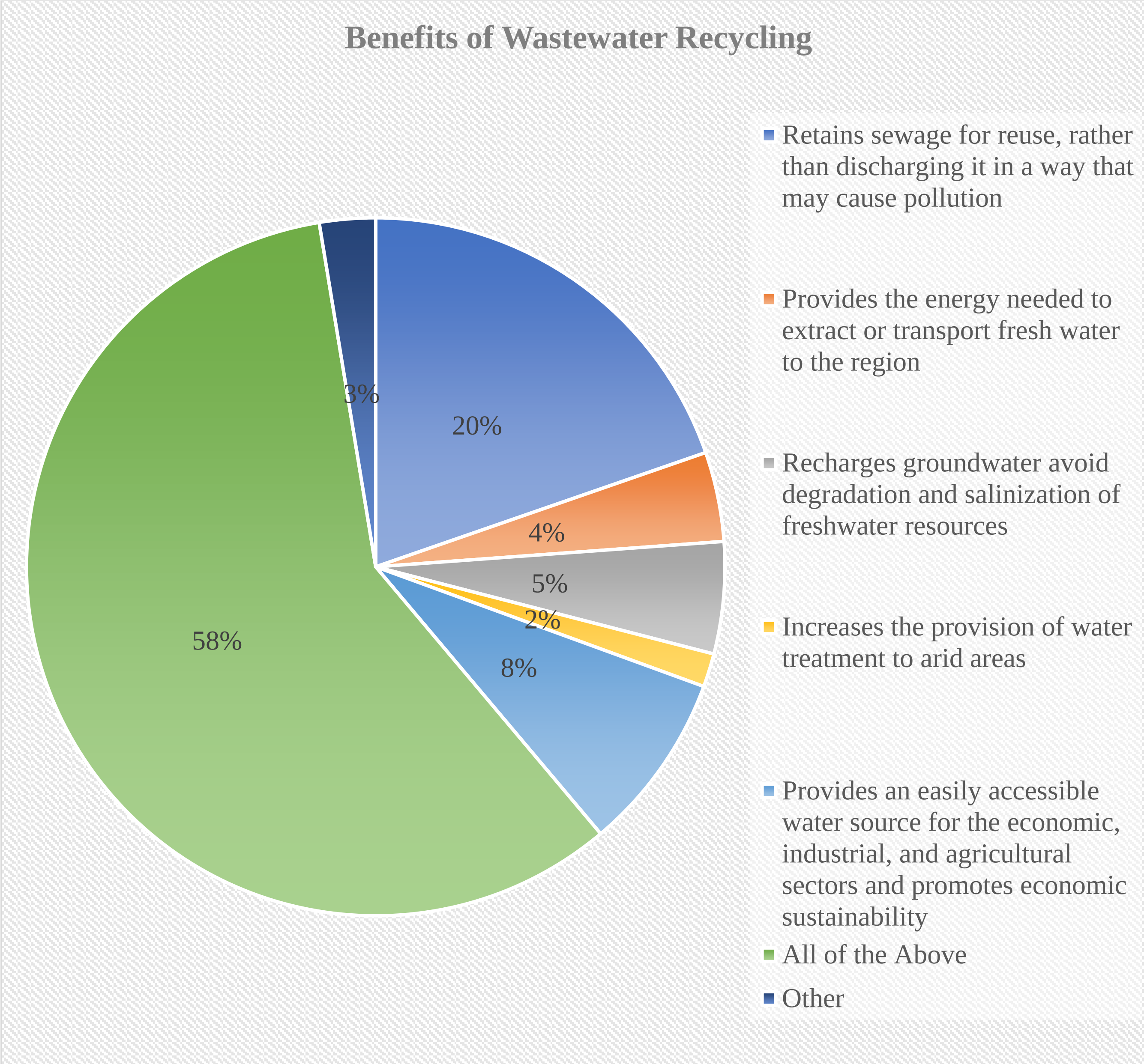

Figure 41: Benefits of Wastewater Recycling

P4.1: Figure 41 show, 58% of respondents agree that all of the benefits of wastewater recycling all the above, compared to 20% of respondents agree that provide an accessible water source for the economic, industrial and agricultural sectors and promote economic sustainability.

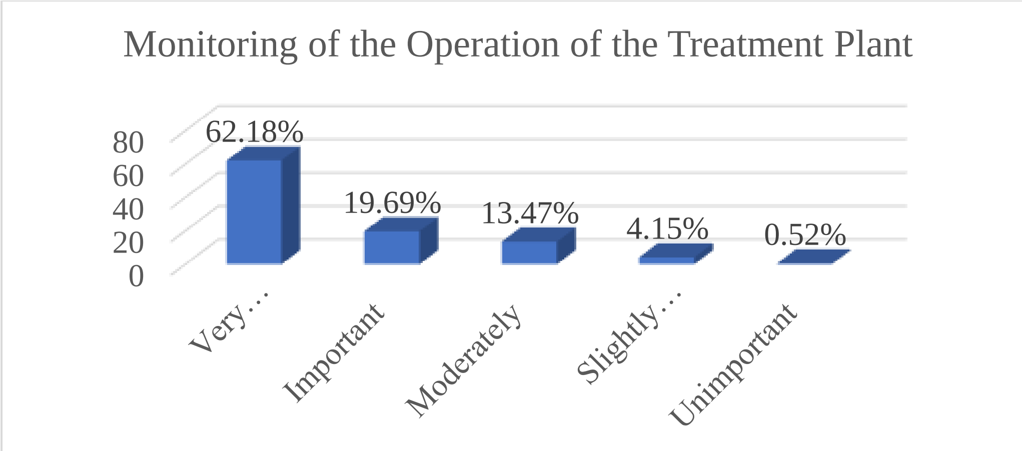

Figure 42: Monitoring of the Operation of the Treatment Plant

P4.2: 62% of respondents agreed that continuous monitoring of the operation of the treatment plant is effective in reducing the risk of deteriorating wastewater quality is very important compared to others, around 20% of them said is important and 0.52% agree that unimportant to monitor operation of treatment plants as it shown in Figure 42.

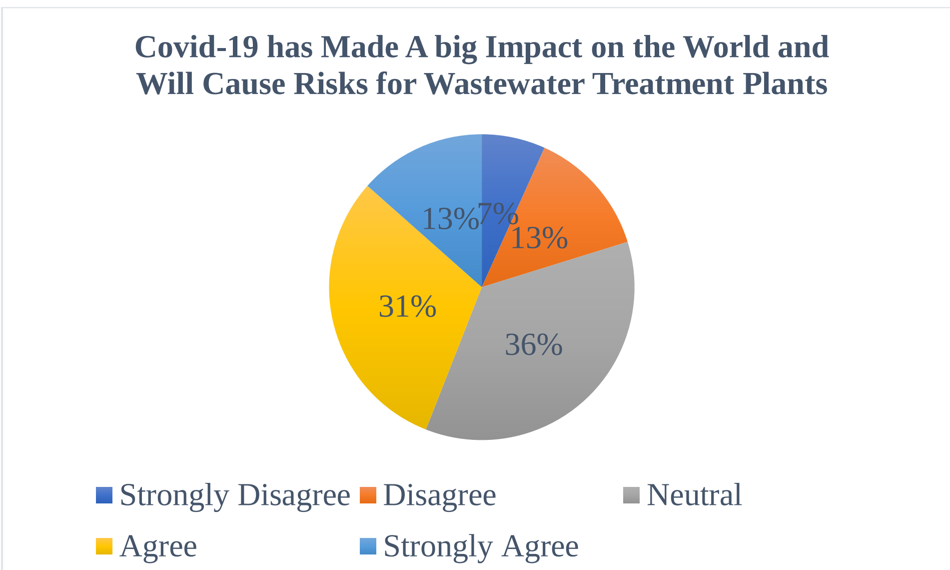

Figure 43: The Impact Covid-19 in Wastewater Treatment Plants

P4.3: The highest percentage of respondents' responses were neutral that Covid-19 had a significant impact on the world and would cause risk to wastewater treatment plants with 36% compared to 31% of respondents who agree that Covid-19 has a high impact on sewage plants.

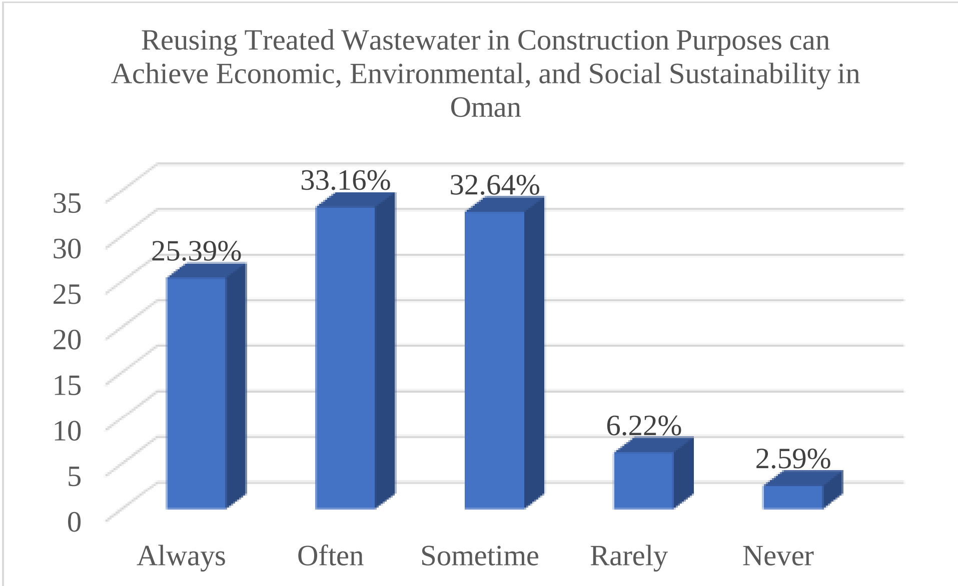

Figure 44:Reusing Treated Wastewater in Construction Purposes can Sustainability in Oman

P4.4: According to chart above, 33% of respondents said that the reuse of treated wastewater for construction purposes can often lead to economic, environmental, and social sustainability in Oman. Analysis of data from respondents' responses showed that sometimes the reuse of treated wastewater can have an impact on sustainability with 32%. 25% of the participants' responses that the reuse of treated wastewater has a high role to play in increasing the economy, protecting the environment and accepting society in order to achieve sustainability.

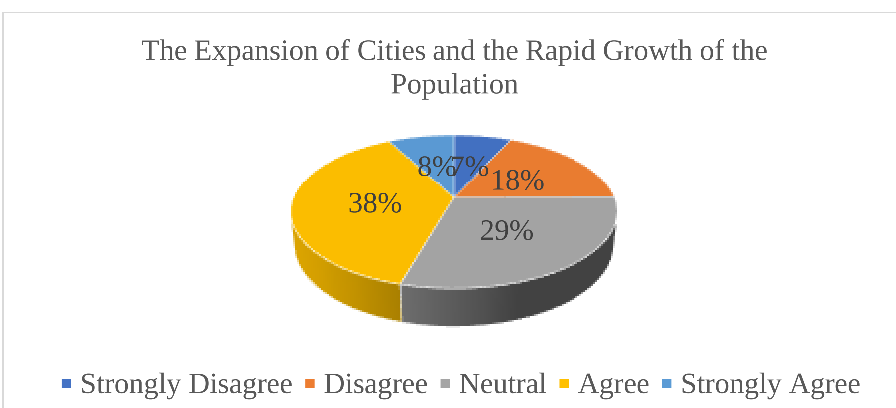

Figure 45: The Rapid Growth of the Population

P_4.5: 38% of respondents agree that the expansion of cities and rapid population growth, which directly affects the development of countries, the growth of civilization and the impact of the economy, may affect the government's plans to complete the construction of sewage plant projects, compared to 7% of respondents believe that the increase in the population do not has any effects on the economy.

