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# A Novel Approach Using Integrated Greywater Treatment System Applying Net Zero Wastewater Concept for Sustainable Urban Communities

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# A Novel Approach Using Integrated Greywater Treatment System Applying Net Zero Wastewater Concept for Sustainable Urban Communities

prepared in partial fulfillment of the requirements of PhD in Environmental Engineering

by

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## Abstract

We are blessed with endless resources that are naturally existing in our world and we fully rely-on without envisioning the bigger picture of what would happen if these resources came to an end, or how can we even ensure sustainable lives by regenerating or reusing or utilizing the naturally existing resources? The surrounding ecosystem, the land we live on, the air we breathe, the water we drink and use for cooking, laundry, shower, irrigation, and many other usages are examples of the resources that we, as global users, are taking for granted.

It is a common knowledge that we are almost 8 billion people living in this world with approximately 6% annual global population growth rate; this is reflected into higher economic levels, more demand, more jobs and more need and reliance on the previously mentioned resources. Infrastructure sector is one of the fastest moving and highly impactful sectors with population growth, as more housings and near-by facilities and jobs are constructed. This leads to having higher density areas in capitals which are the center of services for every human need and high pressure on naturally existing resources like water, which is considered in risk of scarcity as announced by the UN. As a result, some countries are impacted with poor access to drinking water.

Egypt is not an exception to the previously mentioned fact; it is the 3rd most populous country in Africa and the most populous country in the Arab world, which is witnessing around 4 million growths in population rates between newborns and urbanization each year. As much as this reflects advancements in economic levels, more job opportunities, and safer lives, it also reflects that there is a need to have more housing, services and facilities accommodating this growth. This all adds pressure on the existing resources that need to be properly and sustainably managed. Saying this, to respond to the population and urbanization rates, Egypt has a vision to increase its infrastructure by almost 9% by 2025, as mentioned in Egypt-Country Commercial Guide, while shifting styling into more sustainable and even smart idealized communities. These are ideas to solve the population accommodation concern, but what about the resources that if not properly managed and efficiently reused and utilized, they will come to scarcity and hence, jeopardize the availability of resources for future generations? Water use and optimization is a major focal point as committed by Egypt under the National Water Resource Strategy (2017-2037) addressing the national water related challenges for the next years while putting solutions proposals under 4 main pillars of developing water resources by desalination

and recycling, rationalizing water use, creating an enabling environment and lastly, enhancing water quality [1].

Egypt produces 16.4 billion cubic meter wastewater annually with 26.8% of which are sewage wastewater and 73.2% are agricultural waste [2]. Hence, Egypt has a 2030 vision for treated wastewater reuse with a division of agricultural expansion related cities and non-agricultural related ones including Cairo; the direction is to maximize the treated wastewater for non-potable uses to decrease the load on potable water [2].

The objective of this research is to study the effect of treating greywater using an in-series integration of sand filter and aquatic plants; the collected and treated greywater from the community is intended to be reused again in the community irrigation system and toilet flushing, and this is to be integrated with a community and occupants' rating system. The study is covered under 2 main novel approaches: the first is through an in-series experimental integration of greywater treatment systems and the second is on integrating occupants' rating system through Tarsheed-Community while adapting a C2C wastewater treatment approach to include both community rating standards and occupants' rating standards with Net Zero Approaches Addition.

For the experimental work, the greywater treatment in-series system study was covered under 5 main pilot scale experimental phases in which phase 1 covered the sand filter design by selecting the best sand granule size and sand depth; with output sand size of 0.8-1.2mm and sand depth of 65cm. Phase 2 is a buildup on phase 1 outputs intended for studying the best rate of filtration to operate the sand filters, rates of filtration 2 $m^3/m^2/d$, 4 $m^3/m^2/d$ and 6 $m^3/m^2/d$ are studied; the phase conclusion is that 4 $m^3/m^2/d$ is the best rate of filtration to operate the sand filter. Phase 3 is focused on integrating the aquatic hyacinth plants in series with the sand filters, it is split into three main sub-phases, 3.A is for 2 $m^3/m^2/d$ vs different plant densities, 3.B is for 4 $m^3/m^2/d$ vs different plant densities and 3.C is for 6 $m^3/m^2/d$ vs different plant densities; the phase output is that with 4 $m^3/m^2/d$, 3.5 $kg/m^2$ plant density is the best to use. Phase 4 focused on studying intermittent and continuous system operational hours under the best conditions outputs from the previous phases; phases 1 through 4 used synthetic greywater mix prepared in the lab. Phase 5 covered the full system continuous run using real greywater collected from the AUC faculty housing. Both phases 4 and 5 outputs concluded that the treated greywater either with synthetic lab mix or real collected greywater meet the Egyptian code of wastewater reuse for irrigation parameters levels (Category-A).

For Tarsheed-Community Rating System, a thorough research was held first by comparison and analysis of known global rating systems like LEED-Cities and Communities and Estidama Pearl Community, with a highlight on the gaps and applicability for local use, while also leveraging available and accessible tools and resources proposal in the framework. In addition, occupants' related rating systems like Well and Fitwel were also studied for comparison while highlighting the gaps and community rating system integration possibilities. Lastly, Living Community Challenge (LCC) was studied as it is the first integrated community and occupants' rating system; however, it is complicated and costly to use. Out of all the studied rating systems the highlighted gaps and opportunities were added into the newly proposed Tarsheed Community and Occupants' integrated rating system with an inclusion of C2C wastewater treatment approach.

This research is studied with alignment to the 3 main sustainability pillars of being environmentally friendly, socially acceptable, easy to implement and maintain, as well as economically viable.

## List of Publications

1. Khattab, M. , Haggar, S. and Gendy, A. (2022) Comparative Analysis between Community and Occupants' Rating Systems for Sustainable Urban Communities (SUC). Journal of Environmental Protection, **13**, 881-894. doi: 10.4236/jep.2022.1311056.
2. Khattab, M. , Haggar, S. and Gendy, A. (2023) A Cradle-to-Cradle Novel Approach for Wastewater Management in Sustainable Urban Communities. Journal of Environmental Protection, **14**, 163-171. doi: 10.4236/jep.2023.143011.
3. Khattab, M. , Haggar, S. and Gendy, A. (2023) Proposed Net Zero Certificate for Buildings and Communities. Net Zero International Conference. 26$^{th}$-28$^{th}$ of May, 2023. The American University in Cairo [Submitted].
4. Khattab, M. , ElWattar, A., Haggar, S. and Gendy, A. (2023) Slow Sand Filter Design Optimization for Greywater Treatment in Urban Communities [Ready for Submission].
5. Khattab, M. , Haggar, S. and Gendy, A. (2023) In Series Integration of Sand Filtration and Aquatic Filtration for Greywater Treatment in Urban Communities [Ready for Submission].

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~"اللهم إني أسألك علما نافعا، ورزقا طيبا، وعملا متقبلا"

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The actual environmental impactful journey is starting now after earning this degree الحمد لله.

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## Acronyms and Abbreviations:

| | |
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| AF: | Aquatic Filtration |
| BCM: | Billion Cubic Meters |
| BOD: | Biological Oxygen Demand |
| BREEAM: | Building Research Establishment Environmental Assessment Method |
| BW: | Blackwater |
| C2C: | Cradle to Cradle |
| COD: | Chemical Oxygen Demand |
| COP: | Conference of the Parties |
| DO: | Dissolved Oxygen |
| ECP: | Egyptian Code of Practice |
| EGBC: | Egyptian Green Building Council |
| EIA: | Environmental Impact Assessment |
| EPA: | Environmental Protection Act |
| FC: | Fecal Coliform |
| GDP: | Gross Domestic Product |
| GHG: | Greenhouse Gas |
| GW: | Greywater |
| HLR: | Hydraulic Lauding Rate |
| IAIA: | International Association for Impact Assessment |
| LCC: | Living Community Challenge |
| LEED-EN: | Energy and Greenhouse Gas Emissions |
| LEED-IN: | Innovation |
| LEED-IP: | Integrative Process |
| LEED-MR: | Materials and Resources |

LEED-NS: Natural Systems and Ecology

LEED-QL: Quality of Life

LEED-RP: Regional Priority

LEED-TR: Transportation and Land Use

LEED-WE: Water Efficiency

LEED: Leadership in Energy and Environmental Design

MDG: Millennium Development Goals

ND: Neighborhood

NDC: Nationally Determined Contributors

NEPA: National Environmental Policy Act

NTU: Nephelometric Turbidity Unit

PD: Plant Density

Pearl-IDP: Integrative Development Process

Pearl-IP: Innovating Practice

Pearl-LC: Livable Communities

Pearl-NS: Natural Systems

Pearl-PW: Precious Water

Pearl-SM: Stewarding Materials

PH: Potential of Hydrogen

ROF: Rate of Filtration

RSF: Rapid Sand Filter

SC: Sedimentation Column

SDG: Sustainable Development Goals

SF: Sand Filter

SSF: Slow Sand Filter

| | |
|---|---|
| TC: | Total Coliform |
| TSS: | Total Suspended Solids |
| UN: | United Nations |
| UNEP: | United Nations Environment Program |
| UNFCC: | United Nations Framework Convention on Climate Change |
| UNICEF: | United Nations International Children's Emergency Fund |
| WB: | World Bank |
| WHO: | World Health Organization |
| WTP: | Water Treatment Plant |
| WW: | Wastewater |
| WWTP: | Wastewater Treatment Plant |

# Chapter 1

# INTRODUCTION

## 1.1: Background

A prosperous and booming city is known of having high rates of urbanization attracting more citizens from rural areas. The urbanization move is considered when seeking better lifestyles, better job opportunities, better health access, better food, and better education. Yet, with high urbanization rates along with the area's increasing population levels, a pressure is added on the existing resources to meet the increasing demand. Some of these resources that are naturally existing and in essential need for living is water. Poor management/utilization of the scarce resources along with the pressure applied on them is leading some to scarcity; global water scarcity driven by both human activity and climate change is one red flag of consideration.

Water scarcity is the lack of availability of water or in other words, the difficulty of having access to freshwater. Water scarcity is an outcome to several reasons from which is the climate change and human activities abusing the freshwater. The rise in greenhouse gases (GHG) impacts climate change, and this is witnessed through the extreme weathers in some countries, the floods, and the glaciers meltdown. Climate change has been an issue of concern raised in COP21 in 2015; and till date it is still a global concern severely impacting water availability.

Historically, climate change has been the topic of focus on sustainability related conferences. Starting with the Sustainable Development Goals (SDG) introduced by the UN issued in 2015 aiming at a better future by 2030; along with COP21 held in Paris back in 2015, which started with a focus on Climate Change and how human activities contribute to it. Later along the years and through several COP events, in COP26 the focus was on introducing Net Zero Approaches in any plans to ensure not only proper utilization of resources but also reducing, reusing, and recycling as needed to decrease the load on the initial source. Climate change problem and water scarcity threat are a global concern in which Egypt is no exception to such impacts [3].

Egypt is the 3rd biggest African country, which is rated number 14 in the global population rates with approximately 2% population growth rate every year and around 1.8% increase urbanization moves to Cairo. In the light of that, Egypt's Infrastructure sector projected a 9% growth by the year 2024. This sector growth aims at building 14 new smart cities throughout the country, as per Egypt Country Commercial Guide [4]. As much as this is promising to meet the rising demands fast on a short term, yet sustainability measures are not guaranteed. Sustainability considerations focuses on enhancing the use of the existing resources without jeopardizing the needs of the future generations. An essential resource that is being deprived to scarcity globally and locally, is water.

Most of the human body and the Earth's surface is covered with water; it is also a must-include-resource for daily activities. Hence, with the increase in population rates, urbanization levels, and industrial and infrastructure sectors expansion, more pressure is added on the freshwater. This water pressure is interconnected with the globally addressed climate change problem linked with and negatively impacting water access and availability. An action on most of the developing countries is to mitigate the water scarcity concern discussed in COP27. The alternative solution is to find and implement techniques to treat the used water to be reused again in irrigation or domestic uses. In Egypt, national actions are addressed around finding solutions towards the limited freshwater availability, climate change and its impact on the water quality and supply, preserving water from any pollution resulting from sewage or waste. Also, increasing national level awareness on the need of water savings is a national action plan [4].
Several wastewater treatment (WWT) technologies have been introduced from decades; these technologies are being taken into high consideration for reuse majorly in irrigation. Not only

that, but also, some measures ensuring proper utilization of resources meeting the needs under sustainable act are further referred to in several frameworks and rating systems. These rating systems act as guidance to the investor, the contractor and the consultant proposing sustainable credits to implement within their infrastructure build like buildings or communities; and in return the user is guaranteed the related rating system certification. LEED, BREAAM, Tarsheed, and Pearl are examples of the buildings and communities rating systems. These frameworks are focused on the related infrastructure measures during the design and build stage. But to ensure a full angle of sustainability measures in design and application, couple of occupants' rating systems like Fitwel and Well were introduced. The edge of the occupants rating systems is the focus on their daily activities credits to ensure that the built sustainable infrastructure is complimented by daily sustainable activities that meets their comfort and well-being.

An integration of the building or community related framework along with the occupants' framework under one rating system acts as a one-stop-full-user-guide. Hence, Living Building Challenge (LBC) and Living Community Challenge (LCC) were designed considering the building or community credits integration with the occupants' wellbeing credits. The main problem with this integrated rating system is that it is complicated to apply and highly costly. So, it only meets one pillar of sustainability which is contributing to saving the environment, but it is not economically viable nor socially acceptable.

### 1.2: Problem Statement

Fast Population increase and high urbanization levels are adding pressure on the existing resources with more generated demand. Water is no exception to the daily necessities to all the living organisms, humans, and industries; nevertheless, it is getting more scarce day after day due to the poor management and utilization of freshwater and the lack of awareness on the need for treating the produced wastewater specifically greywater for a more sustainable society.

United Nations (UN) recently announced that water availability in Egypt has crossed the threshold of water scarcity, with 560 cubic meters available per person per year, leaning towards absolute water scarcity [5]. This is in comparison to 1000 cubic meters per person per year as per Reuters, 2020 [6]. Such a problem means that within a couple of years, a lot of people will have difficulty in accessing fresh drinking water to suffice their daily needs. A solution to reducing the reliance on the fresh drinking water is to consider treating wastewater; there are several technologies and success stories published for reusing treated wastewater for irrigation. Yet few papers considered reusing treated greywater, which contributes to almost 70% of the produced used water, for irrigation and domestic use. Hence, there is a need to utilize the available treatment technologies in treating greywater while working in parallel in integrating Net Zero concept in an integrated community and occupants' rating system that will act as a reference framework to all users.

### 1.3: Objective

This research aims at proposing an **integration** of **occupants' health and wellbeing** rating system along with Tarsheed-Communities rating system. This rating system integration will not only guide and measure infrastructure and community levels, but it also compliments with sustainable daily activities leading to a better lifestyle**.**

The second objective of this research study is **studying the implementation of a net zero water approach** under the use of an integrated slow sand filter, as primary treatment, connected in series with water hyacinth plant, as secondary treatment, for **community applicable greywater treatment** for reuse in landscape irrigation, toilet flushing and firefighting systems. This study is held through a pilot scale experimental model conducted at the American University in Cairo.

Another novel approach in this study is **the proposal of a net zero community and occupants' rating system complimentary certification.** Lastly, in this research, the proposal of a greywater management code framework for Egypt is established.

By achieving the above main objectives, this research will successfully meet and interlink three SDGs, SDG#11: Sustainable Cities and Community, SDG#6: Clean Water and Sanitation and SDG#3: Good Health and Well-being.

### 1.4: Scope of Work

The work presented herein reflects the advancement of using an in-series integrated greywater treatment system of sand filter as a primary treatment and aquatic filtration using water hyacinth plants as a secondary treatment for community landscape irrigation through a pilot scale experiment. In addition to the experiment, another study focused on the current community rating systems and occupants' health and wellbeing rating systems is held to propose a rating system integration between both that also includes a highlight on the experimental outputs recommendations. In addition to that and to meet the global 2050 vision of carbon dioxide reduction, a net zero community and occupants' certification is proposed complimenting the main community and occupants' rating system. Lastly, as the trend is heading towards greywater treatment due to its low toxicity and high availability levels, a local greywater management code is proposed with reference to the existing ones in similar conditions countries.

### 1.5: This Research's Novel Approach

- The first novel approach in this research is proposing an integration between occupants' health and wellbeing rating system along with Tarsheed-Communities that meets the three pillars of sustainability.
- The second novel approach in this research is the proposal of a complimentary net zero certification integration for the community and occupants' rating system proposed.

- The third novel approach in this research is experimentally studying the impact of treating greywater in a series integration of sand filter and aquatic hyacinth plants. The treated greywater is studied for confirmation in use applicability in landscape irrigation and toilet flushing.
- The fourth novel approach in this research, which is considered on a high level under the appendix section, is to propose a local greywater treatment code that shall act as a guide to users considering this kind of water conservation mitigation. Currently in Egypt, most of the Middle East Countries and globally, most of the treated codes of reference are related to wastewater treatment; very few countries started issuing a specified greywater treatment code for irrigation reuse majorly and some considered toilet flushing use. These countries include KSA, Jordan, Australia, and California.

**1.6: Structure of the Dissertation**

Chapter 1 is representing the introduction to this dissertations' work. The introduction section is divided into the background information, problem statement, objective, scope, and then what is new/novel in this research study. The background information paves the way from the water scarcity crisis globally and specifically to Egypt, the country of focus in this study. After the water scarcity, a highlight on the integration of water-related-relevant solutions under SDGs and COP conferences is mentioned. Also, the proposed solutions of conserving freshwater by treating wastewater and greywater specifically are highlighted in the introduction with a reflection on the sustainable communities' frameworks taken of reference in this research study.

Chapter 2 entitled "Literature Review", is the following chapter. It represents the literature study related to this research work reflecting on data from other books, academic journals, environmental conferences press talks or governmental press releases and statements that are restating the impact of climate change and high urbanization levels on the water scarcity issue globally and in Egypt; highlighting the effect of having sustainable urban communities, what are the measures to implement them through the communities' frameworks and also the occupants; related frameworks that are available globally and locally. Also, as a mitigation to reduce the reliance of freshwater on daily needs, the research includes the reflection on the existing wastewater and greywater techniques and codes. Lastly, the study of greywater composition, quality, available codes for treatment, if any, and the reuse purposes was presented.

Chapter 3 entitled "Integrated Community and Occupants' Rating System for Egypt ". It is one of the novel approaches in this research which proposes an integrated community and occupants' rating system for Egypt. This is proposed relying on the literature of the community and occupants' rating systems comparison, highlighting the gaps and the needed credits to ensure meeting the 3 sustainability pillars (environmentally friendly, socially acceptable by being easy to implement and maintain, and economically viable an affordable). In this chapter another new proposal framework is added considering a net zero certification meeting COP27 objective and the vision for 2050. This net zero certification is complimentary added to the community and occupants' integrated rating system. In addition to that, a complimentary net zero community and occupants' rating system certification is proposed. In this section, the proposed integrated community and occupants' community rating system on the existing Tarsheed- Communities is described. Also, the proposal of a net zero certification guide is mentioned under chapter 3.

Chapter 4 entitled "Experimental Study" and it represents the experimental novel approach work held in this research study by integrating sand filter and aquatic filtration treatment methods in series. In this chapter, 5 phases of experimental work were studied varying the design parameters for the sand filter alone, then studying the design parameters for the aquatic plants alone, and finally studying the full integrated system effectiveness while running under both intermittent and continuous runs. Phases 1 through 4 were studied using synthetic greywater mix prepared in the lab. The synthetic mix was built on both, references and lab trial and error for some components within. Phase 5 was conducted using real greywater collected form the AUC housing.

Chapter 5 entitled “Results and Discussion” is presenting the experimental work results of the 5 experimental phases.

Chapter 6 entitled “Conclusion.” Where a conclusion of this study is presented.

Chapter 7 entitled “Recommendations” proposing some guidance to build on for future research and studies to further widen the topic’s scope as this is study highlights alarming focal points that needs further investigation to be able to implement.

# Chapter 2

# LITERATURE REVIEW

## 2.1: Water Scarcity

Water, the heart of every living organism and a core source to any industry and process, is threatened to scarcity due to several drivers from which are the improper allocation and utilization of its use as well as the climate change globally. Water crisis reflecting scarcity or lack of water access for drinking, started back in the 1800s with the industrialization and high urbanization levels, more water was used to suffice the needs [7]. Water scarcity is a serious threat that has been flagged by several global organizations including the UNICEF and UN-Water in which several facts were highlighted as a result to water scarcity. By 2025, half of the world's population is projected to be living in water scarcity areas as stated by UNICEF [8] [9]; and by 2030, more than 700 million people globally will be displaced with intense water scarcity that can reflect to no drinking water access at all. And lastly, more than 2/3$^{rd}$ of the world's population is facing extreme water scarcity at least once a month per year as stated by UNICEF [8] [9].

Finding solutions and rectifying actions to eliminate the impact of water scarcity is a life-dependent action because with water scarcity and lack of access, areas will be drought, crops will die, people will be sick, and the countries economics will drop. As a reaction to that, and as stated during COP27, net zero water approach must be taken into consideration.

### 2.1.1: Water Crisis Threat in the Middle East

The Middle East and North Africa region (MENA) is considered among the highly vulnerable places to climate change and high-water scarcity levels faced currently and projected for 2040 [10]. Figures 2.1 and 2.2 show a current situation of water stress levels faced globally and in the MENA region specifically; while figure 2.3 shows the projection of water stress levels globally with a highlight on several middle eastern and north African countries projected to threat facing extremely high-water stress levels.

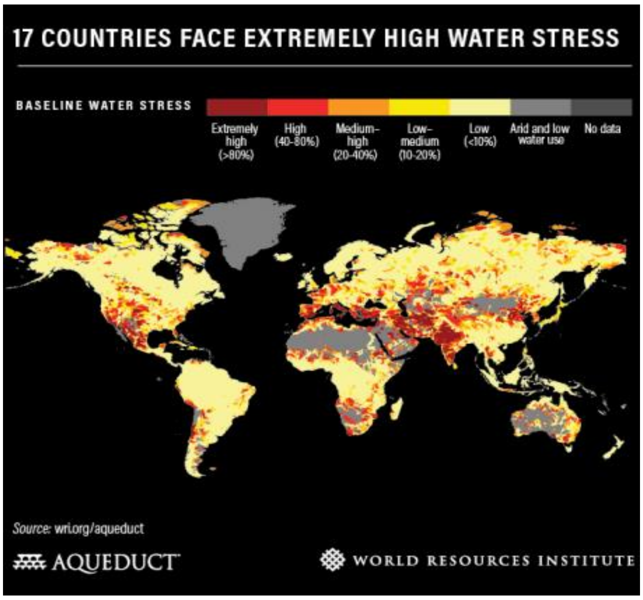



Figure 2.1: Water Stress Level Mapping- Globally [11]

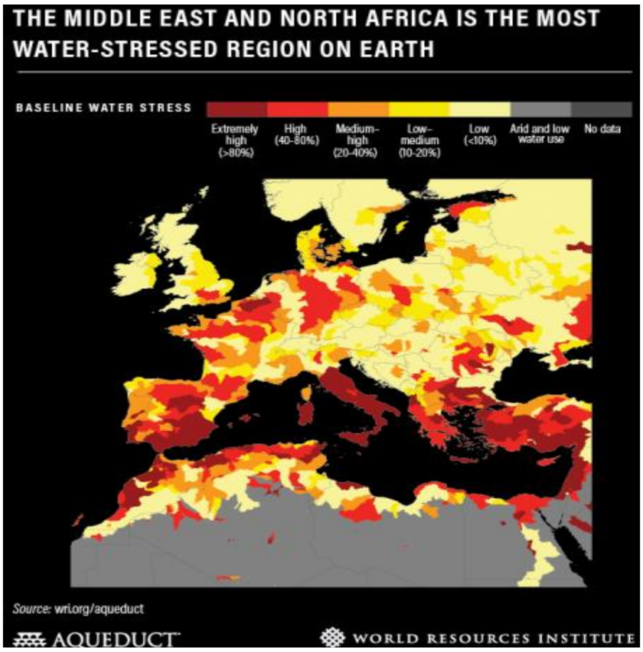



Figure 2.2: Water Stress Levels Mapping- Middle East [11]

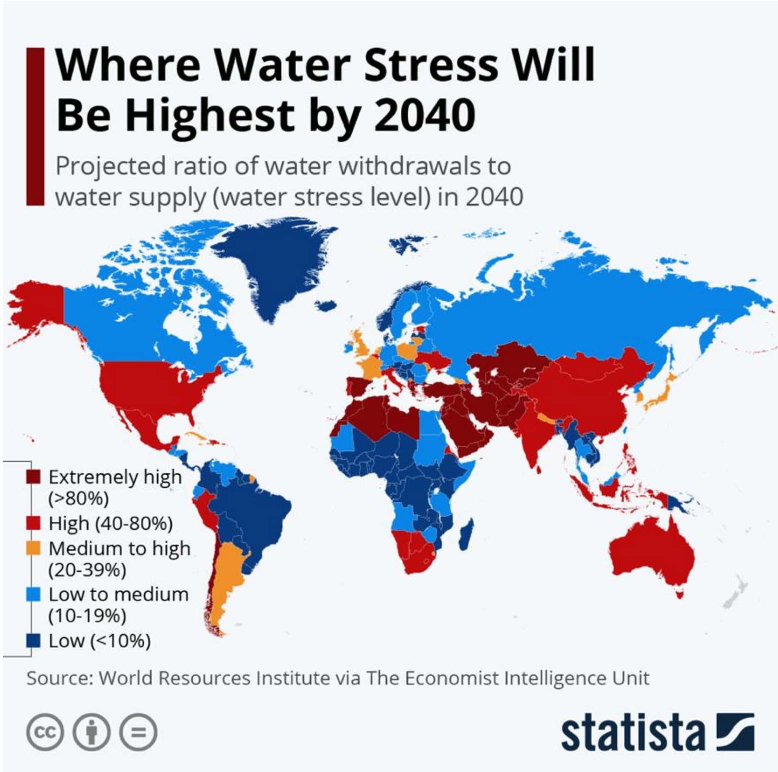



Figure 2.3: Water Stress Reflection by 2040 [12]

**2.1.2: Water Crisis Threat in Egypt**

Numbered 43- High Baseline Water Stress on the National Water Stress Rankings as shown in figure 2.4, Egypt is facing a serious threat of water crisis especially with the high population rates and urbanization levels faced annually. The water crisis faced in Egypt is impacting the whole nation that can lead to adding more people under the poverty line. The agricultural sector in Egypt supports more than 50% of the total Egyptian population using almost 86% of the nation's natural fresh water; hence, water scarcity will lead to losing jobs, insecurity, and health implications [13]. UNICEF stated that "Egypt is facing an annual water deficit of around seven billion cubic meters and the country could run out of water by 2025, and climate change is a key part of the problem" [14]. As a result, the Egyptian government is acting towards adding more funding investments towards the water sector to further support in increasing desalination of water capacity and supply, as well as, encouraging for wastewater treatment and reuse [13].


Figure 2.4: National Water Stress Rankings [11]

### 2.2: Sustainability

UN defined sustainability as "the act of meeting the current needs without impacting the future generations" [15]. Sustainability measures focus on optimizing resources, ensuring that the current generations' needs are fulfilled without jeopardizing the needs of the upcoming generations. Another definition of sustainability provided by the U.S. National Environmental Policy Act (NEPA) in 1969 is: "Sustainability creates and maintains conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations." [16].

Sustainability is initially measured through 3 main pillars known as Social Acceptance, Environmental Friendliness and Economic Viability. The social acceptance pillar focuses on securing the availability of resources necessity for human lives like water, land, and food. It also focuses on justice, improving health, education, and lives. The social pillar also promotes having sustainable communities planning and development that will support in meeting the sustainability resources optimization goal while providing a better social level. The second pillar of sustainability is the environmental pillar, and it focuses on ensuring better health and lives through better air quality, better water quality and availability, waste management, green engineering activities like reuse, reduce and recycle. The environmental pillar also aims at reducing the greenhouse gas (GHG) emissions and pollutants. The third and final pillar of sustainability is the economic pillar. The economic pillar reflects the economic implication of activities through adding reasonable costs on the services and products in addition to the economic security through job availability and incentives [16].

A fourth pillar of sustainability has been in proposal by some organizations, yet it is not considered by the EPA or any other official environmental activity related organization.

This pillar is the Human Sustainability which reflects the need of investing more into people's education, skills, and health especially those who are providing a service to ensure a better living and economic standards [17]. This is seen to be like the social pillar of sustainability; however, it is further branched out to focus on workers.

There is a difference between "Sustainability" and "Green". A green community or society is concerned about preserving the environment through the naturally existing resources; unlike sustainability which focuses on the previously mentioned pillars completing one another.

**2.2.1: Sustainability Challenge and EIA**

Recently, there is a sustainability challenge in balancing the available natural resources used to meet the needs. This challenge is driven by the rapid increase in population and urbanization rates globally. As a result of this fast-track increase in population, a higher demand is generated leading to a pressure on all the servicing segments like the infrastructure, construction, agriculture, and many others to accommodate this rise. This pressure is sometimes leading to poor management/ allocation of resources with an increase in waste generation. As a mitigation to that, the Environmental Impact Assessment (EIA) came in place. EIA is defined as the process for decision making to study, analyze, predict, and mitigate any environmental, economic, or social implication of a project prior to its development. In other words, it is a report that supports in investigating and assessing a project idea before its construction.

This assessment supports in early monitoring, management of resources, studying risks and enhancing the design -if needed- to prevent any future complexity, or negative environmental impact. UNEP defines EIA as "a tool used to identify the environmental, social, and economic impacts of a project prior to decision-making. It aims to predict environmental impacts at an early stage in project planning and design, find ways and means to reduce adverse impacts, shape projects to suit the local environment and present the predictions and options to decision-makers" [18] [19].

EIA has 4 main overview steps starting with the developer responsible for application preparation, then the primary screening auditing phase where the initial documents are revised, then the environmental assessment step highlighting and predicting any environmental implications which are then studied and measured in depth through the main forth step of the environmental impact review analysis. [19]. During the assessment phase, the project can be marked either White (A), Grey (B) or Black (C) reflecting its impact on the environment with white meaning that the project has a minor environmental impact, grey means it has some environmental impact and black means it has major impact. After which, each category is qualified to a different form or follow up procedure.

EIA has 8 steps within the 4 main overall ones mentioned earlier; these 8 steps reflect project screening, project scoping highlighting the possible environmental impacts to be further investigated, impact analysis further assessing the highlighted environmental issues, mitigation actions to lessen them, reporting the end result and proposal solution or modification, then the document goes back for EIA revision, regulatory decision making and finally post monitoring implementation and follow up on the project ensuring that the asked for actions are taking place and that no further unseen impact is taking place [19].

### 2.2.2: Sustainability Ethics

Just like any other concern of continuation and properly meeting the objective, ethical contribution and commitment to the matter is always a key. Sustainability is no exception to ethical behaviors and responsibility, which are essential, since the problem lies within abusing scarce naturally existing resources. Sustainable Ethics majorly reflects human's contribution to the resources' and towards one another; meaning that the wealthiest citizens shouldn't be privileged into having a wider access to resources than others [20]. At the end of the day, any environmental problem arising can have one cause, yet it impacts several citizens and indirectly negatively feeds into services, businesses, and communities. In a nutshell, Ethics should be a core pillar either standalone reflection within the previously mentioned 3 sustainability pillars or being embedded within each pillar alone.

### 2.2.3: Sustainability Rise Historical Reflection

In synchronization with the sustainability pillars, SDGs are 17 goals segmented into objectives to serve the environmental, economic, and social pillars. Officially established in 2015, SDGs are the core of any sustainable development or sustainability activity, or framework introduced. Looking on a historical trend showing from where the SDGs rose and ensuring that sustainability has been a point of nation's considerations since 1970s, yet it came into vital action nowadays due to the earlier mentioned problems with rapid population growth, urbanization, and lack of natural resources management. Starting with 1972, the first environmentally related world conference was held in Stockholm managed and held by the UN highlighting international concerns, air and water pollution and the impact of industrialization along with the developing countries at the time. The outcomes of these conferences stated three main action points related to **international management to activities impacting the environment**, **global environmental assessment program** and lastly, **environmental management activities** [21].

20 years later, in 1992, celebrating through the Earth Summit held in Rio de Janeiro by the UN aiming at updating the previously issued agenda and blueprint to suit international cooperation in the 21st century development. It also assured that the environmental, social and economic pillars are interconnected together for sustaining healthy human lives with managed resources [22].

Five years later, an agenda review was held by the UN in NYC in 1997. This agenda aimed at assessing the implementations of the Earth Summit blueprint by countries globally [23]. In 2000, another meeting was held by the UN in NYC, but this time it was to celebrate the new millennium to preset the development strategies meeting the new millennium needs with the available resources. The output of this celebration concluded into 8 Millennium Development Goals (MDGs) related to poverty, education, gender equality, child mortality, improving maternal health, combating diseases, environmental sustainability, develop a goal partnership with organizations and governments for development [24].

In 2002, building on the MDGs, The World Summit on sustainable development, which was held in Johannesburg adopting A Political Declaration and Implementation Plan restated the commitment of the attending countries to reinforce sustainability pillars and sustainable development goals on a local, global, national, and regional levels. Action plans were issued after days of study related to water, agriculture, diversity, health, energy, and other issues of concerns were answered in plans of action [25] [26].

In 2005, back again at the headquarters of the UN in NYC, World Summit was held reviewing the passing of 5 years since the MDGs were established. More than 170 countries supported by attending and being part of this summit while more contributions were added to further fight poverty and add more investment into innovation to support in meeting the goals with stronger commitments with a responsibility to protect every nation from any negative environmental impact [27]. This World Summit action plan was reviewed again two years later in 2008 in NY, and it resulted out in a prosperous conclusion that countries are acting in line with their goals, however more international rigor is need in support. This led to drive another MDGs review summit in 2010 in NY, which added on the focus on women's and children's rights by launching a Global Strategy for Women's and Children's Health in support with MDGs for gender equality, child mortality and infant maternal health [28] [29]. Building on the MDGs, Rio de Janeiro hosted another UN conference after 20 years from the Earth Summit in 2012 but this time establishing the Sustainable Development Goals (SDGs) plus it's financing to ensure proper implementation; this was in addition to introducing green economy guidelines. This had a follow up event in 2013 in NY to revisit the MDGs and the draft of the SDGs that shall be launched in 2015 in commitment to the environmental sustainability [29] [30].

In 2015, a new plan named (Transforming the World, the 2030 agenda for Sustainable Development) was introduced. This entails the official launch of the 17 SDGs including 169 targets to achieve within. The 2030 agenda held a commitment to achieving the established goals within the next 15 years to support the planet and humanity under people, prosperity, peace, and others [31]. This had a slight follow up 2 months later in Paris at the first Conference of the Parties (COP21). COP21 is majorly focused on climate change which is impacting the surrounding ecosystem, marine lives, and human lives. Named 21 as it aimed at enhancing climate change by reducing the global rise in temperature by 1.5-2 degrees Celsius maximum by the year 2021 [31]. In 2016, COP22 was held in Morocco, with the climate change support and contribution to enhancement by 122 countries out of the total registered 193 countries [32]. In 2017, COP23 was held in Germany and revisited the Paris Agreement with a highlight of how to locally minimize the GHG emissions from the source, especially in land management and agriculture.

In 2018, COP24 was held in Poland further and assessed the local implications with a global reflection on the climate change plus carbon footprint. In 2019, COP25 was held, and it took bigger attention than the previously mentioned local ones as it focused on problem solving in global countries struggling to implement acts in support with the Paris Agreement and Climate Change.

In 2021, COP26 was hosted by the UK to renegotiate and modify global and local strategies and targets in ease of meeting the SDGs and the Paris Agreement [33]. Lastly, as of this date, in 2022 UN held a final conference in Stockholm to accelerate the implementation of the SDGs and the 2030 agenda. For the COP27, it took place in 2022 in Egypt with a main objective in highlighting the urgency in action towards climate change activities and mitigations while fastening the net zero water approach application.

### 2.2.4: Sustainable Development Goals (SDGs)

With reference to the 2015 Rio de Janeiro conference held by the UN, sustainable development goals entailed 17 main goals that act with response to the environmental, economic, and social pillars of sustainability as shown in figure 2.5.


Figure 2.5: Sustainable Development Goals (SDGs) [33]

Goals 1 and 2 complement each other, in which goal 1 is focused on ending poverty all around the world while hunger, known as an extreme dimension to endless poverty is aiming at ensuring the availability of food security while encouraging more agriculture. Goal 3 aims at having healthier lifestyles, lives, and wellbeing for people. This is complimented by the rest of the goals for example, a sign of good health and wellbeing is having access to good quality education and awareness which can lead to good job opportunities. Another example of good health and wellbeing is having access to clean water and sanitization as well as affordable and clean energy for sustained lives as mentioned in goals 6 and 7.

Another sign of healthy and stable wellbeing is gender equality between male's vs females and children as stated in goal 5 as well as reduced inequalities between countries specially developed and developing ones as mentioned in goal 10.

This is in addition to having access to decent work and economic growth that supports productive employment environment as in goal 8; and again, it is complimented with the gender equality in goal 5. An example of healthy environment is benchmarked into sustainable cities and communities which are the pioneers in driving and promoting such need by offering safe and resilient cities with accessible needs and services settlements as in goal 11. This goal, like other SDGs, is indirectly linked with the Peace, Justice, and Strong Institutions stated in goal 16 which promotes inclusive societies with accountable institutions. When considering accountability, managing resources with responsibility is a core pillar to ensure sustainable production as mentioned in goal 12.

Last but not least, when talking about accountability, taking action towards climate change, preserving aquatic lives and marine resources plus protecting and managing the habitat and forests on land is a must for the balance of the ecosystem and the sustainability of the surrounding environment as stated under goals 13, 14 and 15. All of these goals are important initiatives that every human being is held responsible to fulfil their own role; yet with global unity and partnerships for macroeconomic management and stability while supporting development [34].

Another SDGs assessment is taking place post the global pandemic COVID-19 hit, which aims at capturing its multidimensional implications over the upcoming decades by studying its impact under different scenarios. One of these scenarios is modelling which supports governments in visualizing future impacts of current decisions. A major outcome from the COVID-19 related study is that focused SDG investments are put in plan while focusing on low- and medium-income countries [35].

## 2.3: Climate Change and Global Water Crisis

The earth's ecosystem is all interconnected, and any variance in any pillar out shifts the other; an example for that is climate change and the water crisis faced globally. A change in temperature leading to change in weather patterns are majorly driven by human activities that disrupts the ecosystem, such as, the use of coal or gas. So, how is climate change connected to the water crisis? As defined by the UN, climate change is the root cause for the globally faced water crisis as in extreme temperatures, water tends to evaporate into water vapor which holds the high temperatures within impact the faced surface; thus, a reduction of water level is encountered as per the evaporation phase. With unpredictable weathers, flooding and droughts and high temperatures are leading to increase in sea salt water, increase of pathogens levels in freshwater making it dangerous for drinking, overfeeding for agricultural lands and destruction of houses. This is all leading to water scarcity as well as an imbalance in the Earth's ecosystem [36][37]. The impact of water scarcity leads to limited access of fresh drinking water while it also impacts nations on economic levels reflecting industry, irrigation, and incomes by almost 6% reduction in GDP as shown in figure 2.6 (World Bank) (UNICEF).

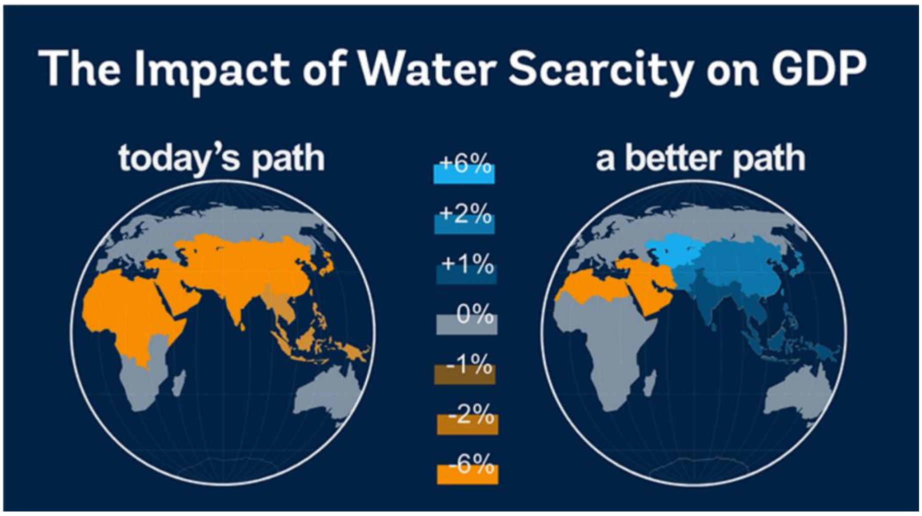



Figure 2.6: The impact of water scarcity on GDP by 2050, relative to a baseline scenario with no scarcity [37]

The risks of such imbalance is described by UN which states that by 2050, an increase in number of people at flood risk will rise from 1.2 billion to 1.6 billion and 3.2 billion people globally will be living in severe water scarcity countries. That is why a fierce climate change action plan has been in discussion since the Paris Agreement in 2016 and COP 21 back in 2015 up until COP 27 in 2022. All the COP events focused on climate change action plans yet with recent integration of natural water conservation and wastewater treatment for non-potable reuse is considered under fierce action plans for 2030. This is covered under focus areas for better water allocation and treatment planning for conservation, optimization, and reuse [37] [38].

### 2.4: Local Water Crisis and National Direction

Egypt, a developing country counted as the third most populous African Country after Nigeria and Ethiopia, is facing huge water crisis of annual 7 billion cubic meters of water deficit and the country is projected to run out of water by 2050 as highlighted by UNICEF [39]. The main fresh water source for Egypt is the Nile River which supplies the country with almost 55.5 billion cubic meters (BCM) per year with some additional water sources that can be seasonal like rainfall accounting for additional 1.3 BCM and ground water aquifers (2.1 BCM); this is not sufficient for the total country demand of 114 BCM [40]. The delta between the water supply and demand is covered under the reuse of agricultural drainage and treating produced wastewater equivalent to 21 BCM. Egypt’s supply per capita fell from 1,972 cubic meters per year from 1970s to 570 cubic meters in 2018 and it is projected to drop further to 390 cubic meters per year by 2050 (UNFCC) [40].

Several local public announcements were issued highlighting the country’s water deficiency levels since the annual water supplies dropped below 1,000 cubic meter per capita which is the case in Egypt as highlighted by the Egyptian Minister of local Development, this means that the country is facing water scarcity. In addition, the current Egyptian president announced that the country’s water supplies are not in line with the demand with respect to the population growth rates, 1 person is born every 19 seconds, and urbanization levels leading to water needs of 114 billion cubic meters per year; He also confirmed that the government is taking serious steps into conserving water supply through water management strategies as mentioned at COP27 [41].

Egypt's 2030 vision is designed in line with the SGDs, mainly to reduce GHGs by 10% from the relevant industries; this includes several environmental programs to support in meeting the vision from which are water management and utilization programs starting with the rationalization of the local fresh water use, local water resources management systems, encouraging sustainable water and natural resources consumption, environmental awareness and incentives implications for water conservation technologies and implementing sustainable water systems. Quantifying the previously stated programs visions, Egypt's 2030 KPIs include reducing the water consumption from 107% as of current projections to 80% by 2030, increasing the reliance on renewable freshwater sources from 650 $m^3/year$ as of date to 950 $m^3/year$ by 2030, increasing the ratio of nontraditional water resources to be a relevant water source addition from 20% reliance to 40% by 2030, decreasing water transfer loss in networks from 15% to less than 5% and lastly, ensuring that 100% of the population have safe drinking water access as per the demand levels [42].

Egypt's first updated Nationally Determined Contributors (NDCs) issued in 2022, is a national level plan highlighting the mitigation towards climate change as stated in the Paris agreement earlier and now towards water crisis management and solutions as mentioned in COP27 recently covering a period of study and analysis from 2015-2030 [43]. The local NDC covered several plans under Waste Management, Energy Efficiency under different sectors, Buildings and Urban Cities initiatives for sustainability measures and contribution to climate change adaptation which entails water resource and irrigation as a measure. Under the Water Resource and Irrigation NDC subsection is addressing the River Nile declines with the needs in place under agriculture, industrial and municipal measures; an example for that is the development of non-conventional water resources by capturing seasonal rainwater, water desalination using solar energy, solar pumping for irrigation and the consideration and construction of wastewater treatment plants with a utilization in treated wastewater and greywater plus sewage sludge recovery for energy use and recycling [43].

The" 2030- Strategic Vision for Treated Wastewater Reuse in Egypt" is issued jointly by several ministries reflecting more on the current water and wastewater situation assessment in Egypt plus focusing on wastewater treatment and reuse while considering the mixed agricultural drainage and wastewater and in conclusion to that a highlight of the existing plans, strategies, obstacles, and next steps are mentioned with a revision of the code reuse [43]. Since there is a projected further increase in urbanization levels and population rates, this is translated into an increase of wastewater generated; figure 2.7 projects the levels of increase of wastewater from 2010 till 2030. Hence, an action plan focusing on considering treated wastewater as a domestic water source comes in place as mentioned in the 2030 vision. The national domestic water supply capacity is shown in figure 2.8 reflecting that the water supply for domestic use will increase to almost 15 BCM by the year 2030 relying on the Nile River in addition to Water and WWTP which are 358 in total number across Egypt responsible for treating 3.65 BCM annually [43] [44].

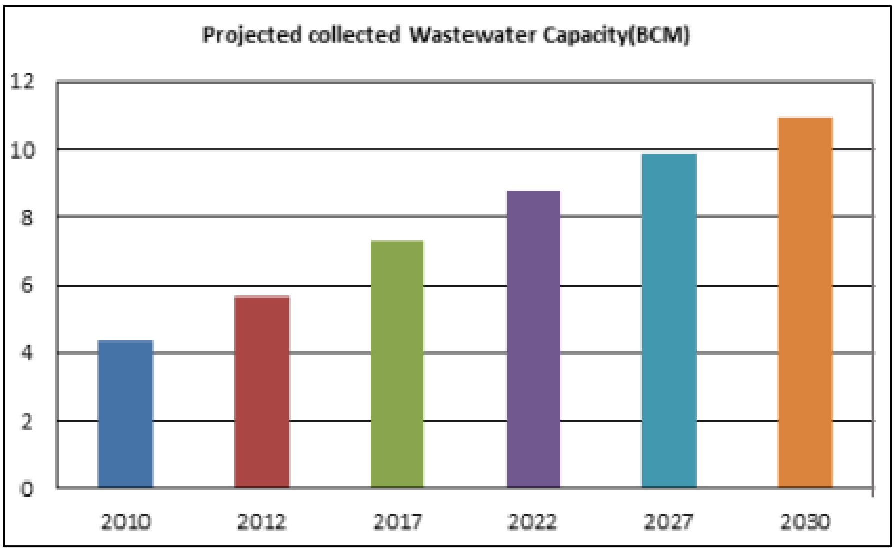


Figure 2.7: Projected Water Supply (BCM), Egypt 2030 Vision [43]

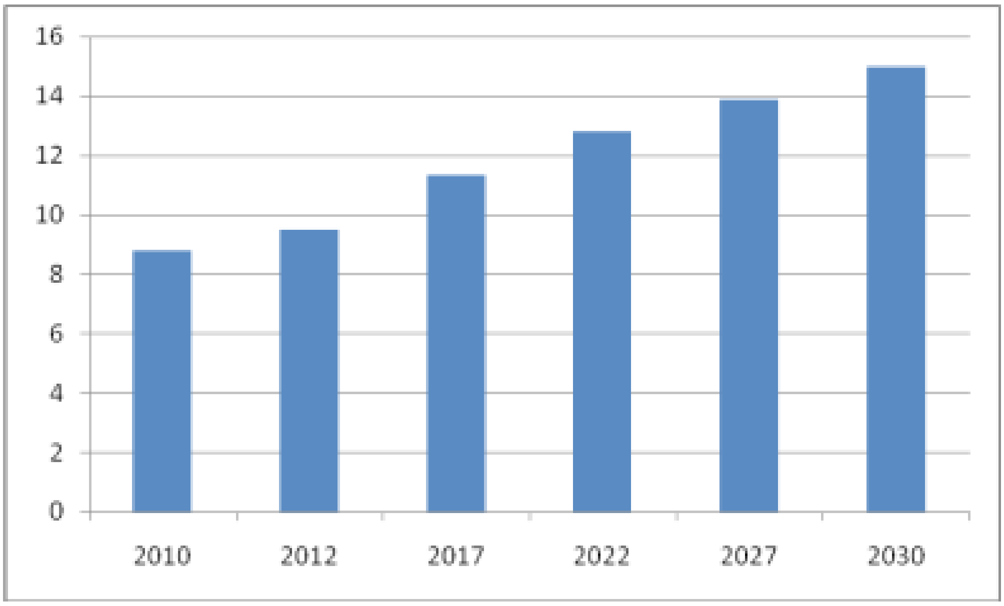


Figure 2.8: Projected Wastewater Collection Capacity (BCM), Egypt 2030 Vision [43]

Several Egyptian regulations are in place to ensure that the treated wastewater is safe for reuse, starting with Law 93/1962 focusing on the wastewater disposal assigning the ministry of housing as a responsible member for issuing any wastewater discharge to the public sewage system permits. Law 48/1982 prohibits wastewater discharge into any water way like drains. Egyptian Code No. 501/2015 for wastewater reuse classifying the treated wastewater into 3 degrees based on the reuse application [32] [44].

### 2.5: Sustainable Communities

As defined by the Institute for Sustainable Communities, sustainable communities ensure utilizing the needs to meet the sustainability pillars in parallel. It is also a place where diverse backgrounds with different needs come together all seeking the essentials of lives for a secure living, educational opportunity, security and a healthy place with clean air and clean water accessibility with land conservation and encouraging the use of renewable resources and this is defined as ecological integrity. Lastly, the right to express opinions and take responsibility and this is defined under leadership, engagement, and responsibility [45].

Another definition of sustainable communities is apart from the fact that their investors work on optimizing the resources used during the design and build phase; yet they also have the ability to be self-sustained with resources. In other words, encouraging local gardening and harvesting, local market, supporting the local community economy, water treatment, waste management, energy conservation and lastly, gender equality with fair job opportunities and the right for each citizen's voices to be heard and innovative ideas to be addressed (Salah El-Haggar, 2019). The elements for sustainable community are defined under leadership and responsibility, ecological integrity, social well- being and economic security [45] [46].

#### 2.5.1: Sustainable Communities and SDGs

Sustainable Development Goal#11 (SDG#11) focuses on sustainable cities and communities. The purpose behind this aim is to ensure safe and affordable housing with accessible transport system with green areas and public spaces by 2030. All of this shall be achieved with a sustainable responsibility manner ensuring better land use, encouraging local harvesting, encouraging freedom of opinion, and giving space for innovative ideas proposal while having gender equality; yet sustainable infrastructure supports in meeting the other 16 SDGs as shown in figure 2.9 [46].

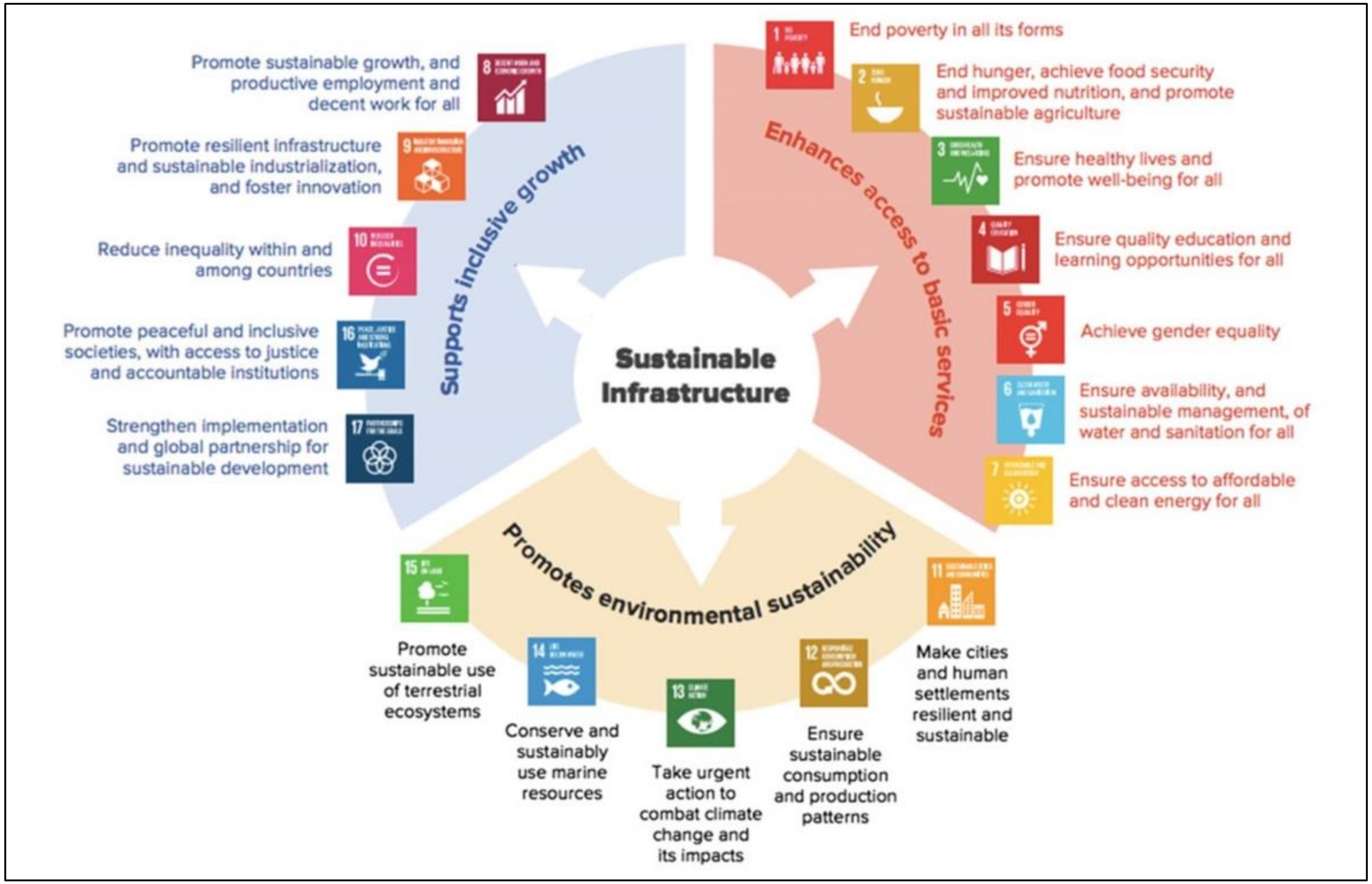



Figure 2.9: Sustainable Infrastructure and SDGs Link (El Haggar, 2019) [20]

Even though, SDG#11 is focused on the sustainable cities and communities however, some of the remaining SDGs can be further tailored in consideration to complement this goal. For example, in order to have a sustainable community, a sustainable consumption of products and items plus the addition of resilient infrastructure and innovation shall be considered. Also, there is a need to ensure healthy lives and wellbeing for the residents, ensure having clean water and proper waste management. In addition to that, ensuring clean energy use and access for on-site renewable energy promotion and energy savings. Furthermore, the need to invest in the community members in education and awareness to act with sustainability while also, providing sustainable community growth is needed for a healthy ecosystem. Lastly, most of the previously mentioned human activities are interconnected with the climate change and GHG impact. All of the examples are grouping several SGDs in parallel like SDG#3, 4, 6, 7, 9, 8, 11, 12 and 13.

### 2.5.2: Sustainable Community Rating Systems

Different community scale rating systems are present globally to support in guiding investors, designers, and engineers in applying sustainable measures during the design and construction phase. From the most used and referred to community rating systems is LEED cities and communities which is studied further in the next sections. Similarly, referring to one middle east rating system of reference, Estidama – Pearl is studied for comparison and lastly, while considering local rating system applications, Tarsheed- Communities is studied below. A summarized community rating system comparison is presented in table 2.1.

**A. LEED Cities and Community Rating System**

Leadership in Energy and Environmental Design (LEED), US designed framework by US green building council which has evolved more since 1998 and it is the most widely known and commonly used rating system certified under which are more than 80,000 projects worldwide. Ever since then, several projects worldwide have been considering building their communities and/or facilities while following LEED rating systems [47]. This is to ensure that they are not negatively impacting the surrounding environment while also being commercially benchmarked differently or uniquely compared to other infrastructures. The main challenge with LEED is that it is US based meaning that it takes into consideration their local standards, materials availability, and cost effectiveness. LEED for cities and communities focuses on 8 main categories under water, waste, energy, education, transportation, and others. It is slightly different than LEED for Neighborhood as LEED-ND is more focused on connected neighborhoods sustainability and not on a one- community scale building and efficiency. Maximum credits add up to 100 [47].

**B. Tarsheed Community Rating System**

In 2015, Egypt Green Building Council (EGBC) developed an Egyptian rating system which entails locally driven measures suiting more the Egyptian Market. Tarsheed rating system consists of 3 main certification processes starting with the registration, preliminary assessment and then the final assessment. The rating system is inspired by the global rating systems developed to support the investors, businessmen and developers to follow sustainable measures as per the sustainable development goals [48].

Tarsheed Rating System focuses on 3 main categories, Energy, Water and Habitat, landing a maximum score of 100 credits. The below section shows a comparative analysis between LEED- ND and Tarsheed Ration System. Maximum credits add up to 110 [48].

**C. Estidama- Pearl Community Rating System**

Estidama- Pearl community rating system is developed in Abu Dhabi, UAE under Abu Dhabi Urban Planning Council aiming at having a sustainable foundation for the new developments taking place across UAE while enhancing life quality. It was first issued in 2010 with several updated versions that took place through the years. It has sections under Water, Energy, Livable Communities, Materials and Waster, and Innovation. Maximum credits add up to 22* pts, Excludes Innovating Practice credit points which are offered as bonus credit [49] [50].

Table 2.1 provides a summary of the main highlights for the previously mentioned community rating systems with a specification of their country of establishment, total number of credits, sections available within the rating system and the cost of registration and fulfillment.

Table 2.1: Comparison between Community Rating Systems

| Rating System Name | LEED-Cities and Communities | Tarsheed-Community | Pearl Community |
|---|---|---|---|
| Established In | USA | Egypt | UAE |
| Date of Establishment | 1998 | 2018 | 2010 |
| Max. number of credits | 110 | 100 | 22+ |
| Levels of Certification | Certified (40-49 points)<br>Silver (50-59 points)<br>Gold (60-79 points)<br>Platinum (80+ points) | Bronze (40-49 points)<br>Silver (50-59 points)<br>Gold (60-69 points)<br>Platinum (70+ points) | pearl (all mandatory credits)<br>pearls (all +65 extra)<br>pearls (all +85 extra)<br>pearls (all +115 extra)<br>pearls (all +140 extra) |
| Categories | Natural System Ecology, Water, Energy, Materials, Quality of Life, Innovation, Transportation | Energy, Water, Habitat | Integrated Development Process, Natural Systems, Precious Water, Livable Communities, Resourceful Energy, Stewarding Materials and Innovating Practice |
| Applicable For | New Community and Existing Community | New Community and Existing Community | New Community and Existing Community |
| Application Cost (Registration, precertification, and certification) | For silver, gold, platinum members/ non-organizations without expedited review: Registration ($2,500 for silver, fold, platinum level members) + precertification ($8,000), Certification is based on area | Registration is EGP 20,000 ($ 1000) and certification is based on area | No fees are associated for the review of projects under the Pearl rating system |

### 2.5.3: Occupants' Health and Wellbeing Rating Systems

In this study, the potential of integrating occupants' rating system with the community scale ones is considered. Fitwel and Well are the known examples of reference for the occupants' rating system. Living Community Challenge is also explored in this section as it is the first integrated community and occupants' rating system however, due to its complexity and high cost, it is not commonly used. A summarized occupants' rating systems is presented in table 2.2.

#### A. Fitwel Rating System

Fitwel is a lifestyle rating system like WELL, however, it is considered more for building scale applications, more focused on location and healthy eating accessibility and habits. It was introduced in 2016 by US CDC and it has 3 certification levels, Single Star (90-104 points), Two Star (105-124 points) and Three Star (124-144 points). 12 Elements or focal points of the Fitwel system include Location, it measures the connectivity of a building with the amenities aside giving higher score to the shortest/ walkable distances. The main aim of LCC is to link between sustainable communities' infrastructure and the day-to-day activities for occupants' health [51] [52].

#### B. WELL Community Rating System

It is a rating system designed to measure day to day wellbeing of the citizens within a community. It was developed in 2014 by the International Well Building Institute (IWBI) aiming at improving human health via measuring and monitoring the performance of the surrounding built environment [53].

The WELL rating system includes 10 main categories of focus, starting with Air, Water, Nourishment, Light, Movement, Thermal Control, Sounds, Material, Mind and lastly, Community. These categories measure the ecosystem performance around and human acceptance based on several measures and continuous check points with the community citizens. Communities can receive 3 different seals based on their achieved points: Silver (50 points), Gold (60 points) and Platinum (80+ points) [53].

### C. Living Community Challenge (LCC) Rating System

Living Building Challenge is the first joint community and occupants' health and wellbeing system established by United States Green Building Council (USGBC) and Canada Green Building Council (CGBC) in 2006. It includes 7 main petals that focus on Water, Energy, Equity, Materials, Health and Happiness, Beauty and Spirit, Place [54]. Even though LCC is a good initiative merging between community design and build rating system with occupants' health and wellbeing rating systems since it links between the overall sustainable infrastructure builds and the day-to-day activities that inhabitants need to maintain for the sustainability carry on of the community; yet it is complicated for investors and stakeholders to implement plus it is relatively of high cost to be embedded [54].

Table 2.2 provides a summary of the main highlights for the previously mentioned occupants' rating systems with a specification of their country of establishment, total number of credits, sections available within the rating system and the cost of registration and fulfillment.

Table 2.2: Occupants' Health and Wellbeing Rating Systems Comparative Analysis

| | Fitwel | Well | LCC |
|---|---|---|---|
| Established By | US Centers for Disease Control and Prevention (US CDC) | IWBI | USGBC and Canada Green Building Council |
| Date of Establishment | 2016 | 2014 | 2006 |
| Max. number of credits | 110 | 100 | 22+ |
| Levels of Certification | (90-104 points- Single Star), (105-124 points- Two Star), (125- 144 points- Three Star) | Silver (50), Gold (60), Platinum (80) | |
| Categories | Air, Water, Community, Movement, Materials | Air, Water, Light, Community, Thermal Comfort, Mind, Nourishment, Movement, Sound, Materials | Water, Energy, Equity, Materials, Health and Happiness, Beauty and Spirit, Place |
| Application Cost (registration, precertification, and certification) | ($500- Registration), ($5,500- $10,000 Certification) | ($1,500- $10,000) based on the project size. Usually it is ($0.42- $0.58/ square foot) | $6,000 for single family resident or depending on square footage from 0 – 750,00 can cost from $0.110 till $0.19 per square footage |

## 2.6: Net Zero Concept

### 2.6.1: What is a Net Zero Approach?

A net zero approach is a strategy ensuring cutting emissions to as close as possible to a theoretical zero value. It is a balance of resources usage since any built environment or community relies on materials, natural scarce resources, water, GHG emissions, electricity, and energy; hence, any newly built or to be modified community causes a pressure on the surrounding environment. Thus, a net zero concept reflects balance of sum between inputs of resources and output produced for a sustainable development and production. Net Zero concept has always been utilized under the energy sector yet with the climate change effect from all the human activities, thus net zero concept has been the focus under different sections like water, waste, and pollution [55].

### 2.6.2: Net Zero concept embedded with SDGs and Community and Occupants' rating systems

Since net zero is getting more attention and it became the goal statement of COP26 approaching net zero by mid-century while keeping climate change at a 1.5 degree Celsius [56]; under SDG goal 13 for climate change, there is an objective of reaching net zero concept under different pillars by 2050 since every activity again impacts climate change. And since the community and occupants' rating systems are an inspiration driven to abide to SDGs; LEED rating system issued a LEED ZERO, LEED Zero Energy, LEED Zero Water, LEED Zero Waste and LEED Zero Carbon, complimentary rating system that is highly recommended for investors to use in addition to their community rating system. Tarsheed community rating system has also considered net zero concept implemented in the design process providing solutions for different infrastructure types within the community. Lastly, Estidama Pearl on the contrary didn't yet include a net zero concept link within its rating system during the latest version however, the UAE government has a national initiative of approaching net zero carbon by 2050 [57].

### 2.6.3: Net Positive

Net Positive approach is an additional step on the net zero where it ensures producing more than what is consumed to refill back to the environment. This is majorly focused with net zero energy where the energy output outweighs the energy consumed leading to a positive balance in storage. Even though it has been in consideration since 2013 in several climate change and environmental forums however, it is not yet for a focus since the world is still on the roadmap trying to approach a net zero concept for starters [58].

### 2.6.4: Net Zero Water focus area

Even though there are several focus areas for the net zero approach to be applied in and none of them is of least importance than any other; yet since water is getting scarcer with the rise of population, high reliance on water in all the industries and the improper use of water in all the activities is leading to abusing a naturally existing resources leading to scarcity. Statistics show than around 10 billion tons of fresh water is used annually globally through organizations, households, irrigation and agriculture and others; while the average person uses 5 L of water to drink yet with a total of around 100 – 175 gallons of water consumed daily per person in other uses [59]. Water is very important for human survival, nevertheless for every organization and daily use. Hence, optimizing the use of natural fresh water is essential while working on treating used water will support in applying a net zero water approach for sustainable communities.

## 2.7: Greywater

As defined by the UN, “Water is at the core of sustainable development and is critical for socio- economic development, energy and food production, healthy ecosystems and for human survival itself. Water is also at the heart of adaptation to climate change, serving as the crucial link between society and the environment" [60]. And as known, the human body is composed of approximately 60% water with the bigger composition is in the heart, brain, and lungs; this shows how much Water value is high for human survival, communities' survival, and economic survival. Yet, with Earth being covered by approximately 70% water; still Water is becoming a scarce resource not sufficient for the 8 billion population on it, and it is being further impacted with the fast population growth rates and high urbanization levels adding more pressure directly on daily water needs and indirectly on industries and businesses that all rely indirectly on water supply.

To date, around 27.5% of the total population globally are facing lack of drinking water access, around 297,000 children passed away annually due to lack of clean, sanitized water access for drinking [61]. To add to that, a lot of natural disasters are related to water distress like floods which account for 47% of natural disasters occurrence and 5% for drought as shown in figure 2.10 [62]. To add to that, 80% of the wastewater gets back into the ecosystem untreated [62] [63]; hence increasing the risk of lack of hygiene and sanitation while reflecting sustainability commitment to the environment or the upcoming generations.

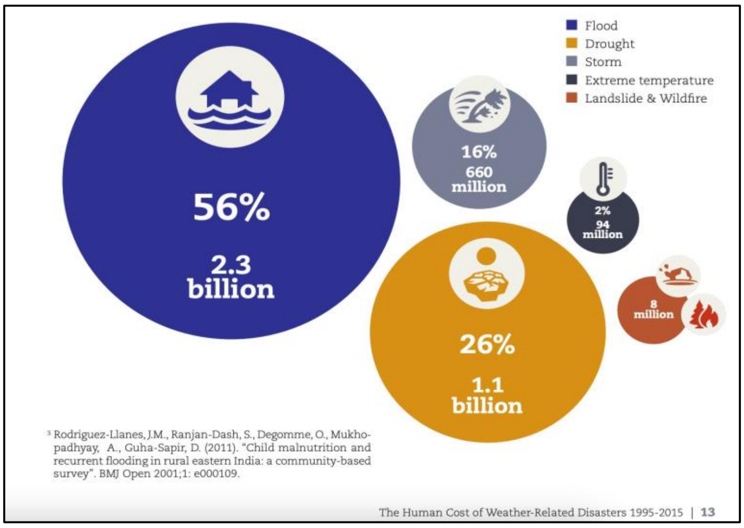


Figure 2.10: Natural Disasters Effect on Water Stress [62]

### 2.7.1: Greywater Definition and Global Problem Statement

In the light of water scarcity and the urge to treat wastewater, several wastewater treatment methods like physical, chemical, and biological have been introduced over time. This evolution in treatment processes has been positively impacting human health, the surrounding environment, and the full ecosystem. Knowing that wastewater is usually segregated based on the origin of use, use examples, the quantity, where is it coming from meaning industrial or domestic and is it from showers and sinks or toilet flushing? All these points fall into account when looking at any wastewater treatment method, application, and durability. Until the 19th century, wastewater was not a point of focus since the impact was not big enough or noticeable as nowadays. Several dams and aqueducts have been constructed throughout history trying to save water and transport it to other areas along the globe; however, the water management and treatment engineering perspective itself wasn’t taken into consideration thus sustainability measures weren't studied [63].

When studying wastewater treatment (WWT) methods, one is usually concerned about the treatment method rather than the origin of presence or the history of evolution. WWT is divided into three main treatment methods divisions including biological treatment, chemical treatment and physical treatment that can be used separately or jointly to meet the purpose of WWT use and can even be used in preliminary treatment focused majorly for protecting the WWT plant through removing any materials that can block or break the pumps, pipes or any others like screening or grits [64], primary treatment aiming at reducing BOD and TSS in the wastewater sample; this can be achieved through sedimentation process. Secondary treatment aiming at removing further organic matters includes leveraging the usage of the item’s bacteria in its activated sludge to remove organic matter and it is known to treat water by almost 85% through aerobic and bio filtration options [64] [65]. These methods can be used separately or mixed at by then they are identified as tertiary treatment methods aiming at further enhancing the parameters for the purpose of water reuse [66] [67].

With the broad range of treatment categories and technologies included underneath, Wastewater is further divided based on its specifications into Blackwater and Greywater which includes light Greywater and heavy Greywater. Blackwater is the water coming from bathrooms and toilets mainly including fecal coliform (FC) [68]; while Greywater is the remaining water produced from a household including bathroom sinks, bathroom showers, bathroom floors and kitchen sinks. Even though kitchen sinks and dishwashers are considered by some sources to be Blackwater due to the high level of organics and bacteria in them, some references refer to them as heavy greywater since they do not include fecal coliform like the actual definition of Blackwater; while light Greywater is that produced from bathroom showers and sinks containing low pathogens, fats, oils, and grease.

Greywater contributes to 50% to 80% produced only from households and it is known to be higher in urban areas vs rural zones [69], so with the evolution of treatment methods along with the water crisis hitting the world with the rise in population and urbanization rates, Greywater treatment is getting more attention and in need. Tables 2.3 and 2.4 below [69] show a brief comparison in parameters range for Greywater and Blackwater along some countries; Egypt however does not have official publications with similar parameters however the ecosystem conditions and usage in Egypt can be compared with Oman and Australia as a reference. The main objective for treating Greywater is to meet the usage parameters mentioned by the Egyptian Code for Wastewater Treatment in Irrigation.

Table 2.3: GW characteristics across different countries

| Parameters | Unites | Australia(1) | Taiwan(2) | Korea(3) | France(4) | Germany(5) | UK(6) | Spain(7) | Morocco(8) | Oman(9) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | bath | shower | Floor cleaning | Bath+ shower | Bath+ shower | Bath+ shower+washbasin | Bath+ shower+washbasin | shower | shower+ washbasin |
| pH | | 6.4-8.1 | 6.5-7.5 | 7.27 | 7.58 | | 6.6-7.3 | 6.8-7.6 | 7.6 | 7.1-7.4 |
| EC | $\mu S\ cm^{-1}$ | 82-250 | | 194 | 468 | | | 921 | 645-855 | 14-15 |
| Turbidity | NTU | 60-240 | 43.1 | 12.6 | 150 | | 35-42 | 20-38.8 | 29 | 133-375 |
| TSS | $mg\ L^{-1}$ | 48-120 | 29 | | 125 | | 29 | 32.2-44 | | 353-505 |
| $NO_3^-$ | $mg\ L^{-1}$ | <0.05-0.2 | | | | | 3.9-7.5 | | 0 | 10.2-28.7 |
| Ammonia($NH_3/NH_4^+$) | $mg\ L^{-1}$ | <0.1-15 | 0.146 | | | | 0.7-1 | | 6.6-11.8 | |
| Total Kjeldahl nitrogen (TKN) | $mg\ L^{-1}$ | 4.6-20 | | | | | | | 11.9-15.2 | |
| Total nitrogen (TN) | $mg\ L^{-1}$ | | | | 9.5 | 5-10 | 7.6-16.4 | 4.1-11.4 | | |
| Phosphate ($PO4^{3-}$) | $mg\ L^{-1}$ | | | | | | 0.5-1.3 | | 1 | |
| Total phosphorus (TP) | $mg\ L^{-1}$ | 0.11-1.8 | | | 0.42 | 0.2-0.6 | | | 0.98-1.6 | |
| $BOD_5$ | $mg\ L^{-1}$ | 76-200 | 23 | | 240 | 50-300 | 20-166 | | 53-59 | 42.1-130 |
| COD | $mg\ L^{-1}$ | | 55 | | 399 | 100-633 | 86-575 | 72.7-171 | 109-122 | 58-294.3 |
| TOC | $mg\ L^{-1}$ | | | | 50.6 | 26-95 | 12-56 | 41-58 | | 70.2-83.5 |
| Surfactant | $mg\ L^{-1}$ | | | | 6.8 | | | | | 14.9-41.9 |
| Total coliform | CFU /100mL | 500 to $2.4\times10^7$ | | 0 | | 10 to $1.0\times10^3$ | 4.0 105 | | | >200.5 |
| faecal coliform | CFU /100mL | 170 to $3.3\times10^3$ | | | $3.42\times10^5$ | 0.1-10 | | | $1.4\times10^3$ to $2.48\times10^5$ | |
| Escherichia coli | CFU /100mL | 79 to $2.4\times10^3$ | $5.1\times10^3$ | | $4.76\times10^5$ | | | | | >200.5 |

References:*Boyjoo *et al.* (2013) and the detailed references in Boyjoo's study were (1) Christova-Boal *et al.* (1996); (2) (Lin *et al.*, 2005); (3) (Kim *et al.*, 2007);(4) (Chaillou *et al.*, 2011); (5) (Nolde, 2000);(6) (Pidou *et al.*, 2007) and(Winward *et al.*, 2008); (7)(March *et al.*, 2004); (8)(Merz *et al.*, 2007); (9)(Prathapar *et al.*, 2005).

Table 2.4: Black Water Characteristics across different countries

| Parameters | Unites | Australia[1] | Japan[2] | Korea[3] | India[4] | Brazil[5] | Germany[6] | Turkey[7] | Jordan[8] | Oman[9] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | laundry | kitchen | kitchen +shower | Mixed | Mixed | Mixed | Mixed | Mixed | laundry |
| pH | | 9.3-10 | | | 7.3-8.1 | | 6.9-8.1 | 7.1-7.2 | 6.35 | 8.3 |
| EC | µS $cm^{-1}$ | 190-1400 | | | 489-550 | | | 401-495 | 1830 | |
| Turbidity | NTU | 50-210 | | 19-84.8 | 20.6-38.7 | 254 | | | | 444 |
| TSS | mg $L^{-1}$ | 88-250 | 105 | 30-130 | 12-17.6 | 120 | | 48-54 | 168 | 315 |
| $NO_3^-$ | mg $L^{-1}$ | 0.1-0.31 | | | 0.5-0.63 | 0.05 | | 0.13-1.3 | | 25.8 |
| Ammonia($NH_3/NH_4^+$) | mg $L^{-1}$ | <0.1-1.9 | | | | 2.4 | | 1.2-1.3 | 75 | |
| Total Kjeldahl nitrogen (TKN) | mg $L^{-1}$ | 1.0-40 | | | | | 27.2 | 7.6-9 | 128 | |
| Total nitrogen (TN) | mg $L^{-1}$ | | 21 | | 42.8-57.7 | 8.8 | 9.7-16.6 | | | |
| Phosphate ($PO4^{3-}$) | mg $L^{-1}$ | | | | 1.52-3.36 | 5.6 | 9.8 | | | |
| Total phosphorus (TP) | mg $L^{-1}$ | 0.062-42 | 4 | | | | 5.2-9.6 | 7.2-7.3 | 19.5 | |

### 2.7.2: Treated Greywater Guidelines

Following existing greywater guidelines after treatment is essential to ensure that whichever treatment technology used is meeting global and local recommended and needed criteria based on the water utilization trend in the country. The greywater treatment guidelines vary from one country to another based on conditions and resources of use [70]; however, upon comparison it is seen that the parameters of study post greywater treatment are almost the same and the expected acceptable range for each parameter falls in a similar range of number as shown in table 2.5. In this table references for both wastewater treatment parameters like in Egypt, UAE, South Africa (SA), California and Australia are presented as the concept of having dedicated greywater treatment codes is not that common in all countries for as long as the treated wastewater or greywater meets the assigned code of use parameters. However, WHO has a section on the permittable limits for greywater reuse based on the purpose (WHO,2006) in addition to that, some country levels established greywater treatment codes were established like in KSA and Jordan. The parameters of consideration under this study's scope are Turbidity, TSS (mg/l), COD (mg/l), BOD-5 (mg/l), pH and E. Coli.

The reference of parameters in acceptable range that is relied on for this study is based on the Egyptian code of practice- Category A as shown in table 2.6.

Table 2.6: Global and Organizations Codes for Treated Greywater to be used in Irrigation, Toilet Flushing, and Firefighting Systems

| Country (year) | TSS | PH | BOD5 | COD | E. Coli | Turbidity | Nematode | TC |
|---|---|---|---|---|---|---|---|---|
| Egypt (2015) | 15 | - | 15 | - | 20 per 100 ml | 5 | 1 per L | - |
| KSA (2008) | 10 mg/l | 6 - 8.4 | 10 | 50 mg/l | 2.2 per 100 ml | - | - | - |
| UAE (2016) | <50 | <7 | - | - | - | - | - | - |
| South Australia (2013) | <30 mg/l | - | <20 mg/l | - | <10 org per 100 ml | - | - | - |
| Victoria Australia (2013) | <30 | - | <20 | - | <10 cfu per 100 ml | - | - | - |
| Western Australia (2010) | <10 | - | <10 | - | <1 per 100 ml | - | - | - |
| Amman, Jordan (2020) | 30 - 50 mg/l | - | 30 mg/l | 100 | 100 per 100 ml3 | - | - | - |
| WHO (2006) | < 10 | - | < 10 | - | - | - | - | < 10 |
| EPA (2012) | - | 6.5 - 8.4 | | - | - | - | - | <2.2 cfu/100 ml |
| California (2016) | 30 mg/l | 6.0 - 9 | 30 mg/l | - | - | - | - | - |

Table 2.5: Egyptian Code of practice for reusing treated wastewater in irrigation (Code 501/2015)

| Acceptable Treatment Grade | Parameter | Category: A – Landscape Irrigation |
|---|---|---|
| Acceptable Range for Chemical Parameters | TSS (mg/L) | 15 |
| | Turbidity (NTU) | 5 |
| | BOD-5 (mg/L) | 15 |
| Acceptable Range for Biological Parameters | E. Coli (1/100 mL) | 20 |
| | Intestinal Nematodes (1/1 L) | 1 |

## 2.8: Greywater treatment methods

Several methods have been defined over decades for greywater treatment to meet the main purpose; some of those treatment methods can be used alone of small-scale water capacity and minimum water reuse reliance but in most cases globally the methods are applied on a bigger design scale to be able to treat a whole building or cluster of buildings water for toilet flushing or green landscape irrigation. Table 2.7 briefly highlights the difference between the treatment methods known as physical wastewater treatment method, chemical wastewater treatment method, biological wastewater treatment method and natural wastewater treatment method; specifying the differences between each of them, the pros and the cons of each usage and reliance.

Table 2.7: Greywater Treatment Methods Comparison

| | Physical [76] [77] | Chemical [72] [75] | Biological [72] | Natural [73] [74] |
|---|---|---|---|---|
| Definition | Type of treatment that focuses more on filtration methods or gravity treatment like sedimentation | Treatment of wastewater by infusing a chemical (like chlorine or hydrogen peroxide) that expedite the disinfection and killing of any organisms | Type of treatment that relies on bacteria and microbes to breakdown the waste matters included and treat the wastewater | Ecological self-treatment systems that ensure ecosystem balance relying on natural factors like sunlight and temperature. They are considered as a biological treatment division. |
| Examples | Sand Filters<br>Activated Carbon Filters<br>Membrane Filters | Coagulation<br>Chlorination<br>UV Disinfection | Rotating Biological Contactor (RBC)<br>Sequencing Batch Reactor (SBR) | Stabilization ponds, wetland, aquatic plants |
| Pros | Partially removing organics, particulate pollutants, nitrogen, and phosphorus nutrients.<br>Also, it reduces the risk of damage for the next treatment phase as it removes any solids mixed in the wastewater used | Faster disinfection process when compared to other solutions, might produce high amounts of sludge which ensures effective wastewater treatment. The chemicals used are mostly available and not expensive in cost. Sometimes lesser treatment exposure time is | Effective, cost efficient when compared to mechanical systems and it is the optimal option for organics removal | More cost effective and efficient based on the primary treatment method used, also easy to install and in some used it is used as a decorative treatment method with good look |

| | | | | |
|---|---|---|---|---|
| | | used like in the UV treatment stage. | | |
| Cons | Inefficient total suspended solids removal.<br><br>Requires longer time for treatment.<br><br>Doesn't remove any organic matters or kill any bacteria or pathogens | The addition of a chemical needs or acids for pH adjustment there is a need to be counteracted by a removal stage. With the high amounts of sludge produced, toxicity levels and volumes need to be considered when disposed. Electricity might be used like in the Ion Exchange or Electrochemical coagulation, hence more cost. Sometimes not all pathogens or microorganisms are removed like in the chlorine treatment and even if TSS is high some can be ineffective like UV. | Preferred to be used after a sedimentation tank.<br><br>High levels of sludge are produced with aerobic treatment. | Preferred to be used as a secondary treatment specially in domestic post-treatment usages.<br><br>Needs maintenance as the plants can populate fast and can be seasonably reliable based on the plants used. |

Since the focus of study of this paper is to integrate commonly used and more applicable biological treatment method of slow sand filter with the uncommonly integrated and used natural treatment using aquatic plants. Hence the following sections will review deeper both treatment methods with a highlight on the needed design criteria and parameters supporting in the experimental chapter work of this dissertation.

Since the focus of study in this research is to integrate between a slow sand filter and water hyacinth plants; hence sections 2.8.1, 2.8.2 and 2.8.3 elaborate more on these treatments.

### 2.8.1: Biological Greywater Treatment

As the name refers, biological treatment methods rely on micro-organisms that through biological treatment and aerobic processes treat or clean the greywater passing through. They are comparatively cost effective and easy to apply on several scales treatment system is the sand filter.

### 2.8.2: Physical Treatment Process

The physical treatment reflects the use of a physical component that supports in the initial screening of the influent wastewater. This physical treatment can include mesh screens like that used in the case study of Madinaty presented in the dissertation; another example of physical treatment is the sedimentation tank which allows, by the effect of gravity and low flow rate, large suspended particles to settle and hence initially purifying the influent wastewater. Lastly, the sand filter which is a combination example of physical and biological.

### 2.8.3: Natural Treatment Process

Natural treatment processes are considered a biological treatment method relying on naturally existing plants for final treatment stages, they usually do not require high energy levels, mechanical parts or electrical equipment to operate.

Table 2.8 presents a comparison between several natural treatment plants based on literature for wastewater treatment that are taken into study consideration for the experimental aquatic plant selection. In the table, the main characteristics are highlighted with the advantages and disadvantages for each type's use. Lastly, the effect on using a relevant plant type for wastewater treatment is stated based on the sources of reference.

Table 2.8: Natural Treatment Plants

| Aquatic Plant | Water Hyacinth [84] [85] | Papyrus Reed [86] [87] | Common Reed [88] [89] | Duckweed [90] [91] | Water Iris [92] [93] | Water Lettuce [94] [95] |
|---|---|---|---|---|---|---|
| Origin | Native to South America | Nile Delta, Egypt | Europe | Western Northern America | Europe and Western Asia | Africa, Nile River |
| Characte r-istics | Floating Plants with spongy feel leaves, dark purple feathered like roots, produce light purple flower | Long plants with feathery heads or leaves | Long and stiff stem | Flat ovoid shaped leaf, more fibrous roots and little fibers leaves when compared to others. Mostly found in waterless deserts, tropical areas and can within stand temperature s extremes. | Average height 3 stemmed green plants with a royal blue seasonal flower | Floating Plants with overlappin g light green leaves |
| Waste-water Treatm-ent Edge | High level of Algae, BOD, SS, Organic Matter and Nitrogen removal and reduces turbidity | Reduces COD and BOD | Digests wastewater pollutants and reduces TSS | Removes high amounts of organic matters | Removes high rates of toxins and metals | Removes heavy metals and other pollutants |
| Pros | Found in big quantities, not seasonal based. Can | Easy to manage | Non-invasive plant. Can spread fast through | Purifies wastewater mainly via bacteria, reducing O2 | Low maintenan ce and easy to grow if | Reduces algae, grows into heads of lettuce and |

| | | | | | | |
|---|---|---|---|---|---|---|
| | be used as an animal fertilizer and can be processed as a compost due to its high N, P and K levels.<br>Gets acquainted to the surrounding environment fast. | | its seed when in the proper environm-ent. | levels in water and converting nitrogen and phosphorus into protein | it's not your native plant | sometimes can be used as an aquatic fish tanks natural filter |
| Cons | Increase massively in few weeks and if not properly biodegraded, they can cause soil toxicity and disturb groundwater.<br>These plants use a huge amount of water hence they need proper maintenance/ extraction to equalize the ecosystem | Invasive plant, fragile and dries fast. | Dominant species to an extent that they can eliminate any native plants or habitat. They have very dense roots can cause clogging for fish moving. | Can deoxygenate the water when grown blocking out any sunlight. Needs manual labor or mechanical equipment to extract and maintain. | Invasive Plant, doesn't look good and can produce odors | High propagation rate/Spreads fast and hard to maintain |

## 2.9: Sand Filters Definition and Types

It is a purification process relying on a porous medium that is used for groundwater treatment post human use. It is a biological and physical treatment method relying on schmutzdecke layer consisting of a huge number of micro-organisms formed by time on the top sand layer acting aerobically on breaking the organic matters, pathogens, viruses, and impurities; hence cleansing the greywater. Sand Filter is segmented under Slow Sand Filter (SSF) vs Rapid Sand Filter (RSF) as highlighted in table 2.9.

Why specifically is sand used in the sand filters? It is because of its features including silica material, durable, global availability under several grades and sizes while also being cheaper in cost and easier in maintenance and cleaning when compared to other materials and technologies.

Table 2.9: Slow Sand Filters vs Rapid Sand Filters

| | Slow Sand Filter (SSF) [82] [83] | Rapid Sand Filter (RSF) [82] [83] |
|---|---|---|
| Definition | Types of sand filtration used for water purification/ treating wastewater for reuse in irrigation | |
| Preferred ROF | 100-200 L/hr/$m^2$ | 3000-6000 L/hr/$m^2$ |
| Features | Removes mainly small to medium suspended particles by biological treatment | Removes mainly large, suspended particles by physical processes. |
| | Schmutzdecke layer (10-20 mm on top of the sand layer) is the main thin layer for cleaning and treatment | Cleaning required backwash |
| | Cleaning can be done every 3 months | Cleaning is recommended to be held every 3 days- depending on the use |
| | No need for highly skilled maintenance personnel | A need for highly skilled maintenance personnel |
| | Ease of cleaning by periodical removal of the top Schmutzdecke layer with the scrapping of the top layer of the sand itself | Harder to clean, as specific backwashing methods are needed for better operation |

| | | |
|---|---|---|
| | More efficient for bacterial removal | More efficient for color and turbidity enhancement and removal |
| | Sand Grain Size is distributed uniformly across the sand filter | Sand Grain Size is non-uniformly distributed across the sand filter with coarse sand at the bottom and fine on top |
| | Filter Head is recommended to be from 15-75 cm | Filter Head is from 2-4 m high |
| Recommendations | WHO suggests keeping the ROF at 0.1-0.2 $m^3/m^2/$ $bed$ area/hour [81] | |
| | As per WHO, the expected treated greywater output shall be free from organic matter with +99% removal of bacteria, <10NTU turbidity level. In this experimental work, The Egyptian code for wastewater treatment for reuse in irrigation is used as a reference of output parameters [81] | |
| Limitations | SSF require **big space** for installation and initially high sand bed depth. Also, if the greywater influent criteria massively change during operation, this can impact the performance especially with high turbidity that can occur during rainy seasons. | Post-treatment disinfection is a must.<br>Higher cost of operation. |
| Pros | Pros for urban areas in developing countries<br>Easy to install with locally present materials.<br>No special equipment is needed.<br>Ease of maintenance, no specific skill is required for operation and maintenance.<br>Doesn't require backwashing unlike RSF. | Requires Smaller space to setup and operate, unlike SSF. |

| | | |
|---|---|---|
| | No specific power supply for operation is needed unless for a pump-to-pump water into the Sand Filter<br>When the Schmuztdecke layer resistance increases and the ROF starts to decrease, it is time for cleaning the filter by removing the layer using flat shovels.<br>WHO projects the need to re-sand the SSF after 3-4 years of operation or 20-30 times of the schmuztdecke layer shoveling.<br>It is also recommended to add the new sand levels under ±0.4 m of the old sand filter | |

**2.10: Sand Filters Mixing Materials**

Several sand filter research and studies were conducted assessing its efficiency using several packing materials and ingredients mixed in ratios with the sand. A study compared mixing charcoal or sponge foam polyurethane foam or ceramic for enhanced agricultural drain treatment effluent [78] resulted in high pollutants removal, COD and TSS levels with the sand mixed with sponge at a ratio of (1:0.35) operating at a ROF of 2 m3/m2/d. Another study studied the mix of sand with phosphorus adsorbing biotite layer; and it showed enhanced results in microbes and nutrients removal with low nitrates and phosphorus concentrations [79]. A third study included sand layer mixed with carbonized rubber wood sawdust on top of another sand bed layer focused on treating wastewater contaminated with high levels of carbon [80]. The results of these studies reflect efficient treatment with high removals of turbidity, TSS and organic matters in addition to other contaminants in the influent wastewater.

Several other studies were focused on exploring the needed sand mixes with other materials to better treat wastewater for reuse based on the need; however, few recent papers focused on treating greywater for domestic reuse. And that is a gap of study considered in this paper however, the sand filter used in studying of this experiment contains no additional mixes with the sand granules and sand bed; yet it showed the needed enhanced results of treatment as mentioned later in the results and analysis section.

**2.11: Slow Sand Filter Design Considerations**

A SSF starts with a supernatant water head added on top of the sand level in the filter. The water head can vary from one design to another, but it is recommended to be from 1-1.5m above sand level in real life applications. This water level supports in adding up head pressure for water treatment plus it acts as a reservoir holding a bigger amount of water for treatment on the same system [81].

In addition to that, the water head supports in creating detention time which allows more organic matters to settle and hence have better treatment. In the proposed used experimental design, a pre-settling stage is used to further support in the matters settling and enhancing the water treatment quality by placing a sedimentation tank pre-the sand filters. This supports as a minor pretreatment stage reducing the sludge amount getting into the sand filter for treatment and hence enhancing the treated water quality [81].

On top of this water reservoir there is an overflow nozzle which allows further extra water to fall out of the system getting back into the main greywater to be treated as a collection bucket, if designed as such on the community. Then there is the sand bed which its depth varies from one design application to another however, it is recommended by WHO to have the sand bed around 0.6m depth [81].

The final layer is the coarse gravel underdrain layer (suggested by the WHO to be from 0.4-0.7mm) and it acts as an unobstructed pathway for the final treated water collection; while it also prevents the sand from getting carried away out of the sand filter system due to its small size. If the oxygen level gets $<0.5$ mg/l, pre-aeration or pre-sedimentation of water can be used to increase the oxygen level in the greywater to be treated. Algae produced inside the sand filter during the operation are actively working during morning time by using more sunlight and hence the output effluent water will include less oxygen levels than at nighttime sample collection [81].

### 2.12: How a Slow Sand Filter works

Supernatant water is being poured into the watertight top of the sand filter, with gravity, the bigger particles will settle faster on the sand top layer. The formation of the Schmuztdecke layer is taking place with algae and bacteria forming on the sand top layer with the presence of sunlight too; this supports their growth and hence consuming oxygen and treating the organic matter in the water through biological activity. A supernatant water head is essential to have on top of the sand filter bed and that is why in the design of the sand filter, WHO recommends including a depth of range 1 – 1.5m of supernatant water layer; yet, in this dissertation experiment a 65cm is used with a freeboard on top level 0f ±0.4cm with an overflow nozzle. The main purposes of this supernatant head are first to act as a sedimentation tank or a reservoir on top of the sand bed adding more greywater for treatment while also creating a pressure head of water that is needed to push the water through the closely intact sand particles within the sand filter medium; this supernatant water level should be kept constant across the treatment process. Lastly, a detention time is created further supporting the greywater to settle, for its organic matters to be trapped on top of the sand bed.

The greywater purification process in the sand filter primarily starts with the supernatant water level on top of the sand bed where the larger organic matters start to settle first on top of the sand surface. Since the sand filter is open from its top level hence allowing air and sunlight to pass through and incentivizing algae growth which will start producing oxygen inside the sand filter. On the schmuztdecke layer with micro-organisms, it contains the algae, planktons and other bacterium types that use the produced oxygen in their biological activities to break down the organic matters and feeding on the impurities present in the greywater [81].

As the supernatant water applies pressure head, the greywater is pushed down through the sand filter bed in several directions allowing more frictional intact with the sand particles which by time become covered with impurities from the passing water. As the water passes through the sand bed, a lot of sand particles get covered with organic matter sticky surfaces getting intact leading to further cleaning. The biological treatment activity decreased gradually along the sand bed depth and that is due to the purification of water by then with less impurities. The depth of the sand bed reflects how deep the groundwater treatment can be however, in the experiment of this dissertation a 65cm depth sand bed is used. And then the final bottom treatment step in the sand filter is for the gravel layer which traps any final missed out particles from the groundwater [81].