Table 34: Mixing Sewage Sludge with Cement and clay for the Production of Lightweight Aggregate Slightly

Mixing sewage sludge with cement and clay for the production of lightweight aggregate slightly reduces the likelihood of polluting the environment with harmful heavy metals					
P_4.6	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Never	1	11	5.7	5.7	5.7
Rarely	2	24	12.44	12.44	18.13
Sometime	3	100	51.81	51.81	69.95
Often	4	44	22.8	22.8	92.75
Always	5	14	7.25	7.25	100
Total		193	100	100	

P_4.6: Mixing sewage sludge with cement and clay to produce lightweight debris reduces the likelihood of contaminating the environment with harmful heavy metals, with 100 participants answering that sometimes with 51%, 44 participants often, 14 participants and 11 participants never as shown in Table 34.

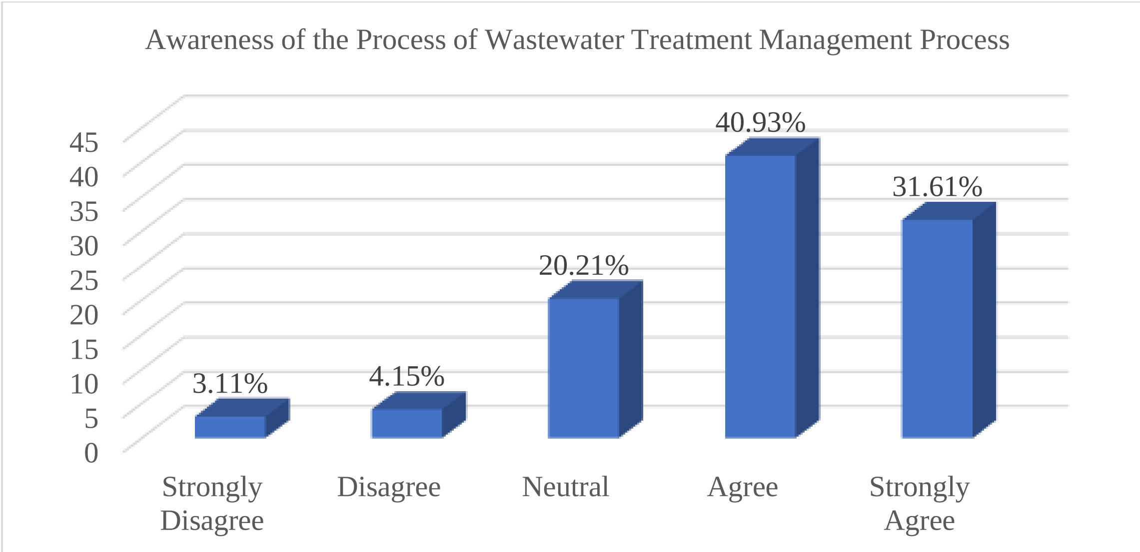

Figure 46: Awareness of the Process of Wastewater Treatment Management Process

P4.7: The highest percentage of participants was about 41% who agreed that the process of managing wastewater treatment should be understood and awareness of this issue spread in the community by spreading the benefits of using treated wastewater in construction compared to 31% strongly agree, 20% neutral and 4% strongly agree, while the lowest 3% disagree.

Table 35: Economic Risks of Treating Wastewater

One of the economic risks of treating wastewater projects might be refusal of customers to pay the fees of treatment cost or using treated water					
P4.8	**Value**	**Frequency**	**Percent**	**Valid Percent**	**Cum Percent**
Strongly Disagree	1	5	2.59	2.59	2.59
Disagree	2	14	7.25	7.25	9.84
Neutral	3	51	26.42	26.42	36.27
Agree	4	92	47.67	47.67	83.94
Strongly Agree	5	31	16.06	16.06	100
Total		193	100	100	

P4.8: According to Table 35, one of the economic risks of treating wastewater projects might be refusal of customers to pay the fees of treatment cost or using treated water, as the results of the analysis showed that 92 participants were agree, 51 were neutral, 31 strongly approved and 19 disagreed.

4.2.5 Crosstabs Analysis

Crosstabs Analysis is a method used in statistical analysis (quantitative) to understand the correlation, trends, and probabilities between multiple variables within the preliminary data. It is important to know the variables and the relationship between them to enhance the results statistical analysis by using SPSS software.

4.2.5.1. Level of education and knowledge of wastewater treatment in the Sultanate of Oman.

Table 36: Level of education and knowledge

	Knowledge of Wastewater Treatment in the Sultanate of Oman			
Level of education	Yes	No	Maybe	**Total**
General Education Diploma	9	8	6	23
Diploma	19	18	14	51
Bachelor	**45**	20	23	88
Master	12	8	10	30
Ph.D.	0	0	**1**	1
Total	85	54	54	**193**

The results of the analysis showed that the highest number of participants with knowledge of wastewater treatment in Oman have a bachelor's level of education, while the smallest number of participants at the Ph.D. level they answers were that may be had awareness and knowledge in treatment of wastewater as shown in Table 36.

4.2.5.2 Oman's infrastructure is highly efficient for wastewater treatment and Treatment Company in Oman can do its part in wastewater management.

Table 37: Wastewater Management and Oman's Infrastructure

	Treatment Company in Oman can do its part in wastewater management					
Oman's Infrastructure	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	**Total**
Strongly Agree	21	5	0	2	0	28
Agree	19	**41**	12	2	0	74
Neutral	8	35	18	3	0	64
Disagree	2	7	4	8	0	21
Strongly Disagree	2	**1**	0	2	1	6
Total	52	89	34	17	1	**193**

According to Table 37, most of participants agree that Oman's infrastructure is highly efficient in wastewater treatment and the company responsible for wastewater treatment in Oman can play its part in wastewater management. This indicates that society has accepts the idea of reusing wastewater in different fields.

4.2.5.3 Exploitation of solid waste from wastewater treatment in the cement and brick industry and investing of treated wastewater in Oman

Table 38: The Exploitation of Treated Wastewater in the Cement and Brick Industry and Investing of Treated Wastewater

	Exploitation of solid waste from wastewater treatment in the cement and brick industry					
Investing of Treated Wastewater in Oman	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	**Total**
Strongly Agree	**51**	26	17	6	4	104
Agree	13	30	12	3	0	58
Neutral	2	5	11	2	**1**	21
Disagree	0	0	4	2	2	8

Strongly Disagree	0	0	0	0	2	2
Total	66	61	44	13	9	193

According to Table 38,51 participants strongly agree that an investment of treated sewage helps reduce treatment and disposal costs by turning waste into a useful resource and can provide economic and social benefits. In addition, participants support the exploitation of solid waste from wastewater treatment in the cement and brick industry. While 1% of participants see the exploitation of treated sewage in agriculture as the best way.

4.2.5.4 Wastewater treatment equipment in Oman is efficient and challenges of reusing treated Wastewater in construction industry in Oman

Table 39: The Efficient of Equipment and Challenges of Reusing Treated Wastewater

	The Efficient of Equipment in Wastewater Treatment			
Challenges of Reusing Treated Wastewater in Construction Industry in Oman	Yes	No	Maybe	**Total**
Environmental Factors	9	14	18	41
Social Factors	9	6	7	22
Economic Factors	3	8	20	31
Religious factors	**2**	0	3	5
All of the Above	25	18	**40**	83
Other	5	4	**2**	11
Total	53	50	90	193

The 40 of participants answered maybe about the efficiency of the equipment used in wastewater treatment and the challenges could be faced in reusing treated wastewater in construction in Oman. That indicates of the lacked information and awareness on wastewater treatment equipment used in Oman as shown in Table 39.

4.2.5.5 The Expansion of Cities and the Rapid Growth of the Population and Reusing Treated Wastewater in Construction Purposes can Achieve Economic, Environmental, and Social Sustainability in Oman

As shown in Table 40, 28 participants believe that urbanization and rapid population growth are affecting in the economy, which is could affect the government's plans to complete the construction of sewage plant projects, and that idea of reusing treated sewage for construction purposes may help achieve economic, environmental and social sustainability. While 23 participants agree to reuse sewage, which has economic benefits, which may help the government complete the infrastructure compared to one participant who opposes this view.

Table 40: Population and Sustainability

	Reusing Treated Wastewater in Construction Purposes can Achieve Economic, Environmental, and Social Sustainability in Oman					
The Expansion of Cities and the Rapid Growth of the Population	Always	Often	Sometime	Rarely	Never	**Total**
Strongly Disagree	8	3	2	0	0	13
Disagree	9	15	10	**1**	0	35
Neutral	5	19	**28**	3	2	57
Agree	18	23	23	7	2	73
Strongly Agree	9	4	0	**1**	**1**	13
Total	49	64	63	12	5	193

4.3 THE FINDINGS OF QUALITATIVE RESEARCH FINDING (INTERVIEWS WITH EXPERT ANALYSIS)

In this section, interview data was collected, organized, and text encoded with a specific code to facilitate data analysis. Interviews were conducted by sending e-mails to people with experience in wastewater treatment.

4.3.1 Participates of Qualitative Method

Six interviews were conducted from different organizations (government and private). Table 41 show the general details of interview participants.

Table 41: Participants Details in Interview

Organization Name	Your Occupation	Years of Work Experience	Age	Level of Education
Diwan Royal Court/ Office for Conservation Environment	Senior Wildlife Conservationist	13	37	Bachelor
Environment Engineering Services	Mechanical Engineer	30	50	Bachelor
Muna Noor Groupe	Chemist	40	12	Bachelor
Oman Cement Company	Environmental Engineer	10	34	Bachelor
Oman Wastewater Services Company (Haya Company)	Act Head of Lab	13	35	Master
Environment Authority	Environmental Technician	7	32	Diploma

4.3.2 Coding the data

A code is a short descriptive word for collecting or classifying data related to qualitative research in order to reduce the volume of data by inferring to data and topics of interest to analysis(Lee 2021). In this research, the codes were used where P symbolizes the participants in the interview.

P_1 Working in Diwan Royal Court as Senior Wildlife Conservationist, he has experience in environment management and nature conservation.

P_2 Working in Environment Engineering Services as Mechanical Engineer, he has experience in supervision of sewage treatment plant (STP).

P_3 Working in Muna Noor Groupe as Chemist, he has experience in lab in wastewater quality insurance and STP in operation and maintenance.

P_4 Working in Oman Cement Company as Environmental Engineer, he has experience in pollution control, waste management, wastewater treatment and environment management system.

P_5 Working in Haya Company as Act Head of Lab, he has experience in wastewater quality assurance.

P_6 Working in Environment Authority as Environmental Technician, he has experience in environmental rules and regulations.

4.3.3 Main Themes of Data

The data was divided into main interview themes as shown below:

- ❖ Theme one: The efficient of wastewater treatment infrastructure in Oman.
- ❖ Theme two: Operational and maintenance (O&M) cost of the municipal wastewater treatment plant.
- ❖ Theme three: Challenges might be faced in reusing treated wastewater in the construction industry.
- ❖ Theme four: Control the risks arising from wastewater use in construction.

4.3.4 Interview Questions Analysis

The following are analysis of interview questions and participants answers:

Q_1: Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is Yes, could you give us some information in general?