**2.13: Recommendations to take into consideration pre-developing the system**

Sand sieve analysis is needed because it is hard to find the exact needed sand size to use. Proper sand washing and drying is highly needed to remove any already existing organic matters or clay that will impact the effectiveness of treatment. In this experiment, sand was washed for several rounds under clean water tabs, and it was collected and left to dry for days in a closed chamber [81].

To avoid blockage of the sand filter and depending on the to-be-treated greywater, a pretreatment stage should be used named Sedimentation Tank, which is applied in this dissertation’s experiment, to primarily support in settling the organic matters and enhancing the quality of the greywater getting into the sand filter that shall be compiled in the supernatant water reservoir on top of the sand bed [81].

For durability, the Schmuztdecke layer is 10-20mm at the top of the sand bed and it needs to be removed regularly based on the application. However, WHO recommends providing the sand filter bed with a 1 m thick layer additional to avoid refilling the sand filter more than once every year and hence, ensuring cost effectiveness. WHO suggests that in the situations of using several gravel sizes for application, the coarse gravel size shall be at the bottom of the sand filter with gravel size reduction as it commences in layers to the top [81].

### 2.14: Devices to include for smart integration or lessen human interactions

Flow rate measurement device for the effluent flow water out of the system to avoid overfilling or under filling causing negative pressure into the system, the supernatant water into the system; hence, affecting the water treatment quality. Backfilling the SF with clean water post any treatment step as advised by the WHO [81].

Valves and flow meters before and after the sedimentation tank allow supernatant water to flow into the sand filter at constant rates while shutting down when there are lower water levels than needed. The addition to floaters inside the sedimentation tank can be an essential trigger to the minimum and maximum allowable supernatant water levels triggering the valve opening or closing [81].

### 2.15: Wastewater Treatment Systems for Reuse in Irrigation- Examples in Egypt

#### A: Irrigation System at The American University in Cairo as an Educational Community Example

The American University in Cairo (AUC)- New Cairo campus has a water treatment plant that further treats the initially received treated wastewater collected from the municipality to irrigate 100% of the on-campus landscapes.

AUC water treatment plant relies mainly on a sedimentation collection tank followed by three activated carbon sand filters and finally disinfection stage. The sand filters are of 90cm high and composes of layered mixed size gravel of 3-5mm, 5-10mm and 10-16mm layered on top followed by sand bed of 0.1-0.8mm diameter. The activated carbon is mixed with the sand bed for removal of odors and enhanced wastewater treatment.

The wastewater is collected in a closed top tank of volume 1500$m^3$ usually full with 1200$m^3$ maximum volume of wastewater. The tank is connected to three pipes, each is feeding a separate sand filter as shown in figure 2.11 and 2.12.


Figure 2.11: AUC WWT: Piping and Pumps connection with the Sand Filters for WWT delivery


Figure 2.12: AUC WWT: Step 1: Sand Filters

The final effluent treated wastewater is collected in a second tank of 1500 $m^3$ volume where it holds maximum threshold of treated wastewater of 1200 $m^3$ in volume. Chlorine is added on the effluent treated wastewater resulting in parameters levels of: 7.5 pH, ~7.5 mg/l COD, ~8 mg/l BOD-5, ~1.5 NTU Turbidity and 0.1 mg/l Phosphorus. The chlorine tank is shown in image figure 2.13.

This tank is connected to the piping system linked to the on-campus irrigation sprinklers. For the system maintenance, sand filter backwash is required every 2 months approximately depending on the season and capacity on campus; while for the activated carbon, it can be reactivated again with phosphoric acid or by heating at 550 degrees C or even replaced fully if still the treated wastewater effluent includes odors.

Figure 2.13: AUC WWT: Step 2: Chlorine Disinfection Tank

Figure 2.14 is a schematic summarizing the previously mentioned wastewater treatment stages for better visualization.

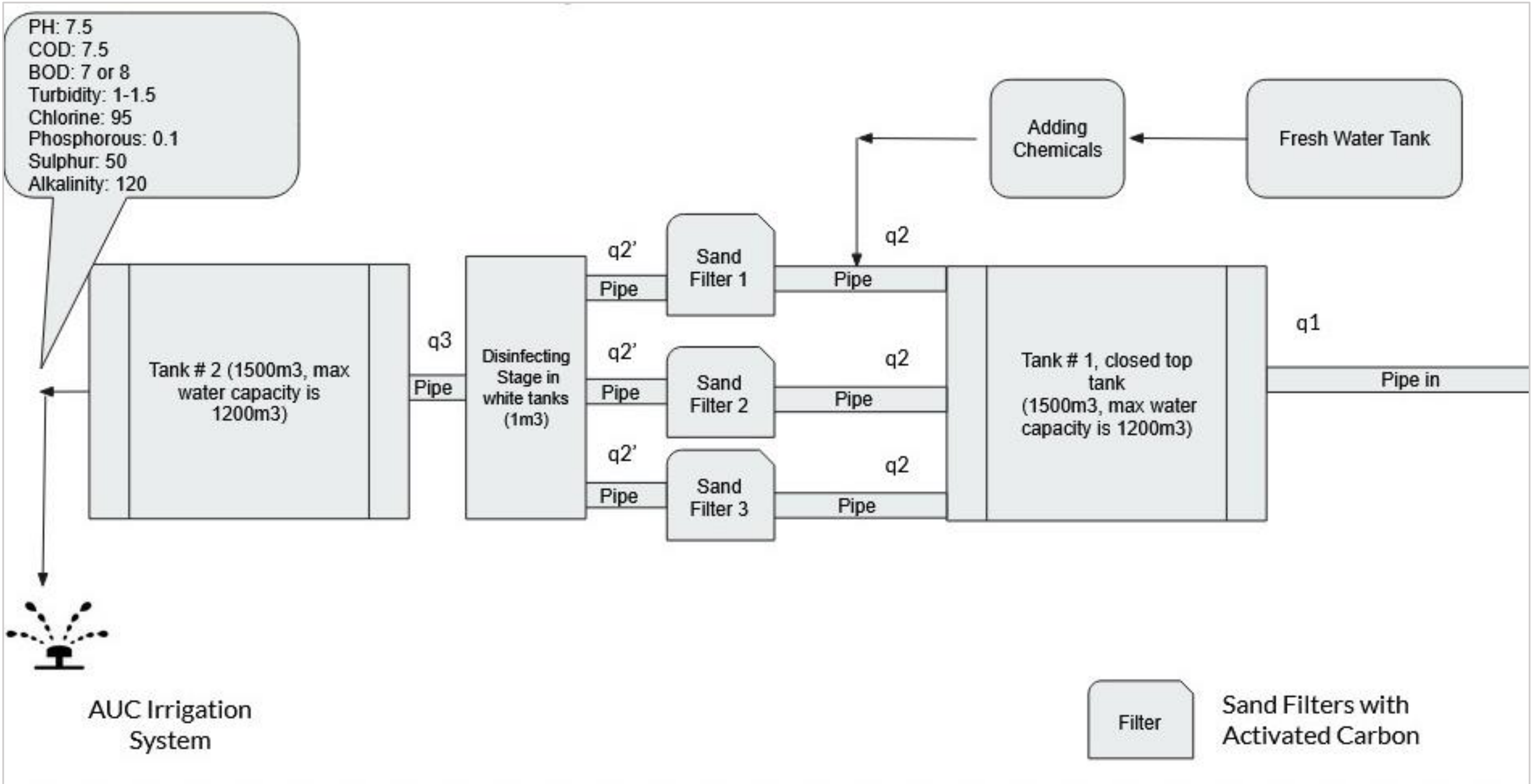



Figure 2.14: AUC WWT: Schematic

**B: Irrigation System at Madinaty as a Residential Community Example**

Madinaty is a high-end gated community with around 550,000 citizens living in different infrastructures from buildings to stand alone villas. Madinaty has an on-community wastewater treatment plant for phases 1 and 2 that supports in treating the generated wastewater from the residents' homes and being treated for reuse in the on-community landscape irrigation. The treatment plants receive around 80,000 $m^3/d$ of wastewater to be treated.

The treatment process in Madinaty includes two main approaches, one is for the wastewater treatment and the second if for the sludge compaction and send-out to landfills. The wastewater treatment includes four main treatment stages in itself starting with mechanical screens that are needed to remove any big objects suspended in the wastewater like cans and bottles for example as shown in figure 2.15.


Figure 2.15: Madinaty WWT: Step 1: Mechanical Screens

The effluent water from the previous step enters a grit narrow chamber, a cross sectional image is shown in figure 2.16, that slow down the flow of the wastewater hence allowing any suspended particles to further settle at the bottom of the chamber. At this step, the treatment parameters reflect ~35% removal of BOD-5 and 60% removal of TSS.


Figure 2.16: Madinaty WWT: Step 2: Grit Removal

The effluent water enters the aeration tanks for the second main wastewater treatment step. In the aeration tank, shown in figure 2.17, air diffusers placed at the bottom of the tanks to increase the oxygen level increasing microbial rates from the entering sludge. These bacteria are important in the biological treatment as they support in breaking down organic matters present in the wastewater. The output parameters of this phase lead to ~98% removal of BOD-5 and ~99% removal of TSS.


Figure 2.17: Madinaty WWT: Step 3: Aeration Tanks

After the aeration step, the wastewater treatment lines are divided into two main treatment stages. One is to continue on the wastewater treatment by going through filtration and disinfection; while the other stage is to treat the sludge produced.

The next of wastewater treatment is the sand filtration step where water levels of around 1.5m are added onto the sand bed for filtration. There is an ultrasonic placed on top of each sand filter to ensure that wastewater levels do not exceed the needed treatment level as shown in figure 2.18. After the sand filter step, the treated wastewater is sent for chlorination by injecting chlorine gas from 0.5 mg/l to maximum of 1 mg/l for disinfection as shown in figure: 2.19. The treatment output parameters at this step ensure that COD level is around 40 mg/l, BOD-5 level is below 10 mg/l and TSS is below 10 mg/l.


Figure 2.18: Madinaty WWT: Step 4: Sand Filter

Figure 2.19: Madinaty WWT: Step 5: Chlorination

For the sludge treatment step, the sludge is collected as shown in figure 2.20 and sent to the decanter centrifuge where the sludge is thickened as shown in figure 2.21. Any wastewater in it is removed and sent along with the wastewater treatment line as shown in figure 2.22 and the thickened sludge is collected to be disposed in the nearest landfill.


Figure 2.18: Madinaty Sludge Treatment: Step 1 – Sludge In


Figure 2.19: Madinaty Sludge Treatment: Step 2 – Decanter

Figure 2.20: Madinaty Sludge Treatment: Step3 - Sludge Compression, Wastewater Out

## 2.16: Community Infrastructure

The proposed community scale in figure 2.23 is an average of existing communities either under construction or those already constructed in Cairo, Egypt. The purpose of this scale proposal is to align on the full proposed treatment process scale with the greywater treatment system of use while also, considering the relative scale for the community and occupants' rating system consideration. The proposed community scale is in the moderate range of the currently existing gated communities within New Cairo, Egypt and 6th of October City, Egypt.

In the conclusion section, the greywater collected for treatment will be a mix from standalone villas, residential buildings and a shopping mall, as shown in figure 2.11. For the open parks and fountains, this will be reflected with the amount of greywater treated to be used partially for irrigation in these attractions and the remaining will be utilized under firefighting system and returned for toiled flushing.

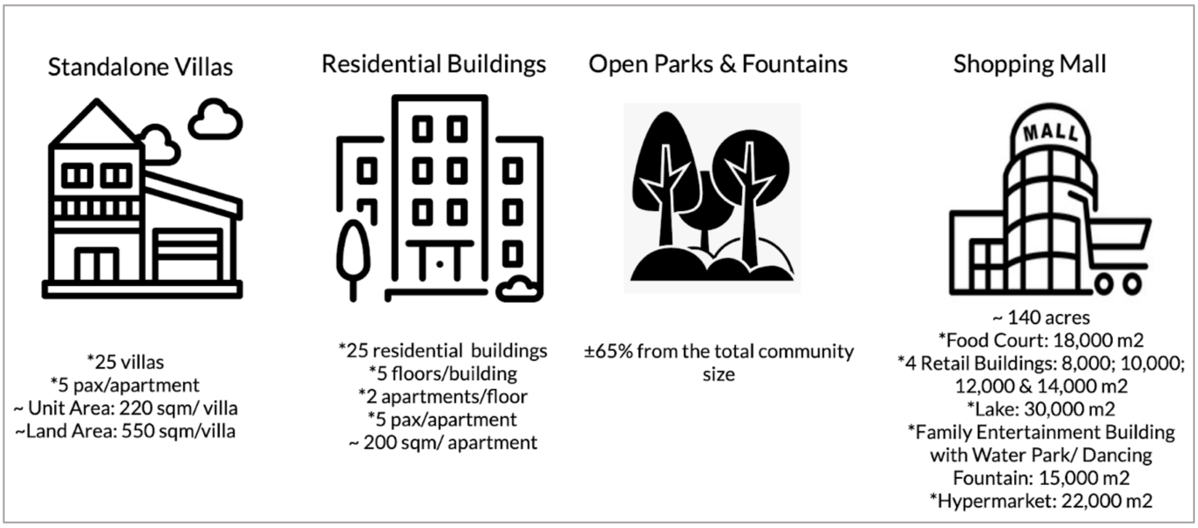



Figure 2.21: Proposed Community Scale

Figure 2.24 represents the optimum proposal for ease of greywater collection and it is a recommendation if affordable to be taken into consideration during the construction phase. The grey lines shown below reflect the greywater piping systems connected to the bathroom sink and shower basin while the black one is that coming from the toilets and kitchen sinks.

It is not recommended to treat water collected from the kitchen sink using the proposed solution as it contains organics, grease, oil and other components that will impact the filtration process and the effluent quality. This also applies even if the kitchen sinks include a grinder like some commonly used nowadays. It is advised to follow other treatment methods that fit better with high organic levels, oil and grease.

So, the greywater is collected as previously mentioned, then it goes to the equalizing tank in the proposed system; which is used to collect greywater from a zone or cluster of buildings and a cluster of villas and equalize the collected water conditions to be more homogenous. That is because greywater specification varies from one person's use to another, from one home to another and even it varies from an hour to the other with the same user. So, it is important to ensure equal conditions with equalized collected greywater.

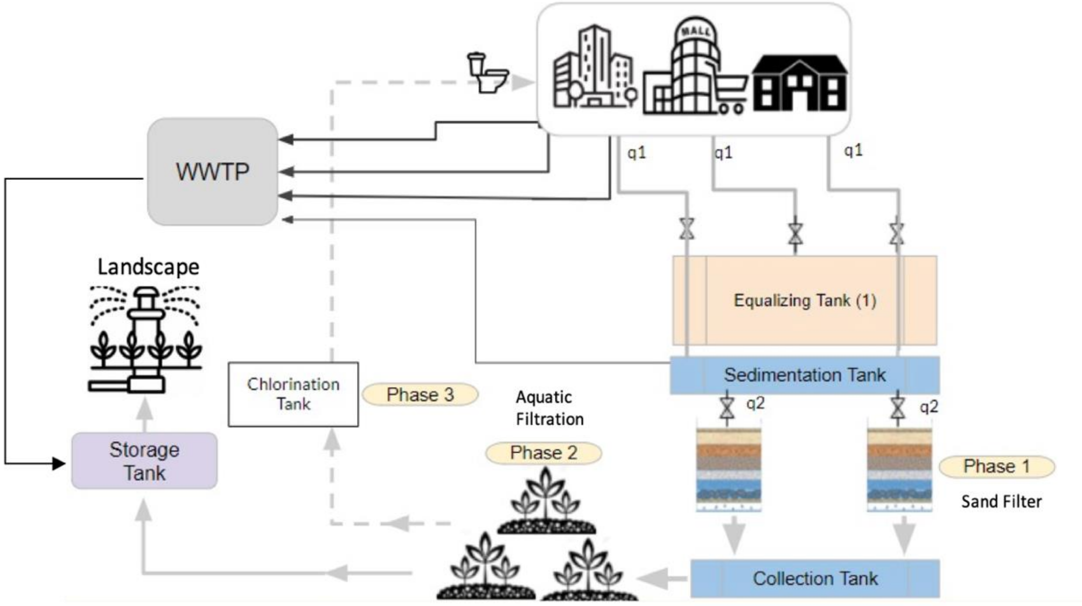



Figure 2.22: Proposed Community Piping System

After the equalizing tank, the greywater will pass to the sedimentation tank which can be considered as a pre-treatment filtration step. The greywater in the sedimentation tank shall be flowing at a low flow rate to avoid any particle disturbance and water turbulence to any existing water in it for as long as the system has been running. The sedimentation tank plays a vital role in ensuring that any suspended matters or organics are settled at the bottom of the tank and this is for better greywater treatment management and more efficient filtration rate.

After that, the greywater will flow to the first treatment phase under the Sand Filter, in-which a similar design constructed in the lab for the experimental scale is mentioned later in this chapter. A proposal of 3 sand filters is to be used but this shall vary based on the community size and the equalizing tank dimensions ensuring continuous flow of water between them even at smaller flow rates during low peak hours; and this can be managed through solenoid valves.

Then the water coming out of the sand filter s will be collected in a collection tank that acts as a bridge storing the semi-treated greywater all together and passing it on to the next treatment phase which is the Aquatic Filtration. In the Aquatic Filtration, plant hyacinth is used due to their massive availability locally, ease of access, low cost, optimum water usage in watering and good greywater treatment as it will be shown in the coming chapters; plus, they propagate quickly increasing the surface area for filtration. Yet, this is a double-sided coin because they need proper cleaning before being used in any water treatment. As these plants are populous in conduits and they contain a lot of bacteria and organic matters. Also, they need proper harvesting when installed in a community for greywater to mitigate their growth and manage their loading rate to be able to reach the desired treated greywater quality as it will be shown later in this chapter.

After the aquatic filtration step the treated greywater can be utilized in any/both proposed solutions. First, it can undergo a third treatment phase named (Chlorination) where chlorine gas or liquid is being used to further disinfect the water and enhance the effluent quality to be able to return to the home piping system for toilet flushing. And/or the other proposed solution is to collect the treated greywater from the aquatic filtration step into a storage tank which is accessible upon need for landscape irrigation systems on-community. For the black lines shown in the figure, it is the wastewater collected through a different piping that goes all the way to the sewage or wastewater treatment plant.

# Chapter 3

# INTEGRATED COMMUNITY AND OCCUPANTS' RATING SYSTEM

As community frameworks are the known guidelines directing investors, engineers, designers, and other stakeholders into building a resilient and sustainable community as ensuring that the built sustainable community still meets the needed sustainability pillars while meeting the occupants' comfort level for a better lifestyle. This is met through few occupants' rating systems that were established in the past decade.

To pave the foundation for proposing an integrated community and occupants' rating system for Egypt, a thorough comparative analysis between the globally commonly used or referred to rating system like LEED-Cities and Communities and, a selected eastern community framework edition like Estidama- Pearl Community along with a local rating system designed for Egypt named Tarsheed-Community are all taken into comparison study highlighting the edge or need versus the gaps in between. The same strategy is followed on the occupants' level rating systems like Fitwel and Well. Lastly, since the concept of integrating a community and occupants' rating system has been recently introduced into the market yet at a higher cost and complexity in application; so, Living Community Challenge (LCC) is taken into the comparative study consideration.

The Methodology of this chapter is:

1. Section by section comparison between community rating systems under Water, Waste, Energy, and others.
2. Section by section comparison between occupants' rating systems under Water, Waste, Materials, Sound, and others.
3. A comparison between living building challenge (LBC) and living community challenge (LCC) is considered. For the LBC, it is studied as an example for a green

certified building highlight as needed in the community related credit certification.

4. A proposed integrated community and occupants; rating system that is an uplift to the existing local community rating system in Egypt – Tarsheed, is proposed under the results and analysis chapter.

### 3.1: Community Rating Systems

#### 3.1.1: LEED-ND, LEED-Cities and Community, LEED-Zero Comparison

The differences between LEED-ND, LEED-Cities and Communities and LEED-ZERO which is a complimentary separate additional rating system that can be considered for application by investors and designers is presented in this section. In this study, LEED-Cities and Communities is considered for the analysis as it is focused on the scope of study for community scale plus it entails more elaborative and inclusive credits under each section unlike LEED-ND.

Table 3.1 represents a comparison between LEED-Neighborhood (LEED-ND) and LEED- Cities and Communities; it is essential to understand the main difference between them for the sake of deciding which rating system of them shall be in further comparison with the other community rating systems of study. As a starter, the difference between a neighborhood and a community is mainly that the neighborhood is a cluster of areas and cities together accommodating larger number of populations from diverse societies however, a community is a cluster of residents living in the same area and sometimes sharing the same standards and economical levels. LEED-Cities and Communities is the main study of community rating system comparison as it is more applicable to the focus of study.

From table 3.1 it is seen that LEED-Cities and Communities is more thorough detailing sections for water, energy, waste, smart technology, mobility, and location. LEED-ND is detailing location, transportation, and green infrastructure; while the water, waste and energy areas are considered as subsections under the main categories; even though both categories have the same number of credits, yet LEED-Cities and Communities is more inclusive to the sections of sustainability implications like Energy, Waste and Water. For example, renewable energy is included under the energy and atmosphere (EA) subsection, Infrastructure Energy Efficiency and Optimize Building Energy Performance are located under the Green Infrastructure and Buildings (GIB) section.

The Water dedicated subsections are focused on Wetland and Water Body Conservations under the Smart Location and Linkage (SLL) section; other indoor and outdoor water use reduction subsections, Rainwater Management and wastewater Management are located under the Green Infrastructure and Buildings (GIB) section. Finally, for the related Wastewater Management and Solid Waste Management, they are located as subsections under the GIB section.

In LEED- Cities and Communities, there is a dedicated and more detailed Water Efficiency (WE) section, Energy and Greenhouse Gas Emissions (EN), Materials and Resources (MR) including solid waste management, waste performance and waste stream management subsections. LEED-Cities and Communities is more thorough providing detailed credits alternatives under different sections and hence, facilitating the investors and designers' options of credits they are able to consider and apply within their community.

Table 3.1: LEED Rating Systems Comparison

| LEED- ND | | | LEED- Cities and Communities | |
|---|---|---|---|---|
| Version: | V4, 2018 | | Version: | V4.1, April 2021 |
| Objective | For more sustainable and well-connected neighborhoods | | Objective | For more sustainably planned and executed cities and communities |
| Total Credits | 110 | | Total Credits | 110 |
| Total Number of Sections | 5 | | Total Number of Sections | 9 |
| Sections | Smart Location and Linkage (SLL) | | Sections | Integrative Process (IP) |

| | | | | |
|---|---|---|---|---|
| | Neighborhood Pattern and Design (NPD) | | | Natural Systems and Ecology (NS) |
| | Green Infrastructures and Buildings (GIB) | | | Transportation and Land Use (TR) |
| | Innovation (IN) | | | Water Efficiency (WE) |
| | Regional Priority (RP) | | | Energy and Green House Gas Emissions (EN) |
| | | | | Materials and Resources (MR) |
| | | | | Quality of Life (QL) |
| | | | | Innovation (IN) |
| | | | | Regional Priority (RP) |
| Sections Illustration | Total 14 sub sections with 5 Prerequisites | | Sections Illustration | 2 sub sections |
| SLL | SLL: Smart Location | | IP | IP: Integrative Planning and Leadership |
| | SLL: Imperial Species and Ecological Communities Conservation | | | IP: Green Building Policy and Incentives |
| | SLL: Wetland and Water Body Conservation | | Sections Illustration | 5 sub sections with 1 prerequisite |
| | SLL: Agricultural Land Conservation | | NS | NS: Ecosystem Assessment |
| | SLL: Flood Plain Avoidance | | | NS: Green Spaces |
| | SLL: Preferred Location | | | NS: Natural Resources Conservation and Restoration |
| | SLL: Brownfield Remediation | | | NS: Light Pollution Reduction |
| | LT: Access to Quality Transity | | | NS: Resilience Planning |
| | LT: Bicycle Facilities | | Sections Illustration | 6 sub sections with 1 prerequisite |

| | | | | |
|---|---|---|---|---|
| | SLL: Housing and Jobs Proximity | | TR | TR: Transportation Performance |
| | SLL: Steep Slope Protection | | | TR: Compact, Mixed Use and Transit Oriented Development |
| | SLL: Site Design for Habitat or Wetland and Water Body Conservation | | | TR: Access to Quality Transit |
| | SLL: Restoration of Habitat or Wetlands and Water Body Conservation | | | TR: Alternative Fuel Vehicles |
| | SLL: Long Term Conservation Management of habitat or Wetland and Water Body Conservation | | | TR: Smart Mobility and Transportation Policy |
| Sections Illustration | 18 sub sections with 3 prerequisites | | | TR: High-Priority Site |
| NPD | NPD: Walkable Streets | | Sections Illustration | 5 sub sections with 2 prerequisites |
| | NPD: Compact Development | | WE | WE: Water Access and Quality |
| | NPD: Connected and Open Community | | | WE: Water Performance |
| | NPD: Walkable Streets | | | WE: Integrated Water Management |
| | NPD: Compact Development | | | WE: Storm Water Management |
| | NPD: Mixed- Use Neighborhoods | | | WE: Smart Water Systems |
| | NPD: Housing Types and Affordability | | Sections Illustration | 6 sub sections with 2 prerequisites |
| | LT: Reduced Parking Footprint | | EN | EN: Power Access, Reliability and Resiliency |
| | NPD: Connected and Open Community | | | EN: Energy and Greenhouse Gas |

| | | | | |
|---|---|---|---|---|
| | | | | Emissions Performance |
| | NPD: Transit Facilities | | | EN: Energy Efficiency |
| | NPD: Transportation Demand Management | | | EN: Renewable Energy |
| | NPD: Access to Civic and Public Places | | | EN: Low Carbon Economy |
| | NPD: Access to Recreational Facilities | | | EN: Grid Harmonization |
| | NPD: Visibility and Universal Design | | Sections Illustration | 6 sub sections with 2 prerequisites |
| | NPD: Community Outreach and Involvement | | MR | MR: Solid Waste Management |
| | NPD: Local Food Production | | | MR: Waste Performance |
| | NPD: Tree-Lined and Shaded Streetscapes | | | MR: Special Waste Streams Management |
| | NPD: Neighborhood Schools | | | MR: Responsible Sourcing for Infrastructure |
| Sections Illustration | 21 sub sections with 4 prerequisites | | | MR: Material Recovery |
| GIB | GIB: Certified Green Building | | | MR: Smart Waste Management System |
| | GIB: Minimum Building Energy Performance | | Sections Illustration | 8 sub sections with 2 prerequisites |
| | WE: Indoor Water Use Reduction | | QL | QL: Demographic Assessment |
| | SS: Construction Activity Pollution Prevention | | | QL: Quality of Life Performance |
| | GIB: Green Certified Buildings | | | QL: Trend Improvements |
| | GIB: Optimize Building Energy Performance | | | QL: Distributional Equity |

| | | | | |
|---|---|---|---|---|
| | GIB: Indoor Water Use Reduction | | | QL: Environmental Justice |
| | GIB: Outdoor Water Use Reduction | | | QL: Housing and Transportation Affordability |
| | GIB: Building Reuse | | | QL: Civic and Community Engagement |
| | GIB: Historic Resource Preservation and Adaptive Reuse | | | QL: Civil and Human Rights |
| | GIB: Minimized Site Disturbance | | Sections Illustration | 1 sub section |
| | GIB: Rainwater Management | | IN | IN: Innovation |
| | GIB: Heat Island Reduction | | Sections Illustration | 1 sub section |
| | GIB: Solar Orientation | | RP | RP: Regional Priority |
| | GIB: Renewable Energy Production | | | |
| | GIB: District Heating and Cooling | | | |
| | GIB: Infrastructure Energy Efficiency | | | |
| | GIB: Wastewater Management | | | |
| | GIB: Recycled and Reused Infrastructure | | | |
| | GIB: Solid Waste Management | | | |
| | GIB: Light Pollution Reduction | | | |
| Sections Illustration | 2 sub sections | | | |
| IN | IN: Innovation | | | |
| | IN: LEED Accredited Professional | | | |

Table 3.2 presents a brief highlight on LEED-Zero which is an additional complimentary rating system that includes four main sections under carbon, energy, water and waste which are all recognizing the reach offset or balance of zero within the mentioned sections during 12 months of study on operation. The Zero Waste is interconnected with another system approach rating named (TRUE) which focuses on the utilization of waste produced and studying the overall waste lifecycle and optimization efficiency.

LEED-Zero can be applied for while having a building or community related certification, it also requires no registration cost while the 3 years certification validity ($) cost is based on the square feet [107].

Table 3.2: LEED Zero Certification

| LEED- Zero | |
|---|---|
| Version Referred To | v1, April 2020 |
| Objective | Complimentary rating system for LEED O+M |
| Total Number of Sections | 4 |
| Sections | LEED Zero Carbon Certification |
| | LEED Zero Energy Certification |
| | LEED Zero Water Certification |
| | LEED Zero Waste Certification |
| If the difference between consumption and production under any or all of the sections is <= 0; then the project can submit for the relevant certification | |

With conclusion to the LEED rating systems, LEED-Cities and Communities is further studied along with Pearl Community Rating System and Tarsheed Community Rating System. Pearl Community Rating System is a UAE issue tailoring the credit needs based on the society's conditions; similarly, Tarsheed which is the first Egyptian related community rating system focused on having more economically viable and socially accepted local resources community rating system to facilitate its implementation for users and hence, encouraging its consideration.

### 3.1.2: LEED-Cities and Communities

Leadership in Energy and Environmental Design (LEED), US designed framework by US green building council which has evolved more since 1998 and it is the most widely known and commonly used rating system certified under which are more than 80,000 projects worldwide. Ever since then, several projects worldwide have been considering building their communities and/or facilities while following LEED rating systems. This is to ensure that they are not negatively impacting the surrounding environment while also being commercially benchmarked differently or uniquely compared to other infrastructures. The main challenge with LEED is that it is US based meaning that it takes into consideration their local standards, materials availability, and cost effectiveness [47].

### 3.1.3: Pearl- Community

Pearl community rating system is developed in Abu Dhabi, UAE under Abu Dhabi Urban Planning Council aiming at having a sustainable foundation for the new developments taking place across UAE while enhancing life quality. It was first issued in 2010 with several updated versions that took place through the years. It has sections under Water, Energy, Livable Communities, Materials and Waste, Innovation. Maximum credits add up to 22* pts, Excludes Innovating Practice credit points which are offered as bonus credit [49] [50].

### 3.1.4: Tarsheed- Community

In 2015, Egypt Green Building Council (EGBC) developed an Egyptian rating system which entails locally driven measures suiting more the Egyptian Market. Tarsheed rating system consists of 3 main certification processes starting with the registration, preliminary assessment and then the final assessment. The rating system is inspired by the global rating systems developed to support the investors, businessmen and developers to follow sustainable measures as per the sustainable development goals [48].

Tarsheed Rating System focuses on 3 main categories, Energy, Water and Habitat, landing a maximum score of 100 credits. The below section shows a comparative analysis between LEED- Cities and Communities and, Tarsheed-Community Rating System.

Table 3.3 reflects a comparison between the chosen community rating systems of study highlighting the components with respects to the main sections, the applicable number of credits and the cost registration and certification [48].

Table 3.3: Community Rating Systems Comparison

| | LEED-Cities and Communities | Pearl Community | Tarsheed-Community |
|---|---|---|---|
| Developed in | USA | Abu Dhabi | Egypt |
| Developed By | U.S. Green Buildings Counsil | Estidama and Abu Dhabi Urban Planning Council | Egypt GBC |
| Dated since | 1998 | 2010 | 2015 |
| Usage | Any Construction | Any Construction | New and Existing Buildings |
| Scorecard Elements | IP: Integrative Process (5 crs) | IDP: Integrated Development Process (3 crs required + 6 crs. optional) | (H) Habitat Efficiency |
| | NS: Natural System and Ecology (13 crs) | NS: Natural System (4 crs required + 3 crs. optional) | (W) Water Efficiency |
| | TR: Transportation and Land Use (18 crs) | LC: Livable Spaces (2 crs) | |

| | | | |
|---|---|---|---|
| Scorecard Elements (continued) | WE: Water Efficiency (12 crs)<br><br>EN: Energy and Greenhouse Gas Emissions (31 crs) | PW: Precious Water (4 crs required + 4 crs. optional)<br>RE: Resourceful Energy (2 crs required + 8 crs. optional) | (E) Energy Efficiency |
| | MR: Materials and Resources (11 crs) | SM: Stewarding Materials (5 crs required + 13 crs. optional) | |
| | QL: Quality of Life (10 crs) | IP: Innovating Practice (2 crs required) | |
| | IN: Innovation (6 crs) | | |
| | PR: Regional Priority (4 crs) | | |
| | Total (110 pts) | Total (22* pts, Excludes Innovating Practice credit points which are offered as bonus credit) | Total (100 pts) |
| Rankings | | | |
| | Certified (40-49 pts) | 1 Pearl (All Mandatory Credits) | Bronze (40-49 pts) |
| | Silver (50-59 pts) | 2 Pearls (for all Gove. buildings + achieving additional credits under buildings and villas) (+65) | Silver (50-59 pts) |
| | Gold (60-79 pts) | 3 Pearls (+85) | Gold (60-69 pts) |
| | Platinum (80+ pts) | 4 Pearls (+115) | Platinum (70+ pts) |
| | | 5 Pearls (+140) | |
| Cost Reflection | | | |
| Registration | $900 | $0 | EGP 0 |
| Precertification | $3,250 | Not Available Online | EGP 4800 |
| Certification | $970 | Not Available Online | EGP 7200 |
| Total | $5,120 | Not Available Online | EGP 12,000 |
| Total in $ | $5,120 | Not Available Online | $750.00 |

### 3.2: Occupants' Rating System

### 3.2.1: Fitwel Rating System

Fitwel is a lifestyle rating system is considered more for building scale applications, more focused on location and healthy eating accessibility and habits. It was introduced in 2016 by US CDC and it has 3 certification levels, Single Star (90-104 points), Two Star (105-124 points) and Three Star (124-144 points). 12 Elements or focal points of the Fitwel system include Location, it measures the connectivity of a building with the amenities aside giving higher score to the shortest/ walkable distances [51] [52].

### 3.2.2: WELL Rating System

WELL rating system is similar to Fitwel; however, it is a rating system designed to measure day to day wellbeing of the citizens within a community. It was developed in 2014 by the International Well Building Institute (IWBI) aiming at improving human health via measuring and monitoring the performance of the surrounding built environment [53].

The WELL rating system includes 10 main categories of focus, starting with Air, Water, Nourishment, Light, Movement, Thermal Control, Sounds, Material, Mind and lastly, Community. These categories measure the ecosystem performance around and human acceptance based on several measures and continuous check points with the community citizens. Communities can receive 3 different seals based on their achieved points: Silver (50 points), Gold (60 points) and Platinum (80+ points). Both Fitwel and WELL are considered for building scale occupants' rating system [53].

Table 3.4 summarizes a comparison between the two occupants' rating systems with the highlights of the sections, credits applicable to achieve and cost. Table 3.5 represents in depth comparison between the sections within both rating systems; this study is intended to highlight how Fitwell is more inclusive of occupants' comfort credits while WELL is considered more generic [53].

Table 3.4: Occupants' Rating System Comparison

| | WELL | FITWEL |
|---|---|---|
| Focus | User Experience and Facility Environment | |
| Developed In | 2014 | 2016 |
| Developed By | IWBI | US Centers for Disease Control and Prevention (US CDC) |
| Objective | Improving human health and well-being through the built environment. It focuses on measuring, certifying, and monitoring features of the built environment | Evaluating and rating the health-affecting aspects of the built environment to improve occupant wellbeing |
| Building Types | All, Residential, Commercial, Health and Clinics, Schools | All, Residential, Commercial, Health and Clinics, Schools |
| Certification Process | 5 steps: Registration, Documentation, Performance Verification, Certification and Recertification | |
| Certification | Silver (50), Gold (60), Platinum (80) | (90-104 points- Single Star), (105-124 points- Two Star), (125- 144 points- Three Star) |
| Process Duration till Certification | Depends on the optimization revisions | Up to 12 weeks |
| Certification Validity | 3 years with annual assessment | 3 years |
| Notes | Engaging a consultant is highly needed | No preconditions or on-site validity are needed. Also, no need to engage a consultant |
| Advantages | Good economic sense, better living ecosystem. Also, it can easily overlap with other rating systems under IAQ, Thermal, Comfort and Materials | Faster, less expensive than WELL and Practice |
| Disadvantages | High Cost and hard to measure the productivity based on the WELL measures placement | Focused majorly on awarding points on shared facilities, healthy food access and location |
| Recertification Needed | Yes after 3 years | Yes after 3 years |
| Target Audience | Customers seeking added edge to their community by highlighting the sustainable ecosystem around | Customers with limited budget and short time span for certification that supports in increasing property market value as well |
| Cost | ($1,500- $10,000) based on the project size. Usually it is ($0.42-$0.58/ square foot) | ($500- Registration), ($5,500- $10,000 Certification) |

Table 3.5: WELL and Fitwel Sections Comparison

| | WELL | FITWEL | |
|---|---|---|---|
| Air | Air Quality, Smoking Ban, Less Vehicle dependance and Awareness | Entrances and Ground Floor | Tobacco Free buildings, walking-off mats and proper lighting |
| | | Indoor Environment | IAQ policy and smoking free building policy |
| Water | Access and drinking water quality, stormwater management and Overflow water management | Water Supply | Annual water testing for contaminants is held regularly plus water access is provided everywhere |
| Light | Exterior lighting, Interior Lighting, Obstructive light control, light control schedule | - | - |
| Community | Streetscape greenery, scenic views and play areas, sanitation | Building Access | Building access to several transportation options like bus, bicycle. |
| | | Workspaces | Increasing access to natural light and nature view |
| | | Shared Spaces | Cleaning protocols are in place for every shared place |
| Mind | Access to mental health services, mental health, responsible driving | - | - |
| Nourishment | Urban Agriculture, Heathy food access, Food security and accessibility, Nutrition Education | Outdoor Space | Fitness Space, Walking Trails, Farmers Market |
| Movement | Walkability, Cyclist, Pedestrian Lane | Cafeterias and Prepared Food Retail | Promoting and incentivizing healthy food |

| | | | |
|---|---|---|---|
| Sound | Community sound mapping, noise level limit and planning for acoustic | - | - |
| Materials | Landscape and pesticide use, waste management and construction remediation | Location | Mixed-Use location with Shops, Grocery Stores, Parks, Schools, etc. Also, it should be connected and safe. |
| | | Stairwells | Appropriate stairwells in case of elevator failure |
| | | Vending Machines and Snack Bars | On site ones are to incentivize still healthy food |
| | | Emergency Procedures | Building emergency addresses and contacts |

### 3.3: Present Integrated Community and Occupants' Rating System

#### 3.3.1: Living Community Challenge (LCC)

Living Community Challenge (LCC) is a focused framework integrating between community designing and building standards with the occupants' comfort and wellbeing that was introduced in 2014 by the Living Future Institute. LCC rating system has a mix of community pillars and lifestyle plans integrated together developed with the integration of USGBC and Canada Green Building Council 8. It has seven petals under Water, Energy, Equity, Materials, Health Happiness, Materials, Place. Even though there are around 50+ projects registered for certification a few of which are certified; it is a relatively expensive rating system that is not tailored enough to suit different markets [54]. Table 3.6 represents all of the petals included under LCC with a brief description.

Table 3.6: Living Community Challenge (LCC) Petals Description

| LCC | | |
|---|---|---|
| **Petal 1** | **Place** | Description |
| Imperative 1 | Limits to growth | Projects can only be built on Greenfields or brownfields for as long as it doesn't have any impact on ecological habitats |
| Imperative 2 | Urban Agriculture | Integrating on0community agricultural opportunities based on floor area ratio |
| Imperative 3 | Habitat Exchange | Working with the Living Future Habitat Exchange Program giving back to other habitat, animals or other living organisms in an urban environment |
| Imperative 4 | Human-Powered Living | The community should be designed for human powered activities like pedestrian lanes, bicycle networks and storage, electric vehicles |
| | | |
| **Petal 2** | **Water** | |
| Imperative 1 | Net Positive Water | Treating GW and BW while purifying water to be used again within the community with a decrease in demand on potable water. |
| | | |
| **Petal 3** | **Energy** | |
| Imperative 1 | Net Positive Energy | 105% of the community's needs must be supplied by community generated renewable energy on net annual basis, including all energy for water and waste conveyance. |
| | | Providing one week energy storage for community emergency services as fire stations, community centers and water treatment systems. |
| **Petal 4** | **Health and Happiness** | * Maximizing physical and psychological health and well-being creating robust, healthy, happy and productive communities and people within. |
| Imperative 1 | Civilized Environment | Social civilized connections with community initiative inclusions. |
| Imperative 2 | Healthy Neighborhood Design | Access to walking trails, sidewalks, creation of parks, plazas, pools, tennis or ball courts while having a health and wellness education plan applicable for every resident |
| Imperative 3 | Biophilic Environment | Enriching human/nature connection with access to natural light, open spaces and natural shapes and forms. |
| Imperative 4 | Resilient Community Connections | Having back-up generator network or battery for power emergency needs. While having a fully connected security team for the occupants' safety. Ensuring that all of the sensitive infrastructure like sewage treatment, community centers, schools and hospitals are away from the flood plain. |

| | | |
|---|---|---|
| **Petal 5** | **Materials** | Implementing materials that are regenerative while having no negative impact on human health and ecosystem |
| Imperative 1 | Embodied Carbon Footprint | tCO2e impact on the community from the construction |
| Imperative 2 | Net Positive Waste | Reducing or eliminating the production of waste for design, construction, operations and end of life in order to conserve natural resources and find a way to integrate waste back into either an industrial or natural nutrient loop. |
| Imperative 3 | Living Materials Plan | |
| | | |
| **Petal 6** | **Equity** | |
| imperative 1 | Human Scale and Humane Places | Human scaled vs automobile scaled community promoting culture interaction |
| Imperative 2 | Universal access to nature and places | All transportation, roads and facilities must be equally accessible to the community occupants' plus fair access on sunlight, it shouldn't be blocked with buildings or any heights. |
| Imperative 3 | Universal access to community services | 2 miles walking distance of places to shop, congregate in a community center or place to work or learn |
| Imperative 4 | Equitable Investment | For every $ spent on the community project, the community must set aside and donate half cent to charity. |
| Imperative 5 | Just Organizations | |
| | | |
| **Petal 7** | **Beauty** | Ensures that we have communities elevating our spirits and conserve and serve the greater good. |
| Imperative 1 | Beauty and Spirit | Including meaningful integrations of public are and designs within every block, street, plaza |
| Imperative 2 | Inspirational Education | Educational materials about the design and operation of the community must be provided like open day for the public, educational website, brochures, operation and maintenance manuals. |
| Imperative 2 | Inspirational Education | Public workshops and webinars, Living Future Conference |
| Imperative 2 | Inspirational Education | |
| | | |

## 3.4: Proposed Schematic for the integrated Community and Occupants' Rating System for Egypt

Figure 3.1 schematic simplifies the main integrations of inclusion under the proposed community and occupants' health and wellbeing rating system focusing on approaching net zero concept. It starts with the study of the potable water access and the primary treated water provided by the municipality area; this is a focus for occupants' health and wellbeing. Then how the water is collected within the community, and this is where a proposal for separate piping systems for the GW collection and the BW collection is in place; also, it is reflected as such under the experimental chapter proposed community scale and piping system. This is aimed for ease of collection and possible on-community GW treatment methods which is the third inclusion in the above schematic and that is a community focused credit.

Then how the treated greywater shall be reused within the community for saving potable water or reducing its reliance in non-drinking needs. The treated GW can be reused in irrigation, firefighting systems and toilet flushing as proven post treatment meeting the local and global wastewater treatment codes mentioned under the experimental chapter and that is both a community and occupants' health and wellbeing consideration.

Fifth point is how the TGW is managed, monitored, and tested for efficient use and optimization; hence, the proposal of using smart integration and controllers managing the water out capacity as per the need while also proposing to have a building scale or zone scale laundry room where water used, and detergents are managed by the community. Also, including water storage tanks for emergencies is a must to ensure that water cut-out situations are minimized and thus providing a better occupants' living experience. For water testing, it is proposed to have bi-annual random TGW samples collection for testing to ensure that the water treatment system is working efficiently as needed; so, reducing any health hazards.

As a community commitment from occupants', giving back to the community is a must thing in which the community board members are responsible to educate the citizens about water conservation, measures, dos and don'ts yet giving them the space for more creativity and innovation that shall pay back economically and efficiently to the community.

Scenery and the inclusion of green spaces is a matter of occupants' comfort and community uplifting with cleaner air and more psychological appeal. Therefore, the inclusion of water fountains, lagoons, green open parks that all run and irrigate with the treated greywater is a sign of closed water cycle within the community using treated water for irrigation and fountains while including any additional water post-irrigation for example back into the collected GW piping system cycle for treatment and reuse.

Last point is the Water management impact with Energy is important to consider as including smart water sensors, water treatment systems and all water consumption management will reflect on the energy levels within my community. Hence, a full community overview and offset is highly needed to ensure that one scale like Water section doesn't negatively impact another like Energy management and conservation.

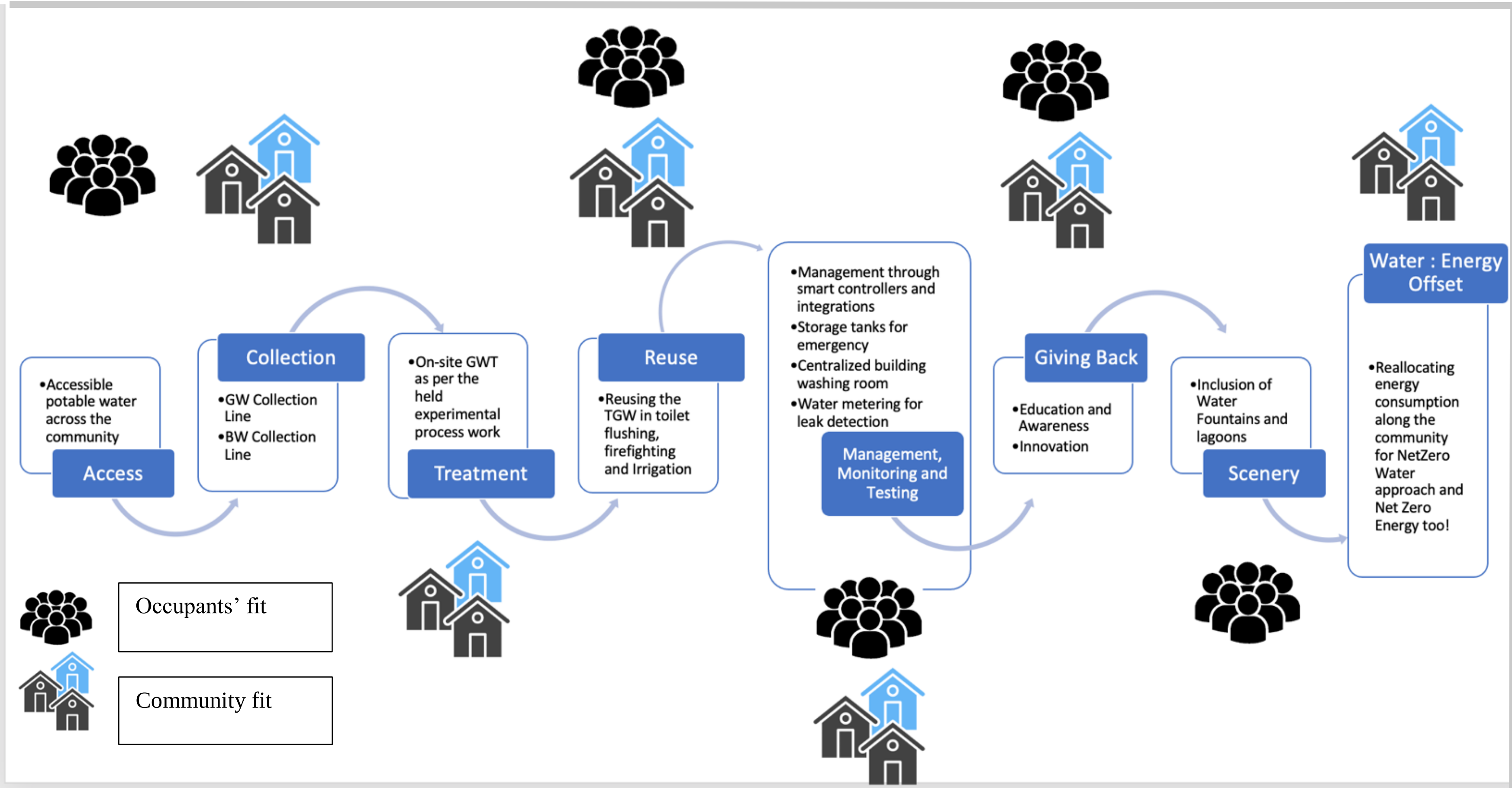



Figure 3.1: Proposed Integrated Community and Occupants' Rating System for Egypt- Schematic

### 3.5: Integrated Community and Occupants' Rating System

This subsection is the proposal of the integration of occupants' rating system along with the currently available Tarsheed-Communities rating system for Egypt. The integration also includes a consideration for the net zero concept approach in the scorecard and illustration. A final additional proposal under this sub-section is a net zero complimentary certification framework that is applicable for buildings and communities.

#### 3.5A: Integrated Rating System- Narrative

The Proposed Integrated Community and Occupants' Rating System for Egypt is built on proposal amendments to the locally issued community rating system (Tarsheed). The Occupants' credits included within are a proposal integration based on Fitwel, Well and LCC rating systems.

This section is a complimentary narrative to the proposed integrated community and occupants' rating system for Egypt- Scorecard. The narratives in this section are focused on the highlighted amended/ new additions in the score card of Tarsheed-Communities.

The proposed integrated community and occupants' rating system has a total of 112 credits with the following additions. Out of the 112 credits there are 45 credits that are community related, 44 credits that are community and occupants related and, 23 credits that are occupants related.

**A) <u>Energy Section</u>**

1. Addition: Credit: E17: Innovation in Energy and Carbon Footprint:

   In this credit, 1 point is assigned to any innovation serving energy saving and enhancing carbon footprint. Carbon footprint shall be calculated by community engineers after 1 years of operation with more than 80% of occupants' capacity, the credit addition is seen in scorecard table 3.7.

**B) <u>Water Section</u>**

1. Modified: Pre-Requisite: Water and Wastewater Management Plan (modified)

   The amendment considers the below sub-points:

   - Community design is to account for C2C for wastewater management design
   - GW Collection, Storage and Treatment for reuse in irrigation and toilet flushing
   - BW Collection and Treatment
   - Water Storage Tanks.

2. Addition: Credit: W07: Quality of Treated Greywater

In this credit, 1 point is assigned to quarterly check for the treated greywater effluent quality to ensure that there are no contaminants or toxicity, while also ensuring that it is safe on Occupants' when in touch.

3. Addition: Credit: W08: Over flooding water management and rainwater management

In this credit, 2 points are assigned with 1 point for design safety consideration to any over flooding water that may over flood from the treatment system, storage tanks or water pipes. This over flooding will lead to Occupants' discomfort with negative health impact.

The second point is assigned for the rainwater management plan and consideration in design especially with coastal areas that are more likely to have occasional higher volumes of water rains during winter season. The rainwater management shall specify how the rainwater will be collected within the community and from the buildings roofs, while also specifying the GW piping system integration with rainwater collection to be treated for community reuse among with the collected GW.

4. Addition: Credit: W09: Ease of Access to Drinking Water

In this credit, 1 point is assigned for design consideration to ease Occupants' access to drinking water. This can be covered through several on-community available freshwater supply spots for example. Over flooding water that may over flood from the treatment system, storage tanks or water pipes. This over flooding will lead to Occupants' discomfort with negative health impact.

5. Addition: Credit: W10: Innovation in Water, Wastewater and Carbon Footprint

In this credit, 1 point is assigned to any innovation serving water savings considering, but not limited, wastewater collection and reduction through on-community greywater treatment. Another idea for water savings is using smart controllers and timed irrigation sprinklers. In this credit also, enhancing carbon footprint shall be mentioned with respect to the water and wastewater consumption and treatment production for reuse. Carbon footprint shall be calculated by community engineers after 1 years of operation with more than 80% of occupants' capacity.

The water section amends and additions under the proposed rating system are presented in the scorecard in table 3.8.

C) **Habitat Section**

1. Modified: Credit: H05: Basic Amenities (Modified)

The amendment in this credit is to consider the inclusion of shared places for Smoking, Fitness, and Laundry Rooms on a community level or cluster of buildings/zone level.

2. Modified: Credit: H21: Green Education and Community Engagement (Modified)
3. Addition: Credit: H22: Smart Devices for security, Bills Payment, Building Water and Energy Consumption Visibility

In this credit, 1 point is assigned to consider including community applications or ease-of-access-tablets that can show the occupants' monthly energy and water consumption, savings, and bills, and others.

4. Addition: Credit: H23: OAQ and Health

In this credit, 1 point is assigned to consider the community outdoor air quality through less vehicle's reliance promoting walkability, cyclist, Pedestrian lanes, landscapes, and designated smoking areas.

5. Addition: Credit: H24: Contribution of water management in Carbon Footprint
6. Addition: Credit: H25: Health and Security: Emergency Addresses and Contacts are identified, access to mental health services through meditation programs and on-community clinic with experts.

   In this credit, 2 points are assigned, with the first point is to consider ease of Occupants' access to mental health services with professional experts. The second credit is for the inclusion of emergency procedures on a building and community scale for available emergency addresses and contacts.
7. Addition: Credit: H26: Innovation in Habitat

   In this credit, 1 point is assigned to innovation in habitat. Some alternatives to choose from are smart integration of technologies, enhancing occupants' on-community living experience, educational, awareness and/fun campaigns or activities for community residents' engagement. Also, innovations under incentive plans for example, upon an occupants' quarterly energy or water savings, they can be incentivized with an on-community local shop discount or recreational facilities discount or reduction in their next community maintenance fee or others.

The habitat section amends and additions under the proposed rating system are presented in the scorecard in table 3.9.

Color coding is represented in the proposed integrated rating system to reflect on the credits that aim for the Net Zero approach versus those for the occupants' health and wellbeing versus both focus areas.

## 3.5B: Integrated Rating System- Score Card

Table 3.7: Tarsheed New Community with Occupants Rating System- Energy Section

| | | **Energy** | 27 |
|---|---|---|---|
| Prereq. | P01 | Energy Management Plan | Prereq. |
| Prereq. | P02 | Commissioning | Prereq. |
| Credit | E01 | Window to Wall Ratio | 1 |
| Credit | E02 | Reflective Roofs | 1 |
| Credit | E03 | Reflective Paint for External Walls | 1 |
| Credit | E04 | External Shading Devices | 2 |
| Credit | E05 | Roof Insulation | 2 |
| Credit | E06 | External Wall Insulation | 2 |
| Credit | E07 | High Performance Glazing for Windows | 2 |
| Credit | E08 | Air Tightness | 1 |
| Credit | E09 | Efficient Lighting for Public Areas | 2 |
| Credit | E10 | Light Pollution Prevention | 2 |
| Credit | E11 | Photovoltaic System for Exterior Lighting | 2 |
| Credit | E12 | Solar Water Heaters | 2 |
| Credit | E13 | Pump Motor Efficiency | 1 |
| Credit | E14 | Energy Metering | 1 |
| Credit | E15 | On-Site Renewable Energy | 2 |
| Credit | E16 | District Heating and Cooling Plant | 2 |
| Credit | E17 | Innovation in Energy and Carbon Footprint | 1 |

| **Color Scheme:** |
|---|
| Net Zero Addition |
| Occupants' Health and Wellbeing |

Table 3.8: Tarsheed New Community with Occupants Rating System- Water Section

| Water | | | 25 |
|---|---|---|---|
| Prereq. | P03 | Water and Wastewater Management Plan (modified) | Prereq. |
| Credit | W01 | On-Site Greywater Treatment & reuse for Irrigation & Toilet Flushing to reduce demand on potable water | 4 |
| Credit | W02 | Native Plats/Reduce Grass | 5 |
| Credit | W03 | Irrigation Efficiency | 5 |
| Credit | W04 | Use of Treated Wastewater for Irrigation | 2 |
| Credit | W05 | Rainwater & AC Condensate Harvesting | 2 |
| Credit | W06 | Water Metering for Leak Detection | 2 |
| Credit | W07 | Quality of TGW | 1 |
| Credit | W08 | Overflooding water management and rainwater management | 2 |
| Credit | W09 | Ease of access to drinking Water | 1 |
| Credit | W10 | Innovation in Water, Wastewater, Carbon Footprint and Water Footprint | 1 |

| Color Scheme: |
|---|
| Net Zero Addition |
| Occupants' Health and Wellbeing |

Table 3.9: Tarsheed New Community with Occupants Rating System- Habitat Section

| | | **Habitat** | 59 |
|---|---|---|---|
| Prereq. | P04 | Construction Activity Pollution Prevention - Dust Control | Prereq. |
| Prereq. | P05 | Solid Waste Management Plan | Prereq. |
| Prereq. | P06 | Green Certified Buildings | Prereq. |
| Credit | H01 | Retain Natural Topography | 2 |
| Credit | H02 | Protect and/or Restore Existing Trees & Water Bodies | 1 |
| Credit | H03 | Heat Island Reduction: Reflective tiles for Outdoor Paving | 3 |
| Credit | H04 | Heat Island Reduction: Shaded Parking and/or Underground Parking | 3 |
| Credit | H05 | Basic Amenities (Modified) | 3 |
| Credit | H06 | Public Landscape Areas, Streetscape greenery, scenic views & play areas with an integration to irrigation using the TGW | 2 |
| Credit | H07 | Recreation Facilities | 2 |
| Credit | H08 | Walkable Streets- Tree-Lined and Shaded | 3 |
| Credit | H09 | Bicycle Facilities | 3 |
| Credit | H10 | Internal Transportation Facilities | 2 |
| Credit | H11 | External Transportation Facilities | 2 |
| Credit | H12 | Nourishment through promoting healthy food, local organic agriculture, ease of healthy food access & nutrition education | 2 |
| Credit | H13 | Design for Individuals with Special Needs | 1 |
| Credit | H14 | Construction Waste Management | 3 |
| Credit | H15 | Municipal Waste Management | 3 |
| Credit | H16 | Organic Waste Management: Composting | 3 |
| Credit | H17 | Local Materials | 3 |
| Credit | H18 | Recycled Content | 4 |
| Credit | H19 | Green Certified Buildings | 6 |
| Credit | H20 | Sustainable Buildings Guidelines | 1 |
| Credit | H21 | Green Education & Community Engagement (Modified) | 1 |
| Credit | H22 | Smart Devices for security, Bills Payment, Building Water and Energy Consumption Visibility | 1 |
| Credit | H23 | OAQ & Health | 1 |
| Credit | H24 | Contribution of water management in Carbon Footprint | 1 |
| Credit | H25 | Health & Security: Emergency Addresses & Contacts are identified, access to mental health services through meditation programs and on-community clinic with experts | 2 |
| Credit | H26 | Innovation in Habitat | 1 |

| **Color Scheme:** |
|---|
| Net Zero Addition |
| Occupants' Health and Wellbeing |

### 3.5C: Integrated Rating System- Net Zero Certification

The objective of the proposed net zero certification is to encourage the reduction of greenhouse gas (GHG) emissions while working harder towards meeting COP26 initiative of reducing climate change and approaching net zero. The below sections of environmental concerns are interconnected together and correlated to human's daily activities.

The proposed net zero certificate is a complementary certification for green rating system. It is encouraging buildings, communities, and industries to apply an integrated net zero approach under any/all of the below sections:

- Net Zero Energy (NZE): Total Energy Delivered = Total Non-Renewable Energy Displaced.
- Net Zero Wastewater (NZWW): Total Water Consumed – (Total Alternative Water Use + Water Returned to Original Source).
- Net Zero Emissions (NZE) or Neutral Carbon Emissions (CE): Total Carbon Emitted – Total Carbon Avoided = Carbon Balance
- Net Zero Solid Waste (NZSW): The waste produced is being reduced, recycled, and reused. This is achieved with 90% diversion of solid waste from the landfill.

**Net Zero Illustrations**

The Net Zero concept doesn't mean no production of the relevant item however, it is a release of carbon, energy, or waste however, it is offset by removing an equivalent amount or utilizing of the same item.

1) Net Zero Energy aims at both reducing the energy consumption while integrating energy saving methods to further utilize the energy use. This is considered under using renewable energy sources which reflects energy being generated or driven from naturally existing sources like the use of windmills or solar panels. Also, the use energy efficient devices are essential.

2) Net Zero Wastewater aims at utilizing the fresh water used in daily uses while also treating generated wastewater like greywater to be reused in domestic uses like toilet flushing or landscape irrigation. Hence, reducing the volume of fresh water used at the source for non-drinking water purposes. The net zero water can also be utilized through using water saving devices.

3) Net Zero Emissions or Neutral Carbon Emissions are similar but on a different scale. Neutral Carbon aims at reducing carbon dioxide emissions which contributes to GHG yet, Net Zero Emissions considers the reduction of GHG emissions which includes ozone, methane, carbon dioxide and other gases. The aim of this approach is to reduce any gases that contribute to the global warming effect. This can be achieved through using non-carbon generating equipment, the use of "smart devices" which integrate sensors that manage the energy consumption versus the actual load or use, the use of electric vehicle or golf carts or bicycles within closed communities and encouraging the increase of green areas and plants integration to further absorb carbon dioxide from the surrounding atmosphere.

4) Net Zero Solid Waste aims at reducing the solid waste disposal and the negative environmental impact through disposing in landfills or disposing waste that can be recycled and reused. The objective of net zero solid waste is to consider both reduction of waste after use or at the disposal stage and reduction of waste at the generation or source stage; and this will be achieved by considering recycling in a sustainable manner to recover materials for reuse.

**Certification Requirements**

1. Pre-Requisite: The full project shall be green if it falls under building, community, or industry.

2. Project must be certified under any relevant rating system like LEED, Pearl, Tarsheed or other.

3. GHG reduction projection must be provided as a proof with the community being occupant by 50% or more of its total residents or with/ around approximate of 12 months of operational performance data (whichever is fulfilled first).

4. Certification shall be renewed every 3 years with datasheets of net zero reach under the certification category of reference.

5. A proof of neutral to positive impact shall be considered when applying to any certification category ensuring that the focus of one net zero approach doesn't negatively impact others. This can be achieved with full building/community/industry carbon footprint/ water footprint and/or waste footprint calculations based on 12 months or more of operation.

6. Upon certification, the certified project must commit to continue the certification related net zero activities and programs that granted the net zero certification in the first place. Annual data performance sheets shall be provided to the certifier to ensure continuity no matter if the certified project is applying for certification renewal.

**Certification Categories**

Four main certification categories are considered under Net Zero certificate identified as: Net Zero Silver, Net Zero Gold, Net Zero Platinum, and Net Zero Diamond. Net Zero Silver is achieved when targeting only one net zero approach section from (net zero wastewater, net zero energy, net zero solid waste or neutral carbon emissions). Net Zero Gold is achieved when targeting two of the net zero approach sections from (net zero wastewater, net zero energy, net zero solid waste or neutral carbon emissions). Similarly, Net Zero Platinum is when three net zero sections are of focus and lastly, Net Zero Diamond is granted when the four net zero sections are fulfilled.

Net positive reach is an additional bonus highlight that can be achieved under net positive energy.

**Certification Stages**

a. **Pre-certification**: The stage of which the project is being registered for with 3 years plan of net zero approach that is presented under data sheets and activities/programs demonstration).

b. **Certification**: The stage of which the project is granted the certificate with respect to the net zero approach/ certification category of focus).

c. **Certification Maintenance**: The stage of which the certified project still presents annual data sheets of continuing the activities/programs that granted the net zero certificate in the first place to prevent subsequent negative environmental impact or lack).

d. **Certification Renewal**: The stage of which the certified project applies for renewal or upgrade in the certification category of focus. This is considered after 3 years of initial certification grant).

**Certification Process: For New Projects**

1. Registration
    - Email: info@egyptgbc.eg with the needed project information listed below:
        - Email Subject: New Project Registration for Net Zero Certificate
        - Project Name
        - Infrastructure type (i.e. Building – Community – Industry)
        - Infrastructure Rating System (i.e. Tarsheed – LEED- Estidama- BREEAM- other)
        - Project address

- Gross built up area
- Plot area
- Building footprint
- Start date
- End date
- Owner
- Consultant
- Contractor
- Project manager
- Registration date
- Certification Stage/ net zero focus area of consideration

2. Performance Datasheets, Demonstration, and 3 years Plan

   Datasheets with 12 months of metered performance data along with a clear action plan of the activities/programs/technologies to be implemented to reach the needed certification stage of focus must be submitted.

   Related carbon footprint calculations or water footprint calculations or waste footprint calculations need to show a net zero balance = 0.

3. Certification Preliminary Review

   Once the needed data in step#2 are provided, the project status will change online to (Under Revision). The preliminary review stage takes around 15 working days ensuring that all the needed documentation is presented before final assessment.

4. Certification Final Review

   Once the project is preliminarily reviewed with all the needed documentation and supporting documents are provided, a final revision is done by Egypt GBC to confirm the certification grant to the requestor. The status on the website will be changed to

(Certified) once the certificate is granted. The certification final review stage takes around 10 working days and the certification print and delivery to the customer site takes around additional 5 working days.

A project number will be provided for ease of reference for the certification renewal after 3 years.

The project is committed to provide annual datasheets of performance once the certification is granted and until the 3 years renewal time is met.

**Certification Process: For Renewal**

1. Email: info@egyptgbc.eg with the needed project information listed below:
    a. Email Subject: Net Zero Certificate Renewal: Project Number (…..)
    b. Project Name
    c. Renewal type (i.e. 3 years renewal or certification stage upgrade)
    d. Project amends (if any): This is to highlight any project data changes from what was provided during the initial net zero certification.
2. Performance Datasheets, Demonstration

Datasheets with the past 3 years of performance data since the initial net zero certification is met along with a clear action plan of the activities/programs/technologies to be added/modified to maintain and exceed on the needed certification stage of focus must be submitted.

Related carbon footprint calculations or water footprint calculations or waste footprint calculations need to show a net zero balance = 0. Net positive approach must be highlighted if the planned for or met.

In case of a project certification upgrade to include additional net zero categories, a proof of reaching net zero under the initially certified for stage is a must in addition to providing datasheets and demonstration plan on the additional net zero approach area of focus.

3. Certification Preliminary Review

Once the needed data in step#2 are provided, the project status will change online to (Under Revision). The preliminary review stage takes around 15 working days ensuring that all the needed documentation is presented before final assessment.

4. Certification Final Review

Once the project is preliminarily reviewed with all the needed documentation and supporting documents are provided, a final revision is done by Egypt GBC to confirm the certification grant to the requestor. The status on the website will be changed to (Certified) once the certificate is granted. The renewal certification final review stage takes around 10 working days and the renewed certification print and delivery to the customer site takes around additional 5 working days.

A project number will be provided for ease of reference for the certification renewal after 3 years.

**Benefits of the Net Zero Certification**

1. Abiding to the 2050 Net Zero roadmap.
2. Simple to achieve, practical to use and cost effective compared to existing net zero certifications globally.
3. Paving the road into the direction of having an actionable framework for positively contributing to the reduction of greenhouse gas emissions (GHG) globally.
4. The net zero certification is optional to apply for, but once applied for, the applicator gets both sustainable community certification and net zero community certification. If the applicator has Community Rating System certification, then there is an additional novel added value of abiding to the community comfort level while meeting net zero credits.

### Community Scale Sustainability Reach Assessment Tool

The availability of a community scale sustainability reach assessment tool might be considered as a reflection of the socio-environmental impacts of human driven actions. The tool shall have sections covering the building and the community scale life cycle assessment, sustainability and environmental reach, social acceptance, cost effective and a business modelling for the current net zero reaches versus the usage; this business modelling is for present reflection and future human-activity-based projections.

### Benefits and Penalties

A Net Zero Certification can further include investor benefits or appreciation models while meeting any of the net zero approaches as a sign of further motivation. Penalties shall be applied to any community that negatively impacts the environment, yet not applicable for any communities not applying for the net zero certification addition.

The output of this chapter is the proposal to integrate occupants' health and wellbeing credits within Tarsheed- Communities rating system. This integration is held with the addition of net zero approach under the rating system main sections (Energy, Water and Habitat). Lastly, the proposal of a separate and complimentary net zero rating system framework is added in this chapter.

With this being in consideration, a focus on net zero water approach application is further studied under the experimental work in chapter 4 with the main objective of treating greywater for on-community reuse in landscape irrigation, toilet flushing and firefighting systems.

**Education and Awareness**

Applying an integrated community and occupants' rating system with net zero approach is meeting two out of the three main sustainability pillars for environmentally friendly and economically viable. For the social acceptance, education and awareness credits are highlighted abiding to the sustainability ethics where there is a gap, and it must be taken into consideration with full community scale plans to adapt in order to ensure that the mindset is aligned with the global, governmental and institutional direction for preserving the resources and having a sustainable community not only through the design, build and construct but also through the day to day occupants' activities ensures longer life span with successful sustainability application and impact.

# Chapter 4

# EXPERIMENTAL WORK

## 4.1: Materials and Methods

The experiment held is focused on the design of slow sand filter and aquatic filtration in-series integration for greywater treatment and reuse. The experimental work is divided into 5 main phases in which Phases 1 and 2 are focused on designing the best slow sand filter design, while phase 3 is focused on studying the best aquatic plants density integration with respect to the best sand filter design. Phase 4 focused on studying the full system once under intermittent run and another time under continuous run. Lastly phase 5 focused on studying the full integrated system under continuous run using real greywater.

Phases 1 through 4 were studied using synthetic greywater mix that is prepared in the lab, while phase 5 was conducted using real greywater.

**In-Series Treatment System Considerations:**

1. The slow sand filter is placed before the aquatic water hyacinth tanks as to ensure that the turbidity, TSS and organics levels are majorly treated at the sand filter stage while also, the treatment plants are considered as a decorative treatment system when applied in a real-life community. Hence, to prevent any odors or insects, mosquitos and other unfavored and unhealthy pathogens, the aquatic plants are placed as a secondary treatment stage after the slow sand filter.
2. The slow sand filter is chosen among other wastewater treatment technologies as it is cost effective, efficient in reaching the needed treatment parameters while also, it doesn’t require highly informative technicians for treatment thus making the maintenance cost effective.
3. During maintenance, the removed schmutzdecke layer shall be collected for

treatment with sludge and be reused again as fertilizers for example hence, preventing any negative eco-system impact with the reduction of solid waste.

4. Water hyacinth plants are selected for the ease of availability locally in the country of study while ensuring the reusing them as they have proven effective wastewater treatment instead of disposing them in landfills and adding higher load on the solid waste.

### 4.1.1: Synthetic Greywater Preparation

Greywater characteristics varies based on the location and consumer usage, it varies from day to day and hour to hour when even considering the same user. In order to have consistent and equalized greywater experimental parameters while relying on controlled conditions with ease of greywater access, collection, storage and management, so, synthetic greywater mix was prepared in the lab. The synthetic greywater mix was prepared with a mix of chemicals that reflect the real greywater organic and inorganic components based on references. The greywater mix was prepared with reference to as an initial point with slight modifications by lab trials to ensure that the greywater mix is as close to the real greywater mix based on the literature.

Table 4.1 [96] is the one of references substituting actual greywater conditions with synthetic mix of chemicals shown on the left side of the table under Product. Each chemical used has its function describing what does this chemical substitute for which product use in real life is mentioned in the table under function. The impact of each chemical and the concentration ranges are mentioned above in the table as well under contribution of material to pollution parameter and range of tested concentration (g/l). After studying the chemicals and with trials and errors, the best recipe used across the experiment presented in table 4.2.

Table 4.1: Synthetic Greywater Formulation

| Product | Function | PSD* | | | | | | | Contribution of material to pollution parameter | Range of Tested Conc. (g/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Sodium dodecyl sulfate | anionic surfactant | | | 3 | | | 6 | 7 | pH, COD, $BOD_5$, TDS, turbidity, $NH_3$-N, $PO_4$- | 0.01-0.15 |
| Sodium hydrogen carbonate | pH buffer | | | | 4 | | | | TDS, color, COD, $BOD_5$ | 0.035-0.125 |
| Sodium Sulphate | viscosity control agent | | | | 4 | 5 | | | TDS, color | 0.025-0.1 |
| Cellulose | suspended solids | | | | 4 | | | | COD, $BOD_5$, TSS | 0.01-0.05 |
| Lactic acid | acid produced by skin | | 2 | 3 | 4 | | | 7 | pH, $NH_3$-N, $PO_4$-, COD, $BOD_5$ | 0.016-0.08 ml/l |
| Clay soil | suspended solids | | | | | 5 | | | TSS, color, turbidity | 0.1-0.15 |
| Septic effluent** | microbiological load | | | | | 5 | | | TSS, COD, $BOD_5$, FC | 1-25 ml/l |

*PSD: pollution stimulated is due to: (1) human body (2) shampoo and shower gel (3) soap (4) deodorant (5) tooth paste (6) shaving and moisturizing cream (7) make-up and make-up remover
**Septic effluent: wastewater effluent which is collected in an underground septic tank. It constitutes from feces. urine and other waste matter that is made of harmless using bacteria

Table 4.2: Synthetic Greywater Mix Recipe used in this Experiment

| Chemical | Concentration (per L) |
|---|---|
| Sodium Dodecyl | 0.07 ml |
| SHC | 0.045 g |
| Sodium Sulphate | 0.0375 g |
| Cellulose | 0.05 g |
| Lactic Acid | 0.032 ml |
| Clay Soil | 0.025 g |
| Septic Effluent | 200 - 500 ml |

### 4.1.2: Sand and Gravel Washing and Preparation

Before using the sand in the experiment, it had to be washed several times to remove any impurities that if placed within the sand filter, it will impact the sand filter efficiency. There is no available sand and gravel dedicated washer at the AUC facility so, manual repeated washing with tab water was conducted. The needed sand quantity from fine sand, medium sand and coarse sand was collected with an increase in weight to account for any sand loss while washing. The sand washing took place in stages, all on the same day, starting with the fine sand being divided into several buckets and hand washed with tab water several times until the water ran clear through it; hence ensuring washing off any impurities or dust. The same procedure was followed for the medium sand, coarse sand and the gravel used in the sand filter.

After washing was completed and ensured that water is coming out of the washing dish clean, a plastic wrap was placed on a clean surface within the lab at night and moved outside during morning time for sun drying, equally spreading each sand size on a separate wrap and the gravel on a separate wrap. The spread out of the sand layers was done to achieve thin spread layer to support in fast drying and avoiding any moisture accumulation. Similar step was done for the gravel. It was left to dry for almost one day, during which sand stirring took place, meaning that on the fine sand wrap, the sand was stirred by hand to ensure that the sand granules on the bottom are drying out properly. Similar step was held for medium sand, coarse sand and gravel used. This whole cleaning step took almost. 1.5 days which was sufficient before the experiment start.

### 4.1.3: Standard Methods used for testing the Experimental Parameters

Table 4.3 groups the devices used during the experimental study for measuring the needed parameters with respect to the greywater treatment experiment.

Table 4.3: Devices Used during the Experimental Study

| | Test Name | Device Name | Program and Frequency |
|---|---|---|---|
| 1. | Absorbents | Shimadzu- UV 1650 PC Spectrophotometer UV-VIS | 254 nm (TSS) and 400 nm (Turbidity) |
| 2. | NTU Turbidity | DR 2000 | Program #750 @450 nm |
| 3. | TSS | Standard Method- DR 2000 | Program #2540 @810 nm |
| 4. | DO | HQ30d Hach Hexi | 254 nm (TSS) and 400 nm (Turbidity) |
| 5. | COD | Warmer: Macherey Nagel Nanocolor Vario 3, Hach DR 2500 Spectrophotometer | Program #750 @450 nm |
| 6. | BOD-5 | Standard Method – #5210 | |
| 7. | pH | HACH- 4500 | |

### 4.2: Experimental Pilot Scale Setup- Brief

The pilot scale experiment was conducted under five main phases, as described below:

- Phase 1: Sand Filter Design: studying the best sand size and best sand bed depth.
- Phase 2: Sand Filter Design: studying the best rate of filtration.
- Phase 3: Aquatic Filtration Design: studying different hydraulic loading rate (HLR) across the aquatic filtration tank vs different plant densities.
    - Phase 3.A: ROF 2 $m^3/m^2/d$ vs 2 kg/$m^2$, 3.5 kg/$m^2$ and 5 kg/$m^2$ PD
    - Phase 3.B: ROF 4 $m^3/m^2/d$ vs 1 kg/$m^2$, 2 kg/$m^2$, 3.5 kg/$m^2$, 5 kg/$m^2$ and 6 kg/$m^2$ PD
    - Phase 3.C: ROF 6 $m^3/m^2/d$ vs 2 $kg/m^2$, 3.5 kg/$m^2$ and 5 kg/$m^2$ PD
- Phase 4: Full Integrated System Run Using Synthetic GW Mix
    - Phase 4.A: Full System Intermittent System Run
    - Phase 4.B: Full System Continuous System Run
- Phase 5: Full Integrated System Run Using Real GW Mix
    - Phase 5.A: Studying Real GW Parameters
    - Phase 5.B: Full System Continuous Run

Since the main treatment systems in this experiment are the slow sand filter, biological and physical treatment, and the hyacinth aquatic filtration plants, natural treatment, hence, the phases were formatted to study the main parameters to best design the slow sand filter and the aquatic filtration for an in-series system integration.

Phase 1 was conducted to study the best sand size and sand bed depth for the slow sand filter using synthetic greywater mix. The sand filter column is constructed from a 1.5m PVC pipe of 4” diameter pipe; 3 identical sand filter columns were used in phases 1, 2 and 3 reflecting different studying parameters as described with each phase. The sand sizes used in this phase are fine sand (0.4-0.8mm), medium sand (0.8-1.2mm) and coarse sand (1-2mm). For the study of the best sand bed depth, 4 sampling tabs were added along the sand filter bed column at different depths starting with a 5 cm depth from the sand bed surface and distanced 15 cm from the following tabs to be located at 20 cm depth, 35 cm depth and 50 cm depth. The output of this phase is the best sand size and best sand bed depth that is to be used forward with the experimental work. The parameters studied in phase 1 are the absorbents at 254nm reflecting organic matter, absorbents at 400nm reflecting turbidity, Delta H and dissolved oxygen (DO).

Phase 2 was conducted to study the best rate of filtration to operate the sand filter using synthetic greywater mix. The 3 sand filter columns were adjusted with the best sand size and sand bed depth output resulted from phase 1. In this phase, 3 different rates of filtration were studied, $2m^3/m^2/d$, $4m^3/m^2/d$ and $6m^3/m^2/d$; each rate of filtration was studied in a separate sand column [97]. The output of this phase is the best sand filter rate of filtration that is to be used moving forward with the experimental work. The parameters studied in phase 2 are the absorbents at 254nm reflecting organic matter, absorbents at 400nm reflecting turbidity, Delta H and dissolved oxygen (DO).

Phase 3 was conducted to study variant hydraulic loading rates versus different plant densities using synthetic greywater mix. Even though the best rate of filtration to run the sand filter, which is also the influent hydraulic loading rate to the aquatic filtration plants was concluded in phase 2; however, studying the behavior of plant densities along different hydraulic loading rates was considered. In phase 3, three different sub-phases were studied; sub-phase 3.A was conducted to study the rate of filtration of $2m^3/m^2/d$ versus different plant densities, while sub-phase 3.B was conducted to study the rate of filtration of $4m^3/m^2/d$ versus different plant densities and lastly, sub-phase 3.C was conducted to study the rate of filtration of $6m^3/m^2/d$ versus different plant densities. The output of this phase is focused mainly on the best PD to use versus $4m^3/m^2/d$. The parameters studied in phase 3 are the turbidity, TSS, pH and COD.

Phase 4 was conducted to study the full integrated sand filter and aquatic system in-series run using synthetic greywater mix. This phase is further divided into two main sub-phases; where sub-phase 4.A was conducted to study the full integrated system behavior under intermittent 9 hours run. Sub-phase 4.B was conducted to study the full integrated system behavior under continuous 24 hours run. The parameters studied in phase 4 are the turbidity, TSS and COD.

Phase 5 was conducted to study the full integrated sand filter and aquatic system in-series run using real greywater. The real greywater was collected from the AUC Faculty Housing on hourly daily basis. Phase 5 is further divided into two main sub-phases; where sub-phase 5.A was conducted to understand the real greywater mix components and parameters, while sub-phase 5.B was conducted to study the full integrated system behavior under continuous 24 hours run. The parameters studied in phase 5.A are the turbidity, TSS and COD while the parameters studied in phase 5.B are the turbidity, TSS, COD, pH, BOD-5 and E. coli.

### 4.2.1: Experimental Pilot Scale Setup- Illustration

### 4.2.1.A: Phase 1: Sand Filter Design: studying the best sand size and best sand bed depth

Phase 1 ran for 5 intermittent initial runs that acted as experimental calibration and start up. A run is intermittent/ 8 hours running of the system that consists of 6-7 sampling collections paced one hour each after the startup of the system. These 4 runs results are not included in the results and conclusion section as with the start up for calibration, some system errors were figured out and enhanced in the following runs which are studied and analyses thoroughly.

In phase1, the samples collected in this phase are hourly samples and the parameters studied are Qin and Q out, delta H, Absorbents at 254nm reflecting organic matter and absorbents at 400nm reflecting turbidity were constantly measured and DO.

In this phase, the starting point is the mixer where the synthetic greywater mix is placed during the 9 hours of experimental run to ensure homogenous parameters along the mix while keeping the mixer stirring-on as long as the experiment is running to avoid any settling of particles. This is intended to reflect the real greywater conditions and parameters. The mixer is linked to a 45L sedimentation bucket where the synthetic greywater mix is flown to settle before passing through the sand filter treatment step. The sedimentation step can be considered as a pre-primary settling treatment step. For the main treatment stage, which is the sand filter, a 1.5m PVC high with 4’ diameter pipe is used as the sand filter column as shown in the Figures 4.1 and 4.2. Three identical vertical sand filter columns were constructed each is filled with a different sand size for the purpose of this phase’s study; however, the three sand columns had the same locations of the sampling tabs as discussed in the pilot scale setup- brief section.

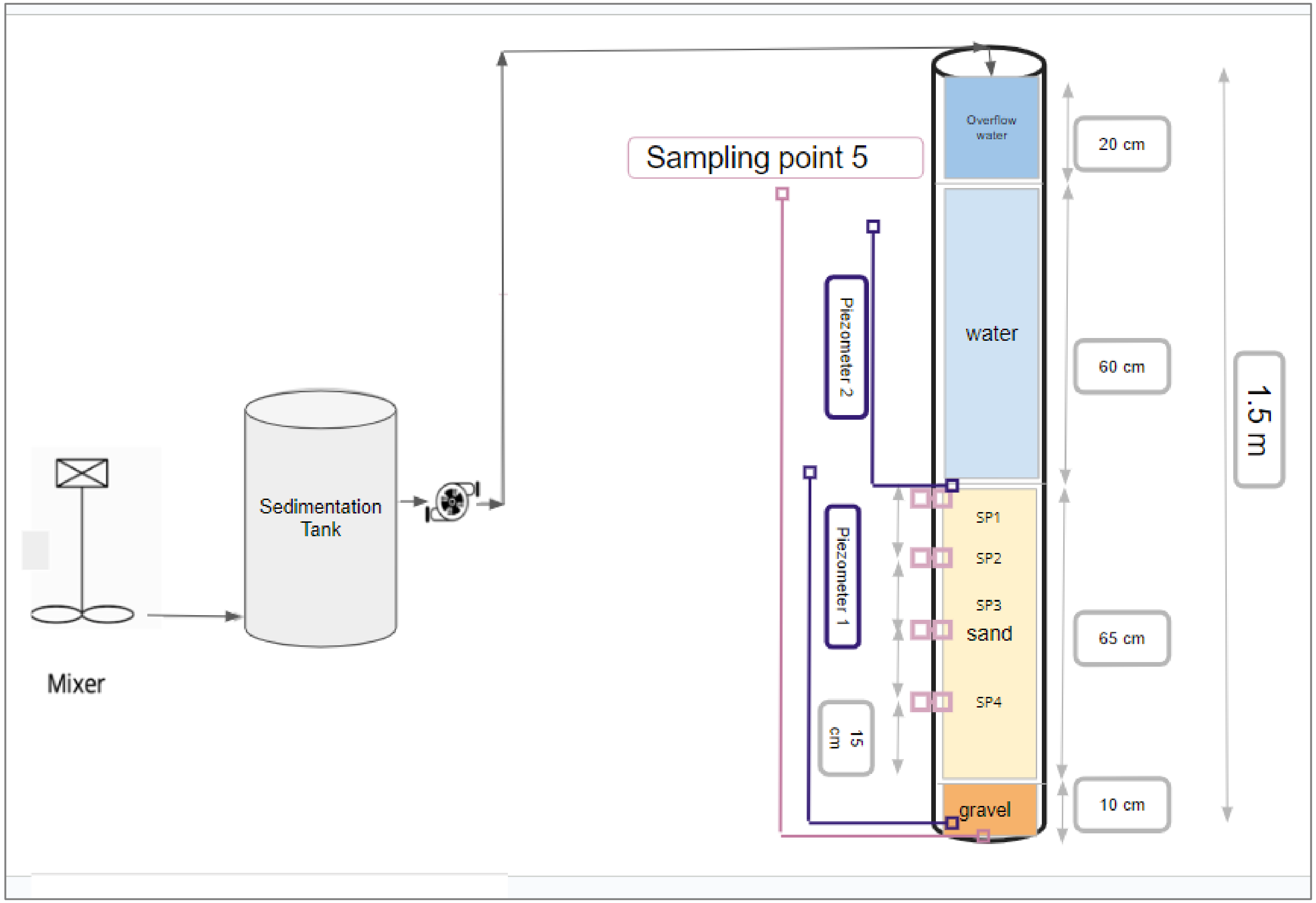



Figure 4.1: Phase 1 Schematic

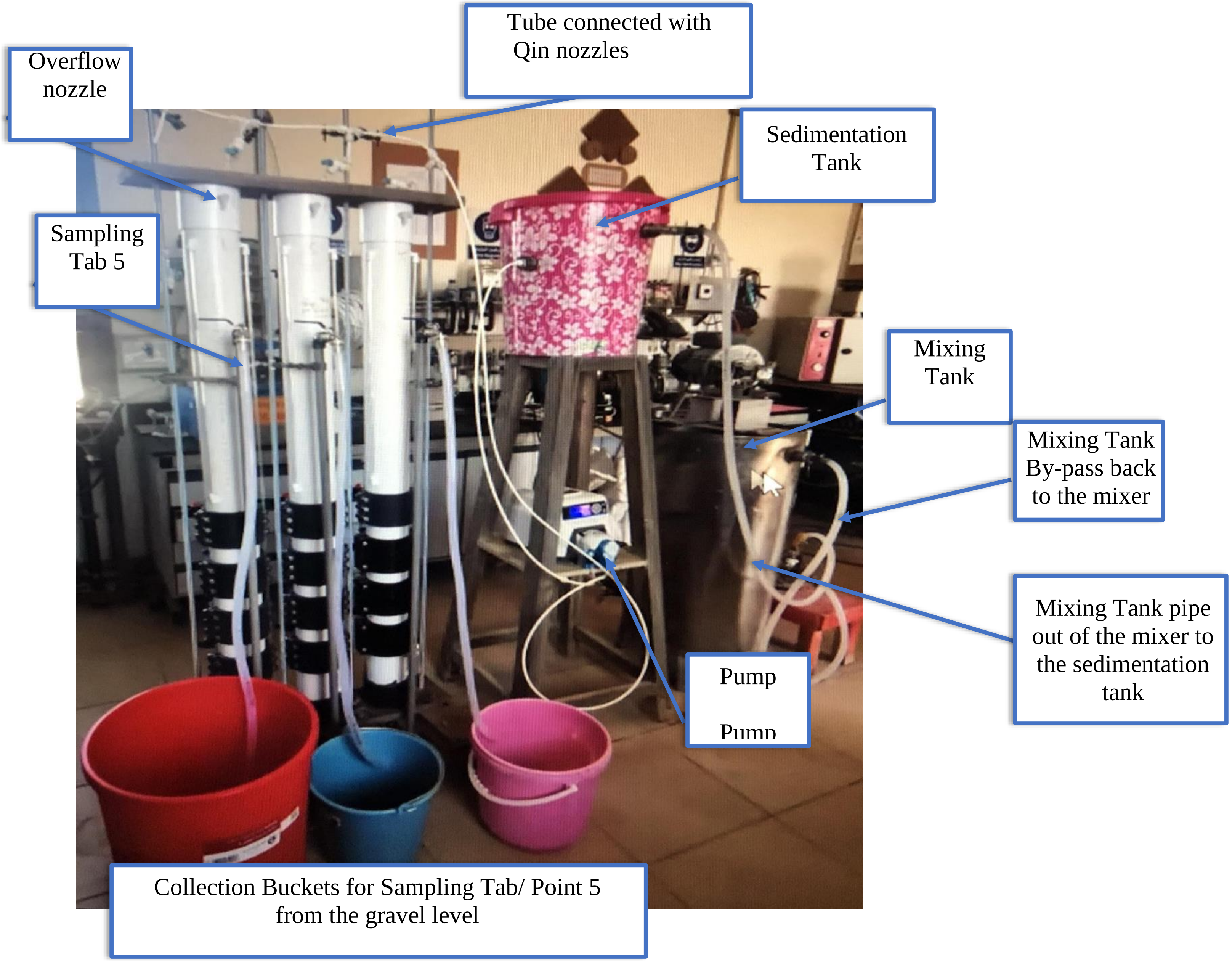
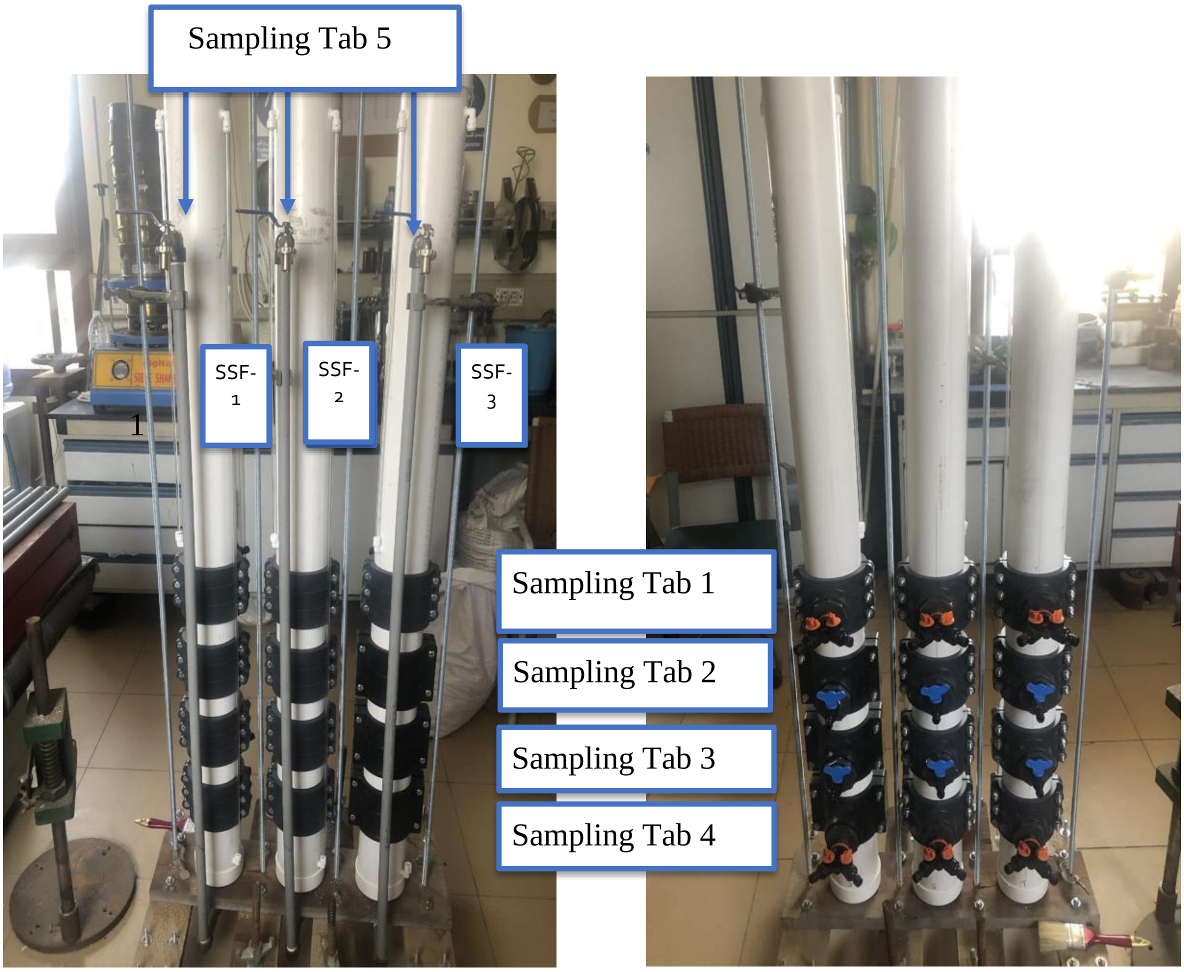



Figure 4.2: Phase 1 Bench Scale System Setup

On each sand filter column, two 6mm transparent tube piezometers are placed, once from the bottom of the treatment body starting at the bottom gravel layer ending at the top of the sand filter at the end of the 65cm water head on top of the sand bed and the other piezometer is placed at the sand bed surface till the water head on top of the sand bed. The piezometers were fitted using L-type elbows. A 12L peristaltic pump is used to pump the greywater from the sedimentation bucket to each sand filter and the effluent treated greywater after the sand filter is collected from each sand filter into a 45L collection bucket for each. The flow control into the sedimentation bucket and out of the sand filters were controlled by tabs however, the greywater flow from the sedimentation bucket into each sand filter is controlled by valves.