"Yes, Oman's Wastewater treatment infrastructure is efficient. All the areas are covered by sewage network connected to the STP & treated water for the irrigation purpose. The industrial estates are having pretreatment plants before discharging to common sewerage system for further treatment as the high BOD and high COD cannot be reduced by the conventional STP Process. And Individual small villas, hotels, malls etc. are also having their own STPs & the treated water is used for their own irrigation area (P_3)"

"Yes, it is efficient. In most of the Wilayats there are small STPs along with the sewerage networks which provide the service & treated water for the irrigation purpose. Most of the industrial estates are having effluent treatment plants which treats the influent & provides the treated water for irrigation in the industrial area. Individual small villas, hotels, malls etc. are also having their own STPs & the treated water is used for their own irrigation area (P_2)"

Some participants believe that sewage treatment plants in Oman are not highly efficient and need to be equipped with high quality treatment equipment. In addition, increasing of the number of treatment plants for cover all various provinces in Oman.

Q_2: Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored?

"Many reasons; lack of clear and adopted vision for different stakeholders. Absence of assessment about the relations between the producer and the community. Weaknesses in the infrastructure of reusing of the processed water (P_1)"

"I think this because there are no many studies like this to explore farther applications to utilize wastewater. Also, our rules and regulations are very old, since 1993, and not updated. Another, aspect might be some religion concerns that avoid using treated water (P_4)"

Most participants were of the view that the main reason is Environmental Authority law providing for the use of treated water and sludge in agriculture only.

Q_3: Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

"Earlier all the STPs were built & maintained by respective Municipalities & outside Muscat area were built & maintained by regional municipalities. Now all the STPs which were with the municipalities are under one entity called Haya Water. They are maintaining all these STPs either by themselves or by local contractors. HAYA is recovering the money based on the freshwater usage at different tariff rate as sewage charges. Earlier it was 1 Baiza per Gallon (P_3)"

"Still the government pays most of the O&M cost and on the other side the government itself utilizing treated water. In the future, I think, the citizens will pay that cost similar to the developed countries (P_4)"

The participants do not have enough information about the maintenance and operation of sewage treatment plants, but they agree that Haya is responsible for the treatment plants.

Q_4: In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

"Mainly logistic challenges, like delivery on demand and assuring water quality (P_1)"

"The main challenge is the quality of the water should be maintained with strict parameters required for the discharging the treated water as per the norms of local controlling authority. The people who are using it should be fully trained & aware of the ifs & buts of the work carrying out. The periodically check on the quality of the treated water (P_2)"

Participants agree that the main challenge of reusing wastewater in the field of construction is product quality, updating laws and regulations and accepting the community.

Q_5: Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

"Yes, Wastewater treatment by various method on chargeable basis and reuse /Supply of the treated water in the same manner by irrigation network will be a circular Economy (P_3)"

"Yes, could be by applying best practices in all steps of collecting wastewater, treatment and utilization. There are now new techniques like lean management to reduce wastes from the process and steps of the production cycle (P_4)"

All participants encourage the application of the circular economy because of its economic and environmental benefits.

Q_6: What are the strategies that can be used to control the risks arising from wastewater use in construction?

"Risk assessment considered the best way now to determine, evaluate and reduce the risk in any process and projects. Contingency Plan another technique which is a procedure that will be followed in case the control measures in the risk assessment didn't work (P_4)"

"Laboratory can give clear view of the quality of the treated water so you can relay to the report of laboratory (P_5)"

Most participants believe that strategies that can be used to control risks are risk assessment and continuous testing to verify samples before they are used for construction.

Q_7: Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

"No, I don't there is any impact actually because the population is the same and the use of water is still almost the same (P_1)"

"I guess yes, since COVID19 affect the Manpower who may operate or maintain the wastewater treatment plants and network (P_4)"

Most participants say there is no financial impact on wastewater treatment plants due to the Covid-19 pandemic.

4.4 Summary

A random sample of 193 participants was specifically surveyed in Muscat with the aim of collecting data to determine their responses to the concept of reusing treated sewage in construction. In addition, six interviews were conducted with various sanitation institutions.

The questionnaire data was analyzed by SPSS and Excel. According to the objectives of the study, this section analyzed the willingness of participants to accept the reuse of treated wastewater in the field of construction, where the questionnaire analysis measures the impact of social, economic and environmental factors on the level of acceptance of participants.

The results of quantitative and qualitative analysis have helped to achieve the objectives of the current study as well as to obtain new ideas that may help in the development of research in the future.

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

5.1 INTRODUCTION

In this chapter has three sections: conclusion, recommendation and future study. The results of analyzing of questionnaire and interviews were collected and summarized in order to match the results with the main objectives of the research. In addition, recommendations and future studies have been formulated which maybe help in the future in examining the challenges facing in reused of wastewater.

5.2 CONCLUSIONS

In order to preserve available natural resources and ensure long-term environmental, economic and social sustainability, the idea of reusing treated wastewater (TWW) is a permanent solution. This paper aimed to investigate public perceptions and knowledge of the direction of using TWW as an alternative source of use for construction purposes. The study revealed that the public has some information about the benefits of reusing treated sewage. In addition, wastewater reuse helps reduce harmful gas emissions, saves seawater desalination costs and promotes the conservation of groundwater sources.

The results indicate that the government has a strategic vision to achieve integrated infrastructure and create integrated and sustainable water resources.

Objective 1: Evaluating the potentials and the effectiveness of reusing the treated domestic wastewater in Oman’s construction industry.

According to analysis of data from the questionnaire and interviews, the results showed that Oman has high efficiency in wastewater treatment, but the infrastructure is not yet complete because the number of treatment plants does not cover all provinces in Oman and wastewater is transported by sewage tankers. The exploitation of treated sewage in various fields will help with maintenance and operation costs.

- 38% and 33% of participate agree and strongly agree that Oman's infrastructure as having a high efficiency in wastewater treatment and can be used in construction.

- 35%, 30% and 24% of participate answered agree, neutral and strongly agree that the government will implement comprehensive strategic plans in the sanitation projects, which will cover all provinces of Oman.
- 46% and 27% of participate answered agree and strongly agree that the treatment company in Oman has a high ability to play its role in wastewater management.
- 34% and 30% of participate answered neutral and agree to the imposition of sewage taxes by companies and foreigners residing in Oman in order to use them in operating, maintenance and environmental protection costs at wastewater treatment plants.

The results of the survey analysis indicate that Oman has highly efficient wastewater treatment plants that can be used in the construction industry. In addition, wastewater can be exploited in various fields not only in agriculture that may help to reduce operating and maintenance costs by disposing of waste into a useful resource.

Furthermore, the results of the interview analysis indicate that the technology used to treat wastewater in Oman is highly efficient. Most states have small sewage treatment plants that provide service and treated water for irrigation. In addition, the company responsible for sewage treatment recovers money based on the exploitation of treated water by selling it at different tariff rates as sewage charges.

Objective 2: Assessing the challenges and opportunities of managing and reusing wastewater in construction.

The analysis of the questionnaire shows that the main factors facing wastewater reuse are environmental, social, economic, and religious factors. In addition, Oman's may face some challenges in create a new investment opportunity to reduce the burden on operating and maintenance costs at sewage plants.

- 34% of participants agree that the main factors in the challenges of re-using sewage in Oman for construction field is are economic, environmental, religious and societal factors.
- 62% of participate answered that the main factors in determining the most appropriate wastewater reuse option are infrastructure costs, total treatment costs of wastewater, institutional constraints and operational and maintenance costs.

- 64% of participate agree that the factors needed to exploit treated sewage in Oman are finance, skilled manpower, administrative support, advanced treatment equipment, and improved operating efficiency.
- 56% of participate support for change in the regulations of the Environment Authority regarding the requirements for the reuse of sewage which includes the characteristics and quality required for treated wastewater and the conditions for its discharge in the environment and reuse in agriculture.
- 43% and 39% of respondents answered agree and neutral in support the application of the circular economy system.

Which gave an indication that the challenges facing in reuse of treated wastewater in various fields is change in Environment Authority regulations and laws. In addition, sewage plants need funding in plant construction projects throughout Oman, skilled labor, administrative support, advanced treatment equipment, and improved operating efficiency. This suggests that sewage treatment plants need economic support in order to be able to reuse treated wastewater in the construction industry.

On the other hand, the results of the interview analysis indicate that the main reason is Environmental Authority law providing for the use of treated water and sludge in agriculture only. The challenges might be faced in reusing treated wastewater in the construction industry in Oman are:

- Lack of clear and adopted vision for different stakeholders.
- Weaknesses in the infrastructure of reusing of the processed water.
- There are no other studies to explore further applications for wastewater use.
- The rules and regulations are very old, since 1993, and not updated.
- The aspect might be some religion concerns that avoid using treated wastewater.
- Absence of assessment about the relations between the producer and the community.

Objective 3: Investigating sustainable techniques in implementing and analyzing risk assessment of sewage by-products that impact to the environment, the economy, and the society.

The management and reuse of treated wastewater is an important role in integrated water resource management and has an important role in reducing cost. Also, reused of WWT in Oman's construction industry will be useful in increasing optimal investment opportunities for wastewater pollutants. The results of quantitative and qualitative analysis have shown that wastewater treatment is instrumental in developing a water management strategy to reduce water shortages in Oman. In addition, it can achieve sustainability in the social, environmental and economic aspects. However, there are concerns about the quality of treated water, which may cause negative risks of reuse of wastewater for various purposes affecting humans and the environment.

Social:

- 41% and 32% of participate answered agree and strongly agree that the process of managing wastewater treatment should be understood and awareness of this issue spread in the community by spreading the benefits of using treated wastewater in construction.
- 34% of participate answered strongly agree and agree that supported the exploitation of sludge from wastewater treatment in the construction industry.

Economic:

- 33% and 32% of participated answered often and sometimes that the expansion of cities and rapid population growth, which directly affects the development of countries, the growth of civilization and the impact of the economy, may affect the government's plans to complete the construction of sewage plant projects.
- 55% and 30% of participate answered strongly agree and agree that investing treated wastewater will help to reduce treatment and disposal costs by turning waste into a useful resource and can provide economic and social benefits.

Environmental:

- 59% of the respondent's answers that all the above benefits of wastewater recycling enable the benefit of preserving natural water resources and reduce environmental pollution.
- 52% and 23% of participate answered sometimes and often that mixing sewage sludge with cement and clay to produce lightweight debris reduces the likelihood of contaminating the environment with harmful heavy metals.

Risk:

- 62% and 20% of participate answered very important and important that the continuous monitoring of the operation of the treatment plant is effective in reducing risks that cause sewage quality to deteriorate.
- 36% and 31% of respondents answered neutral and agree that Covid-19 had a significant impact on the world and would cause risk to wastewater treatment plants.

According to the survey analysis, the results showed that the optimal management of wastewater treatment can achieve environmental, economic and social sustainability. In addition, urban expansion and rapid population growth have an impact on plans to complete infrastructure, affecting the economy. The exploitation of sewage must be understood, and awareness spread among to the public. Continuous monitoring of sewage treatment plants has an effective role in reducing the risk of the exploitation of wastewater treatment products in the field of construction.

According to the interview analysis, the results showed strategies that can be used to control the risks arising from wastewater use in construction are to use risk assessment as the best way to identify, evaluate and reduce risks in any process or project. Continuous laboratory testing of samples before use also reduces risk before they are used for construction purposes. In addition, the financial impact of the Covid-19 pandemic on sewage plants was studied, with the analysis showing that there is no impact on in economic but the effect in the workforce that may operate or maintain sewage treatment plants and networks.

5.3 RECOMMENDATIONS

The management strategy of managing the reuse of sewage for various purposes is one of Oman's sustainable development goals. The following recommendations and suggestions are important outcomes from the research:

- Do Strategic plans to support the government to complete infrastructure for the construction of sewage plants.
- Applying taxes to reduce reliance on the government to pay for the operation and maintenance of sewage plants.
- Pilot study to reuse treated sewage in building materials.
- Involving stakeholders and stakeholders in the field of sanitation in experimental studies.

- Publishing of information on the types of equipment used to treat wastewater.
- Amend some regulations and laws to reuse treated sewage effluent.
- Adoption of circular economy system.
- Considering investments to exploit wastewater in Oman.
- Holding workshops and conferences with representatives of the relevant authorities.
- Raising awareness campaigns on the benefits of reuse of treated sewage effluent.
- Create different experiences and ideas to bring new technologies to sewage plants.

5.4 FUTURE STUDY

As Oman's population continues to increase and urbanize, the challenges of securing water resources and wastewater disposal will become more difficult. The costs of infrastructure development and the construction of sewage plants are often prohibitive, making wastewater reuse less economically feasible. Reuse of wastewater a huge potential for maintaining natural water sources, however, reusing or disposing of vital solids remains a challenge, particularly in high-dense urban areas.

Historical and recent examples of the spread of diseases through mixed water with sewage may significantly affect community concerns about the safety of water reuse in construction. Advanced wastewater treatment techniques can help by using sensors, membranes and oxidation ensure the quality of reused water.

Continuous sample testing and monitoring of the operation and maintenance of sewage plants may pave the way for public and sanitation companies to move forward with wastewater reuse projects. Reuse of wastewater is considered to have many advantages, but the real challenges lie in public acceptance. Academic experts and scientists have a great opportunity to help move forward in the field to develop the effectiveness of the quality of treated wastewater to be used in the field of construction.

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APPENDICES A: QUESTIONNAIRE FORM

Section 1 of 4

Untitled form I am a student at Middle East College engaged in research on sustainable technologies in wastewater reuse in the construction industry: challenges and opportunities as part of the requirements of the Master of Construction Project and Cost Management programmed. Please devote five minutes of your time to sharing your experience and understanding of the reuse of wastewater in the construction field to achieve sustainability (environmental, social and economic) in Oman. أنا طالب في كلية الشرق الأوسط أعمل في بحث حول التقنيات المستدامة في إعادة استخدام مياه الصرف الصحي في صناعة البناء: التحديات والفرص كجزء من متطلبات ماجستير علوم المشاريع البناء وإدارة التكلفة . يرجى تخصيص خمس دقائق من وقتك لمشاركة خبرتك وفهمك لإعادة استخدام مياه الصرف الصحي في مجال البناء لتحقيق الاستدامة (البيئية والاجتماعية والاقتصادية) في عمان

A profile about the research

Reuse of treated wastewater is an important alternative in areas where freshwater shortages are lacking, or the cost of desalination water is extremely high. The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage. The main aim of this research is to explore the environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. Thus, this study may open new opportunities for investment and utilization of wastewater.

Objectives of research:

1. Evaluating the potentials and the effectiveness of reusing the treated domestic wastewater in Oman's construction industry, and critically analyzing the cost and energy efficiency of using treated wastewater for construction purposes
2. Assessing the challenges and opportunities of managing and reusing wastewater in construction.
3. Investigating sustainable techniques in implementing and analyzing risk assessment of sewage by-products that impact to the environment, the economy, and the society.

لمحة عن البحث

تعد إعادة استخدام المياه العادمة المعالجة بديلاً هامًا في المناطق التي تفتقر إلى نقص المياه العذبة ، أو تكون تكلفة مياه التحلية مرتفعة للغاية. كان التطور الاقتصادي السريع والنمو الحضري والتحضر في عمان سببًا في زيادة توليد وتصريف مياه الصرف الصحي. الهدف الرئيسي من هذا البحث هو استكشاف الفوائد البيئية والاقتصادية من أجل تقليل تخزين مياه الصرف الصحي المعالجة ، والتأثير على البيئة ، والاستغلال في صناعة البناء وتحقيق الاستدامة. وبالتالي ، فإن هذه الدراسة قد تفتح فرصًا جديدة للاستثمار والاستفادة من المياه العادمة.

أهداف البحث:

1. تقييم إمكانات وفعالية إعادة استخدام مياه الصرف الصحي المنزلية المعالجة في صناعة البناء في سلطنة عمان ، والتحليل النقدي للتكلفة وكفاءة الطاقة لاستخدام مياه الصرف الصحي المعالجة لأغراض البناء

2.تقييم التحديات والفرص لإدارة وإعادة استخدام المياه العادمة في البناء

3.التحقق في التقنيات المستدامة في تنفيذ وتحليل تقييم مخاطر منتجات الصرف الصحي الثانوية التي تؤثر على البيئة والاقتصاد والمجتمع

Part 1: Personal and general information

(Choice one answer)

1.Your gender/جنسك *

- ◯ Male/ الذكر
- ◯ Female/أنثى

2. Age ranks (years)/عمرك *

- ◯ 18-25
- ◯ 26-35
- ◯ 36-45
- ◯ Above 46/فوق 46

3.Years of work experience/سنوات الخبرة في العمل *

- ◯ 1-5
- ◯ 6-10
- ◯ 11-20
- ◯ More than 20/أكثر من 20
- ◯ None/انا لا اعمل

4. Type of organization you work in/ نوع المنظمة التي تعمل فيها *

- Government sector/القطاع الحكومي
- Private company/شركة خاصة
- Government company/شركة حكومية
- Other/اخرى

5. Your Occupation/مهنتك *

- Engineer/مهندس
- Doctor/دكتور
- Teacher/معلم
- Employee/الموظف
- Student/طالب
- Other/اخرى

6. Level of education/المستوى التعليمي *

- General Education Diploma/دبلوم التربية العامة
- Diploma/دبلوم
- Bachelor/بكالوريوس
- Master/ماجستير
- Ph.D./دكتوراه

7. Do you have any awareness and knowledge of wastewater treatment in the Sultanate of Oman?هل لديك أي وعي ومعرفة بمعالجة مياه الصرف الصحي في سلطنة عمان؟ *

- Yes/نعم
- No/لا
- Maybe/ربما

8. What do you know about the uses of wastewater and sludge treated in Oman?ماذا تعرف عن استخدامات المياه العادمة والحمأة المعالجة في عمان؟ *

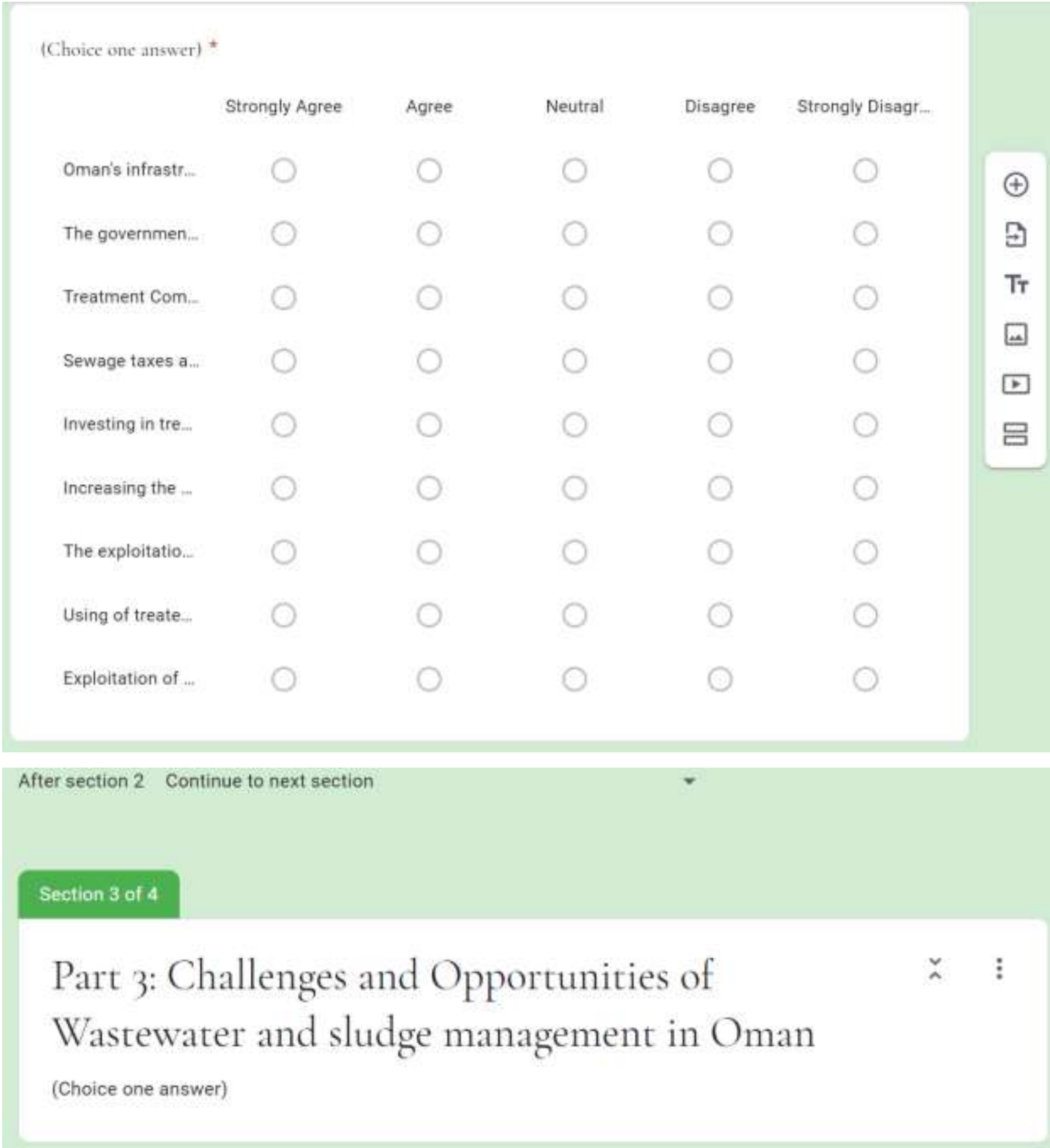
- In the irrigation of green areas في ري المساحات الخضراء
- Making fertilizersصناعة الأسمدة
- In irrigating agricultural cropsفي ري المحاصيل الزراعية
- Recharge of groundwaterتغذية المياه الجوفية
- All of the aboveكل ما سبق

After section 1 Continue to next section

Section 2 of 4

Part 2: The effectiveness of reusing wastewater and analysis of cost and energy in Oman for construction purposes/الجزء الثاني: فاعلية إعادة استخدام مياه الصرف الصحي وتحليل التكلفة والطاقة في عمان لأغراض البناء

Please choose whether you agree or disagree with the statements provided below./الرجاء اختيار ما إذا كنت توافق أو لا توافق على البيانات الواردة أدناه.