Sand filter 1 was filled with fine sand (0.4-0.8mm), sand filter 2 was filled with medium sand (0.8-1.2mm) and sand filter 3 was filled with coarse sand (1-2mm) as shown in Figure 4.3. All of the 3 sand filters (numbered 1, 2 and 3 in Figure 4.3) included 4-6mm gravel mix at the bottom of each sand bed and all of the 3 sand filters included 4 sampling tabs along the sand bed depth starting with 5cm deep tab and separated 15cm from the following tab. A final sampling point 5 tab is placed at 65cm depth for the effluent treated greywater from the sand filter as shown in Figure 4.3. Figure 4.4 shows the different sand used and the gravel included in the sand filters. The sand filter PVC pipe length is 1.5m divided into 10cm gravel height, 65cm sand height with 60cm water overhead and an empty remaining space of 20cm at the top for any overflow. The piezometers and the overflow tab are added onto each sand filter column.

Sieve analysis was held at the end of phase 1 for all the sand sizes to understand the sand mix under each type.




SAND FILTERS- BACK VIEW

SAND FILTERS- SAMPLING TABS VIEW

Figure 4.3: Sand Filters Front and Back View


Figure 4.4: Sand Sizes and Gravel

A sponge is used inside the sand filters before installing each sampling tabs. Before adding the sponge to the system, it was tested first under a tab and a collection beaker to ensure that its porous medium will not pass sand and will pass water as needed. The purpose of this sponges is to ensure that no sand particles will pass through the tabs to clog them. In which, if this happened it will also disturb the sand medium when opening the tab to collect sampled water. So, the sponge is acting as a purifying buffer preventing any sand particles from passing out of the system through the tabs as shown in figure 4.5. In figure 4.6, the 12L/hr total capacity pump used between the sedimentation column and the sand filters is shown.

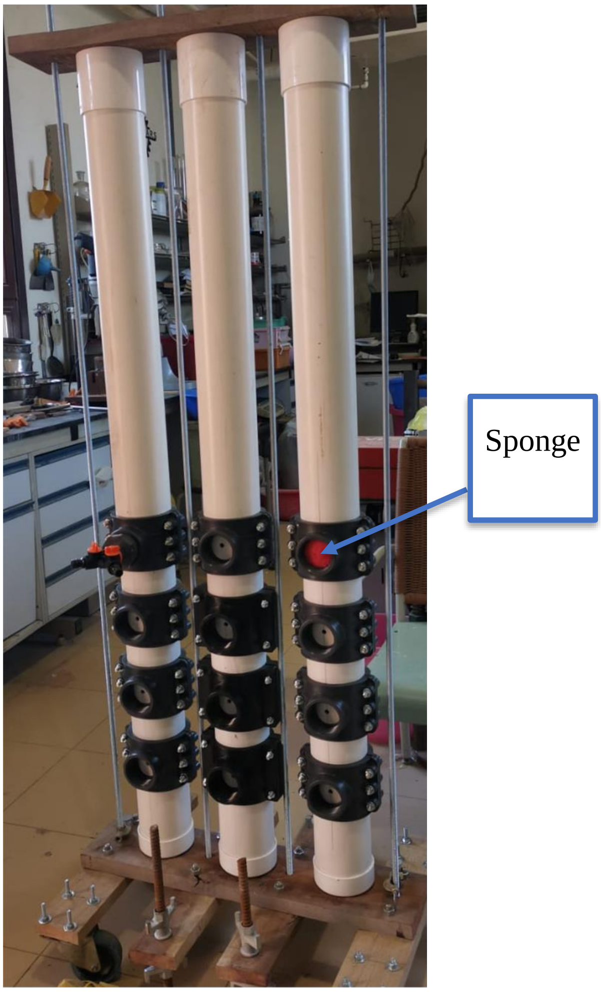



Figure 4.5: Sponge inside the Sand Filter

Figure 4.6: Pump between the Sedimentation Tank and the Sand Filters

At the bottom of each sand filter, tabs are installed right below the gravel layer, as shown in Figure 4.7, to ensure that the filter is drained from any water inside once the tab is opened. This is done on daily basis after the experimental run is held.

Figure 4.7: Sand Filter Emptying Tabs

Figure 4.8 shows the electric 100L capacity mixing tank with 2 levels of mixing fans each has 4 blades. The mixer is used to mix the synthetic greywater mix in phases 1 through 4 and the real greywater in phase 5.

Figure 4.9 shows the 45L sedimentation tank that was used in phase 1. This sedimentation tank was connected to the mixer at the inlet pipe that is placed at $2/3^{rd}$ height of the tank, while the effluent from the sedimentation tank to the pump connected to the sand filters, was placed at the middle of the tank. This sedimentation tank was substituted with a sedimentation column used from phase 2 through phase 5; this is to ease the design and for better appeal.


Figure 4.8: The Mixer


Figure 4.9: The Sedimentation Tank used in Phase 1

### 4.2.1.B: Sieve Analysis

Phase 1 is focused on sand filter design for the best filtration depth with the best sand size varying between 3 different sand sizes, fine sand (0.4 - 0.8 mm), medium (0.8 - 1.2 mm) and coarse sand (1 - 2 mm). Since the available sand packs in the market and as specified before vary in range; meaning that the fine sand ranges between 0.4-0.8 mm... etc.; hence, sieve analysis is held to assess the particle size distribution by identifying the different sizes particles under each mesh number.

Table 4.4: Sieve Analysis Calculation

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total sample weight (grams): 500 | | | | | | | |
| | Shaker Time: 5 minutes | | | | | | | |
| | Fine Sand: (0.4-0.8mm) | | | | | | | |
| | | | | | | | | |
| | | Weight of empty sieve (kg) | soil weight retained (grams) | Soil retained | %ret | cum. %ret | Percent Passing (%) | Particle Diameter |
| Standard Sieve Opening (mm) | Mesh No. | A | B | C=B-A | D= (C)/Total Weight *100 | E= D + E"i-1" | F= 100 - E | |
| 4.76 mm | 4 | | 0 | 0 | 0.00% | 0.00% | 100.00% | 0.001 |
| 2.38 mm | 8 | | 0 | 0 | 0.00% | 0.00% | 100.00% | 0.01 |
| 1.19 mm | 15 | 0.4 | 126.0 | 125.6 | 25.12% | 25.12% | 74.88% | 0.1 |
| 0.595 mm | 30 | 0.3 | 366.0 | 365.7 | 73.14% | 98.26% | 1.74% | 1 |
| 0.297 mm | 50 | 0.3 | 5 | 4.7 | 0.94% | 99.20% | 0.80% | 10 |
| | | | Total Weight= | 496 | | 0 | | |
| | Medium Sand: (0.8-1.2mm) | | | | | | | |
| | | Weight of empty sieve (kg) | soil weight retained (grams) | Soil retained | %ret | cum. %ret | Percent Passing (%) | Particle Diameter |
| Standard Sieve Opening (mm) | Mesh No. | A | B | C=B-A | D= (C)/Total Weight *100 | E= D + E"i-1" | F= 100 - E | |
| 4.76 mm | 4 | | 0 | 0 | 0.00% | 0.00% | 100.00% | 0.001 |
| 2.38 mm | 8 | | 0 | 0 | 0.00% | 0.00% | 100.00% | 0.01 |
| 1.19 mm | 15 | 0.4 | 148.4 | 148 | 29.60% | 29.60% | 70.40% | 0.1 |
| 0.595 mm | 30 | 0.3 | 343.3 | 343 | 68.60% | 98.20% | 1.80% | 1 |
| 0.297 mm | 50 | 0.3 | 6.3 | 6 | 1.20% | 99.40% | 0.60% | 10 |
| | | | Total Weight= | 497 | | | | |

| | C) Coarse Sand: (1-2mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Weight of empty sieve (kg) | soil weight retained (grams) | Soil retained | %ret | cum. %ret | Percent Passing (%) | Particle Diameter |
| Standard Sieve Opening (mm) | Mesh No. | A | B | C=B-A | D= (C)/Total Weight *100 | E= D + E"i-1" | F= 100 - E | |
| 4.76 mm | 4 | | 0 | 0 | 0.00% | 0.00% | 100.00% | 0.001 |
| 2.38 mm | 8 | | 211 | 211 | 42.20% | 42.20% | 57.80% | 0.01 |
| 1.19 mm | 15 | 0.4 | 286 | 285.6 | 57.12% | 99.32% | 0.68% | 0.1 |
| 0.595 mm | 30 | 0.3 | 1 | 0.7 | 0.14% | 99.46% | 0.54% | 1 |
| 0.297 mm | 50 | | 0 | 0 | 0.00% | 99.46% | 0.54% | 10 |
| | | | Total Weight= | 497.3 | | | | |

Steps on how the sieve analysis was held:

1. Meshes weight (A) is measured empty after cleaning and drying, mesh#15 is 0.4 grams, mesh#30 is 0.3 grams and mesh#50 is 0.3 grams.
2. Sieves are stacked on top of each other with the bigger mesh size on top then the smaller on the bottom.
3. 500 grams of each sand type is taken, starting with the fine sand, then medium, then coarse.
4. The 5 identified mesh numbers (4, 8, 15, 30, 50) were used on the shaker for 5 minutes. These specific meshes were chosen as per the range of sand granules of this study.
5. Soil retained weight is the remaining sand weight on the mesh minus the weight of the mesh itself which was measured earlier.
6. % Retention is calculated by dividing the soil retained weight in grams/ total sample weight in grams.
7. The cumulative % represents the summation of the total retention % across the sample, for example the cumulative % of mesh 30 in the fine sand = 73.2 + 25.2 % = 98.4 %.
8. The % passing represents the percentage of sand granules passing through the mesh, i.e., the granules that have a diameter < the mesh sieve diameter.
9. The total weight at the end of each sieve analysis per sand granule size represents the total weight of sand granules on the total meshes used. For example, the fine sand total weight after sieve analysis = 496.7 grams which means that 3.3 grams of fine sand are losses during the sieve shaking. Similarly, to the medium and coarse sand analysis.
10. (Cu) represents the ratio of 10% of the sample particles are smaller than the sieve size while 90% are bigger than the sieve size. From the graphs, (Cu) at 10% and 60% is measured to calculate the coefficient of uniformity (Cu). This is calculated from the graphs in figures 4.10, 4.11 and 4.12.

11. (Cu) value below 4 identifies poorly/ uniformly graded sand size as shown in tables 4.5 and 4.7, while (Cu)>4 is well graded and recommended as shown in table 4.6.

**A) Fine Sand Analysis versus Particle Diameter**

Table 4.5: Fine Sand (Cu) Calculation

| Fine Sand | | range | comment |
|---|---|---|---|
| Cu= D60/D10 | 0.375 | <4 | poorly/uniformly graded |

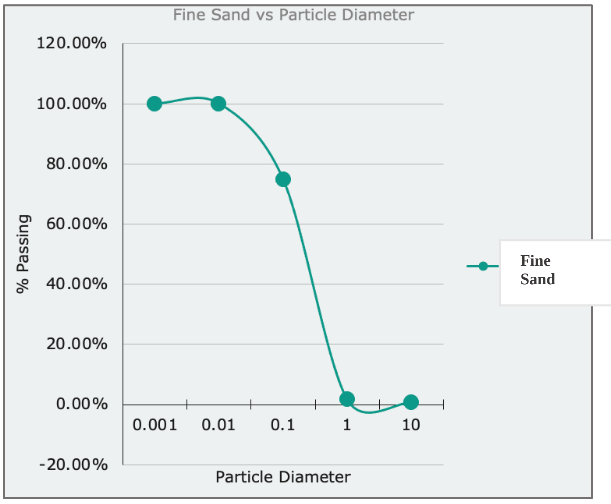



Figure 4.10: Fine Sand Sieve Analysis versus Particle Size

**B) Medium Sand Analysis versus Particle Diameter**

Table 4.6: Medium Sand (Cu) Calculation

| Medium Sand | | range | comment |
|---|---|---|---|
| Cu= D60/D10 | 0.44 | >4 | well graded |

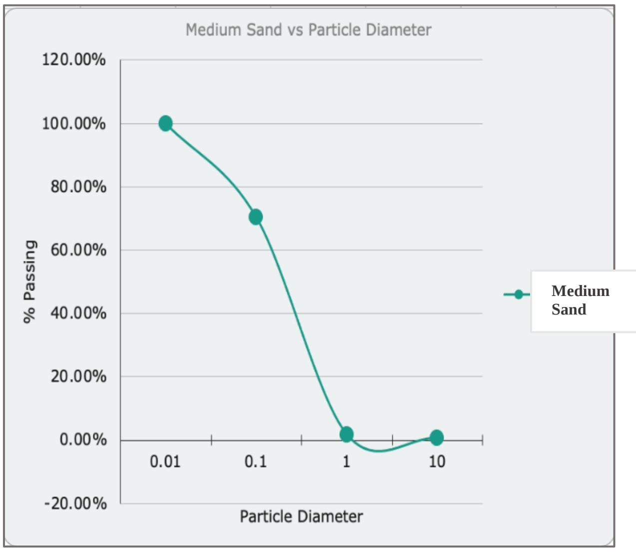



Figure 4.11: Medium Sand Sieve Analysis versus Particle Size

**C) Coarse Sand Analysis versus Particle Diameter**

Table 4.7: Coarse Sand (Cu) Calculation

| Coarse Sand | | range | comment |
|---|---|---|---|
| Cu= D60/D10 | 0.12 | <4 | poorly/uniformly graded |

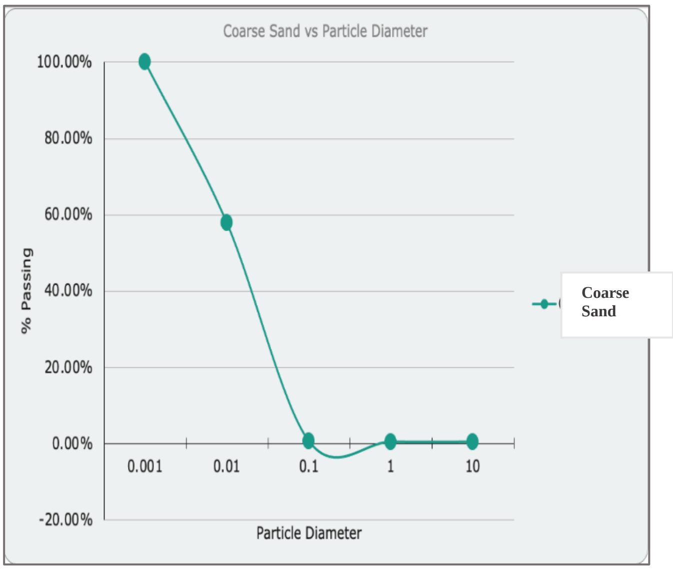



Figure 4.12: Coarse Sand Sieve Analysis versus Particle Size

### 4.2.1.C: Phase 2: Sand Filter Design: studying the best rate of filtration

Phase 2 ran for 12 intermittent runs with an objective of studying the effect of different rates of filtration across the 3 sand filters columns. In this phase, 4 main system modifications were applied to further enhance the system access, appeal, space and energy consumption. The first modification is done with the sand filters in which new sand filter columns designs are used as shown in Figures 4.13 and 4.14, with a middle sleeve at 85cm from the bottom of the sand filter. This modification is recommended as it provides easier access to the sand bed in case of any maintenance required. The second modification is at the sedimentation stage in which the sedimentation tank was substituted with a vertical sedimentation column for smaller space.

The sedimentation column had 3 parallel valves on the same level, each valve is feeding a sand filter. This is adjusted instead of having one tab controlling the flow out of the sedimentation column which is connected to valves controlling the flow into each sand filter as done in phase 1; also, this is for a better rate of filtration change and control by having parallel lines of water flow instead of one line that any change/ blockage through the main tube doesn't affect the 3 tabs at connected to each sand filter at once. One additional add on to the sedimentation column is a transparent piezometer to reflect the greywater level within the column. The third modification to the system design in phase 2, to save energy, the pump between the sedimentation tank and the sand filters in phase 1 was removed and substituted by elevating the sedimentation column in phase 2 at a higher level (60cm above the floor) allowing for gravitational flow of the greywater to the sand filters. The last modification entailed removing the sand bed sampling tabs at different depths as they were no longer needed in the experimental phases 2 through 5 and to avoid any leakage or sand disturbance that might occur.

In phase 2, the three sand filters were adjusted to include the medium sand size (0.8-1.2mm) at 65cm depth as concluded from phase 1. The 65cm sand was added in 10cm layers and compacted hard to ensure removal of any air gaps. Phase 2 ran with different rates of filtration at each sand filter; the rates of filtration studied in this phase are $2m^3/m^2/d$, $4m^3/m^2/d$ and $6m^3/m^2/d$. The rates of filtration considered in this phase are based on several literature reference where a wide ROF between 0.1-0.5 $m^3/m^2/h$ which is equivalent to 2.4$m^3/m^2/d$ – 12$m^3/m^2/d$ [98]. Another reference used $2m^3/m^2/d$, $4m^3/m^2/d$ and $6m^3/m^2/d$ [97]; also, references [99] and [100] suggested a safe sand filter run at rates from 0.1 m/h – 0.2 m/h max. Lastly, as per the World Health Organization (WHO) [101] slow sand filters are suggested to operate at ROF of 0.1-0.4 $m^3/m^2/h$

The samples collected in this phase are hourly samples and the parameters studied for each sample are the absorbents at 254nm reflecting organic matter, absorbents at 400nm reflecting turbidity, Delta H and dissolved oxygen (DO). Towards the end of phase 2, the aquatic filtration tanks were connected to the effluent from the sand filters to fill in the water hyacinth plants after acclimatization as discussed in phase 3.

Figure 4.14 shows a close-up on the sedimentation column 3 output nozzles, each is connected to a valve that to regulate the flow into each sand filter since this phase’s study is focused on studying three different rates of filtration.

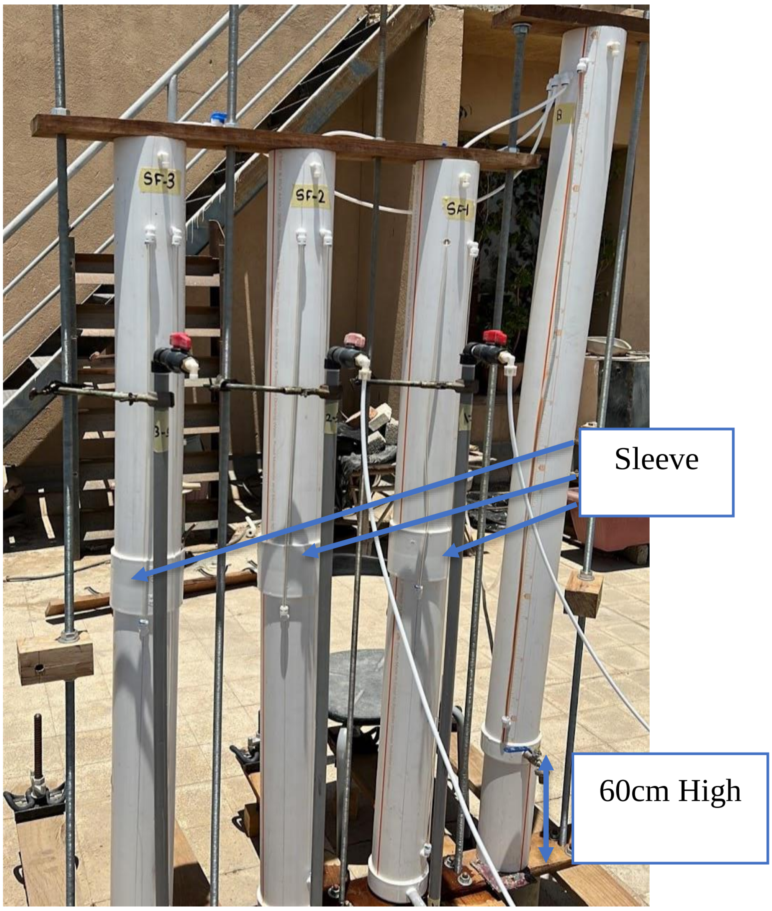



Figure 4.13: Phase 2- Sand Filter and Sedimentation Column Design


Figure 4.14: Phase 2 – Sedimentation Column Nozzles feeding each sand filter

**4.2.1.D: Phase 3: Aquatic Filtration Design: studying the best plant density with variant rates of filtration**

An important step in this phase is the plant acclimatization which started concurrently with the run of experimental phase 2. The water hyacinth plant was collected from a river side and delivered to the AUC New Campus, once received they were placed into water tanks as shown in figure 4.15. These tanks were full of tab water; before placing the hyacinth plants, any dead leaves or suspended impurities on the roots were removed by hands wearing thick gloves for safety. Then the hyacinth plants were added to the tanks for almost 3 weeks until the purple flowers and new leaves were noticed as shown in figure 4.16.

This phase ran for 9 days with intermittent runs and hourly samples with turbidity, dissolved oxygen (DO), pH, COD and TSS parameters of study. The selection of the wet surface plant densities to use in this experiment were initially based on previous literature [96] using different plant densities for greywater treatment, 0.803+0.066, 1.62+0.12, 2.37+0.155 and 4.34+0.242 $kg/m^2$which are in the range of 1 to 4.5 $kg/m^2$concluding that plant density of 2.173 $kg/m^2$ was the best for its equivalent experiment. Another study used 2 $kg/m^2$of wet plant density across the full experiment of for greywater treatment [102]. Hence, the wet surface plant densities used in this phase are 2 $kg/m^2$, 3.5$kg/m^2$ and 5$kg/m^2$. Another smaller scale study considered 1kg/$m^2$ [103]. The 3.5$kg/m^2$ is to resemble full aquatic tank capacity with homogenous plants placement with no congestion or big spacing between. The 5kg/$m^2$ encounter full aquatic tank capacity with slight congestion of plants. In phase 3.B, additional plant densities were added to widen the range of plant density study vs the best equivalent HLR to ROF of 4$m^3/m^2/d$ which is concluded from phase 2.

By the end of the previous phase, phase 2 run, the sand filters were connected to the aquatic filtration tanks shown in Figures 4.15 and 4.16, so that the effluent treated greywater from the sand filters is being collected inside the aquatic filtration tanks to fill them up and be ready for the hyacinth plants to be placed in them once acclimatized.

Figure 4.15: Acclimatizing the Water Hyacinth Plants

Figure 4.16: Acclimatized Water Hyacinth Plants

Figures 4.17 and 4.18 are schematic diagrams for the in-series integration between the sand filter and the aquatic plants. Figure 4.17 is reflecting the brief concept while figure 4.18 is reflecting the schematic for the actual system setup and implementation as applied in the pilot scale experiment in figure 4.19.

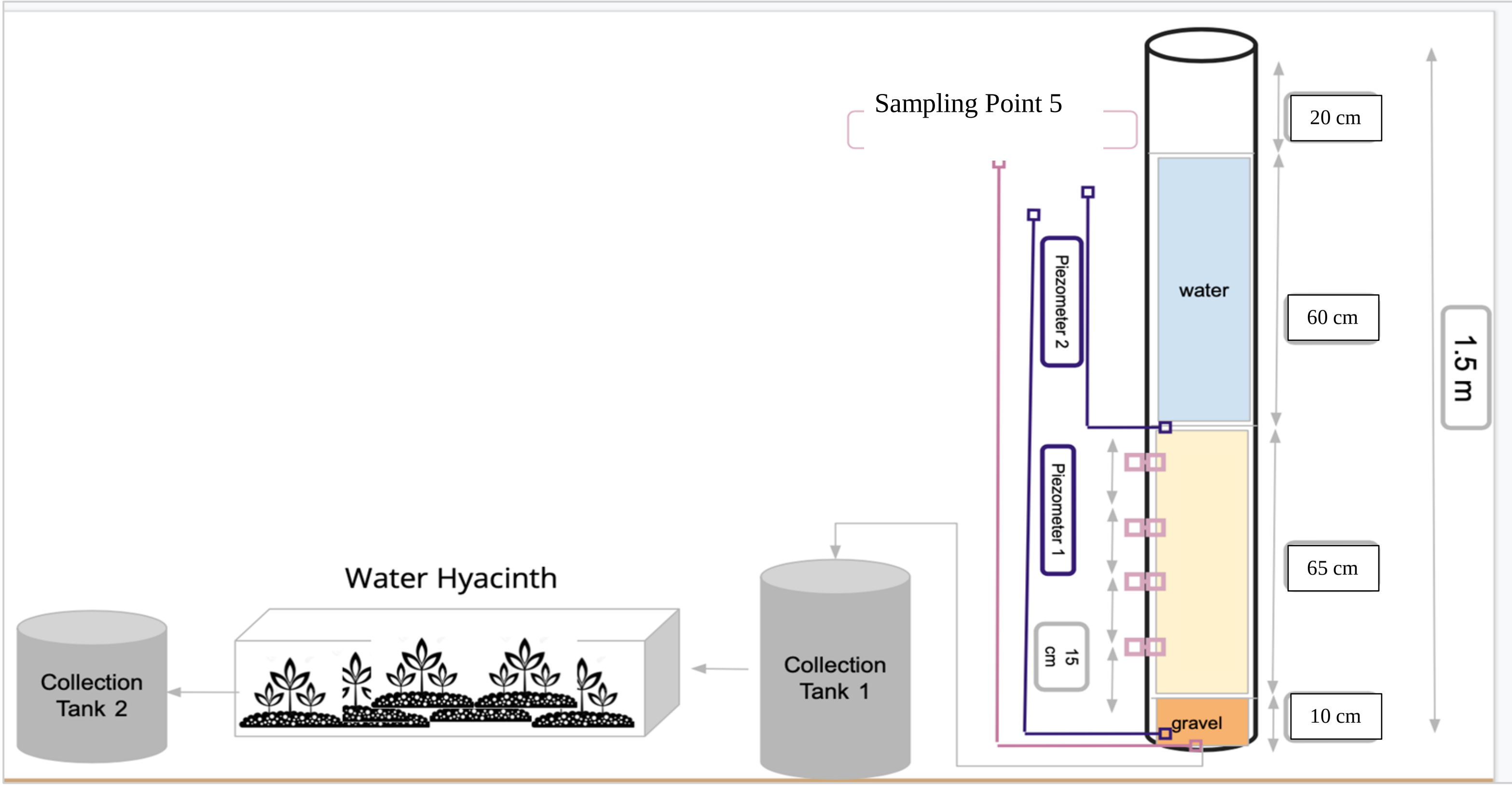



Figure 4.17: Sand Filter Connected with Aquatic Filtration Tanks Schematic

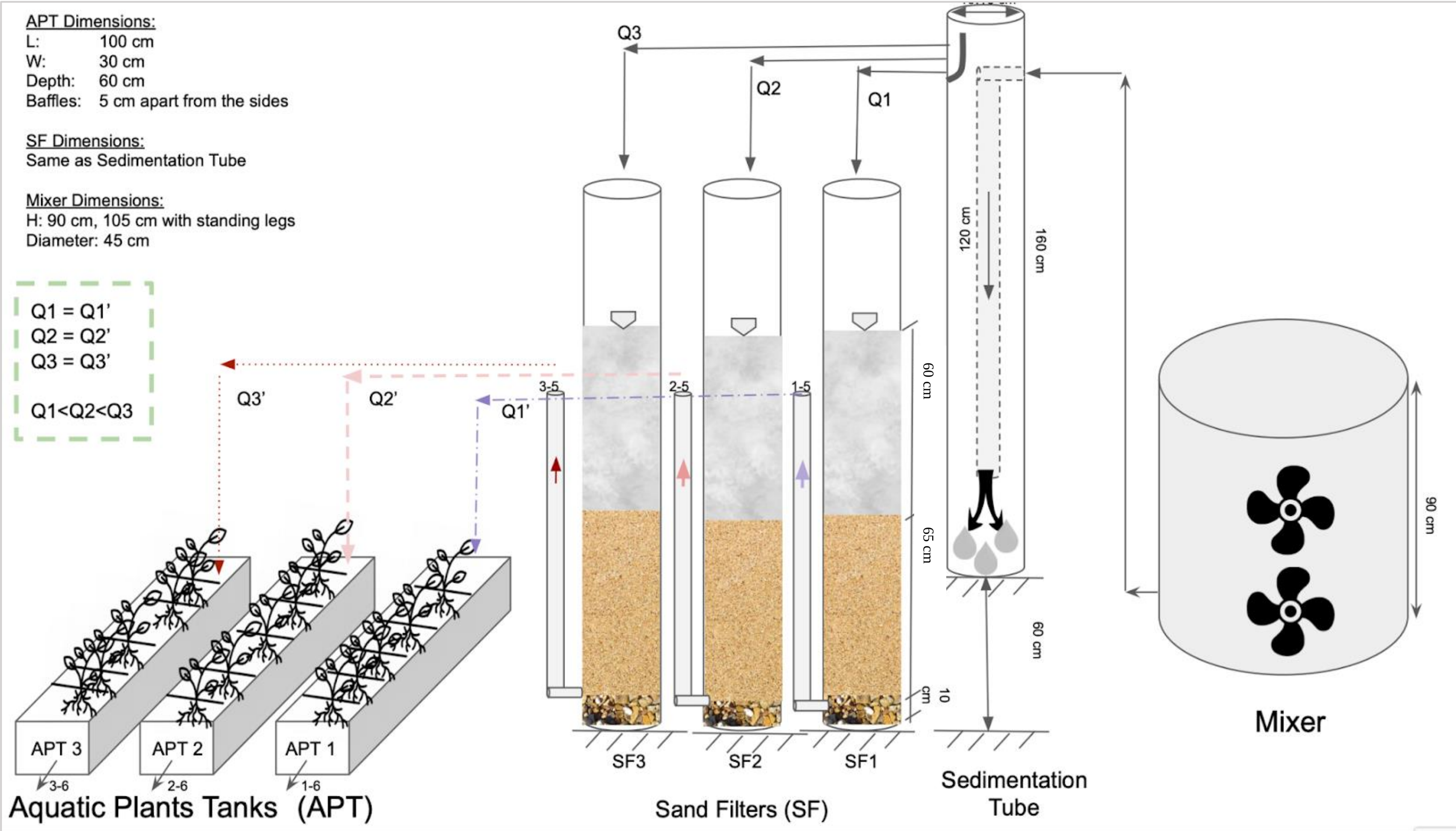



Figure 4.18: Full In-Series System Integration Schematic

Figure 4.19 shows the full integrated system starting with the electric mixer followed by the sedimentation column, then the sand filters and finally the aquatic filtration tanks. After the grey water is treated by the sand filter, it will be collected from SP1 at the gravel level and directly collected in the Aquatic filtration tanks for treatment and afterwards the treated greywater will be collected in collection tank 2 which is now sufficient to be used for toilet flushing and landscape irrigation.


Figure 4.19: Full In-Series System Integration Pilot Scale Image

The aquatic filtration tanks had a specific design with 2 baffles added to the container for better water flow and mixing with the plant's roots. The baffles act as water flow directional plates to further enhance the circulation and mixing while avoiding any short circuiting that might lead to less water and plants contact time and hence, low reaction. Both baffles are of the same dimensions however baffle one (B-1) at the inlet of the aquatic plant from the sand filter is placed at a 35 cm from the top distance and 5 cm from the tank side distance. While baffle two (B-2) at the outlet of the aquatic tank, near the last sampling point #6 is placed at 40 cm from the bottom and 5 cm from the tank side distance.

Also, 2 tabs were added one at the back of the aquatic tank where water from the collection tank 1 after the sand filter is pushed into the aquatic tank. And tab 2 is at the front bottom of the tank for final treated greywater post the aquatic filtration is collected. This is shown clearly in the next sections with actual images. In this phase, each aquatic tank contained different plant density from 2 $kg/m^2$, 3.5 $kg/m^2$ and 5 $kg/m^2$.

The aquatic filtration tank was of a rectangular design with 100cm total length, 32cm width and depth of 45cm; while the baffles included were rectangular shaped hard glass of 30cm length, 35cm width and 3mm thickness as shown in Figures 4.20 and 4.21.

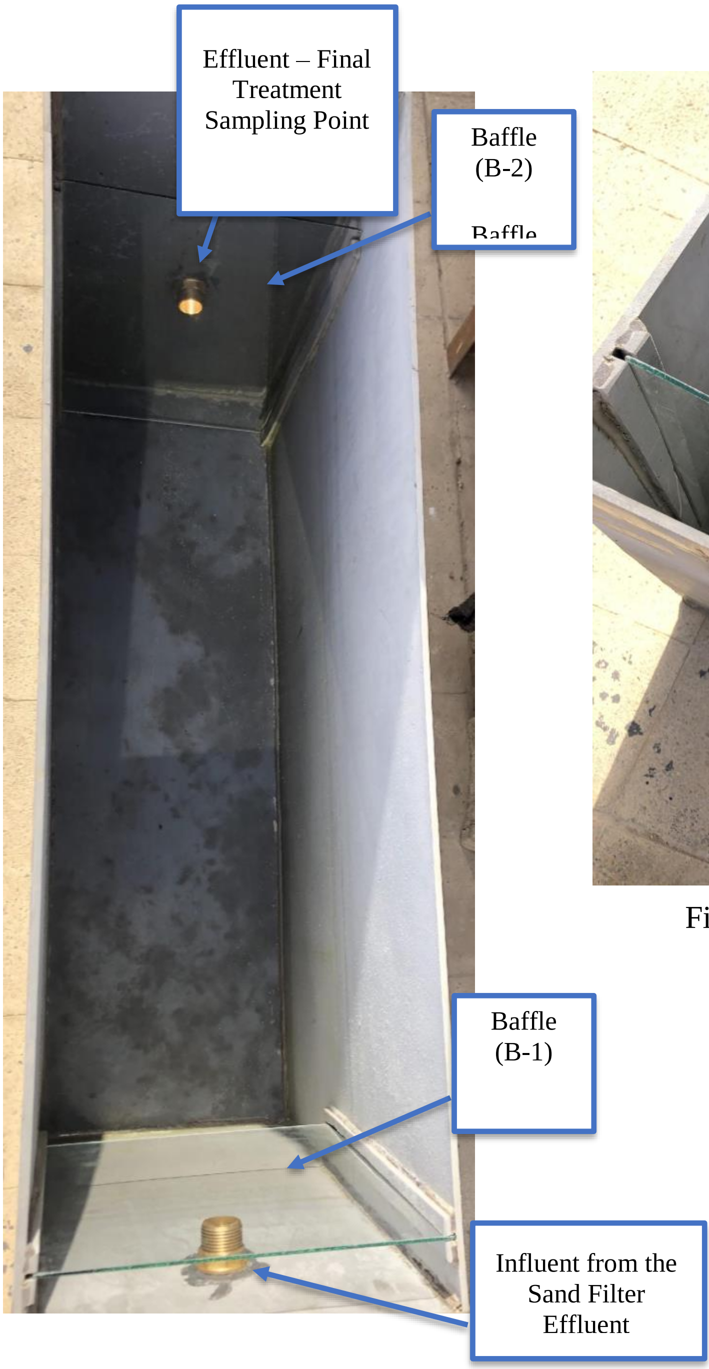



Figure 4.20: Aquatic Filtration Tanks- Top View

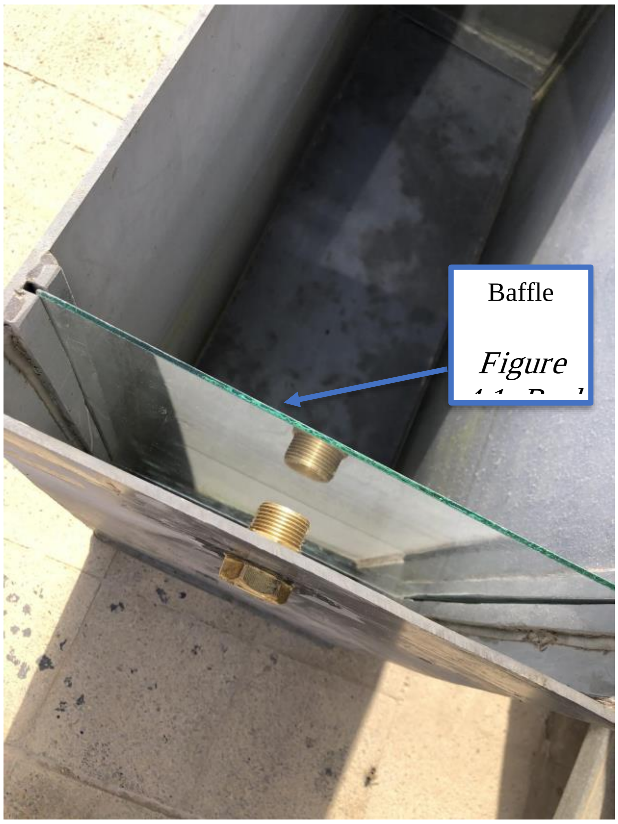



Figure 4.21: Aquatic Filtration Tanks- Baffles

#### 4.2.1.E: Phase 4: Full Integrated System Run Using Synthetic GW Mix

Phase 4 is conducted to study the best system design based on phases 1, 2 and 3 outputs under intermittent run and continuous run using greywater mix. In the intermittent run, the samples were taken on hourly basis for 8 hours per day and at the end of the day, the sand filters were emptied from any greywater within however, the aquatic tanks were ensured that sufficient primary treated greywater from the sand filter effluent is filling them for the plant hyacinth to operate.

For the continuous run, the samples were taken on hourly basis just like the intermittent run however, by the end of each sampling day, the sand filters were not emptied from the greywater inside the sand filter column. So, on the following day of operation, a new greywater mix is being add-on to yesterday's remaining greywater inside the sand filters. The parameters studied in this phase are turbidity, TSS and COD.

### 4.2.1.F: Phase 5: Full Integrated System Run Using Real GW

Phase 5 is conducted to study the best system design based on phases 1, 2 and 3 outputs under continuous run using real greywater. The real greywater was collected from the AUC faculty housing with 65% occupancy. The collected greywater is a result of bathroom sinks, bathroom showers and kitchen sinks. The real greywater was first studied alone to understand the sample parameters and then the system was run continuously. Since the mixer needed around 70L of real greywater to run, so the real greywater was collected in big containers as shown in figure 4.22, on hourly basis from the day before and it was kept in the refrigerator till the following day when the experiment starts. The parameters studied in this phase are turbidity, TSS, COD, BOD-5 and E. coli.

Figure 4.22: Real Greywater Collection Tanks

# Chapter 5

# RESULTS AND DISCUSSION

## 5.1: Proposed Integrated Community and Occupants' Rating System

A proposal framework and scorecard for a community and occupants' rating system to be of reference locally in Egypt while integrating net zero approaches is discussed in chapter 3. This proposal is built on the addition of occupants' health and wellbeing points within the existing Tarsheed- Communities rating system. Also, the inclusion of the net zero concept is added as credits under the related score card. Finally, a proposal for a separate net zero complimentary rating system is proposed as well in chapter 3.

## 5.2: Experimental Study

### 5.2.1: Phase 1: Sand Filter Design: Studying Different Sand Size vs Different Filtration Media Sand Bed Depth

a. Effect of filter media depth of different sand sizes on the removal of organics represented as absorbents @254nm– using Synthetic GW Mix

In phase 1, fine sand (0.4-0.8mm), medium sand (0.8-1.2mm) and coarse sand (1-2mm) types were studied in parallel to choose the best sand size applicable for the sand filter design. Along with each sand size, five different sand bed depths were studied to choose the best sand bed depth providing the best organic removal and filtration. The sand depth data samples were taken at 5cm depth from the top sand bed level, 20cm depth, 35cm depth, 50cm depth and 65cm depth. Understanding the sand bed depth required for the slow sand filter operation is essential for both the treatment efficiency and the lifetime of the sand filter on which the sand change or removal shall occur while sand cost perspective and head loss shall be taken into consideration as the deeper the sand bed the higher is the pressure head loss.

The conclusion of this phase resulted in proceeding with medium sand (0.8-1.2mm) at sand depth of 65cm as reflected in the phase figures and this is in line with the recommendations of a SSF sand bed depth of filtration between 0.5-0.8m as per several studies of reference [107] [108] [110] [111].

Figure 5.1 represents the mean absorbents @254nm reflecting organic matter in comparison between the different sand types where medium sand has the lowest values at both absorbents limits followed by fine sand and then slightly far off is the coarse sand. The closer organic matter removal behavior between fine and medium sand is justified with the smaller sand sizes and sand pores that are more efficient in treatment where bacteria of bigger sizes will be trapped on top of the sand layer only allowing water to pass through the sand granules; during which, this accumulated bacterium will be the schmutzdecke layer. Figures 5.2 through 5.4 reflects mean absorbents @254nm at different depths for fine sand, the lowest value is obtained at 50cm depth; and, medium sand, 35cm and 50cm have very close values at both absorbents levels and lastly, for the coarse sand, 65cm depth shows the lowest absorbents level.

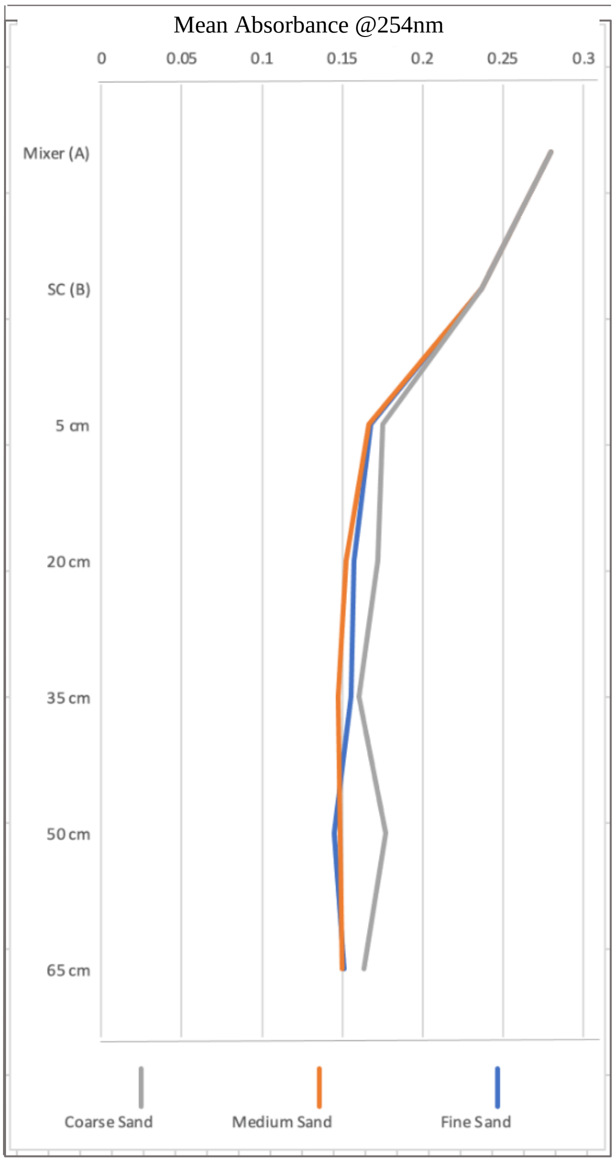



Figure 5.1: Phase 1.a: Effect of different sand sizes at different sand bed depths on the Mean Absorbance @254nm (n=36)


Figure 5.2: Phase 1.a: Fine Sand: Effect of different sand sizes at different sand bed depths on the Mean Absorbance- standard deviation @254nm (n=36)

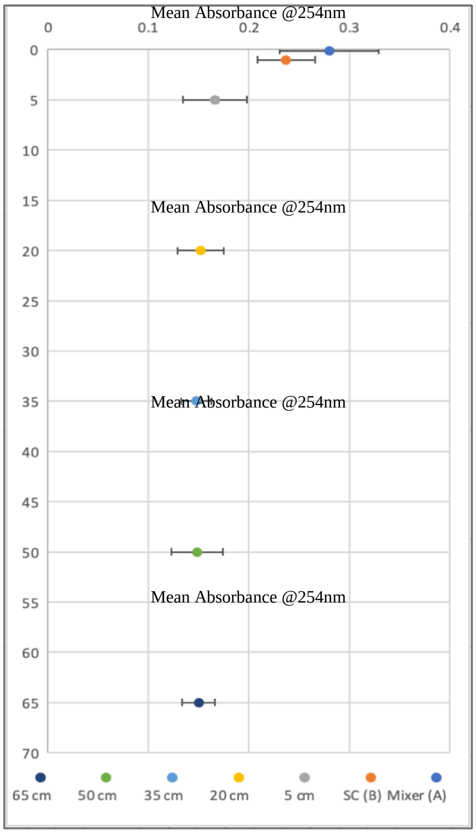



Figure 5.3: Phase 1.a: Medium Sand: Effect of different sand sizes at different sand bed depths on the Mean Absorbance- standard deviation @254nm (n=36)

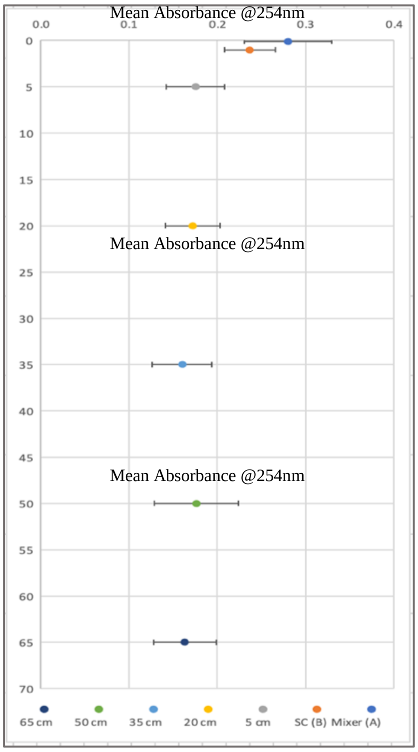



Figure 5.4: Phase 1.a: Coarse Sand: Effect of different sand sizes at different sand bed depths on the Mean Absorbance- standard deviation @254nm (n=36)

b. Effect of filter media depth of different sand sizes on the removal of turbidity represented as absorbents @400nm – using Synthetic GW Mix

Figure 5.5 shows the mean absorbents @400nm reflecting turbidity and figures 5.6 through 5.8 reflecting mean absorbents @400nm at different depths for fine sand, the lowest value is obtained at 50cm depth; while for the medium sand, 35cm and 50cm have very close values at both absorbents levels but the best turbidity removal is at 65cm and lastly for the coarse sand, 65cm depth shows the lowest absorbents level.