(Choice one answer) *

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagr...
Oman's infrastr...	○	○	○	○	○
The governmen...	○	○	○	○	○
Treatment Com...	○	○	○	○	○
Sewage taxes a...	○	○	○	○	○
Investing in tre...	○	○	○	○	○
Increasing the ...	○	○	○	○	○
The exploitatio...	○	○	○	○	○
Using of treate...	○	○	○	○	○
Exploitation of ...	○	○	○	○	○

After section 2 Continue to next section

Section 3 of 4

Part 3: Challenges and Opportunities of Wastewater and sludge management in Oman

(Choice one answer)

1. In your opinion, what challenges might be faced in reusing treated wastewater in construction industry in Oman/برأيك ، ما هي التحديات التي يمكن مواجهتها في إعادة استخدام مياه الصرف الصحي المعالجة في صناعة البناء والتشييد في سلطنة عمان *

- Environmental factors/العوامل البيئية
- Social Factors/العوامل الاجتماعية
- Economic Factors/العوامل الاقتصادية
- Religious factors/العوامل الدينية
- All of the above/كل ما سبق
- Other/أخرى

2. Major factors in determining the most appropriate wastewater reuse option are/ العوامل الرئيسية في تحديد أنسب خيار لإعادة استخدام المياه العادمة هي *

- Infrastructure costs/تكاليف البنية التحتية
- Total treatment costs of wastewater/إجمالي تكاليف معالجة مياه الصرف الصحي
- Institutional constraints/القيود المؤسسية
- Operational and maintenance costs/تكاليف التشغيل والصيانة
- All of the above/كل ما سبق
- Other/أخرى

3. Do you think that sewage treatment equipment in Oman is efficient enough for the possibility of reusing sludge in the manufacture of building materials?/ هل تعتقد أن معدات معالجة مياه الصرف الصحي في عمان ذات كفاءة كافية لإمكانية إعادة استخدام الحمأة في صناعة مواد البناء؟ *

- Yes/نعم
- No/لا
- Maybe/ربما

4. The factors needed to exploit treated wastewater in Oman are: العوامل اللازمة لاستغلال مياه الصرف الصحي المعالجة في عمان هي *

- Finance/المالية
- القوى العاملة الماهرة/Skilled manpower
- Management support/دعم الإدارة
- Advanced processing equipment/معدات المعالجة المتقدمة
- Improved operating efficiency/تحسين كفاءة التشغيل
- All of the above/كل ما سبق
- Other/أخرى

5. A new law should be formulated by the Environment Authority to cover more application of reusing treated wastewater like construction industry.يجب صياغة قانون جديد من قبل هيئة البيئة لتغطية المزيد من تطبيقات إعادة استخدام مياه الصرف الصحي المعالجة مثل صناعة البناء. *

- Excellent/ ممتاز
- Good/جيد
- Fair/معتدل
- Poor/ضعيف
- Very Poor/جدا ضعيف

6. Reusing treated wastewater is a relatively low-cost technology compared to alternatives such as desalination, groundwater extraction and transportation./تعد إعادة استخدام المياه العادمة المعالجة تقنية منخفضة التكلفة نسبيًا مقارنة بالبدائل مثل تحلية المياه واستخراج المياه الجوفية والنقل. *

- Strongly Disagree/أرفض بشدة
- Disagree/غير موافق
- Neither agree nor disagree/محايد
- Agree/أوافق
- Strongly Agree/أوافق بشدة

7. The application of the circular economy (i.e. an application to reduce, reuse, recycle and recover wastewater to ensure sustainability at the lowest cost) is one of the challenges that faces the management and reuse of wastewater sector in Oman./يعد تطبيق الاقتصاد الدائري (أي تطبيق لتقليل المياه العادمة وإعادة استخدامها وإعادة تدويرها واستعادتها لضمان الاستدامة بأقل تكلفة) أحد التحديات التي تواجه إدارة وإعادة استخدام قطاع الصرف الصحي في عمان. *

- Strongly Disagree/أرفض بشدة
- Disagree/غير موافق
- Neither agree nor disagree/محايد
- Agree/أوافق
- Strongly Agree/أوافق بشدة

After section 3 Continue to next section

Section 4 of 4

Part 4: Implementation of sustainable techniques and risk assessment of sewage.

(Choice one answer)

1. One of the most important benefits of water recycling:/من أهم فوائد إعادة تدوير المياه *

- ( ) يحتفظ بمياه الصرف الصحـ/.Retains sewage for reuse, rather than discharging it in a way that may cause pollution
- ( ) يوفر الطاقة اللازمة لاستخراج أو نقل المـ/.Provides the energy needed to extract or transport fresh water to the region
- ( ) اعادة شحن المياه الجوفية لتجنـ/.Recharges groundwater avoid degradation and salinization of freshwater resources
- ( ) يزيد من توفير معالجة المياه للمناطق الجافة/.Increases the provision of water treatment to arid areas
- ( ) ...e water source for the economic, industrial, and agricultural sectors and promotes economic sustainability
- ( ) All of the above/كل ما سبق
- ( ) Other/اخرى

2. In your opinion, the continuous monitoring of the operation of the treatment plant is effective in reducing risks that cause sewage quality to deteriorate/ برأيك ، فإن المراقبة المستمرة لتشغيل محطة المعالجة فعالة في تقليل المخاطر التي تتسبب في تدهور جودة مياه الصرف الصحي *

- ( ) Very Important/مهم جدا
- ( ) مهم /Important
- ( ) مهم إلى حد ما/Moderately Important
- ( ) Slightly Important/مهم قليلا
- ( ) غير مهم/Unimportant

3. Covid-19 has made a big impact on the world and will cause risks for wastewater treatment plants./ لقد كان لـ كوفيد-19 تأثير كبير على العالم وسوف يتسبب في مخاطر لمحطات معالجة مياه الصرف الصحي *

- Strongly Disagree/ارفض بشدة
- Disagree/ارفض
- Neither agree nor disagree/محايد
- Agree/اوافق
- Strongly Agree/اوفق بشده

4. Reusing treated wastewater in construction purposes can achieve economic, environmental, and social sustainability in Oman/ إعادة استخدام المياه العادمة المعالجة في أغراض البناء يمكن أن يحقق الاستدامة الاقتصادية والبيئية والاجتماعية في عمان *

- Always/دائما
- Often/في كثير من الأحيان
- Sometimes/في بعض الأحيان
- Rarely/نادرا
- Never/أبدا

5. The expansion of cities and the rapid growth of the population, which directly affects the development of the states and the growth of civilization and the influence of the economy may affect the government's plans to complete the construction of sewage plant projects/ توسع المدن والنمو السكاني السريع مما يؤثر بشكل مباشر على تطور الدول ونمو الحضارة وتأثير الاقتصاد قد يؤثر على خطط الحكومة لاستكمال بناء مشاريع محطات الصرف الصحي *

- Strongly Disagree/لا أوفق بشدة
- Disagree/لا أوفق
- Neither agree nor disagree/محايد
- Agree/أوفق
- Strongly Agree/أوفق بشدة

6. Mixing sewage sludge with cement and clay for the production of lightweight aggregate slightly reduces the likelihood of polluting the environment with harmful heavy metals/خلط حمأة الصرف الصحي مع الأسمنت والطين لإنتاج الركام خفيف الوزن يقلل بشكل طفيف من احتمال تلويث البيئة بالمعادن الثقيلة الضار *

- Never/ابدا
- Rarely/نادرا
- Sometimes/في بعض الأحيان
- Often/في كثير من الأحيان
- Always/دائما

7. In your opinion, the process of wastewater treatment management process must be understood and awareness of this issue must be spread in the community by publishing the benefits of using treated water in construction./في رأيك ، يجب فهم عملية إدارة معالجة المياه العادمة ونشر الوعي بهذه القضية في المجتمع من خلال نشر فوائد استخدام المياه المعالجة في البناء. *

- Strongly Disagree/لا أوفق بشدة
- Disagree/لا أوافق
- Neither agree nor disagree/محايد
- Agree/موافق
- Strongly Agree/أوافق بشدة

8. One of the economic risks of treating wastewater projects might be refusal of customers to pay the fees of treatment cost or using treated water/ قد يكون من المخاطر الاقتصادية لمعالجة مشاريع الصرف الصحي هو رفض العملاء في دفع رسوم تكلفة المعالجة أو استخدام المياه المعالجة *

- Strongly Disagree/لا أوافق بشدة
- Disagree/لا أوافق
- Neither agree nor disagree/محايد
- Agree/أوافق
- Strongly Agree/أوافق بشدة

APPENDICES B: INTERVIEW QUESTIONS FORM

Interview Questions Form

I am a student at Middle East College engaged in research on sustainable technologies in wastewater reuse in the construction industry: challenges and opportunities as part of the requirements of the Master of Construction Project and Cost Management programmed.

Please devote fifteen minutes of your time to sharing your experience and understanding of the reuse of wastewater in the construction field to achieve sustainability (environmental, social and economic) in Oman.

A profile about the research

Reuse of treated wastewater is an important alternative in areas where freshwater shortages are lacking, or the cost of desalination water is extremely high. The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage. The main aim of this research is to explore the environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. Thus, this study may open new opportunities for investment and utilization of wastewater.

Part 1: General Information

1. Organization Name: ………

2. Your Occupation: ………...

3. Age: …………

4. Years of Work Experience: ………

5. Level of Education: ……….

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is **Yes**, could you give us some information in general?

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

4. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

5. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

6. What are the strategies that can be used to control the risks arising from wastewater use in construction?

7. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

APPENDICES B: INTERVIEW QUESTIONS FEEDBACK

Interview 1:

Interview Questions Form

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Part 1: General Information

1. Organization Name: DRC - OCE
2. Your Occupation: Senior Wildlife Conservationist
3. Age: 37
4. Years of Work Experience: 13
5. Level of Education: Bachelor of Science

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is **Yes**, could you give us some information in general?

No

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

Many reasons; lack of clear and adopted vision for different stakeholders
Absence of assessment about the relations between the producer and the community
Weaknesses in the infrastructure of reusing of the processed water

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

No Idea

4. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

Mainly logistic challenges, like delivery on demand and assuring water quality.

5. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

Sure, one way to transfer the knowledge from some developed countries, and
Looking for the best practices.

6. What are the strategies that can be used to control the risks arising from wastewater use in construction?

Coordinates with other stakeholders and provide processed water for them

7. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

No I don't there is any impact actually because the population is the same and the use of water is still almost the same

Interview 2:

Interview Questions Form

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Part 1: General Information

1. Organization Name: ....Muna Noor
2. Your Occupation: ......Chemist ......
3. Age: ....40...
4. Years of Work Experience: ......12...
5. Level of Education: ...Bachelor ....

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is **Yes**, could you give us some information in general?

Ans: Yes, Oman's Wastewater treatment infrastructure is efficient. All the areas are covered by sewage network connected to the STP & treated water for the irrigation purpose. The industrial estates are having pretreatment plants before discharging to common sewerage system for further treatment as the high BOD and high COD cannot be reduced by the conventional STP Process. And Individual small villas, hotels, malls etc. are also having their own STPs & the treated water is used for their own irrigation area.

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

Ans: The treated water is used for irrigation purpose in most of the cases. The excess sludge taken out from the STPs is dried & sent to fertilizer plant for making manure. And the treated water is using for the construction and road work as well.

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

Ans: Earlier all the STPs were built & maintained by respective Municipalities & outside Muscat area were built & maintained by regional municipalities.

Now all the STPs which were with the municipalities are under one entity called Haya Water.

They are maintaining all these STPs either by themselves or by local contractors.

HAYA is recovering the money based on the fresh water usage at different tharif rate as sewage charges. Earlier it was 1 Baiza per Gallon

4. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

Ans: The main challenge is the quality of the water and the chloride level. The chloride and salinity level is not good for the concrete products. Reverse Osmosis is required to reduce the salinity level which cost more and not economic. The periodically check on the quality of the treated water. The treated water should not be sprink led, it should be only discharged either by drip irrigation or by spray heads.

5. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

Ans: Yes, Waste water treatment by various method on chargeable basis and reuse /Supply of the treated water in the same manner by irrigation network will be a circular Economy .

6. What are the strategies that can be used to control the risks arising from wastewater use in construction?

Ans: Firstly, determine the purpose of use. Accordingly, the required parameters to be determined. Once this is done then to get the treated waster water within that limit. Check points to be set & periodical testing of the same to be done.

7. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

Ans; No. There was not much financial impact of pandemic on the utilities of wastewater treatment.

Interview 3 :

Interview Questions Form

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A profile about the research

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Part 1: General Information

1. Organization Name: Environment Engineering Services
2. Your Occupation: Mechanical Engineer
3. Age: +50
4. Years of Work Experience: +30
5. Level of Education: Bachelor of engineering

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is **Yes**, could you give us some information in general?

Ans: Yes, it is efficient. In most of the Wilayats there are small STPs along with the sewerage networks which provide the service & treated water for the irrigation purpose. Most of the industrial estates are having effluent treatment plants which treats the influent & provides the treated water for irrigation in the industrial area. Individual small villas, hotels, malls etc. are also having their own STPs & the treated water is used for their own irrigation area.

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

Ans: The treated water is used for irrigation purpose in most of the cases. The excess sludge taken out from the STPs is dried & sent to fertilizer plant for making manure. Very less treated water is used for the ground recharge.

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

Ans: Earlier all the STPs were built & maintained by respective Municipalities & outside Muscat area were built & maintained by regional municipalities.

Now all the STPs which were with the municipalities are under one entity called Haya Water.

They are maintaining all these STPs either by themselves or by local contractors.

3. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

Ans: The main challenge is the quality of the water should be maintained with strict parameters required for the discharging the treated water as per the norms of local controlling authority. The people who are using it should be fully trained & aware of the ifs & buts of the work carrying out. The periodically check on the quality of the treated water. The treated water should not be sprinkled, it should be only discharged either by drip irrigation or by spray heads.

4. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

Ans: Yes, by furthermore treatment we can reuse the waste water for different type of reuse/purposes by using new technologies & maintaining them well for better quality.

5. What are the strategies that can be used to control the risks arising from wastewater use in construction?

Ans: Firstly, determine the purpose of use. Accordingly, the required parameters to be determined. Once this is done then to get the treated waster water within that limit. Check points to be set & periodical testing of the same to be done.

6. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

Ans; No. There was not much financial impact of pandemic on the utilities of wastewater treatment.

Interview 4:

Interview Questions Form

I am a student at Middle East College engaged in research on sustainable technologies in wastewater reuse in the construction industry: challenges and opportunities as part of the requirements of the Master of Construction Project and Cost Management programmed.

Please devote fifteen minutes of your time to sharing your experience and understanding of the reuse of wastewater in the construction field to achieve sustainability (environmental, social and economic) in Oman.

A profile about the research

Reuse of treated wastewater is an important alternative in areas where freshwater shortages are lacking, or the cost of desalination water is extremely high. The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage. The main aim of this research is to explore the environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. Thus, this study may open new opportunities for investment and utilization of wastewater.

Part 1: General Information

1. Organization Name: Oman Cement Company
2. Your Occupation: Environmental Engineer
3. Age: 34
4. Years of Work Experience: 10
5. Level of Education: BSc.

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is **Yes**, could you give us some information in general?

I think that the waste water treatment infrastructure in Oman is not bad. However, I can not say it is excellent.

For example, Haya Company has good infrastructure in term of treating the wastewater but I think they still need improvement in wastewater collectiong from citizen and distribution for utilization.

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

I think this because there are no much studies like this to explore farther applications to utilise wastewater. Also, our rules and regulations are very old , since 1993, and not updated. Another, aspect might be some religion concerns that avoid using treated water.

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

Still the government pays most of the O&M cost and on the other side the government itself utilizing treated water.

In the future, I think, the citizens will pay that cost similar to the developed countries.

4. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

I think the challenges might be on:

1. people who may resist new ideas. Also

2. updating the rules and regulations.

3. Meeting the same or better quality of Construction with using treated water which may has undesired matters for construction.

5. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

Yes could be by applying best practices in all steps of collecting wastewater, treatment and utilization. There are now new techniques like lean management to reduce wastes from the process and steps of the production cycle.

6. What are the strategies that can be used to control the risks arising from wastewater use in construction?

Risk assessment considered the best way now to determine, evaluate and reduce the risk in any process and projects.

Contingency Plan another technique which is a procedure that will be followed in case the control measures in the risk assessment didn't work.

7. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

I guess yes, since COVID19 affect the Manpower who may operate or maintain the wastewater treatment plants and network.

Interview 5:

Interview Questions Form

I am a student at Middle East College engaged in research on sustainable technologies in wastewater reuse in the construction industry: challenges and opportunities as part of the requirements of the Master of Construction Project and Cost Management programmed.

Please devote fifteen minutes of your time to sharing your experience and understanding of the reuse of wastewater in the construction field to achieve sustainability (environmental, social and economic) in Oman.

A profile about the research

Reuse of treated wastewater is an important alternative in areas where freshwater shortages are lacking, or the cost of desalination water is extremely high. The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage. The main aim of this research is to explore the environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. Thus, this study may open new opportunities for investment and utilization of wastewater.

Part 1: General Information

1. Organization Name: ………Haya Water
2. Your Occupation: ………... Act Head of Lab
3. Age: …………35
4. Years of Work Experience: ………13
5. Level of Education: ……….Master

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is **Yes**, could you give us some information in general?

Yes, as per Oman regulations and environment wastewater treated efficiently.

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

In any other ways to treat or recycle the waste we have to give a feasibility study to make sure it will be useful and not costly.

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

I have no idea

4. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

It can be used as far as the treated water within the standard range. Sometimes it fail if the conductivity high

5. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

Yes. Actually, treated water can be used in different applications in industrial also in construction. EX; cooling water

6. What are the strategies that can be used to control the risks arising from wastewater use in construction?

Laboratory can give clear view of the quality of the treated water so you can relay to the report of laboratory.

7. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

No

Interview 6:

Interview Questions Form

I am a student at Middle East College engaged in research on sustainable technologies in wastewater reuse in the construction industry: challenges and opportunities as part of the requirements of the Master of Construction Project and Cost Management programmed.

Please devote fifteen minutes of your time to sharing your experience and understanding of the reuse of wastewater in the construction field to achieve sustainability (environmental, social and economic) in Oman.

A profile about the research

Reuse of treated wastewater is an important alternative in areas where freshwater shortages are lacking, or the cost of desalination water is extremely high. The rapid economic development, urban growth and urbanization in Oman have been the reason for the increase in the generation and discharge of sewage. The main aim of this research is to explore the environmental and economic benefits in order to reduce the storage of treated wastewater, impact on the environment, exploitation in the construction industry and achieve sustainability. Thus, this study may open new opportunities for investment and utilization of wastewater.

Part 1: General Information

1. Organization Name: Environment Authority

2. Your Occupation: Environmental Technician

3. Age: 32

4. Years of Work Experience: 7

5. Level of Education: diploma

Part 2: Expert Feedback

1. Do you think that Oman's wastewater treatment infrastructure is efficient? If your answer is Yes, could you give us some information in general?
   No

2. Why is wastewater in Oman used only for making fertilizer and recharging groundwater? Why is it that other ways of exploiting wastewater are not explored??

Because there is only one law in accordance with the Law of Environment Authority in Oman, which includes the characteristics and quality required for treated wastewater only for reuse in agriculture.

Because of Financial cost and Community awareness

3.Who pays the operational and maintenance (O&M) cost of the municipal wastewater treatment plant in Oman? Could you please give us an idea about the annual O&M costs?

Haya water

I don't know

4. In your opinion, what kind of challenges might be faced in reusing treated wastewater in the construction industry in Oman?

Properly the quality of the product

5. Do you think that we can apply the circular economy (CE) in the wastewater management treatment and reuse? How?

I don't know

6. What are the strategies that can be used to control the risks arising from wastewater use in construction?

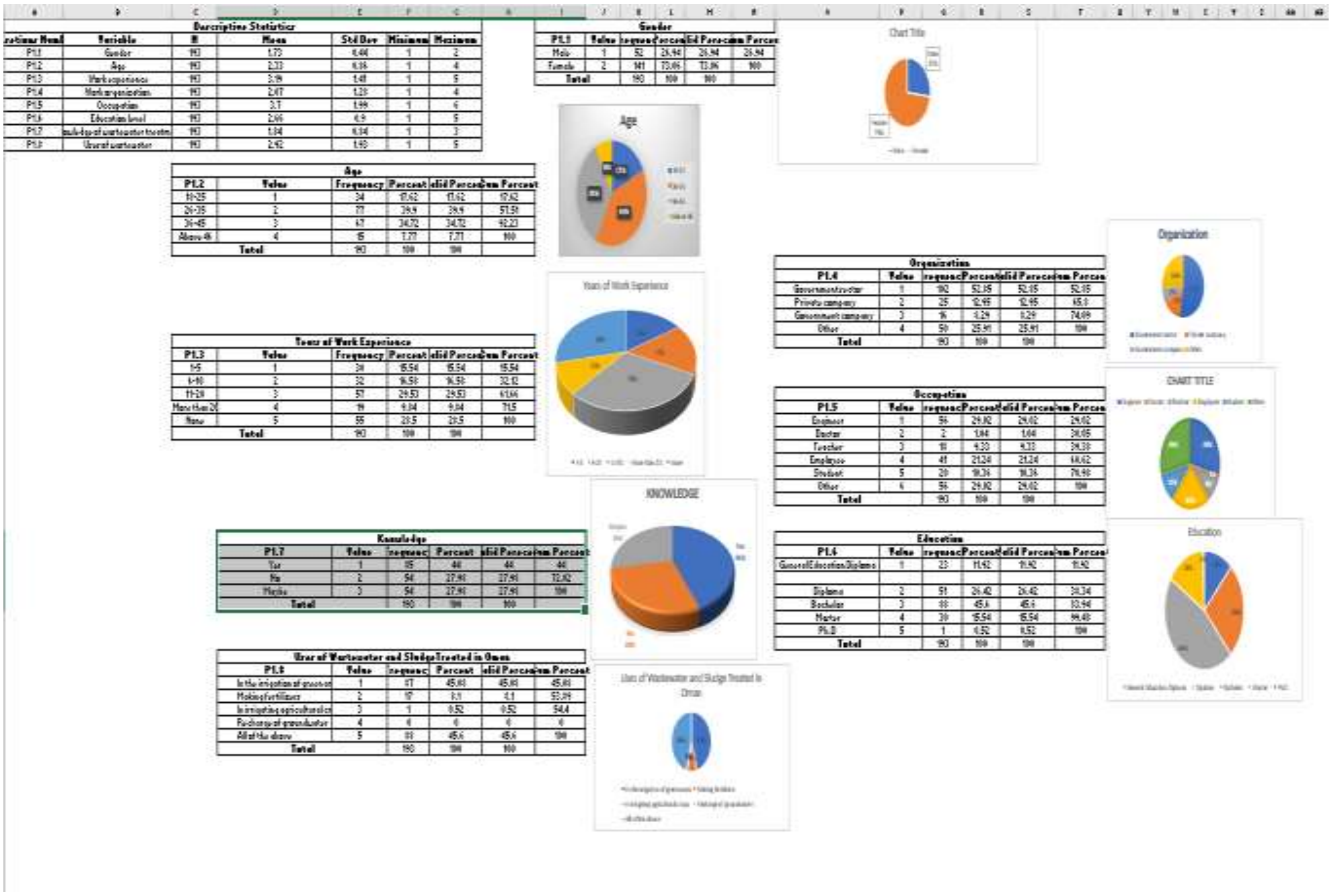
Environment strategy

7. Is there any financial impact of COVID pandemic on the utilities of wastewater treatment? If yes, what are they?

No

APPENDICES C: Questionnaire analysis by using SPSS Software and Excel

Part 1:



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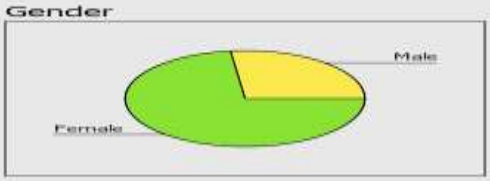
Gender

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Male	1	52	26.94	26.94	26.94
Female	2	141	73.06	73.06	100.00
	Total	193	100.0	100.0	

Gender

N	Valid	193
	Missing	0
Mean		1.73
Std Dev		.44
Variance		.20
S.E. Skew		.17
Minimum		1.00
Maximum		2.00

Gender



Age

Experience

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
1-5	1	30	15.54	15.54	15.54
6-10	2	32	16.58	16.58	32.12
11-20	3	57	29.53	29.53	61.66
More than 20	4	19	9.84	9.84	71.50
None	5	55	28.50	28.50	100.00
	Total	193	100.0	100.0	

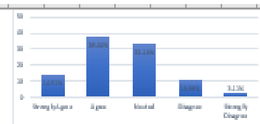
Experience

N	*Valid*	193
	Missing	0
Mean		3.19
Std Dev		1.41
Variance		2.00
S.E. Skew		.17
Minimum		1.00
Maximum		5.00

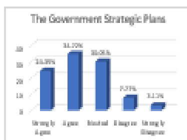
Part 2:

...s Infrastruc	193	2.5	0.7	0.97	0.95	4	1	5
...rnment Strate	193	2.34	0.7	1.02	1.05	4	1	5
...agement of W	193	2.1	0.7	0.92	0.84	4	1	5
Sewage Taxes	193	2.62	0.08	1.14	1.31	4	1	5
...of Treated W	193	1.68	0.06	0.9	0.81	4	1	5
...tion Resulting	193	1.7	0.07	0.91	0.84	4	1	5
...ated Wastewa	193	1.73	0.07	0.97	0.94	4	1	5
...d wastewater	193	2.12	0.08	1.06	1.12	4	1	5
...stewater treat	193	2.16	0.08	1.11	1.24	4	1	5

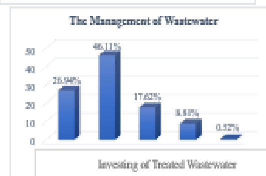
Strongly Agree	1	28	14.51	14.51	14.51
Agree	2	74	38.34	38.34	52.85
Neutral	3	64	33.16	33.16	86.01
Disagree	4	21	10.88	10.88	96.89
Strongly Disagr	5	6	3.11	3.11	100
Total		193	100	100	



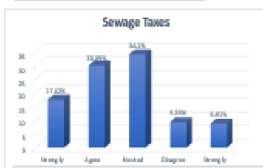
The Government Strategic Plans					
P2.2	Value	requenc	Percent	lid Perc	Cum Percent
Strongly Agre	1	47	24.35	24.35	24.35
Agree	2	67	34.72	34.72	59.07
Neutral	3	58	30.05	30.05	89.12
Disagree	4	15	7.77	7.77	96.89
Strongly Disa	5	6	3.11	3.11	100
Total		193	100	100	



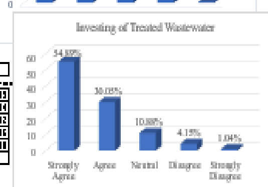
The Management of Wastewater					
P2.3	Value	requenc	Percent	alid Perce	Cum Percent
Strongly	1	52	26.94	26.94	26.94
Agree	2	89	46.11	46.11	73.05
Neutral	3	34	17.62	17.62	90.67
Disagree	4	17	8.81	8.81	99.48
Strongly	5	1	0.52	0.52	100
Total		193	100	100	



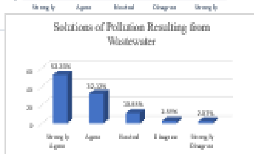
Sewage Taxes					
P2.4	Value	requenc	Percent	lid Perc	Cum Percent
Strongly Agre	1	34	17.62	17.62	17.62
Agree	2	58	30.05	30.05	47.67
Neutral	3	66	34.2	34.2	81.87
Disagree	4	18	9.33	9.33	91.19
Strongly Disa	5	17	8.81	8.81	100
Total		193	100	100	



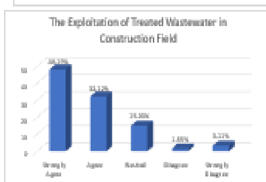
Investing of Treated Wastewater					
P2.5	Value	Frequency	Percent	'alid Perce	Perce
Strongly Ag	1	104	53.89	53.89	53.89
Agree	2	58	30.05	30.05	83.94
Neutral	3	21	10.88	10.88	94.82
Disagree	4	8	4.15	4.15	98.96
Strongly Di	5	2	1.04	1.04	100
Total		193	100	100	



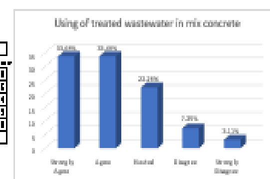
Solutions of Pollution Resulting from Wastewater					
P2.6	Value	requenc	Percent	lid Perc	Cum Percent
Strongly Agre	1	101	52.33	52.33	52.33
Agree	2	62	32.12	32.12	84.46
Neutral	3	21	10.88	10.88	95.34
Disagree	4	5	2.59	2.59	97.93
Strongly Disa	5	4	2.07	2.07	100
Total		193	100	100	



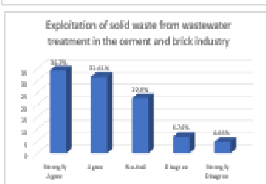
The Exploitation of Treated Wastewater in Construction Field					
P2.7	Value	requenc	Percent	lid Perc	Cum Percent
Strongly Agre	1	93	48.19	48.19	48.19
Agree	2	62	32.12	32.12	80.31
Neutral	3	29	15.03	15.03	95.34
Disagree	4	3	1.55	1.55	96.89
Strongly Disa	5	6	3.11	3.11	100
Total		193	100	100	



Using of treated wastewater in mix concrete					
P2.8	Value	Frequency	Percent	'alid Perce	Perce
Strongly Ag	1	65	33.68	33.68	33.68
Agree	2	65	33.68	33.68	67.36
Neutral	3	43	22.28	22.28	89.64
Disagree	4	14	7.25	7.25	96.89
Strongly Di	5	6	3.11	3.11	100
Total		193	100	100	



of solid waste from wastewater treatment in the cement and b					
P2.9	Value	requenc	Percent	lid Perc	Cum Percent
Strongly Agre	1	66	34.2	34.2	34.2
Agree	2	61	31.61	31.61	65.8
Neutral	3	44	22.8	22.8	88.6
Disagree	4	13	6.74	6.74	95.34
Strongly Disa	5	9	4.66	4.66	100
Total		193	100	100	



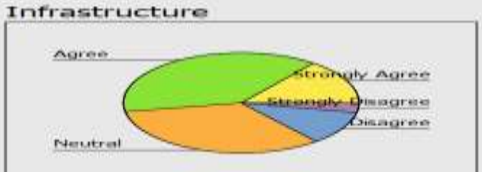
Infrastructure

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Agree	1	28	14.51	14.51	14.51
Agree	2	74	38.34	38.34	52.85
Neutral	3	64	33.16	33.16	86.01
Disagree	4	21	10.88	10.88	96.89
Strongly Disagree	5	6	3.11	3.11	100.00
	Total	193	100.0	100.0	

Infrastructure

N	*Valid*	193
	Missing	0
Mean		2.50
Std Dev		.97
S.E. Skew		.17
Minimum		1.00
Maximum		5.00

Infrastructure



Taxes

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Agree	1	34	17.62	17.62	17.62
Agree	2	58	30.05	30.05	47.67
Neutral	3	66	34.20	34.20	81.87
Disagree	4	18	9.33	9.33	91.19
Strongly Disagree	5	17	8.81	8.81	100.00
	Total	193	100.0	100.0	

Taxes

N	*Valid*	193
	Missing	0
Mean		2.62
Std Dev		1.14
S.E. Skew		.17
Minimum		1.00
Maximum		5.00

Investing

N	*Valid*	193
	Missing	0
Mean		1.68
S.E. Mean		.06
Std Dev		.90
Variance		.81
Range		4.00
Minimum		1.00
Maximum		5.00

Pollution

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Agree	1	101	52.33	52.33	52.33
Agree	2	62	32.12	32.12	84.46
Neutral	3	21	10.88	10.88	95.34
Disagree	4	5	2.59	2.59	97.93
Strongly Disagree	5	4	2.07	2.07	100.00
	Total	193	100.0	100.0	

Pollution

N	*Valid*	193
	Missing	0
Mean		1.70
S.E. Mean		.07
Std Dev		.91
Variance		.84
Range		4.00
Minimum		1.00
Maximum		5.00

Exploitation

N	*Valid*	193
	Missing	0
Mean		1.79
S.E. Mean		.07
Std Dev		.97
Variance		.94
Range		4.00
Minimum		1.00
Maximum		5.00

Concrete

Value Label	*Value*	*Frequency*	*Percent*	*Valid Percent*	*Cum Percent*
Strongly Agree	1	65	33.68	33.68	33.68
Agree	2	65	33.68	33.68	67.36
Neutral	3	43	22.28	22.28	89.64
Disagree	4	14	7.25	7.25	96.89
Strongly Disagree	5	6	3.11	3.11	100.00
	Total	193	100.0	100.0	

Concrete

N	*Valid*	193
	Missing	0
Mean		2.12
S.E. Mean		.08
Std Dev		1.06
Variance		1.12
Range		4.00
Minimum		1.00
Maximum		5.00