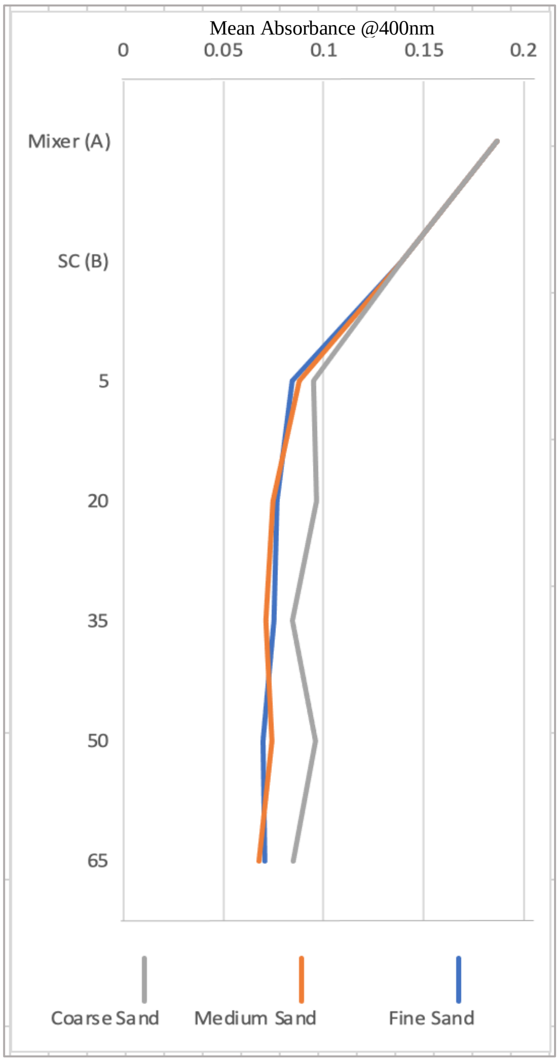



Figure 5.5: Phase 1.b: Effect of different sand sizes at different sand bed depths on the Mean Absorbance @400nm (n=36)

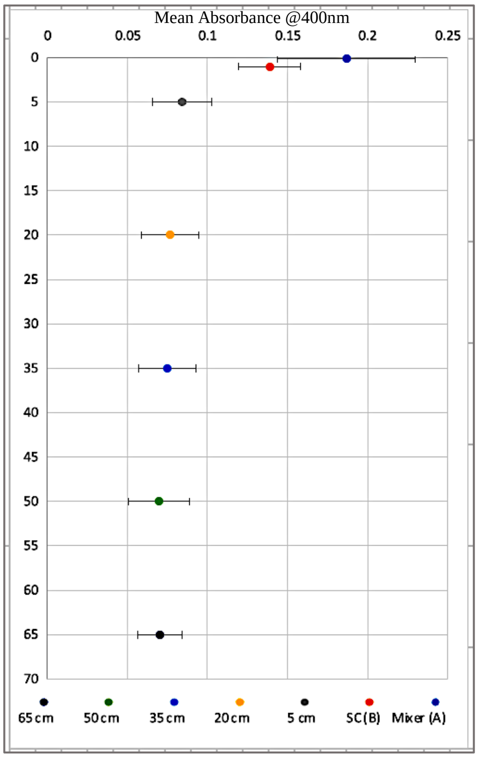



Figure 5.6: Phase 1.b: Fine Sand: Effect of different sand sizes at different sand bed depths on the Mean Absorbance- standard deviation @400nm (n=36)

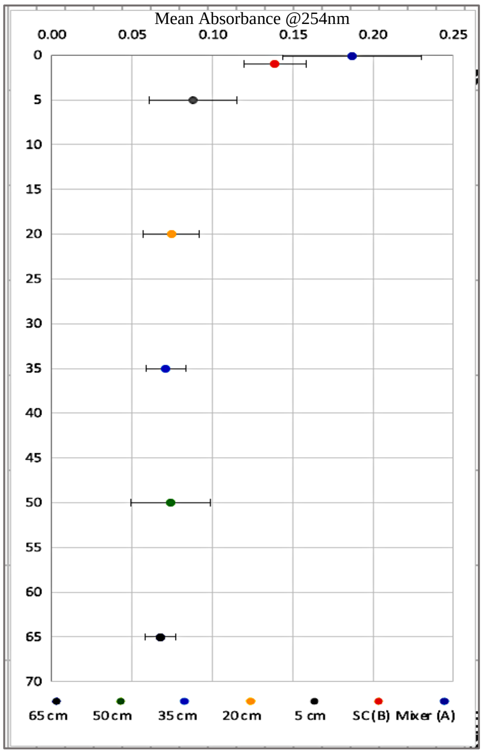



Figure 5.7: Phase 1.b: Medium Sand: Effect of different sand sizes at different sand bed depths on the Mean Absorbance- standard deviation @400nm (n=36)

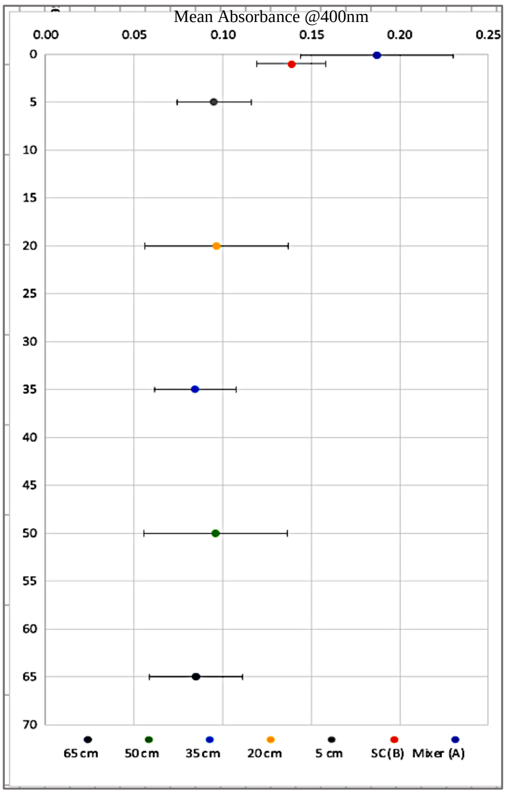



Figure 5.8: Phase 1.b: Coarse Sand: Effect of different sand sizes at different sand bed depths on the Mean Absorbance- standard deviation @400nm (n=36)

c. Effect of Different Sand Sizes on the Filtration Treatment Performance– using Synthetic GW Mix

Figure 5.9 represents the pressure drop (cm) versus different sand sizes. The fine sand has the highest pressure drop followed by medium then coarse and that is due to its bigger sand grain size with less friction between sand granules. Head loss increases with the finer sand as more friction takes place between the influent greywater and the smaller sand granules gaps.

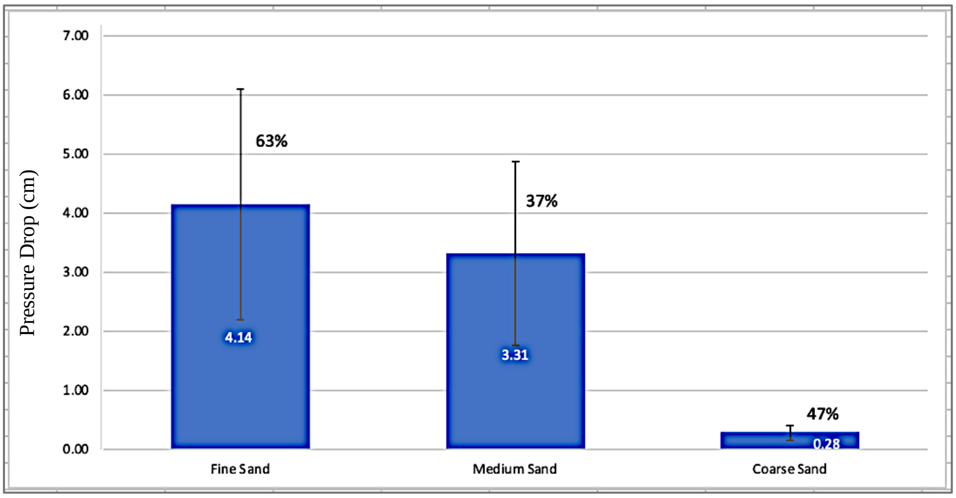



Figure 5.9: Phase 1.c: Effect of Different Sizes on the Pressure Drop (cm)

For the dissolved oxygen (DO) along the slow sand filter, the DO levels should decrease where there is a high aerobic activity due to the formation of the schmutzdecke layer formed highly of bacteria that is consuming the oxygen to break down the organic matter and support in the greywater treatment; this is seen in figure 5.10 at the first 5cm of the sand bed when comparing the values with the influent from the sedimentation column. Along the sand bed, the DO level decrease is slower with fine sand showing lowest DO levels till 20cm depth followed by the medium sand which shows even lower DO value than the fine sand at 50cm depth. Finally, the coarse sand shows almost a homogenous DO levels across all depths which shows lowest formation of the schmutzdecke layer and hence the slowest treatment. A noticeable DO % decrease from the sedimentation column level till the first 5cm sand bed depth where fine sand has the highest DO drop followed by medium sand;

and this indicates a faster formation of the bacterial layer on the fine sand than the medium sand at the same experimental duration run.

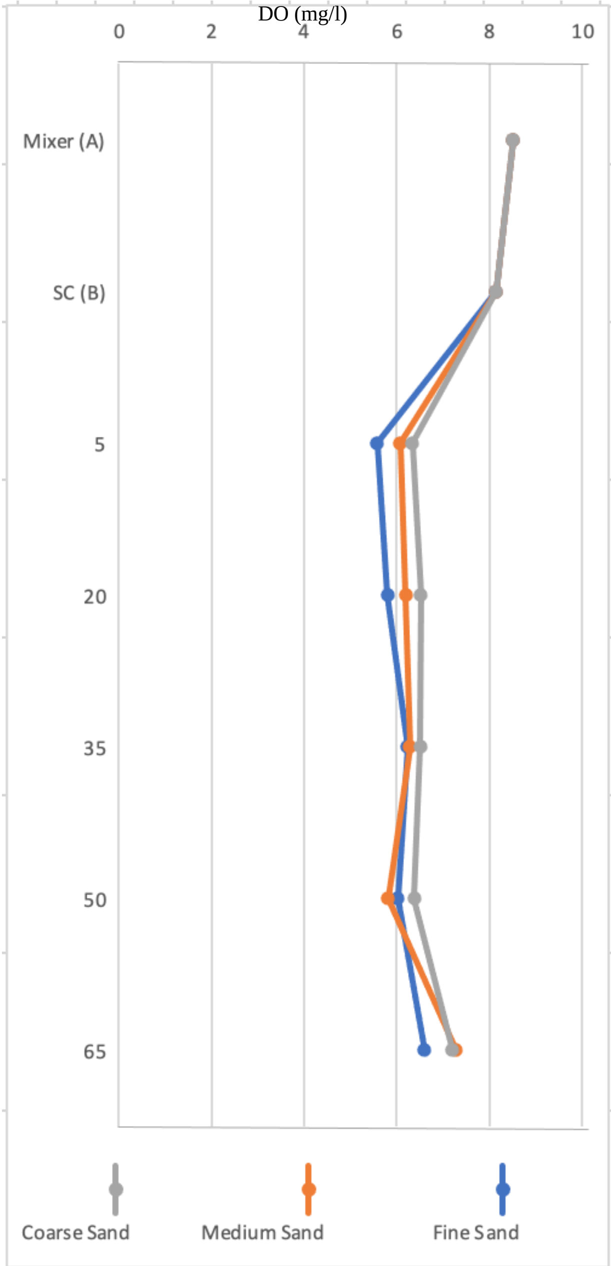



Figure 5.10: Phase 1.c: Effect of Different Sand Sizes on the Dissolved Oxygen (DO) (mg/l)

Figures 5.11 through 5.13 show the DO standard deviation across sand bed depth with the lowest DO level at 5cm depth for the fine sand with DO value of 5.6 mg/l, 50cm depth for the medium sand with DO value of 5.7 mg/l and 50cm depth for the coarse sand with DO value of 6.5 mg/l.

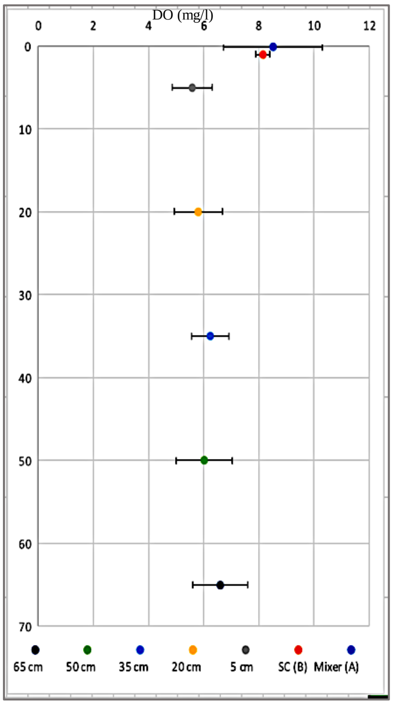



Figure 5.11: Phase 1.c: Fine Sand: Effect of Different Sand Sizes on the Dissolved Oxygen- Standard deviation, (n=6)

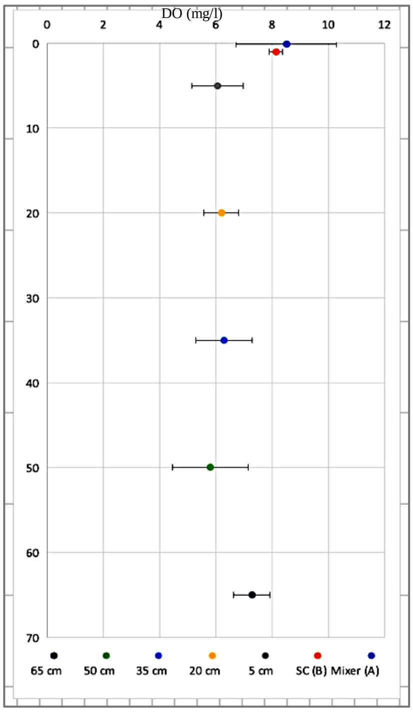



Figure 5.12: Phase 1.c: Medium Sand: Effect of Different Sand Sizes on the Dissolved Oxygen- Standard deviation, (n=6)

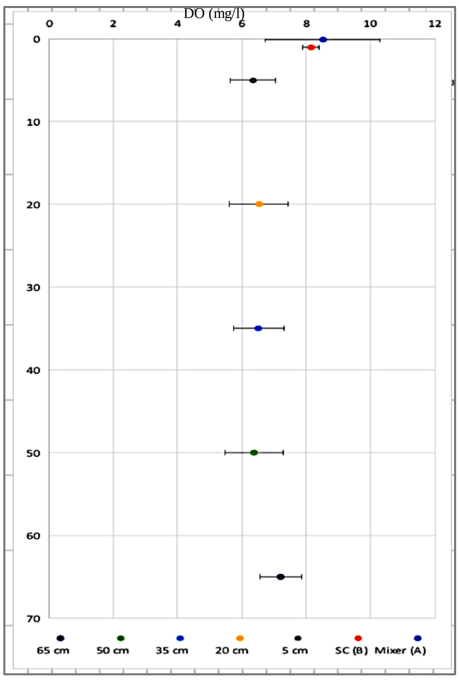



Figure 5.13: Phase 1.c: Coarse Sand: Effect of Different Sand Sizes on the Dissolved Oxygen- Standard deviation, (n=6)

### 5.2.2: Phase 2: Sand Filter Design: Studying the treatment efficiency through different ROF

The objective of this phase is to study the best rate of filtration (ROF) to run the slow sand filter with respect to phase 1 design outputs. The conclusion of phase 2 was to proceed with $4m^3/m^2/d$ for the slow sand filter run.

The output of this phase is to use ROF of 4 $m^3/m^2/d$ for the best slow sand filter treatment results and this is in line with the WHO [104] indicating that a permissible ROF for SSF is between 0.1 – 0.4 $m^3/h$ which is suffice for $2m^3/m^2/d$ and $4m^3/m^2/d$. This result is in line with several studies of reference [78] and [108]

Figures 5.14 and 5.15 show the mean absorbents @254nm reflecting organic matter and @400nm reflecting turbidity with respect to each rate of filtration of study. It is visible that the $4m^3/m^2/d$ has the lowest mean absorbents levels @254nm and @400nm reflecting better treatment and removal of organic matters while also, the sand filter with $4m^3/m^2/$d has the lowest Pressure Drop when compared to the other rates of filtration as shown in figure 5.16. This is justified as it is known from laminar flow rate concept that increasing the flow rate will increase the pressure drop and that is noticed at 6 $m^3/m^2/d$ while also, the formation of the schmutzdecke layer is slower in progress when compared with 2 $m^3/m^2/d$ which is giving higher pressure drop due to the thicker bacterial cake layer causing resistance of flow. 4 $m^3/m^2/d$ shows the lowest pressure drop reflecting acceptable bacterial layer formation allowing the greywater to pass with the relevant flow rate in use.

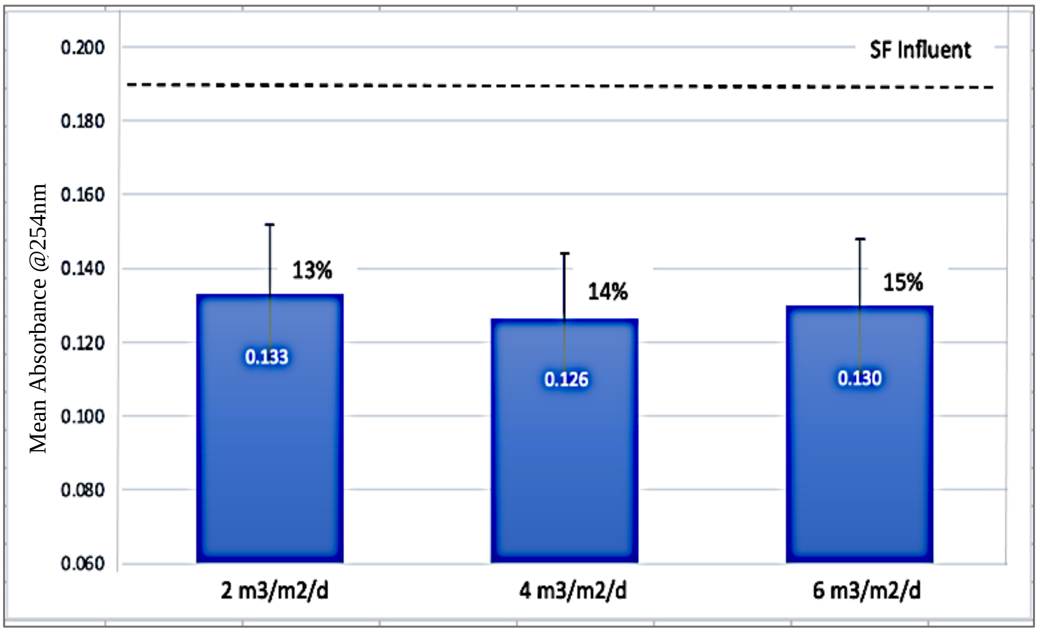



Figure 5.14: Phase 2: Effect of Different Sand Filter Rate of Filtration on the Mean Absorbance at 254nm (n=61)

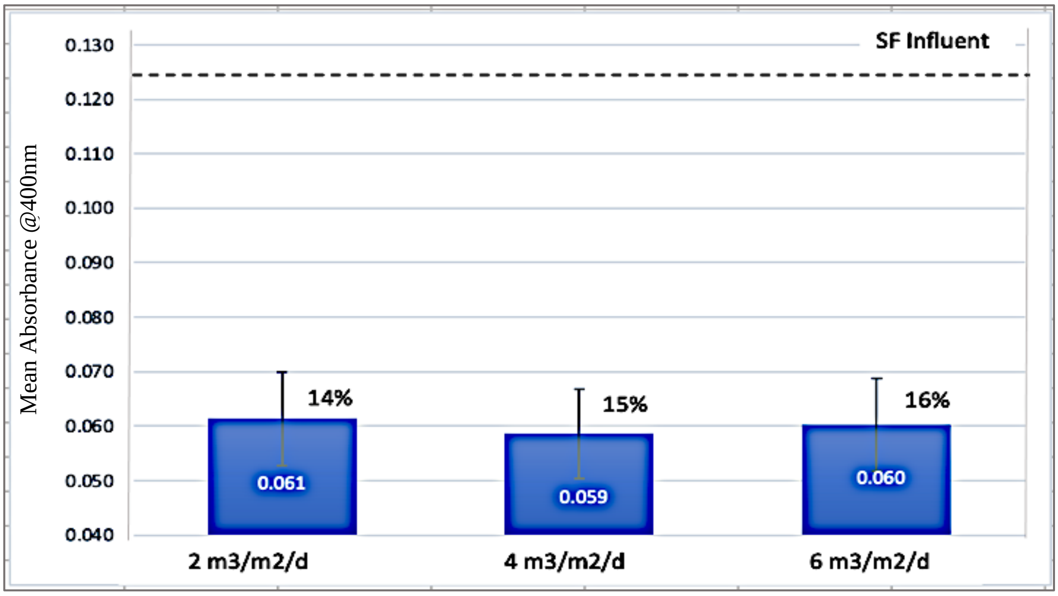



Figure 5.15: Phase 2: Effect of Different Sand Filter Rate of Filtration on the Mean Absorbance at 400nm (n=61)

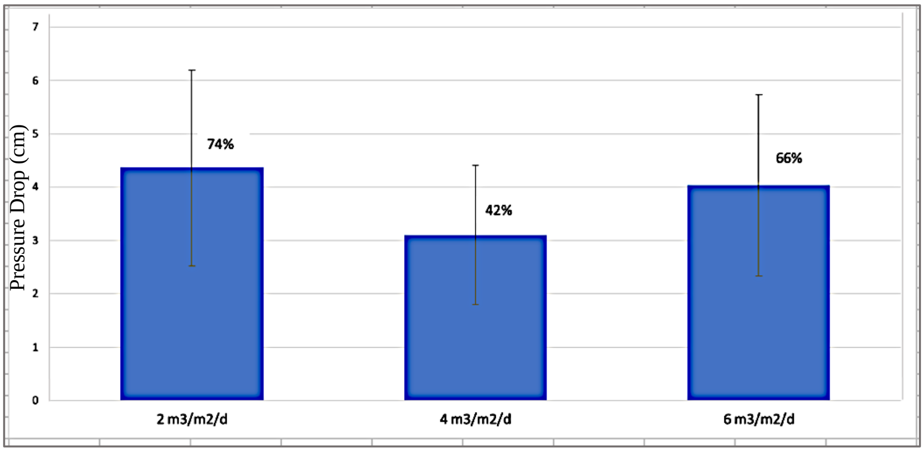



Figure 5.16: Phase 2: Effect of Different Sand Filter Rate of Filtration on the Pressure Drop (cm)

Figure 5.17 shows the mean DO across different rates of filtration; $6m^3/m^2$/d shows the lowest DO followed by $4m^3/m^2$/d then $2m^3/m^2$/d. Even though the $4m^3/m^2$/d has the 2nd best mean DO value however, it is sufficient for organic matter and turbidity removal as shown in figures 5.14 and 5.15.

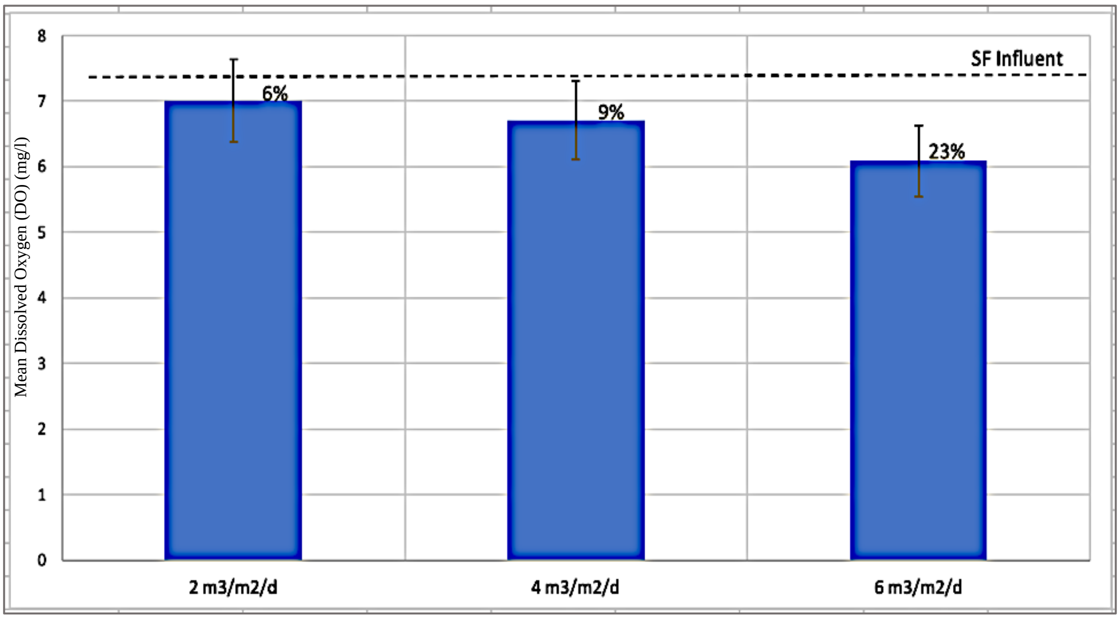



Figure 5.17: Phase 2: Effect of Different Sand Filter Rate of Filtration on the Dissolved Oxygen (DO) (n=61)

**5.2.3: Phase 3: Aquatic Filtration Integration with the Sand Filter Design: Effect of Different Plant Density with different Sand Filter Rates of Filtration**

Phase 3 is studying the effect of different flow rates versus different plant densities. This phase is further divided into 3 sub-phases in which 3.A is studying the effect of ROF of $2m^3/m^2/d$ (equivalent to hydraulic loading rate (HLR) of 0.054 $m^3/m^2/d$) versus 2 $kg/m^2$, 3.5 $kg/m^2$ and 5 $kg/m^2$ water hyacinth wet plant densities. Sub-phase 3.B is studying the effect of ROF of $4m^3/m^2/d$ (equivalent to hydraulic loading rate of 0.078 $m^3/m^2$/d) versus 1 $kg/m^2$, 2 $kg/m^2$, 3.5 $kg/m^2$, 5 $kg/m^2$ and 6 $kg/m^2$ water hyacinth wet plant densities. Additional plant densities were studied in this phase as it is shown from Phase 2 that it is the best ROF to run the slow sand filter; however, studying more PD variance data was added for widening the experimental exposure. Sub-phase 3.C is studying the effect of ROF of $6m^3/m^2/d$ (equivalent to hydraulic loading rate of 0.162 $m^3/m^2/d$) versus 2 $kg/m^2$, 3.5 $kg/m^2$ and 5 $kg/m^2$ water hyacinth wet plant densities. The conclusion of each sub-phase is added at the end of each sub-section however, it is noticed that the mean turbidity levels increase with the increase of flow rate across the same plant density with an increase in TSS (grams) levels on the initial day of study with an enhanced PD TSS removal efficiency along the runs while increasing the flow rate.

Another angle to look at the data in this phase for correlation, increasing the plant density across the same flow rate doesn’t show a consistent mean turbidity trend however, TSS trend is visible to be increasing on the first day of the run while increasing plant density however, the lower the plant density leads to an increase in TSS level or saturation towards the final run as shown with 2 $kg/m^2$ on the contrary, increasing the plant density to 5 $kg/m^2$ shows TSS removal but at a lower rate and this can be due to the high density of roots in the tank. At 3.5 $kg/m^2$ the TSS removal is best towards the final run across the three different flow rates, and this reflects proper balance between the plant density and the roots spacing; yet with increasing the influent flow rate the plant at 3.5 $kg/m^2$ needs more time to accommodate than at lower flow rates.

COD (mg/l) shows a decrease in trend by increasing the plant density as more organic compound oxidization. pH is in the acceptable limit with slight increase across PD within runs.

**Phase 3.A: Effect of different PD at Sand Filter ROF= 2 $m^3/m^2/d$ using Synthetic GW Mix**

In phase 3.A, the sand filter rate of filtration of $2m^3/m^2/d$ was studied versus three different water hyacinth plant densities (PD) of 2 $kg/m^2$, 3.5 $kg/m^2$ and 5 $kg/m^2$. After the below analysis, it is recommended to use PD of 3.5 $kg/m^2$ versus ROF of $2m^3/m^2/d$ for better water treatment levels. The 5 $kg/m^2$ can be used at this ROF as well, however, as seen in figure 5.2.19, it is showing 25% turbidity enhancement from day 1 till day 7 yet, it is taking longer time of treatment as higher time is needed for suspended solids settling shown in the time (days) needed to meet the ECP-category (A) limit. The increase in turbidity among different plant densities can be justified by the growth levels of algae and other bacteria.

The mean turbidity presented below reflects bacteria, algae, and any other dissolved matters than cause sample un-clarity yet the turbidity removal treatment is effective along the sand filter and the water hyacinth plants.

The 3.5 $kg/m^2$ PD shows the best lowest mean turbidity value across the runs as shown in Figure 5.18 even though it is higher than the allowable ECP- category (A) limit however, looking at figure 5.19 reflects the turbidity enhancement along the runs while meeting the ECP-category (A) limit of 5. The 5 $kg/m^2$ is showing a trend line improvement across the runs however, it is taking longer time than the 3.5 $kg/m^2$ to saturate whereas, the 2 $kg/m^2$ is showing almost no treatment effect across the runs.

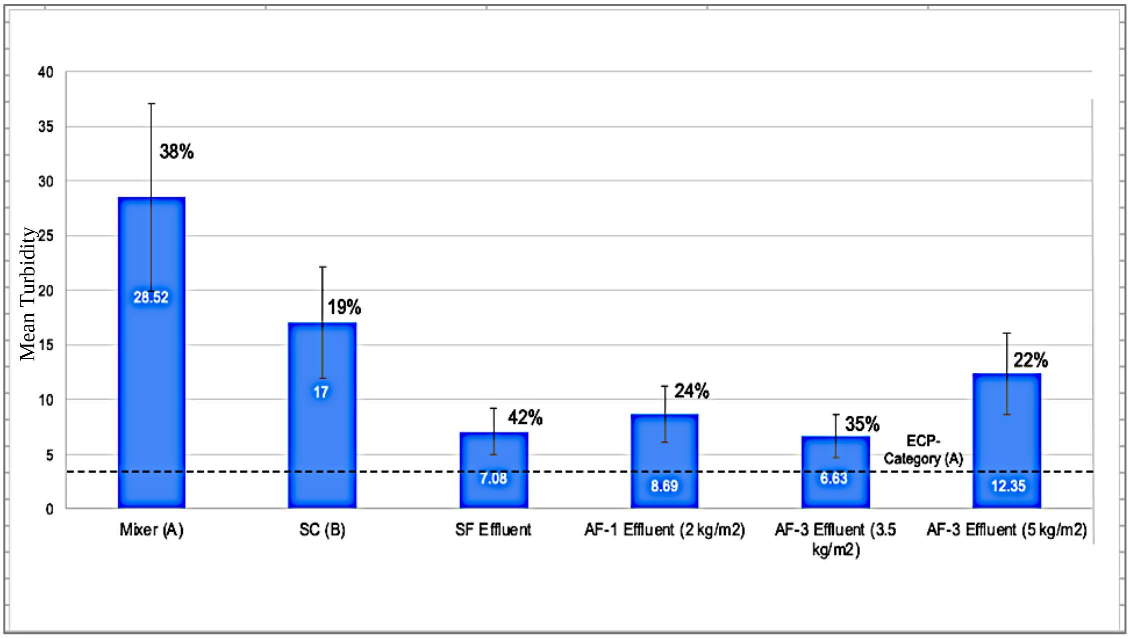



Figure 5.18: Phase 3.A: Effect of Different Plant Density (PD) ($kg/m^2$) on the Mean Turbidity at Sand Filter Rate of Filtration (ROF)= 2 $m^3/m^2/d$

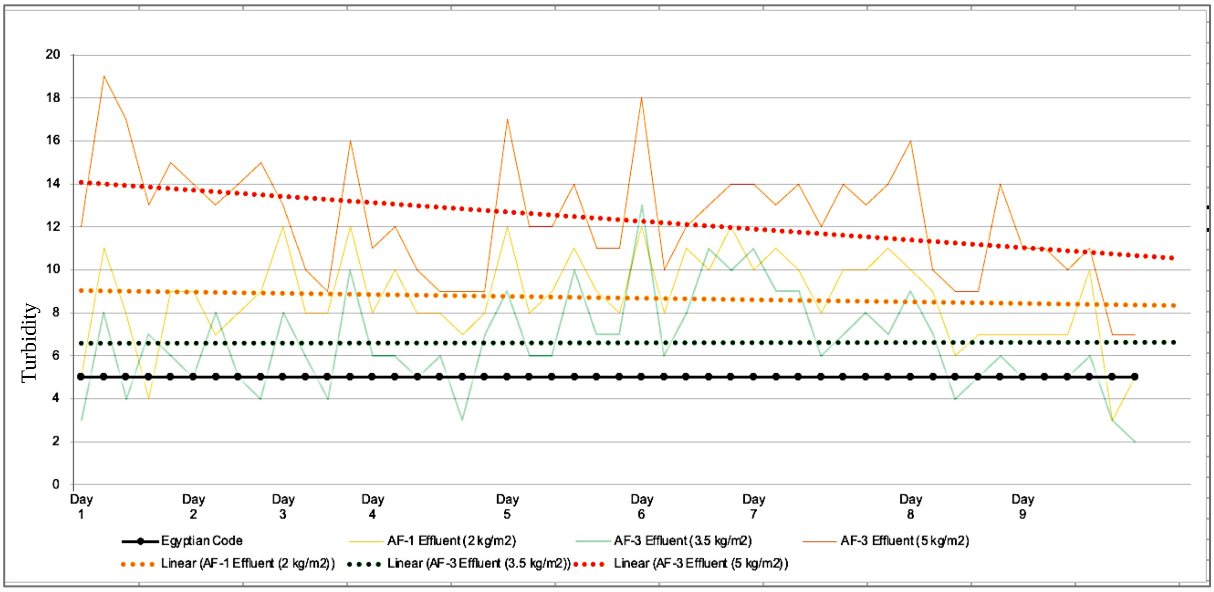



Figure 5.19: Phase 3.A: Effect of Different PD ($kg/m^2$) on the Turbidity at Sand Filter ROF= 2 $m^3/m^2/d$

TSS was measured on day 3 and on day 7 (final run day) to see the effect of the plants treatment behavior of removing suspended solids along the runs. Figure 5.2.20 shows an increase in TSS level at 2 $kg/m^2$ and this reflects low removal efficiency due to inadaptability of low plant density with the influent flow rate in removing the suspended solid. Yet, 3.5 $kg/m^2$ reflect decrease in TSS levels showing that this relevant plant density is sufficient for treatment vs the influent flow rate. For 5 $kg/m^2$ it is showing the highest TSS removal along the experimental run and this is correlated with this PD having the best pH levels among the other PDs; hence having a more inhabitable environment for growth and anaerobic treatment.

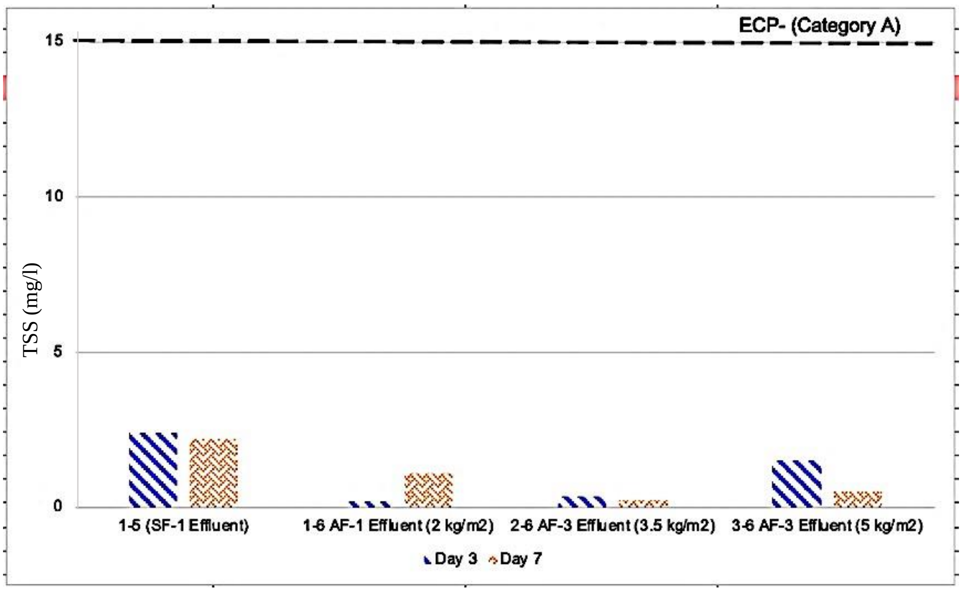



Figure 5.20: Phase 3.A: Effect of Different PD ($kg/m^2$) on the TSS Removal (mg/l) at Sand Filter ROF= 2 $m^3/m^2/d$

COD level is decreasing while increasing the PD with 3.5 $kg/m^2$ and 5 $kg/m^2$ showing the best reflections meeting the KSA code for greywater treatment and reuse a limit as shown in figure 5.21. As plant density increases and so does the plant roots length, as more contaminants degradation occur, more organics removal leading to lower COD levels.

It is witnessed that the best COD level enhancement between the sand filter and the plant density is achieved at PD 5 $kg/m^2$ of 30% and this is correlated with the pH values in figure 5.22 as it is closest to the neutral value 7 as the lower pH the better aerobic activity from the plant's roots.

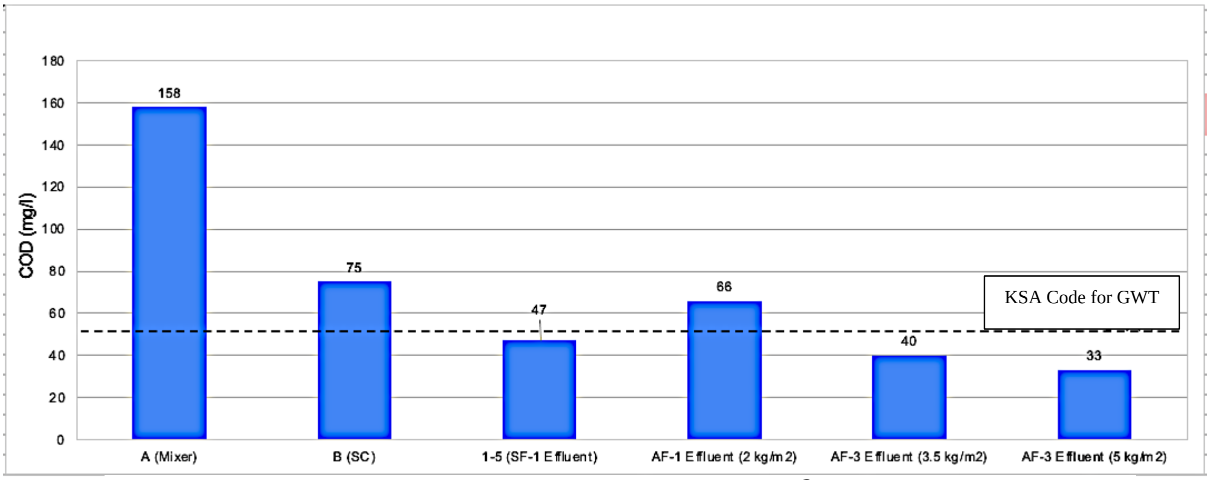



Figure 5.21: Phase 3.A: Effect of Different PD ($kg/m^2$) on COD (mg/l) at Sand Filter ROF= 2 $m^3/m^2/d$

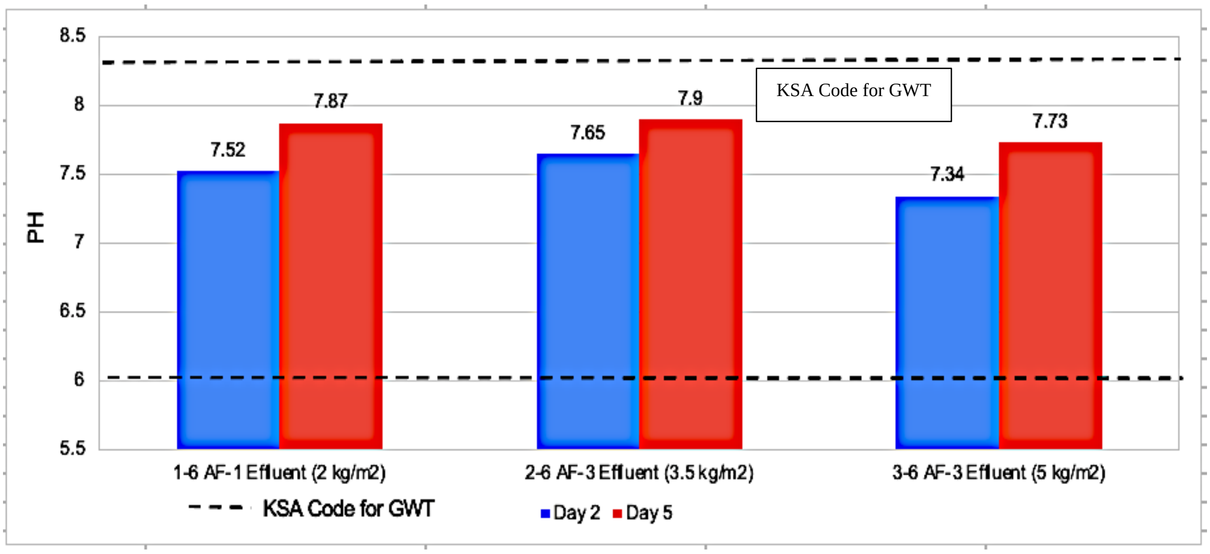



Figure 5.22: Phase 3.A: Effect of Different PD ($kg/m^2$) on pH at Sand Filter ROF= 2 $m^3/m^2/d$

In conclusion to sub-phase A, both plant densities of 3.5 $kg/m^2$ and 5 $kg/m^2$ show treatment improvement from the sand filter stage however, the 5 $kg/m^2$ is leading to higher turbidity values and it is taking longer time for the plants to stabilize while also, the higher the plant density, the denser the roots, the higher the water evaporation rate and the faster the need to clean the tank. The 2 $kg/m^2$ is showing higher values than the ECP- Category (A) limits with an increase in TSS (grams) value across runs which reflects lack of adaptability to treat the influent greywater with such low plant density. Hence, it is recommended to use 3.5 $kg/m^2$ with the 2 $m^3/m^2$/d ROF.

**Phase 3.B: Effect of different PD at Sand Filter ROF= 4 $m^3/m^2/d$ using Synthetic GW Mix**

In phase 3.B, the sand filter rate of filtration of $4m^3/m^2$/d was studied versus five different water hyacinth plant densities (PD) of 1 $kg/m^2$, 2 $kg/m^2$, 3.5 $kg/m^2$, 5 $kg/m^2$ and 6 $kg/m^2$. Plant density 3.5 $kg/m^2$ show the best lowest mean turbidity value across the runs with a slight enhancement on the sand filter mean turbidity level as shown in figure 5.23 which is also reflected in figure 5.24 with the distribution of turbidity values across the runs to show the enhancement of turbidity removal approaching the ECP acceptable value towards day 5. As a conclusion of this phase, the best plant density considered for the $4m^3/m^2$/d rate of filtration is the 3.5 $kg/m^2$.

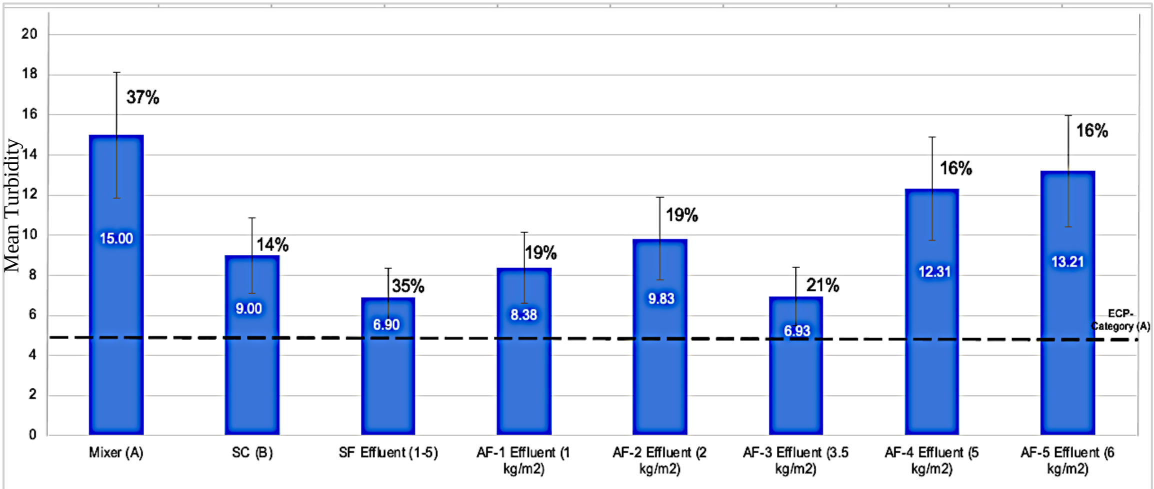



Figure 5.23: Phase 3.B: Effect of Different PD ($kg/m^2$) on Mean Turbidity at Sand Filter ROF= 4 $m^3/m^2/d$

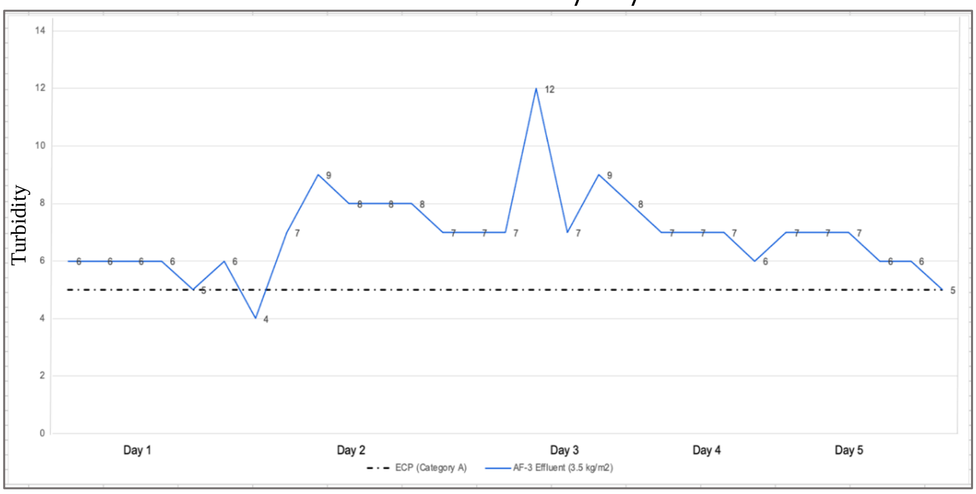



Figure 5.24: Phase 3.B: Effect of Different PD ($kg/m^2$) on Turbidity at Sand Filter ROF= 4 $m^3/m^2/d$

Figure 5.25 shows the TSS levels with 1 $kg/m^2$ and 2 $kg/m^2$ having almost the same values as the sand filter effluent value which is the aquatic filtration influent; hence almost no treatment is done by the aquatic plants at these densities. For the 3.5 $kg/m^2$, a higher TSS value that decreases by the end of the run is shown, and it is considered due to the plant density and the denser roots by time and adapting to the rate of filtration with the presence more roots trapping suspended matters, reflecting TSS value lower than the acceptable ECP value. For the 5 $kg/m^2$ and 6 $kg/m^2$, they reflect very high TSS values than the ECP code due to more dense roots and higher level of impurities; hence they are disregarded.

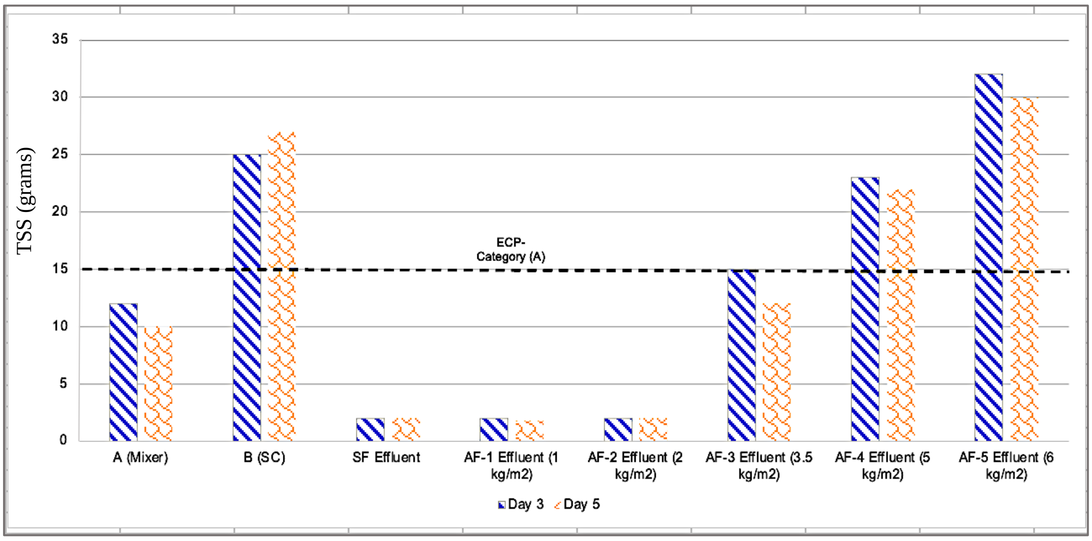



Figure 5.25: Phase 3.B: Effect of Different PD ($kg/m^2$) on TSS (mg/l) at Sand Filter ROF= 4 $m^3/m^2/d$

COD removal efficiency vary along the runs and along the plant densities as shown in figure 5.26; there is a noticeable decrease between day 3 and day 5 along all PD except 1 $kg/m^2$ which is showing low adaptation and treatment reflecting improper PD with respect to the influent flow rate. The best COD removals are seen at PDs of 3.5 $kg/m^2$and 5 $kg/m^2$ due to their fast adaption and adequate pH levels along the full runs as shown in figure 5.27 with a higher pH level towards the final run reflecting the possibility of high algae formation causing the water to be more alkaline. This reflects inhabitable environment for plant growth and treatment meeting ECP- Category (A) limit and KSA Code for GWT code.

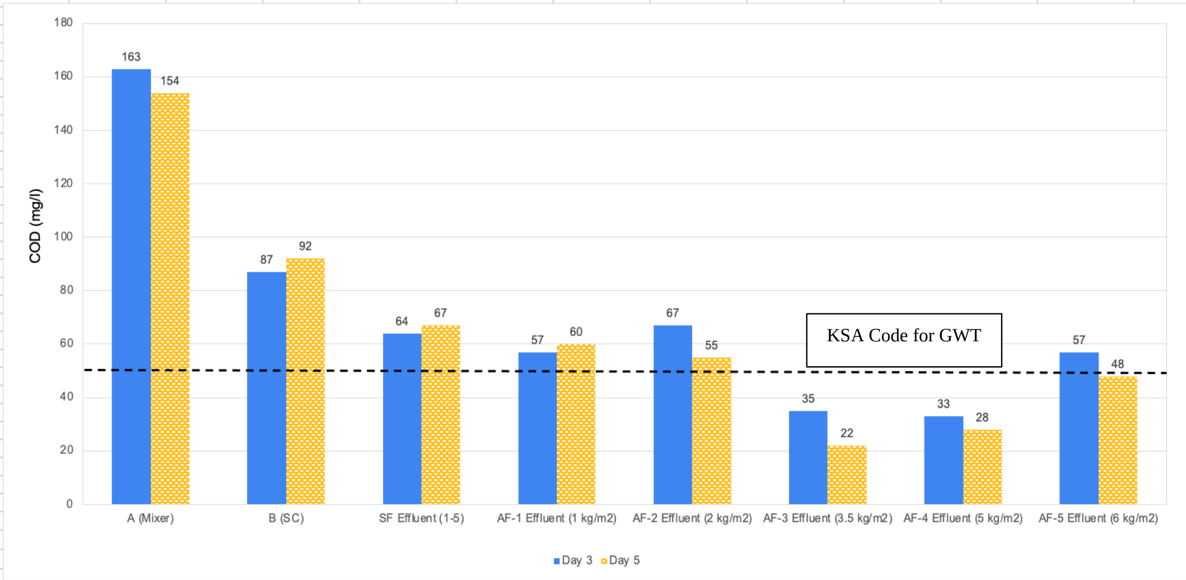



Figure 5.26: Phase 3.B: Effect of Different PD ($kg/m^2$) on COD (mg/l) at Sand Filter ROF= $4\ m^3/m^2/d$

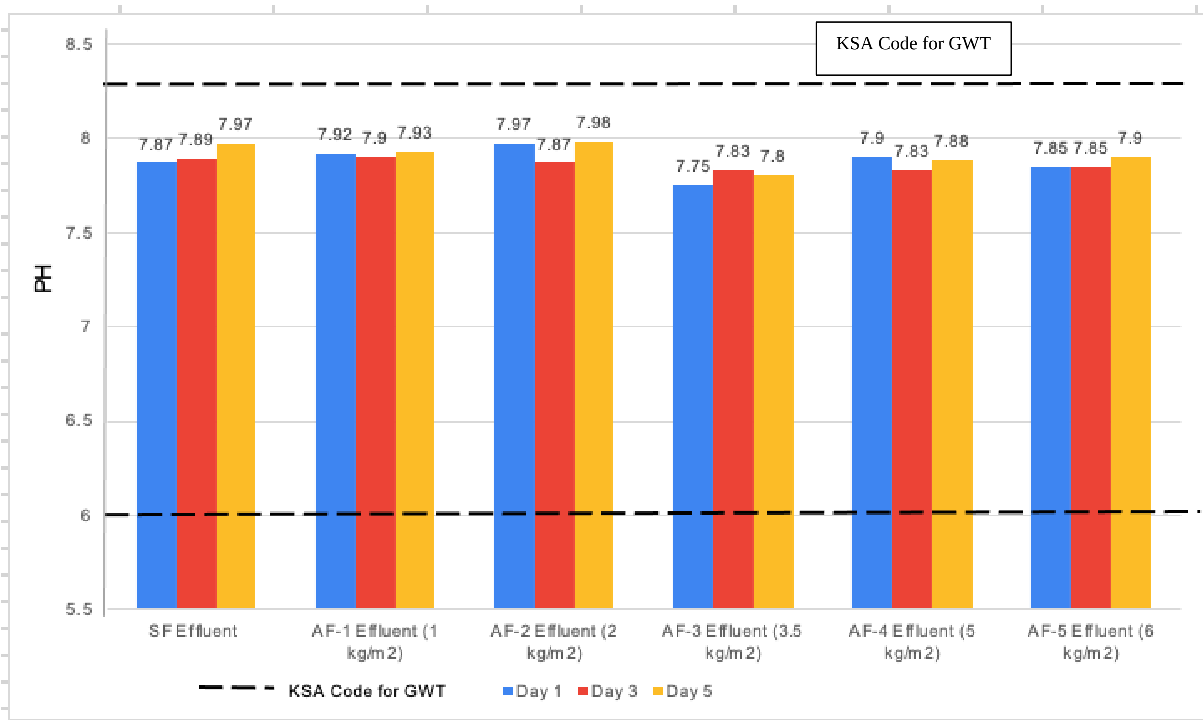



Figure 5.27: Phase 3.B: Effect of Different PD ($kg/m^2$) on pH at Sand Filter ROF= $4\ m^3/m^2/d$

In conclusion to sub-phase (B), as the plant density increases, the TSS (grams) is increasing on day 3 and decreasing across day 5. PDs 1 $kg/m^2$and 2 $kg/m^2$show low to almost no treatment effectives from the sand filter stage unlike the other PDs. 5 $kg/m^2$ and 6 $kg/m^2$reflect high TSS (grams) levels above the ECP- Category (A) limit reflecting denser roots and more suspended particles in the tank. Even though the COD levels are best at both 3.5 $kg/m^2$and 5 $kg/m^2$showing closer values to one another and both are below the ECP-Category (A) limit however, 3.5 $kg/m^2$continues to show the best removal efficiency showing adaptability and proper balance between the plant density, plant growth, tank size and rate of filtration; so, it is recommended to use with rate of filtration of 4 $m^3/m^2/$d.

**Phase 3.C: Effect of different PD at Sand Filter ROF= 6 $m^3/m^2/$d using Synthetic GW Mix**

In phase 3.C, the sand filter rate of filtration of 6$m^3/m^2$/d was studied versus three different water hyacinth plant densities of 2 $kg/m^2$, 3.5 $kg/m^2$ and 5 $kg/m^2$. Figure 5.28 shows the mean turbidity value with the 3.5 $kg/m^2$ having the lowest value with the biggest TSS value reduction between days 3 and 5 of the run as shown in figure 5.29. Even though 2 $kg/m^2$ has the second lowest turbidity value however, it is showing an increase in TSS along the runs and this reflect inadaptability of the plants roots for the needed treatment among the influent flow rate. The 5 $kg/m^2$ is the highest mean turbidity among the plant densities of studies however, it shows higher TSS reduction by the final run.

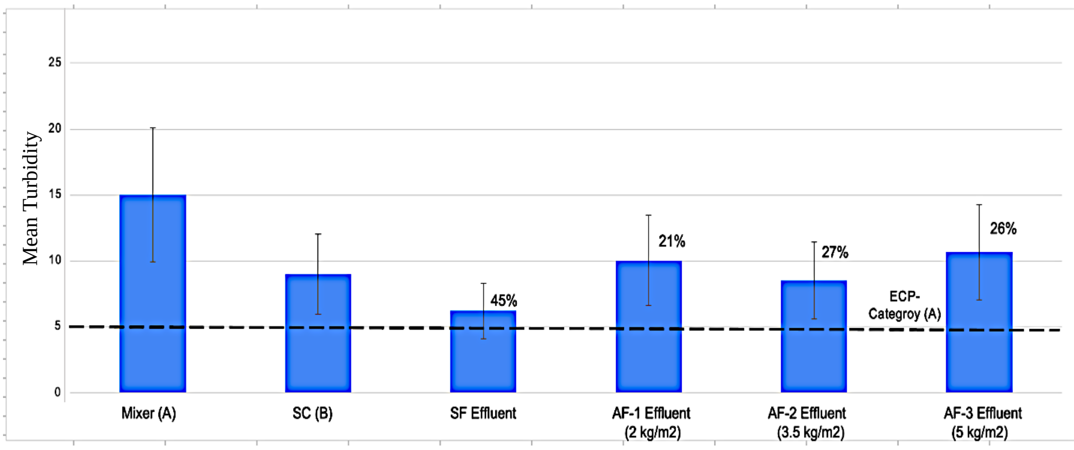



Figure 5.28: Phase 3.C: Effect of Different PD ($kg/m^2$) on Mean Turbidity at Sand Filter ROF= 6 $m^3/m^2/d$

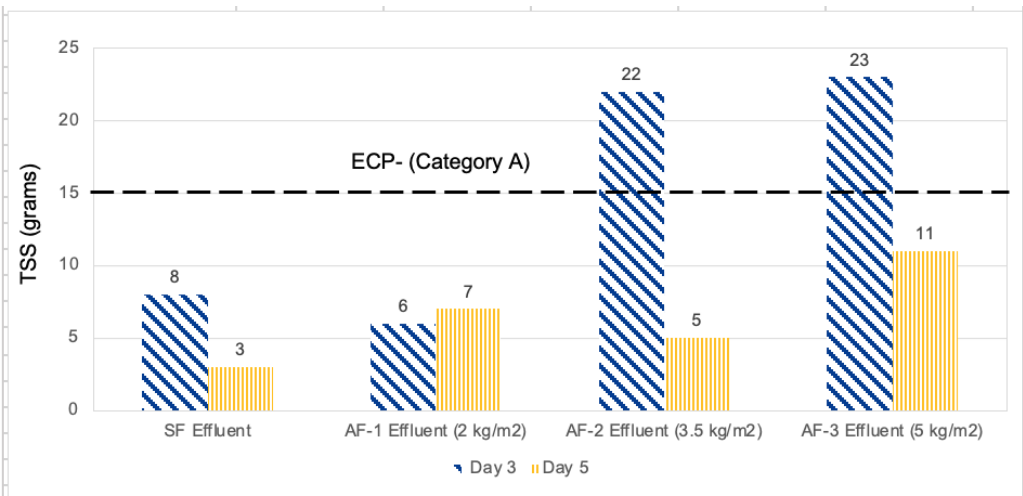



Figure 5.29: Phase 3.C: Effect of Different PD ($kg/m^2$) on TSS (grams) at Sand Filter ROF= 6 $m^3/m^2/d$

The COD trend decreases along increasing the PD and the is interconnected with the reduction of pH from the sand filter level to the aquatic filtration tanks driving enhanced microbial removal efficiencies in a more habitable plants environment. It is seen that the value of the 5 $kg/m^2$ is slightly lower than the 3.5 $kg/m^2$ yet under the acceptable KSA code for GWT for reuse in irrigation range of 50 mg/l as shown in figure 5.30.

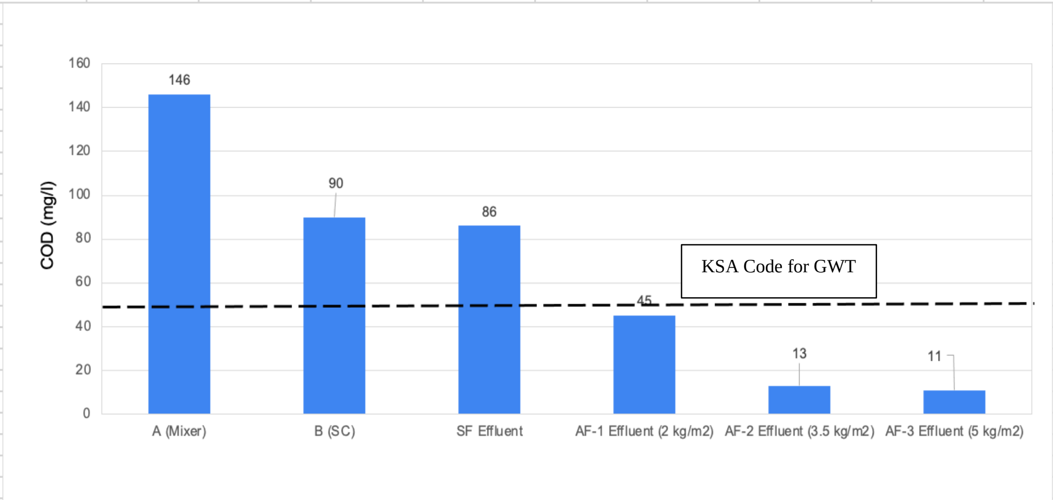



Figure 5.30: Phase 3.C: Effect of Different PD (kg/m^2) on COD (mg/l) at Sand Filter ROF= 6 m^3/m^2/d

Figure 5.31 shows the pH values for the different plant densities with 3 $kg/m^2$ being the lowest by the initial run however, the three plant densities have almost the same pH level towards the final run.

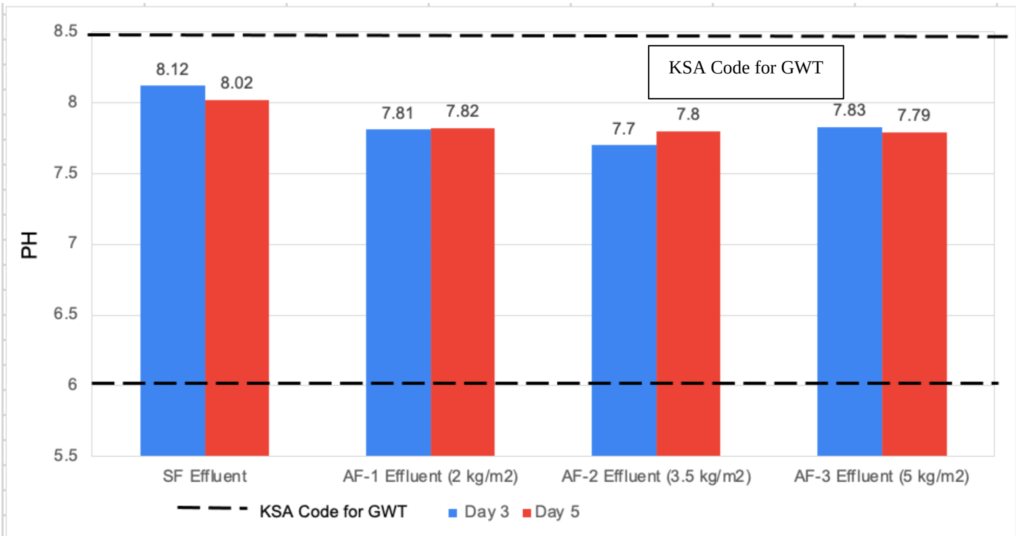



Figure 5.31: Phase 3.C: Effect of Different PD (kg/m^2) on pH at Sand Filter ROF= 6 m^3/m^2/d

In conclusion to this sub-phase C, both 3.5 $kg/m^2$ and 5 $kg/m^2$ show acceptable TSS (grams) and COD (mg/l) removal levels and treatment effectiveness while the 5 $kg/m^2$ shows a slight decrease in pH which reflects better roots adaptability. Hence, either of the plant densities can be used with respect to rate of filtration of 6 $m^3/m^2/$d with a preference of 5 $kg/m^2$ if the pH enhancement is to be taken into consideration and if operated for a longer duration, it might show more decline and improvement. For the high turbidity with respect to the influent flow rate, a slight design modification can be considered by adding a middle sedimentation tank can be proposed to be placed between the sand filter and the aquatic plants leading treated water to further settle before getting into aquatic plants treatment at the same flow rate.

### 5.2.4: Phase 4: Running the Integrated SF and AF system in series with the best design parameters

Phase 4 further studies the in-series sand filter and aquatic filtration integration using the best output design parameters from phases 1, 2 and 3 running the medium size (0.8-1.2mm) slow sand filter of 65 cm bed depth at ROF of 4 $m^3/m^2/$d. This is in-series with the aquatic plant tank of 3.5 $kg/m^2$ water hyacinth plants.

This phase is divided into two sub-phases, one is studying the full integrated system under intermittent (9 hours run per day, for 4 days) and the other sub-phase is to study running the full system under daily continuous runs for 4 days. In the intermittent runs, the slow sand filter was stopped and emptied from any synthetic greywater mixture in it while being allowed to dry over night until the following morning run. The continuous run had the system full with synthetic greywater mix over night and on the following day, the daily synthetic greywater mix was added on that from the previous day run in the slow sand filter.

The output results of this phase studying treated greywater parameters of Turbidity (NTU), TSS (mg/l) and COD (mg/l) are all in-line with the ECP-Category (A).

**Phase 4.A: Intermittent Run using Synthetic GW Mix**

In phase 4.A, the full in-series integrated sand filter and aquatic filtration were studied under intermittent run using synthetic greywater mix. The sand filter design and rate of filtration of $4m^3/m^2$/d were used as concluded from phases 1 through 3, while the best plant density used with reference to the sand filter rate of filtration is the 3.5 $kg/m^2$ as concluded from phase 3.B.

Figures 5.32 and 5.33 shows the mean turbidity and the standard deviation with both the sand filter and the aquatic filtration showing higher values than the ECP value. However, looking at Figure 5.34 reflecting a turbidity values distribution across the runs shows that the aquatic filtration was able to reach the ECP acceptable turbidity value of 5 on day 6 of the run.

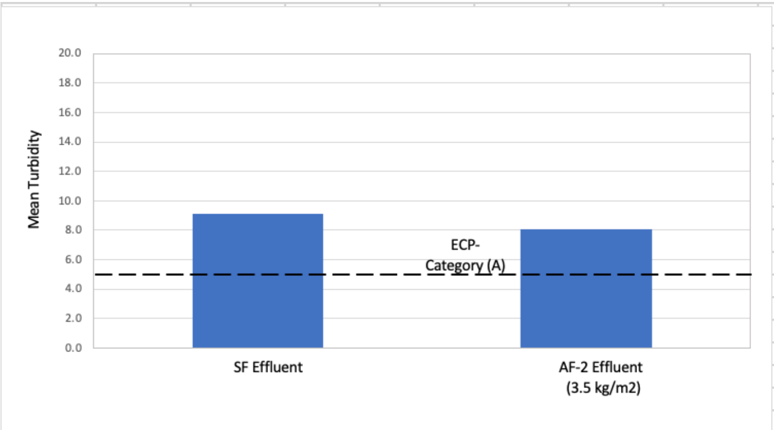



Figure 5.32: Phase 4.A: Effect of Integrated SF and AF System on Mean Turbidity- Intermittent Run (n=27)

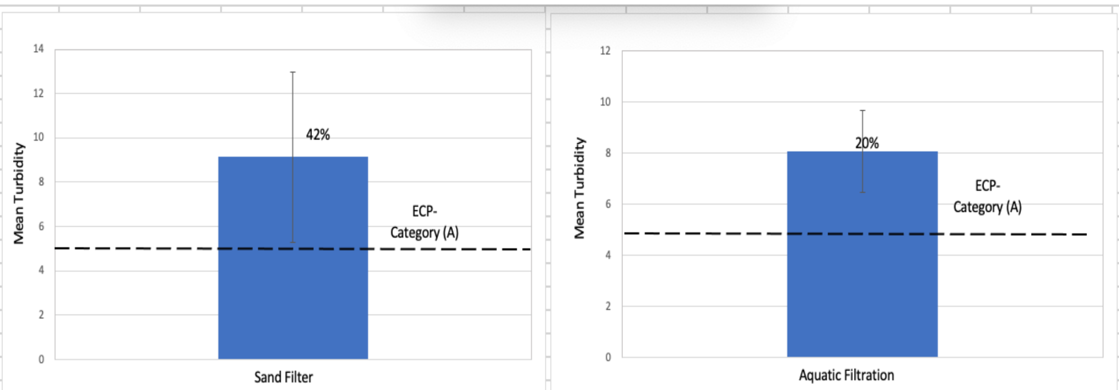



Figure 5.33: Phase 4.A: Effect of Integrated SF and AF System on Mean Turbidity Standard deviation - Intermittent Run (n=27)

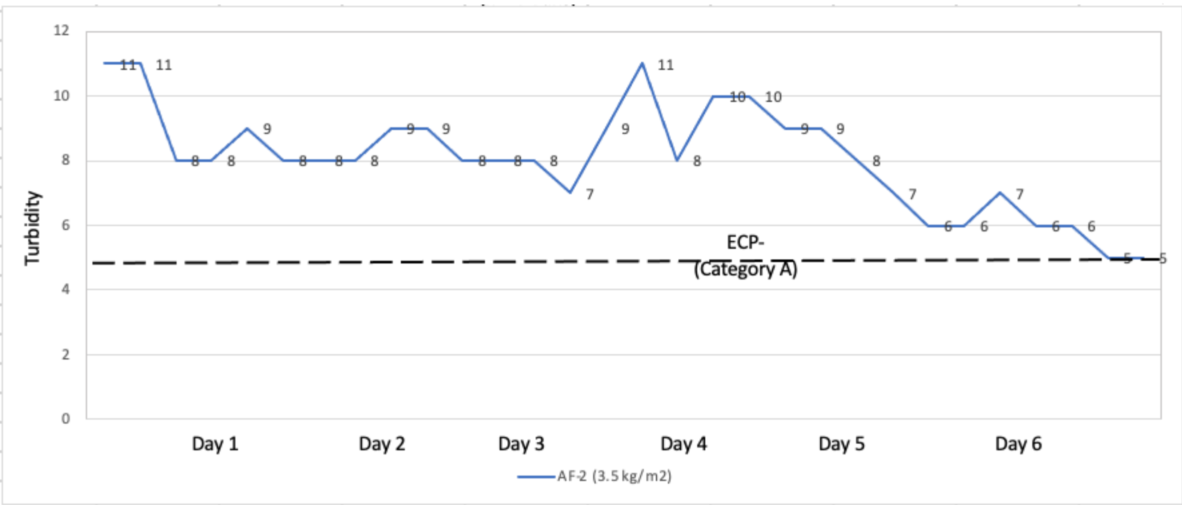



Figure 5.34: Phase 4.A: Turbidity Distribution @3.5 kg/m² PD- Integrated SF and AF System - Intermittent Run

Figure 5.35 shows the TSS values for the sand filter and the aquatic filtration on day 3 of the run and on day 5 of the run. The sand filter shows an enhancement in the TSS removal as shown at the SF Effluent point; however, the aquatic filtration shows an increase in the TSS value, and this could be due to the presence of dead roots within the water or an indication that the tank or the roots might need a clean-up. Yet, both values of the sand filter and the aquatic filtration are below the acceptable ECP TSS value.

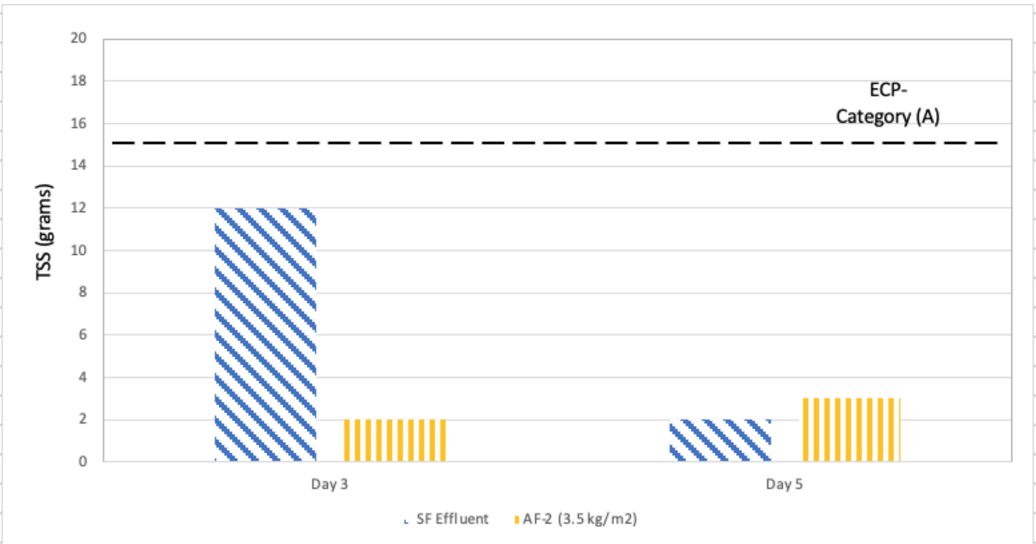



Figure 5.35: Phase 4.A: Effect of Integrated SF and AF System on TSS (grams)-Intermittent Run

Figure 5.36 shows the COD for both the sand filter and the aquatic filtration at day 3 and day 5 of the run. The sand filter shows an increase in the COD value which reflects higher oxygen demand needed by the present bacteria to treat the water yet, the aquatic filtration show an increase as well from day 3 to day 5 reflecting some oxygen deficiency however, the aquatic filtration performance is below the KSA code for GWT for reuse in irrigation acceptable value.

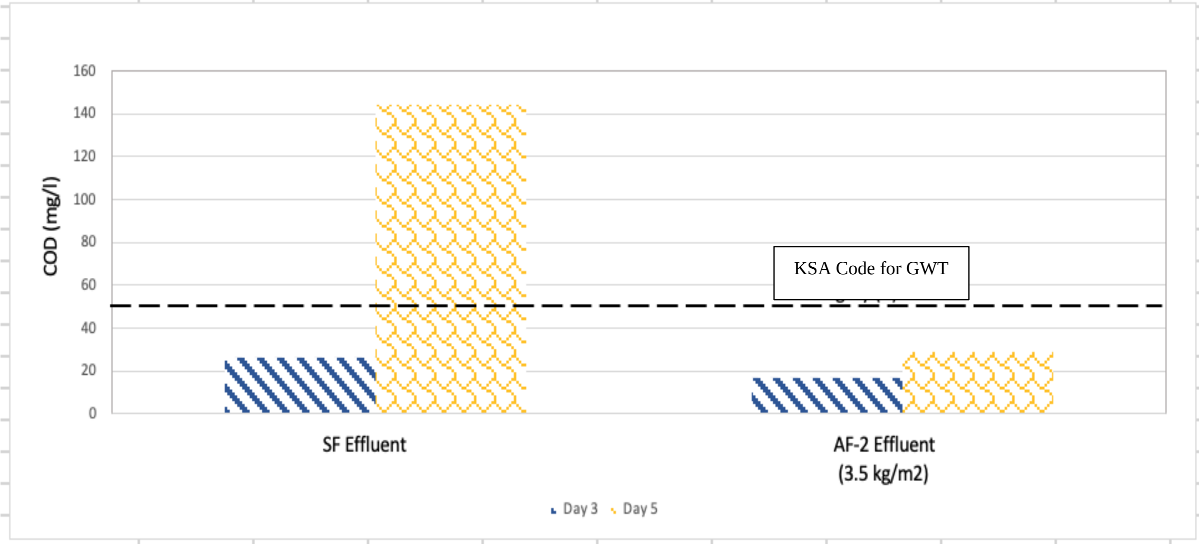



Figure 5.36: Phase 4.A: Effect of Integrated SF and AF System on COD (mg/l) – Intermittent Run

**4.B: Continuous Run using Synthetic GW Mix**

In phase 4.B, the full in-series integrated sand filter and aquatic filtration were studied under continuous run using synthetic greywater mix. Figures 5.37 and 5.38 show the mean turbidity and the mean turbidity standard deviation for the sand filter and the aquatic filtration where both shows a slightly higher turbidity value than the ECP acceptable value.

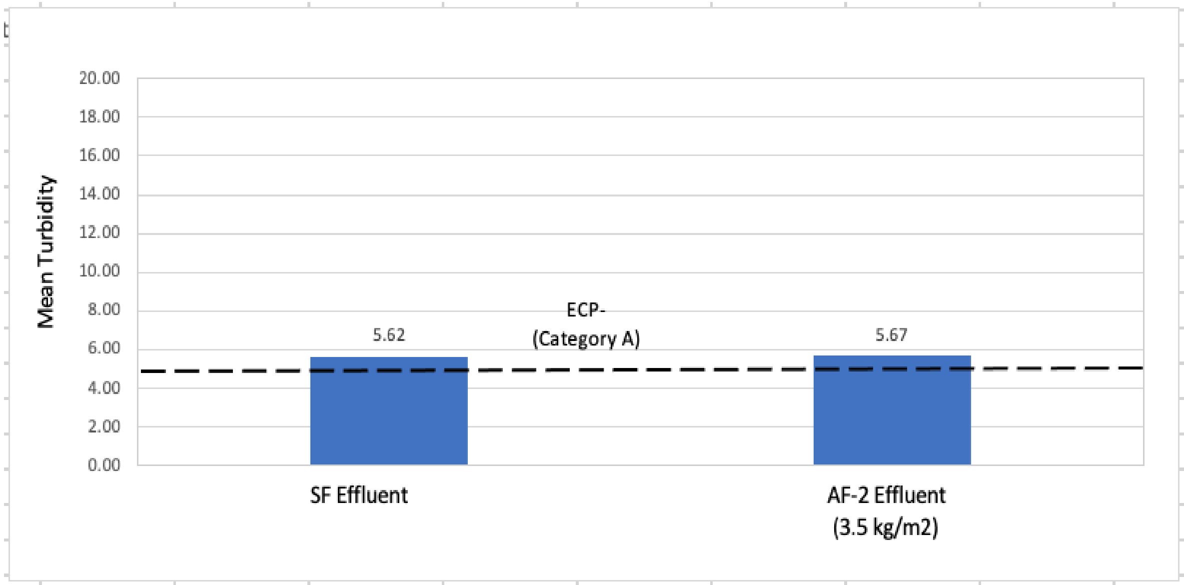



Figure 5.37: Phase 4.B: Effect of Integrated SF and AF System on Mean Turbidity - Continuous Run (n=4 days)

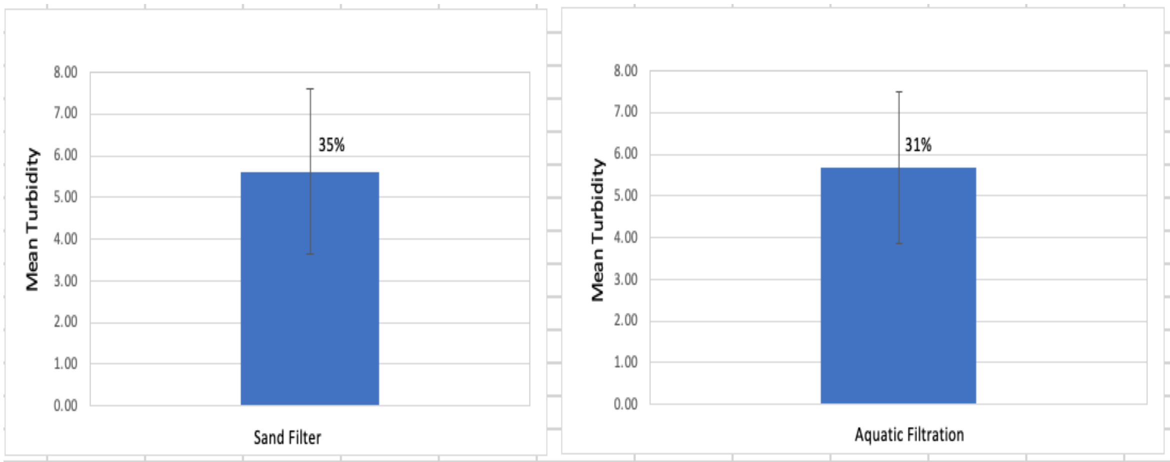



Figure 5.38: Phase 4.B: Effect of Integrated SF and AF System on Mean Turbidity Standard deviation- Continuous Run (n=4 days)

Looking at figure 5.39 representing the turbidity distribution of values across the runs, the aquatic filtration provided turbidity values below the ECP acceptable number since mid-day 3 of the run. It can be confused with why to integrate the aquatic filtration with the sand filter at this step since the sand filter is already providing the needed turbidity values, however, in figures 5.40 and 5.41 the TSS values and the COD values are enhanced through the aquatic filtration along day 3 of the run while meeting the ECP- Category (A) and KSA code for GWT values unlike the sand filter effluent which is showing plants efficiency and adaptation.

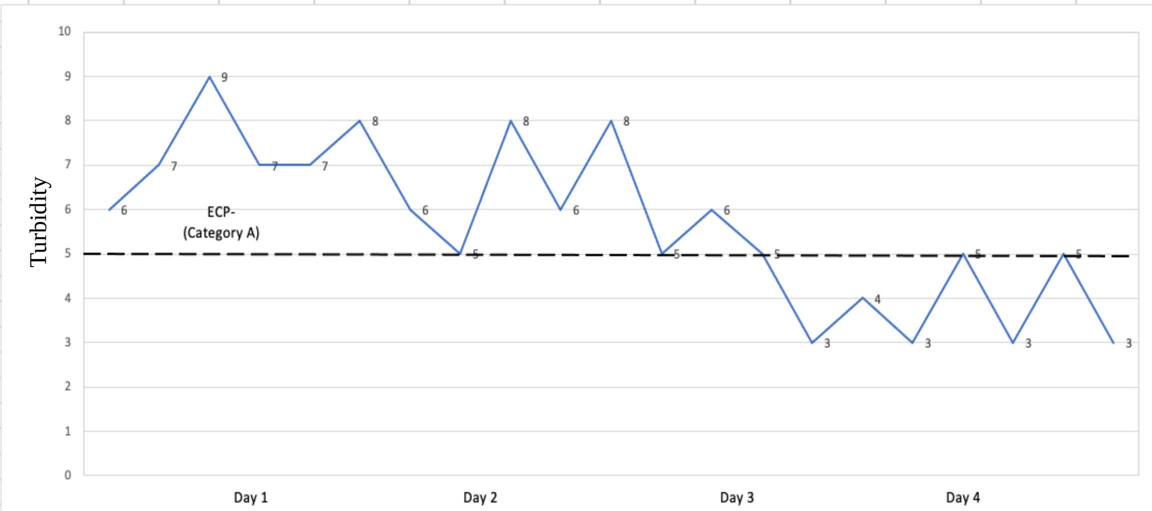



Figure 5.39: Phase 4.B: Turbidity Distribution @3.5 kg/m$^2$ PD- Integrated SF and AF System - Continuous Run (n=4 days)

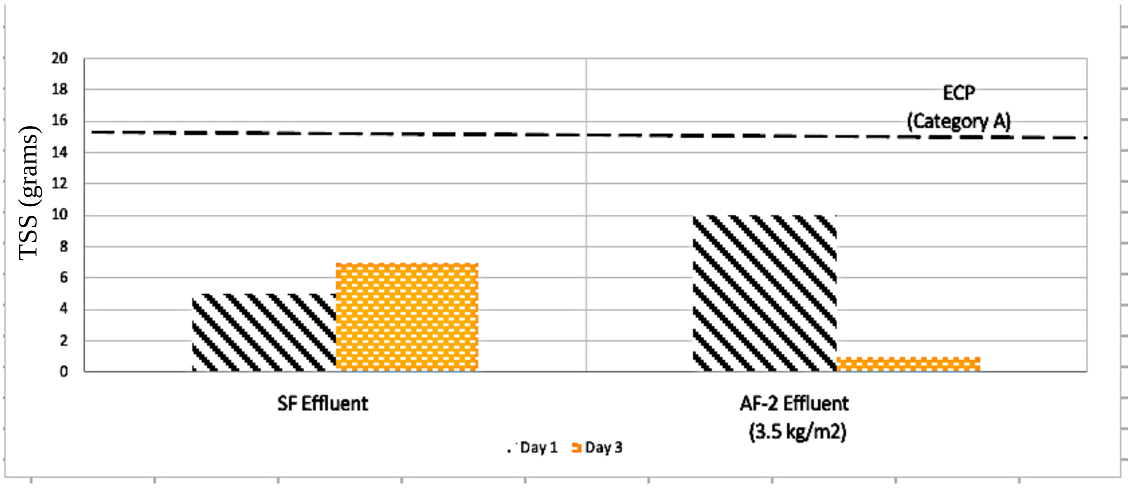



Figure 5.40: Phase 4.B: Effect of Integrated SF and AF System on TSS (grams) - Continuous Run

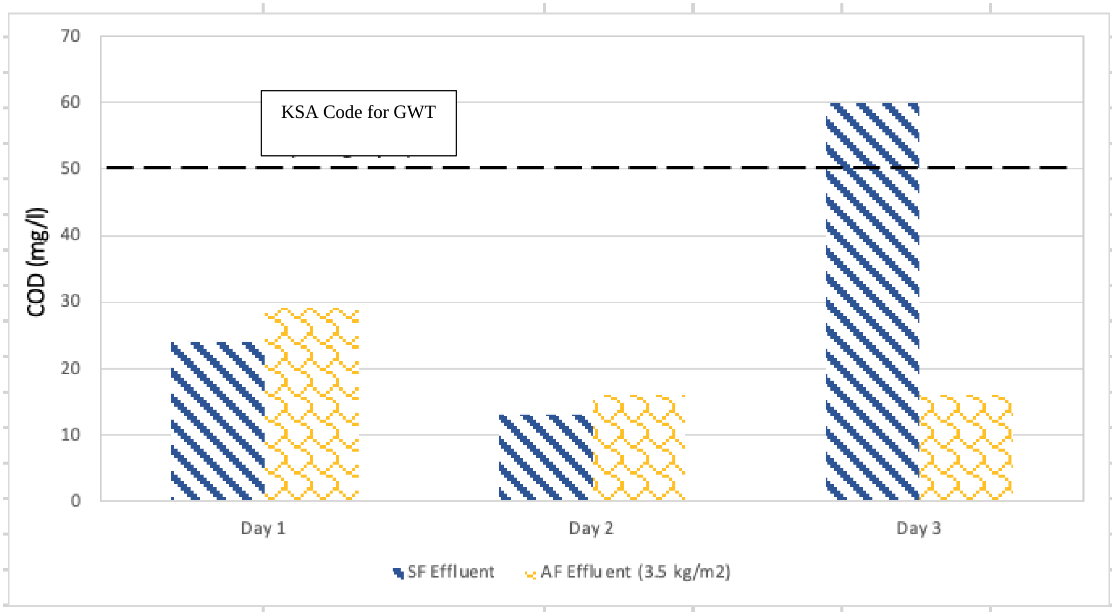



Figure 5.41: Phase 4.B: Effect of Integrated SF and AF System on COD (mg/l)-Continuous Run

In conclusion to this phase, the integrated sand filter of medium size sand (0.8-1.2 mm) at sand bed depth of filtration of 65 cm operating at rate of filtration of 4 $m^3/m^2$/d connected in series with 3.5 $kg/m^2$ wet water hyacinth plant density aquatic filtration step shows acceptable and efficient greywater treatment with treated greywater effluent parameters after the aquatic plant filtration step meeting the ECP-Category (A) under turbidity, TSS (grams) and COD (mg/l) parameters of study for both intermittent and continuous runs.

### 5.2.5: Phase 5: Running the Integrated SF and AF system in series with the best design- Real GW- Continuous Run

Phase 5 is the real greywater full system run. This phase is divided into two main sub-phases, one is studying the parameters of the real collected greywater to understand how they vary along day based on the user's behavior. This was done during a full day study of hourly sample collections from the AUC Faculty Housing in New Cairo, Egypt. The second sub-phase is the full integrated 7 days in-series run for the slow sand filter and the aquatic plants using greywater.

The output results of phase 5.A of the real greywater parameters are in-line with most real greywater studies of reference with turbidity level range from 19-444 NTU, TSS range is from 190-537 mg/l, pH range is from 5-9, BOD-5 in range of 39-188 mg/l and COD is in range from 96-375 mg/l [70] as projected by several countries activities in the reference' table.

Considering another fellow study in Egypt to account for similar consumer behavior in the local country of study while also being from the same source from the AUC faculty housing but at a different time of collection; the results of phase 5.A is compared with the reference study where the real greywater is in the similar range of this study for Turbidity from (74-233 NTU) from the reference study [108] versus (70-426 NTU) in this study. However, for the TSS range in the study reference is from (18-67 mg/l) in comparison to this study range from (70-426 mg/l) which is slightly higher in the maximum value. Lastly, for the COD comparison, the reference of study is within range for the minimum value however it has higher COD maximum limit (384-1168 mg/l) versus this study's range of (226-513 mg/l).

Another local study of [96] which shows real greywater Turbidity levels (~147-175 FTU), TSS (180-230 mg/l) and COD (180-300 mg/l). In the current study, higher maximum ranges of turbidity, TSS and COD were observed compared to the second reference of study which took place in a near-by time frame as this study but with lower percentage of housing occupancy.

The output results of phase 5.B studying treated greywater parameters of Turbidity (NTU), TSS (mg/l), COD (mg/l), pH and E. Coli are all in-line with the ECP-Category (A) however, the BOD-5 is the only parameter that fell out of the code's range even after the final treatment stage at the aquatic filtration and this can be a result of the higher BOD-5 ranges noticed in the raw greywater used versus [106] reference where the BOD-5 range was from (70-100 mg/l) while in this study it was from (93-295 mg/l).

In conclusion to this phase, the system is effective in treating the greywater while meeting all of the ECP- Category (A) parameters and it is considered that if the influent BOD-5 is decreased or the collected greywater didn't include much impurities as the samples of use in this study; then the BOD-5 range after treatment will fall under the ECP- Category (A) code and that is in-line to several water hyacinth treatment plants papers results assuring effective water hyacinth treatment to wastewater and greywater like in references [96] and [109].

**Phase 5.A: Studying the Real GW parameters (n=1)**

Phase 5.A is focused on understanding the real greywater characteristics along real live consumer use. The real greywater is collected from the AUC faculty housing in mid-August with 65% capacity. The piping system at the AUC faculty housing included the kitchen sink, bathroom sink and bathroom shower. 9:00AM high TSS and COD values reflect morning wash-ups and the possible high use of soap and foaming chemicals. The 11:00AM hour data reflects roughly the lunch preparation with a high projection of kitchen use vs bathroom sink. At 3:00PM, reflecting lunch hour, hence high turbidity level and TSS. During the evening, there is a decline in data projection reflecting less use of the kitchen sink and the bathroom sink, this is shown in figures 5.42, 5.43 and 5.44.