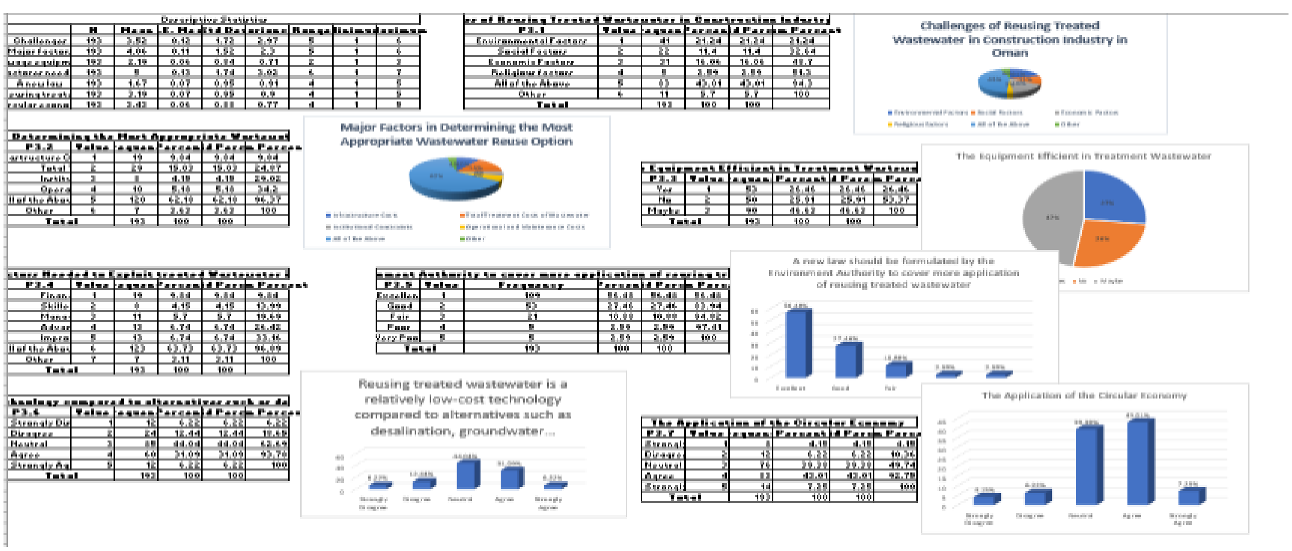
Industry

Value Label	*Value*	*Frequency*	*Percent*	*Valid Percent*	*Cum Percent*
Strongly Agree	1	66	34.20	34.20	34.20
Agree	2	61	31.61	31.61	65.80
Neutral	3	44	22.80	22.80	88.60
Disagree	4	13	6.74	6.74	95.34
Strongly Disagree	5	9	4.66	4.66	100.00
	Total	193	100.0	100.0	

Industry

N	*Valid*	193
	Missing	0
Mean		2.16
S.E. Mean		.08
Std Dev		1.11
Variance		1.24
Range		4.00
Minimum		1.00
Maximum		5.00

Part 3:



Challenges

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Environmental Factors	1	41	21.24	21.24	21.24
Social Factors	2	22	11.40	11.40	32.64
Economic Factors	3	31	16.06	16.06	48.70
Religious Factors	4	5	2.59	2.59	51.30
All of the above	5	83	43.01	43.01	94.30
Others	6	11	5.70	5.70	100.00
	Total	193	100.0	100.0	

Challenges

N	Valid	193
	Missing	0
Mean		3.52
S.E. Mean		.12
Std Dev		1.72
Variance		2.97
Range		5.00
Minimum		1.00
Maximum		6.00

Appropriate

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Infrastructure costs	1	19	9.84	9.84	9.84
Total treament costs of wastewater	2	29	15.03	15.03	24.87
Institutional constraints	3	8	4.15	4.15	29.02
Operational and maintenance costs	4	10	5.18	5.18	34.20
All the above	5	120	62.18	62.18	96.37
Other	6	7	3.63	3.63	100.00
	Total	193	100.0	100.0	

Equipment

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	53	27.46	27.46	27.46
No	2	50	25.91	25.91	53.37
Maybe	3	90	46.63	46.63	100.00
	Total	193	100.0	100.0	

Equipment

N	Valid	193
	Missing	0
Mean		2.19
S.E. Mean		.06
Std Dev		.84
Variance		.71
Range		2.00
Minimum		1.00
Maximum		3.00

Factores

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Finance	1	19	9.84	9.84	9.84
Skilled Manpower	2	8	4.15	4.15	13.99
Management Support	3	11	5.70	5.70	19.69
Advanced Processing Equipment	4	13	6.74	6.74	26.42
Improved Operating Efficiency	5	13	6.74	6.74	33.16
All of the Above	6	123	63.73	63.73	96.89
Other	7	6	3.11	3.11	100.00
	Total	193	100.0	100.0	

law

N	Valid	193
	Missing	0
Mean		1.67
S.E. Mean		.07
Std Dev		.95
Variance		.91
Range		4.00
Minimum		1.00
Maximum		5.00

Reusing

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Disagree	1	12	6.22	6.22	6.22
Disagree	2	24	12.44	12.44	18.65
Neither Agree Nor Disagree	3	85	44.04	44.04	62.69
Agree	4	60	31.09	31.09	93.78
Strongly Agree	5	12	6.22	6.22	100.00
	Total	193	100.0	100.0	

Reusing

N	Valid	193
	Missing	0
Mean		3.19
S.E. Mean		.07
Std Dev		.95
Variance		.90
Range		4.00
Minimum		1.00
Maximum		5.00

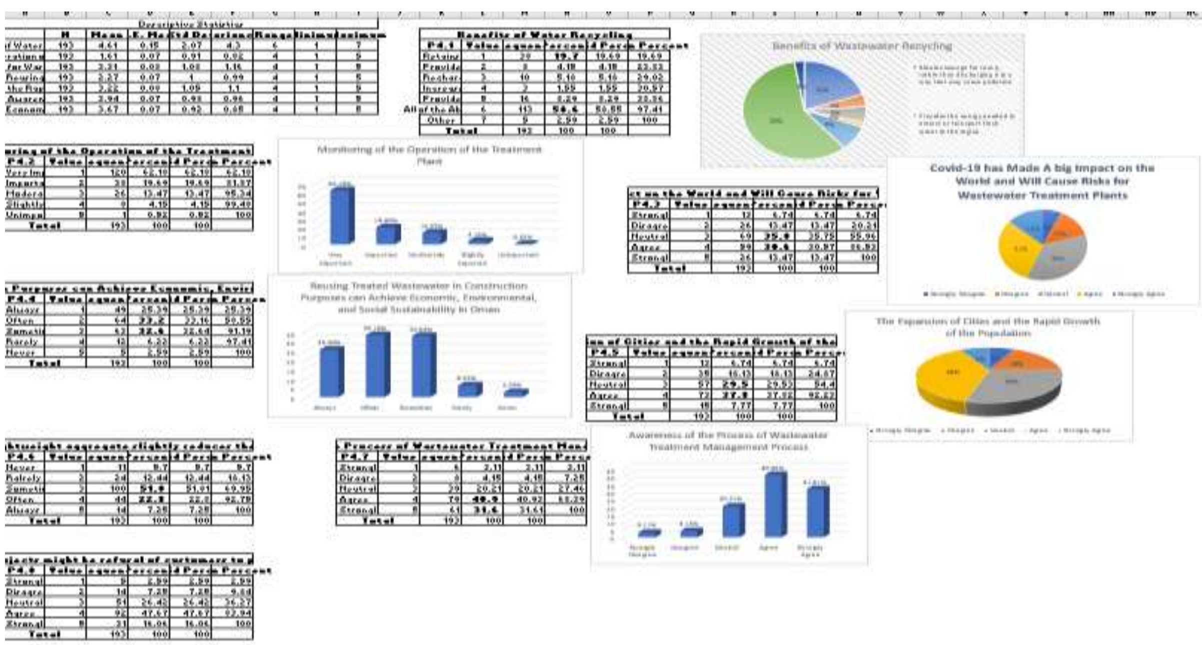
Economic

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Disagree	1	8	4.15	4.15	4.15
Disagree	2	12	6.22	6.22	10.36
Neither Agree Nor Disagree	3	76	39.38	39.38	49.74
Agree	4	83	43.01	43.01	92.75
Strongly Agree	5	14	7.25	7.25	100.00
	Total	193	100.0	100.0	

Economic

N	Valid	193
	Missing	0
Mean		3.43
S.E. Mean		.06
Std Dev		.88
Variance		.77
Range		4.00
Minimum		1.00
Maximum		5.00

Part 4:



Benefits

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Retains sewage for reues, rather than discharging it in a way that may cause pollution	1	38	19.69	19.69	19.69
Provides the energy need to extract or transport fresh water to the region	2	8	4.15	4.15	23.83
Recharges groundwater avoid degradation and salinization of fresh water resources	3	10	5.18	5.18	29.02
Increases the provision of water treatement to arid areas	4	3	1.55	1.55	30.57
Provides an easily accessible water source for the economic, industrial and agricultureal sectors and promotes economic sustainability	5	16	8.29	8.29	38.86
All of the above	6	113	58.55	58.55	97.41
Other	7	5	2.59	2.59	100.00
	Total	193	100.0	100.0	

Benefits

N	Valid	193
	Missing	0
Mean		4.61
S.E. Mean		.15
Std Dev		2.07
Variance		4.30
Range		6.00
Minimum		1.00
Maximum		7.00

Monitoring

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Very Important	1	120	62.18	62.18	62.18
Important	2	38	19.69	19.69	81.87
Moderately Important	3	26	13.47	13.47	95.34
Slightly Important	4	8	4.15	4.15	99.48
Unimportant	5	1	.52	.52	100.00
	Total	193	100.0	100.0	

Risks

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Disagree	1	13	6.74	6.74	6.74
Disagree	2	26	13.47	13.47	20.21
Neithe Agree Nor Disagree	3	69	35.75	35.75	55.96
Agree	4	59	30.57	30.57	86.53
Strongly Agree	5	26	13.47	13.47	100.00
	Total	193	100.0	100.0	

Risks

N	*Valid*	193
	Missing	0
Mean		3.31
S.E. Mean		.08
Std Dev		1.08
Variance		1.16
Range		4.00
Minimum		1.00
Maximum		5.00

Sustainability

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Always	1	49	25.39	25.39	25.39
Often	2	64	33.16	33.16	58.55
Sometimes	3	63	32.64	32.64	91.19
Rerely	4	12	6.22	6.22	97.41
Never	5	5	2.59	2.59	100.00
	Total	193	100.0	100.0	

Awareness

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Disagree	1	6	3.11	3.11	3.11
Disagree	2	8	4.15	4.15	7.25
Neither Agree Nor Disagree	3	39	20.21	20.21	27.46
Agree	4	79	40.93	40.93	68.39
Strongly Agree	5	61	31.61	31.61	100.00
	Total	193	100.0	100.0	

Awareness

N	*Valid*	193
	Missing	0
Mean		3.94
S.E. Mean		.07
Std Dev		.98
Variance		.96
Range		4.00
Minimum		1.00
Maximum		5.00

Cost

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Strongly Disagree	1	5	2.59	2.59	2.59
Disagree	2	14	7.25	7.25	9.84
Neither Agree Nor Disagree	3	51	26.42	26.42	36.27
Agree	4	92	47.67	47.67	83.94
Strongly Agree	5	31	16.06	16.06	100.00
	Total	193	100.0	100.0	

Population

N	*Valid*	193
	Missing	0
Mean		3.22
S.E. Mean		.08
Std Dev		1.05
Variance		1.10
Range		4.00
Minimum		1.00
Maximum		5.00

Environment

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Never	1	11	5.70	5.70	5.70
Rarely	2	24	12.44	12.44	18.13
Sometimes	3	100	51.81	51.81	69.95
Often	4	44	22.80	22.80	92.75
Always	5	14	7.25	7.25	100.00
	Total	193	100.0	100.0	

Environment

N	*Valid*	193
	Missing	0
Mean		3.13
S.E. Mean		.07
Std Dev		.93
Variance		.86
Range		4.00
Minimum		1.00
Maximum		5.00

APPENDICES D: Ethic Approval

كـــلية الشــرق الأوســط
Middle East College

Certificate of Ethical Approval

RollNumber	PG19F2088
Student Name	MARYAM HAMED SALEH AL SHEKAILI
Semester	2021 Summer

Project Title

Towards Sustainable Technologies in Reusing of Wastewater in Construction Industry: Challenges and Opportunities

This is to certify that the above named student has completed the Middle East College Ethical Approval process and their project has been confirmed and approved as Low Risk.

Supervisor	Dr. Mahmoud Dawood
Date of Approval	Aug 31, 2021