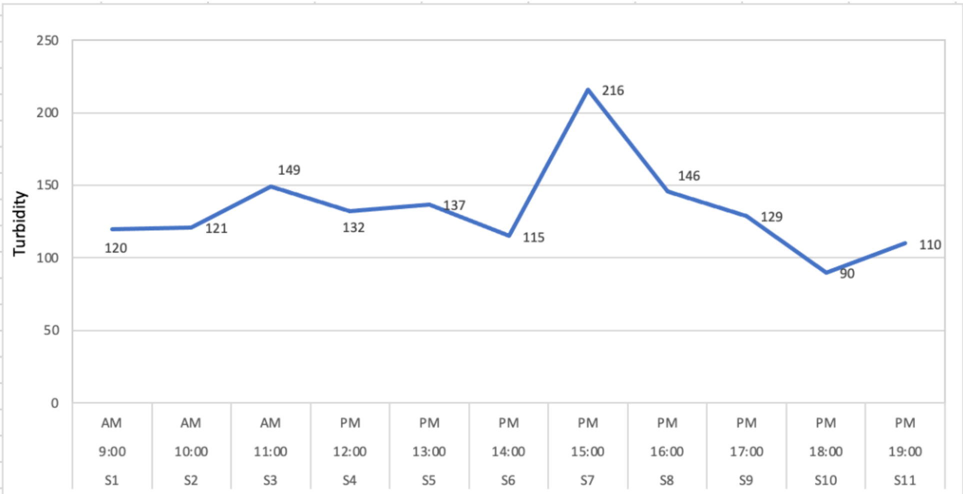



Figure 5.42: Phase 5.A: Effect of Integrated SF and AF System on Turbidity – Real GW Continuous Run (n=1)

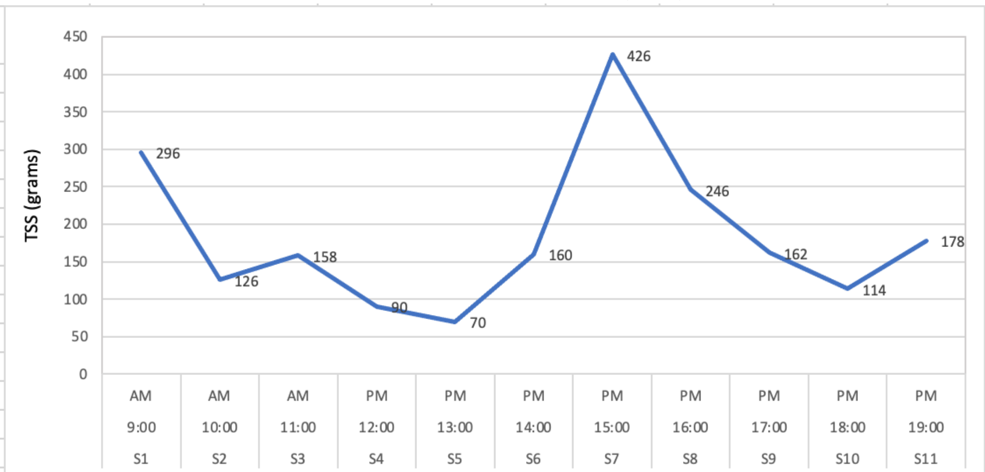



Figure 5.43: Phase 5.A: Effect of Integrated SF and AF System on TSS (mg/l) – Real GW Continuous Run (n=1)

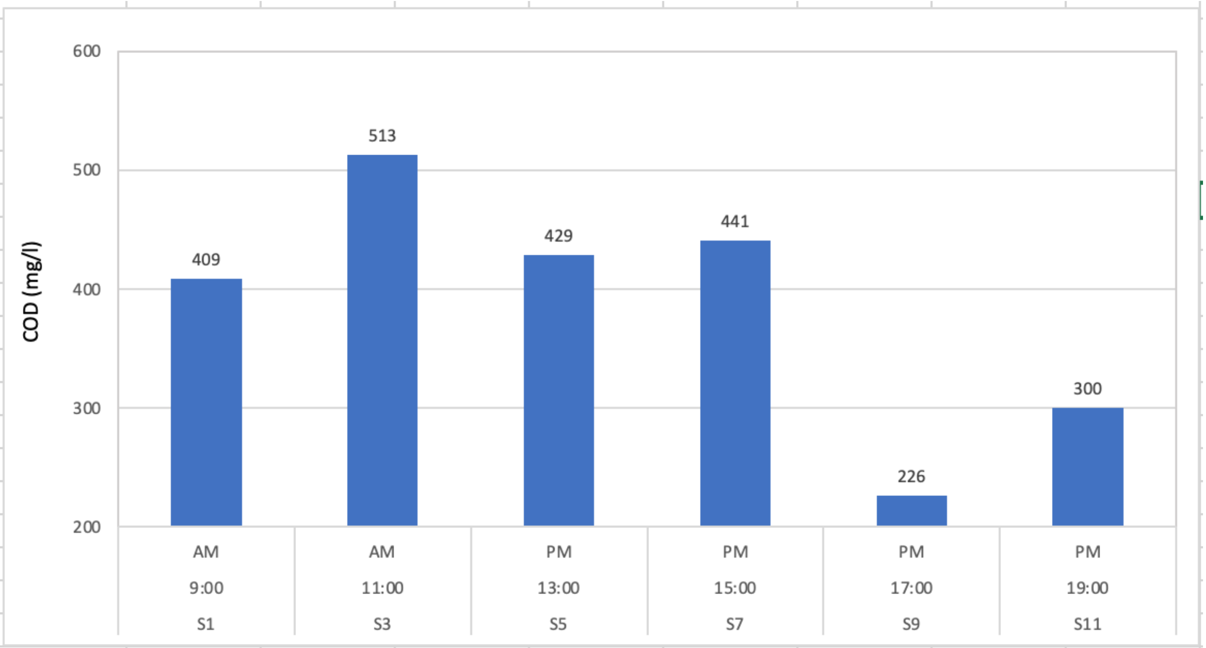



Figure 5.44: Phase 5.A: Effect of Integrated SF and AF System on COD (mg/l)– Real GW Continuous Run (n=1)

Understanding the components within real greywater is beneficial to see how the greywater specifications vary along the day when collected from the same building with the same users' yet different user behavior. This view and even better if studied along different peaks like weekday vs weekend, summertime vs wintertime is essential for community owners and greywater treatment system designers to align on the timing for greywater collection along the day and referencing the input data with the system treatment efficiency.

**Phase 5.B: Studying the Full System Behavior- Continuous Run (n=7)**

In phase 5.B the full in-series integration sand filter and aquatic filtration system ran with real greywater from Day 0 – Day 6 showed the system effectiveness under Turbidity, TSS, COD, pH and E. Coli, with no nematodes inspected in the results. The previously mentioned parameters (except pH) meet the data results of the ECP and KSA code for pH. The only high reflection driven in the data is shown under the BOD-5 however, looking at the removal efficiency it is showing 55% removal levels. The quality of the greywater influent is impacting the data results due to residues noticed in the sampling collecting port.

Figure 5.45 shows the mean turbidity across the mixer, the sedimentation column (SC), the sand filter and the aquatic filtration with all values above the ECP acceptable turbidity value while the aquatic filtration shows the lowest and closest acceptable turbidity values towards the end of the final run as shown in the turbidity distribution graph along the runs in figures 5.47 and 5.48. Figure 5.46 shows the mean turbidity standard deviation for the sand filter and the aquatic filtration.

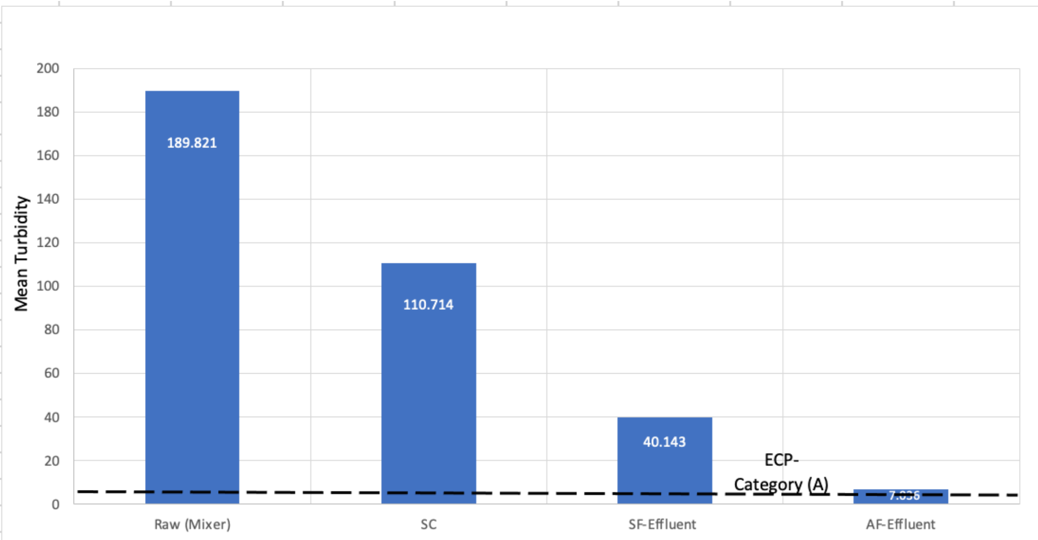



Figure 5 45: Phase 5.B: Effect of Integrated SF and AF System on Mean Turbidity – Real GW Continuous Run (n=7)

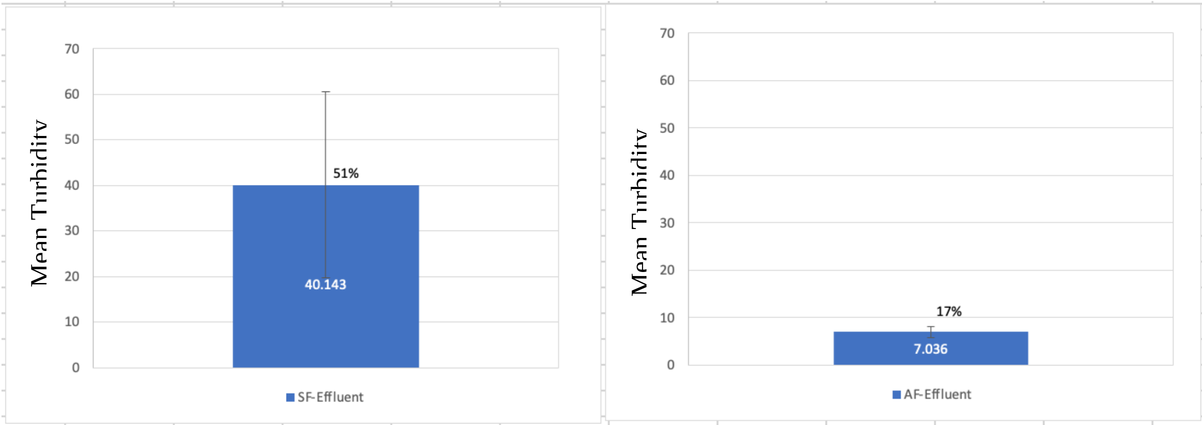



Figure 5.46: Phase 5.B: Effect of Integrated SF and AF System on Mean Turbidity Standard deviation– Real GW Continuous Run (n=7)

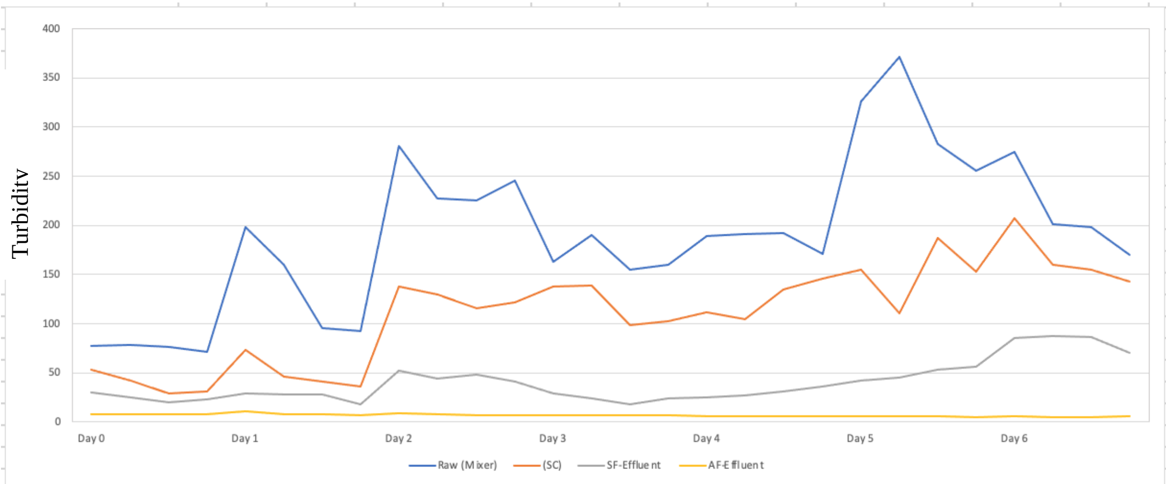



Figure 5.47: Phase 5.B: Turbidity Distribution –Mixer, SC, SF, AF - Real GW Continuous Run

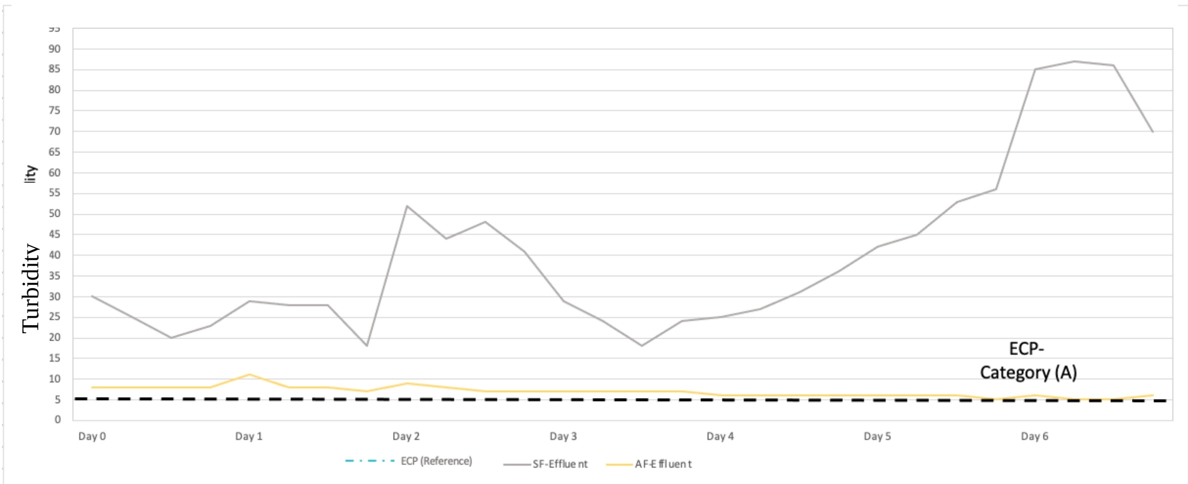



Figure 5.48: Phase 5.B: Turbidity Distribution –SF, AF - Real GW Continuous

Figure 5.49 shows the mean TSS across the mixer, sedimentation column (SC), sand filter and aquatic filtration. The aquatic filtration shows the lowest and acceptable TSS results as shown in figures 5.50 and 5.51 with the TSS data distribution across the runs and when compared to the other system components starting the mixer.

The results at the final treatment step of the aquatic filtration shows acceptable mean TSS and TSS trend values below 15 mg/l as specified by the ECP- Category A.

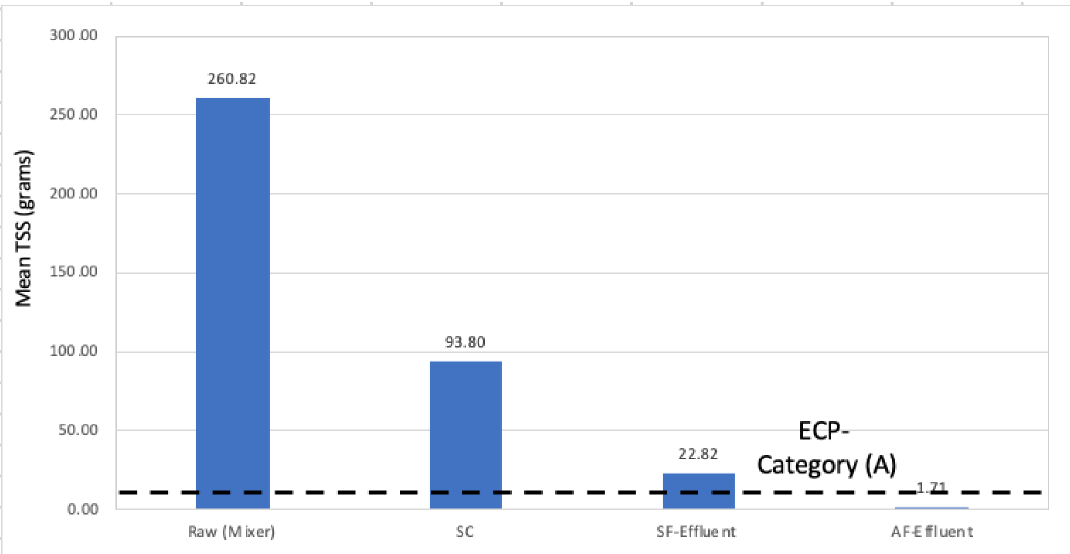



Figure 5.49: Phase 5.B: Effect of Integrated SF and AF System on Mean TSS (grams) – Real GW Continuous Run (n=7)

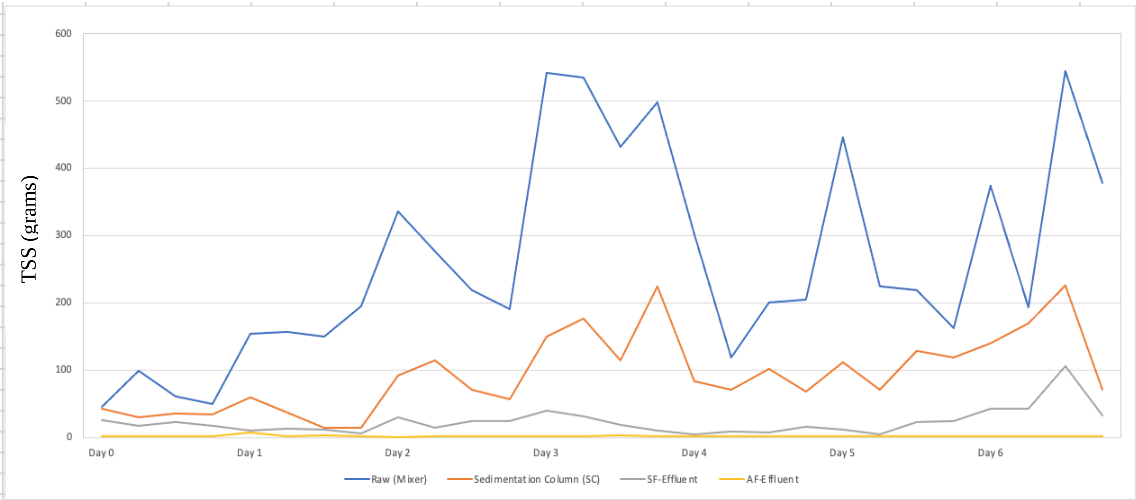



Figure 5.50: Phase 5.B: Effect of Integrated Mixer, SC, SF and AF System on TSS (grams) Distribution– Real GW Continuous Run

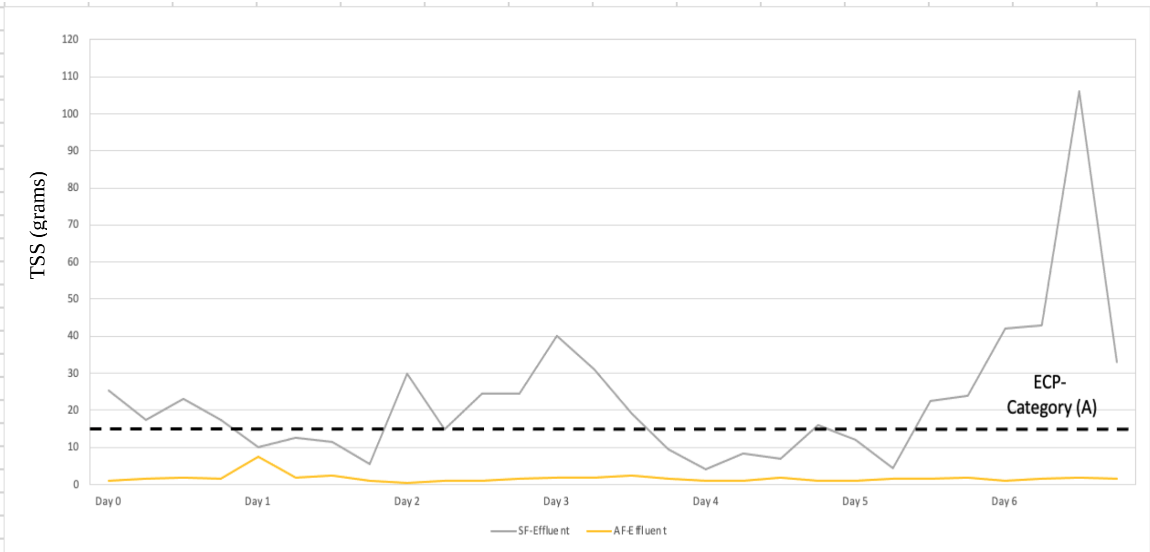



Figure 5.51: Phase 5.B: Effect of Integrated SF and AF System on TSS (grams) Distribution– Real GW Continuous Run

Figure 5.52 shows the mean COD values with the aquatic filtration performing with efficiency reflecting the lowest COD value which is acceptable as per the KSA code for GWT; this is also reflected in the COD distribution graph of values along the runs in Figure 5.53.

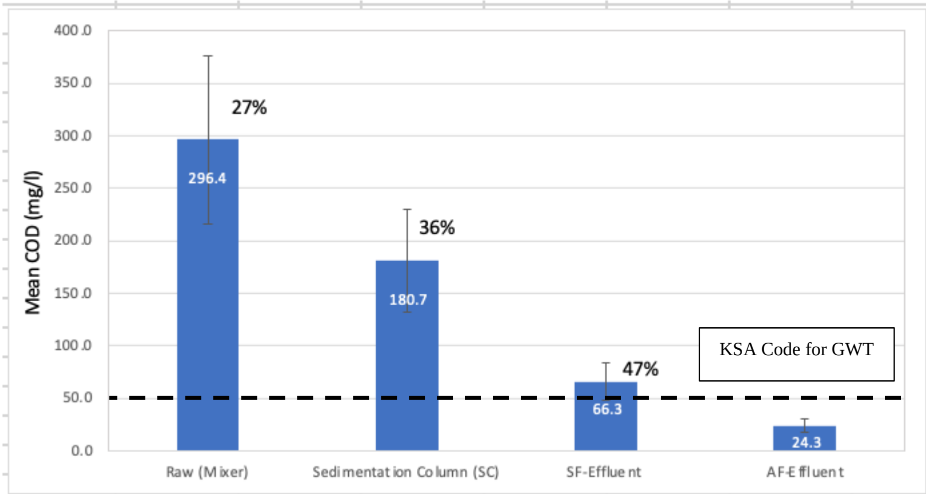



Figure 5.52: Phase 5.B: Effect of Integrated SF and AF System on Mean COD (mg/l)– Real GW Continuous Run (n=7)

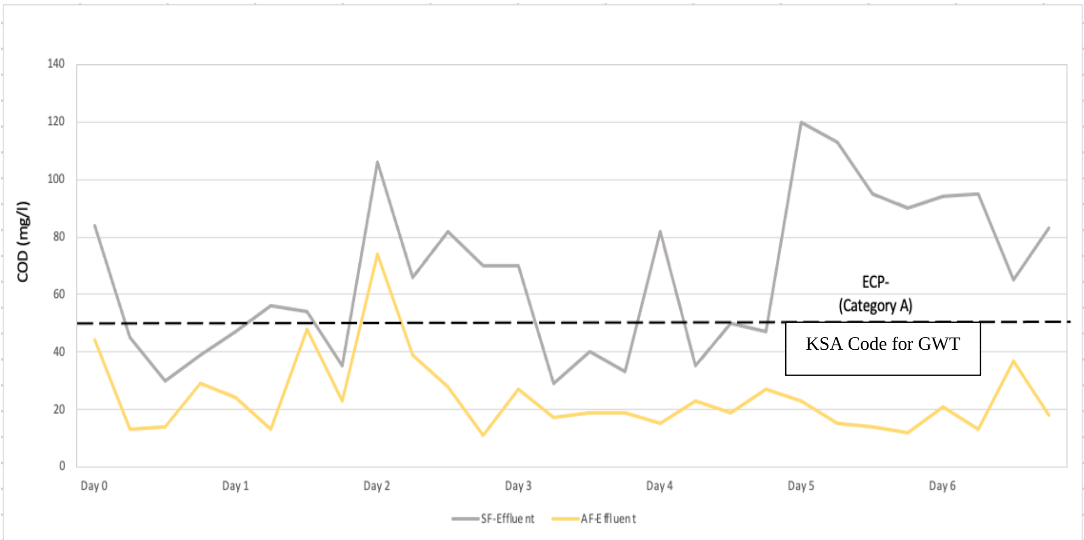



Figure 5.53: Phase 5.B: Effect of Integrated SF and AF System on COD Distribution (mg/l)- Real GW Continuous Run (n=7)

Figure 5.54 shows the mean pH values with a rise at the aquatic filtration step due to the plant's treatment however, still both treatment steps (sand filter and aquatic filtration) provide acceptable range of pH max and min values as per the KSA code of greywater treatment for reuse. Figure 5.55 is a distribution for the pH data showing the positive adaptation to the water hyacinth plants in enhanced and dropped pH levels along the runs. The lower the pH or the closer it is to the neutral level means that the environment is favorable for the plants microbial activity in degrading the COD and BOD-5 from the greywater [109].

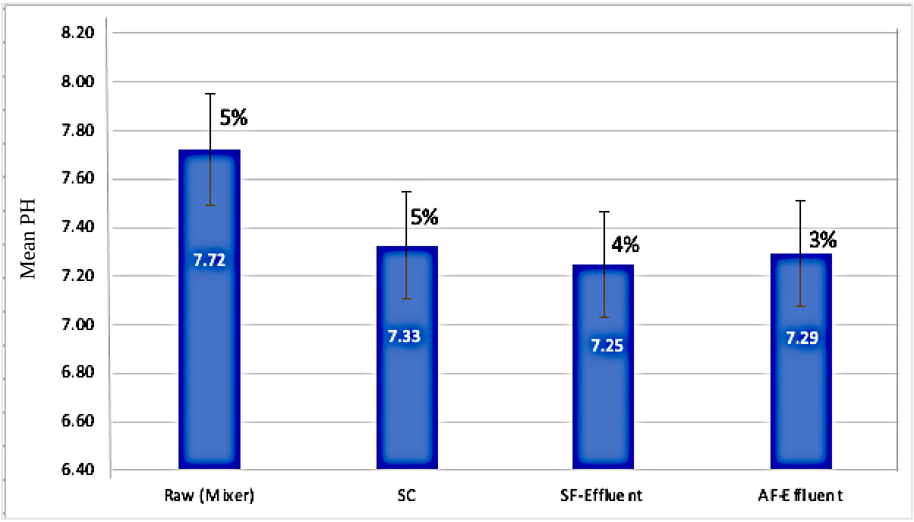



Figure 5.54: Phase 5.B: Effect of Integrated SF and AF System on Mean pH – Real GW Continuous Run (n=7)

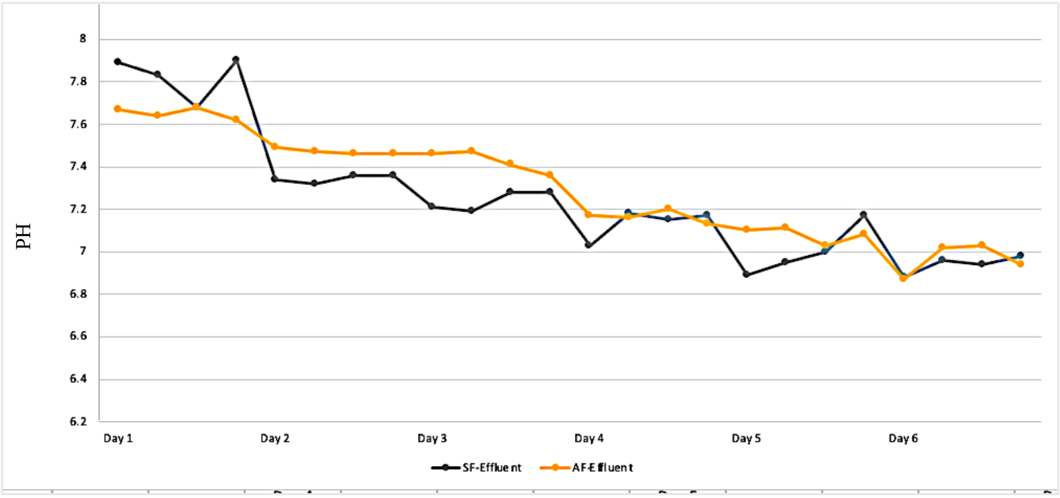



Figure 5.55: Phase 5.B: Effect of Integrated SF and AF System on PH- Real GW Continuous Run (n=7)

Figure 5.56 shows the BOD-5 distribution of values across the 7 day runs and the values are way higher than the acceptable range provided by any wastewater and greywater treatment code as reflected in the literature. The only derivation behind the high BOD-5 values is due to the high organic matter composition in the raw greywater used initially when compared to other studies of similar raw greywater use. However, the system was able to remove 77.3% of the BOD-5 when comparing the maximum value on day 6 at the mixer and at the aquatic filtration step. If in real life the real greywater values were of a similar composition or the treatment BOD-5 values were as conducted in this phase, then it is suggested to add a chlorination step and use the treated greywater afterwards only for water flushing but not for landscape irrigation.

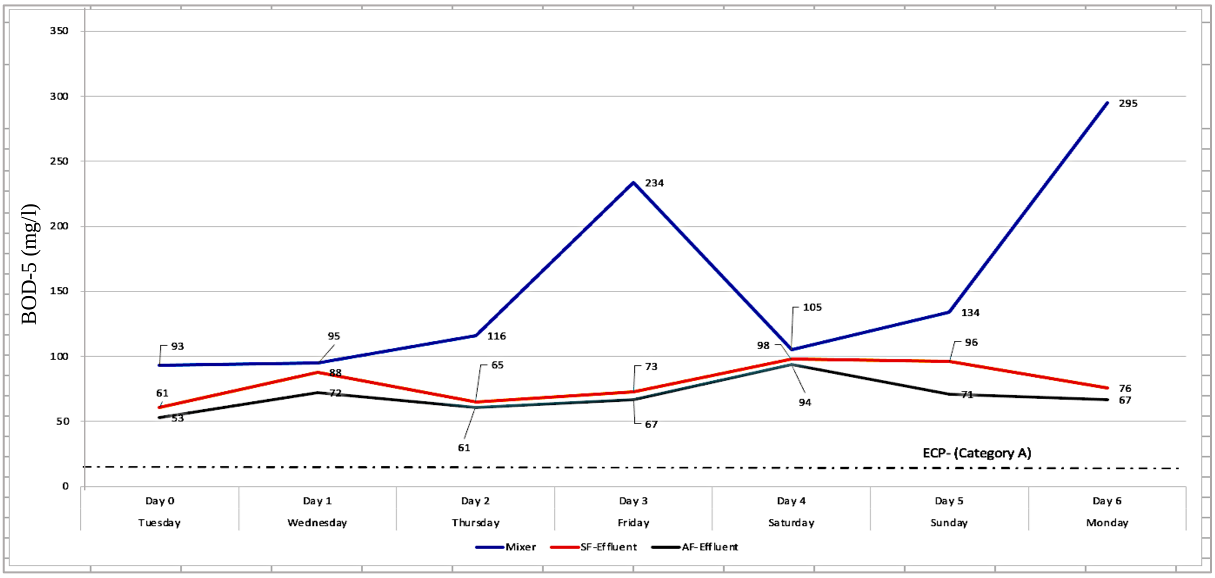



Figure 5.56: Phase 5.B: Effect of Integrated SF and AF System on BOD-5 (mg/l) – Real GW Continuous Run (n=7)

Figure 5.57 represents the effect of the integrated system treatment on the E. Coli removal showing an effective treatment between the mixer, the sand filter and the aquatic filtration final treatment stage. The E. Coli level after the aquatic filtration stage is meeting the ECP-Category (A) limit as shown in figure 5.58 representing the E. Coli value distribution between the mixer, sand filter and aquatic filtration stages.

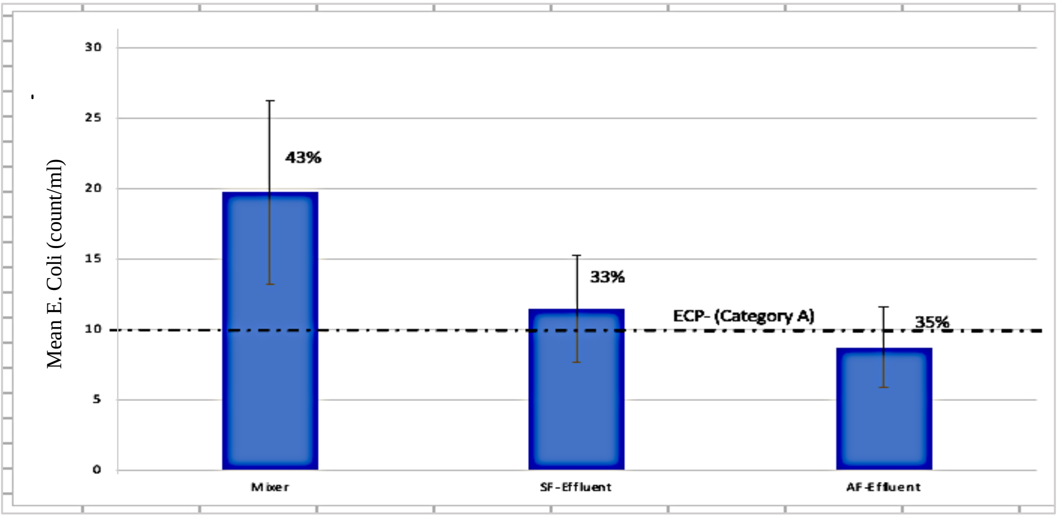



Figure 5.57: Phase 5.B: Effect of Integrated SF and AF System on Mean E. Coli (count/ml) – Real GW Continuous Run (n=7)

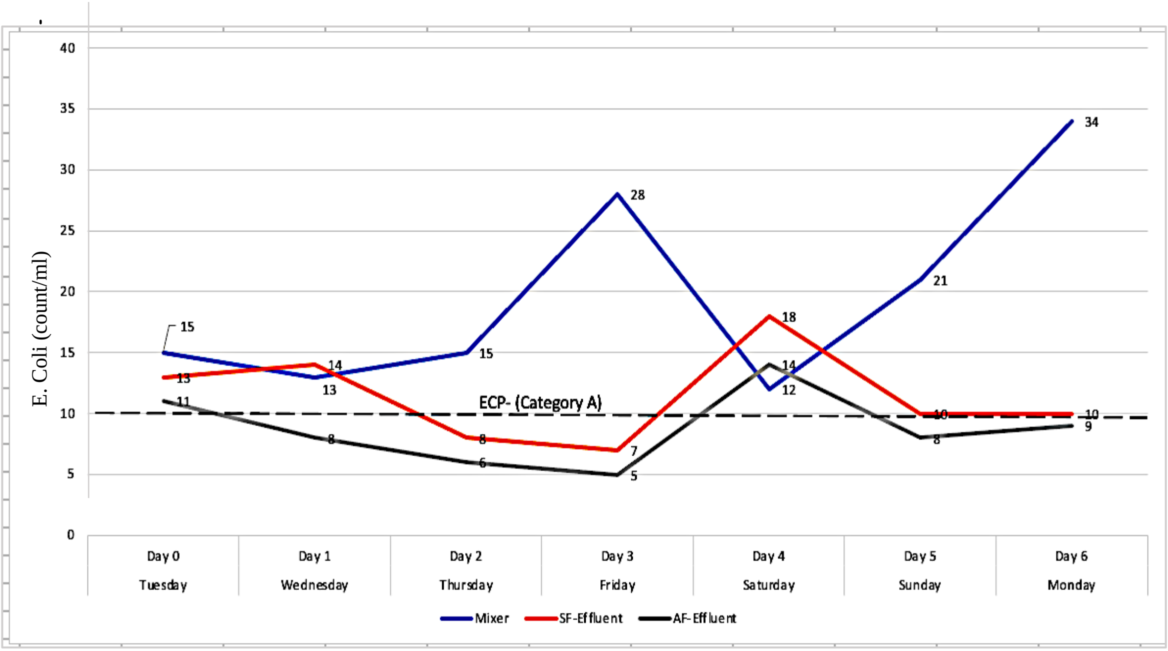



Figure 5.58: Phase 5.B: Effect of Integrated SF and AF System on E. Coli Distribution (count/ml) – Real GW Continuous Run (n=7)

Figures 5.59 and 5.60 represents the actual top layer of the sand including the schmutzdecke layer after conducting the 5 experimental phases. It is obvious that the sand granules at the middle layer (~33 cm depth) are less contaminated with black color and bacteria, while the bottom layer (~50 cm depth) shows clearer sand color and gravel too. The SEM analysis, presented in chapter 5, was held on the sand granules represents higher and variant types of bacteria and fungus on the top sand schmutzdecke layer and their frequency decreases as we go down in depth.


Figure 5.59: Real Sand Image- Top Sand Layer and Middle Sand Layer- Post Experimental Run

Bottom Sand Layer

Gravel

Figure 5.60: Real Sand Image- Bottom Sand Layer and Gravel Layer- Post Experimental Run

In conclusion to phase 5, the novel approach of integrating in-series the slow sand filter and the aquatic water hyacinth plants show effective greywater treatment using real domestic greywater under continuous runs. The parameters of study under turbidity, TSS (grams), COD (mg/l), pH and E. Coli (count/ml) show reduction in values which reflect treatment removal efficiency when compared between the sand filter and aquatic filtration and when compared between the sand filter and the raw in the mixer. For the BOD-5, even though the experimental treatment values are higher than the ECP- Category (A) limit however, as justified with reference to other studies held locally in Egypt using the same source of domestic greywater source, the BOD-5 values in this study are almost the double for the studies of reference which is justified with sample observed residues that was suspected to be from piping system issues. Again, the water hyacinth plants have proven efficiency in greywater treatment when used as a sole treatment method as in reference [96]; so, it is projected to provide much more efficient BOD-5 levels treatment when connected to a pre-treatment slow sand filter step under proper greywater collection system of initial use.

## 5.3: System Removal Efficiency Calculations

Tables 5.1 through 5.54 represent the system components removal efficiency along with the full system removal efficiency. The removal efficiency is calculated as such: (influent – effluent)/ influent * 100%. The influent value for the sedimentation column (SC) is the mixer while, the influent value for the sand filter is the effluent value of the sedimentation column.

The influent value into the aquatic filtration is the effluent of the sand filter and the overall system treatment influent value is the mixer value compared with the final treatment step of the experimental integrated system which is the aquatic filtration.

Table 5.1 shows that the system was able to achieve 95+% treatment efficiency under the TSS removal. Table 5.2 shows a 67% full system removal efficiency of the COD, which is not high however, as shown previously in figures 5.50 and 5.51 that the final COD values are below the acceptable ECP (Category A) limits.

Table 5.3 represents 55% of BOD-5 removal which is not high and yet the spread-out values are not meeting the ECP (Category-A) limits. However, with reference to a sand filter in which the conducted a slow sand filter was able to remove 68% of the BOD-5 with respect to the inlet raw wastewater BOD-5 value of 22.5 mg/l for a 65cm sand bed study [123]. So, the justification behind the BOD-5 is that the aquatic plants will meet the needed ECP- (Category A) limits as per a study conducted by the study reference [96] where her study focused on the greywater treatment using just aquatic filtration. The issue in the high BOD-5 level reflected in figure 5.53 is majorly related to the high Influent Wastewater values at the initial step of the system which is impacting the full BOD-5 values along the treatment stages.

Lastly, table 5.4 represents the E. Coli removal efficiency that even though the percentages are not high, yet the effluent value meets the ECP (Category-A) threshold as previously shown in figures 5.54 and 5.55.

Table 5.1: Treatment System TSS Removal Efficiency

| **Experimental Component** | **Removal Efficiency** |
|---|---|
| Sedimentation Column (SC) | 64% |
| Sand Filter | 76% |
| Aquatic Filtration | 92% |
| Full System | 99% |

Table 5.2: Treatment System COD Removal Efficiency

| **Experimental Component** | **Removal Efficiency** |
|---|---|
| Sedimentation Column (SC) | 39% |
| Sand Filter | 63% |
| Aquatic Filtration | 63% |
| Full System | 92% |

Table 5.3: Treatment System BOD-5 Removal Efficiency

| **Experimental Component** | **Removal Efficiency** |
|---|---|
| Sedimentation Column (SC) | - |
| Sand Filter | 48% |
| Aquatic Filtration | 13% |
| Full System | 55% |

Table 5.4: Treatment System E. Coli Removal Efficiency

| **Experimental Component** | **Removal Efficiency** |
|---|---|
| Sedimentation Column (SC) | - |
| Sand Filter | 42% |
| Aquatic Filtration | 24% |
| Full System | 56% |

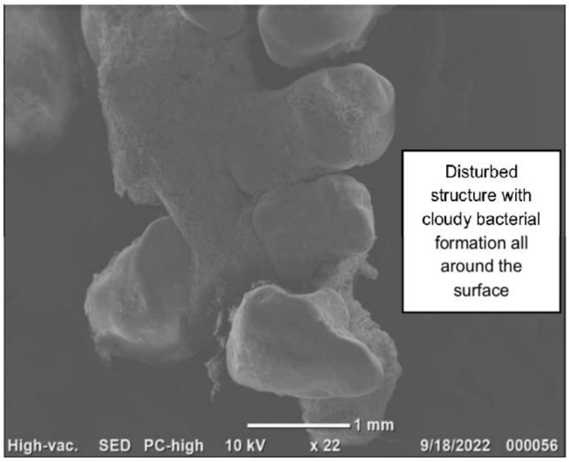
## 5.4: Experimental- SEM Report

The main purpose behind the **S**canning **E**lectron **M**icroscopy is to visualize the microbial formation and features on the biofilm schmutzdecke top surface layer all along the sand bed depth. Gold palladium alloy coating is applied to the samples to easily reflect any microorganisms' emissions while preventing any further surface disturbance or charging.

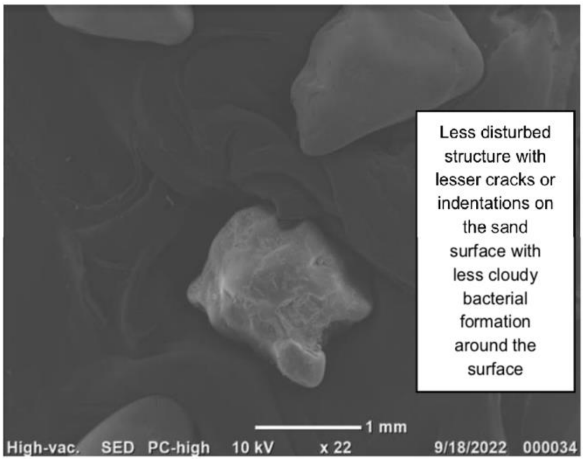
SEM figures 1, 2 and 3 show the three different levels of sand sampling collection. Level 1 (S01) is the surface top layer at (0 cm) sand depth from the top of the sand filter. Level 2 (S02) is the middle layer at approximately (30 cm) sand depth from the top of the sand filter. Level 3 (S03) is the bottom layer at approximately (55 cm) sand depth from the top of the sand filter. It is clear that the top layer of sand has more fragments and deformity which decreases as we go down in depth. This is reflecting higher bacterial levels on top of the sand layer which is projected in the SEM analysis followed below.

* SEM analysis was held after completing all of the experimental runs.

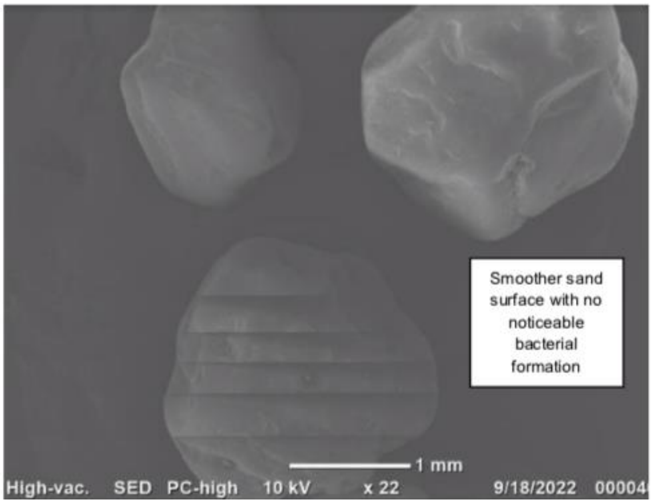
* SEM Analysis was held at the AUC Jamil Center Laboratory.




SEM Figure 1: Top Sand Layer



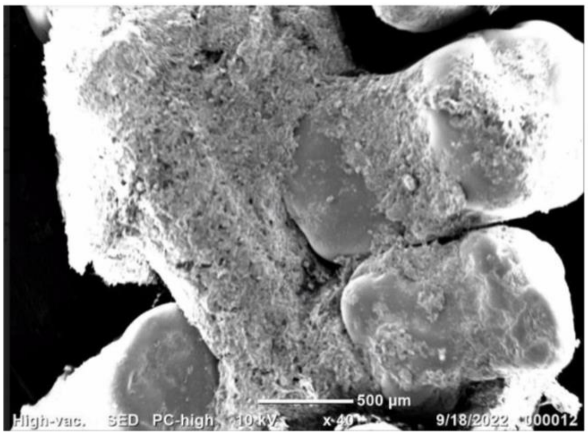

SEM Figure 2: Middle Sand Layer



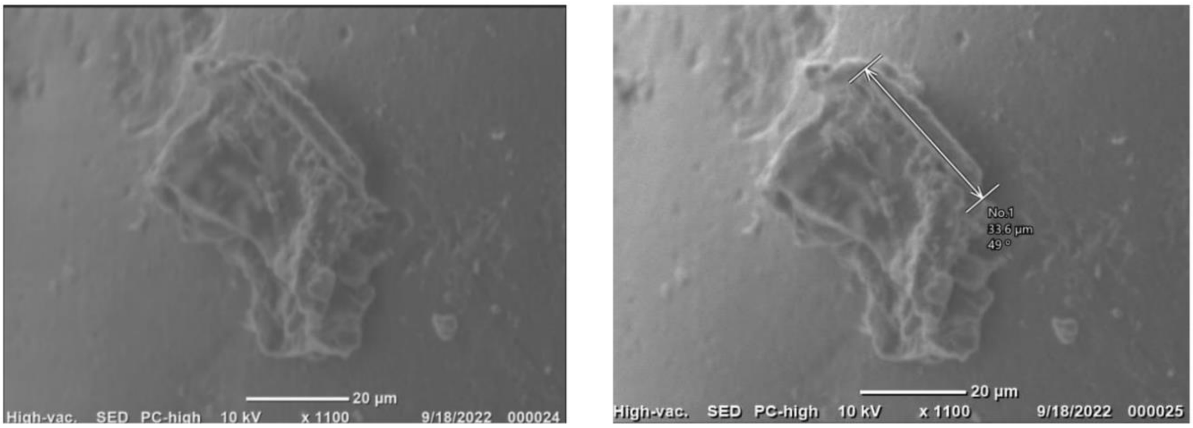

SEM Figure 3: Bottom Sand Layer

Various types of bacteria like Nematode, E. Coli, Coccus, and fungus are clearly shown in high quantities on the top sand sample as shown in SEM figures 4 through 10; while the repetitiveness of similar bacterial has decreased as the sand depth increases reaching almost negligible amount at the bottom sand layer sample SEM figures 11 through 15.

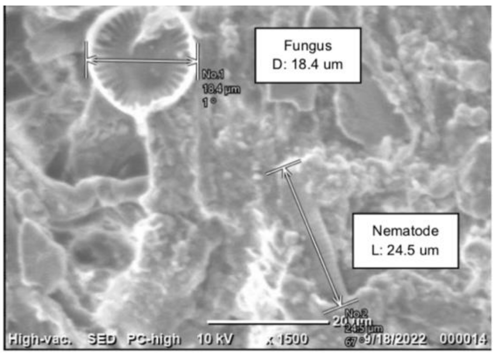
1. Top Layer Sample:



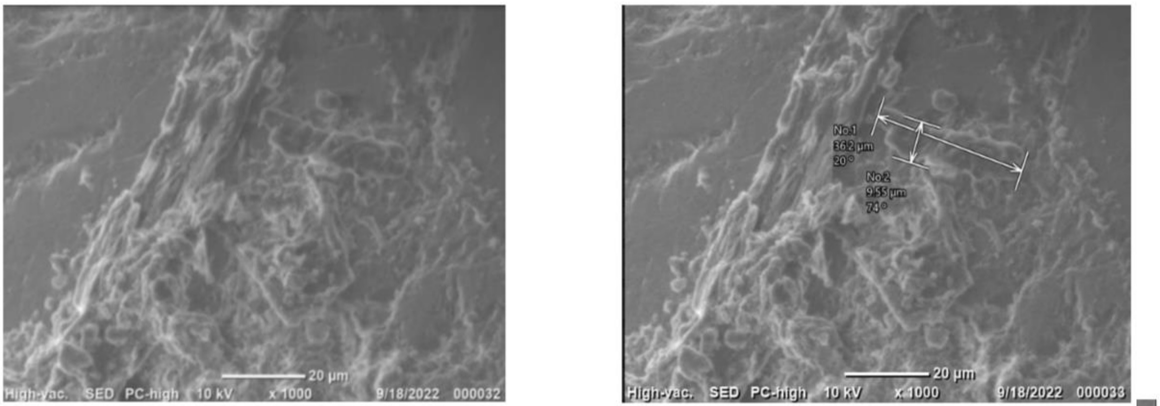
SEM Figure 4: Gold Coating on Sand Granule (x40)



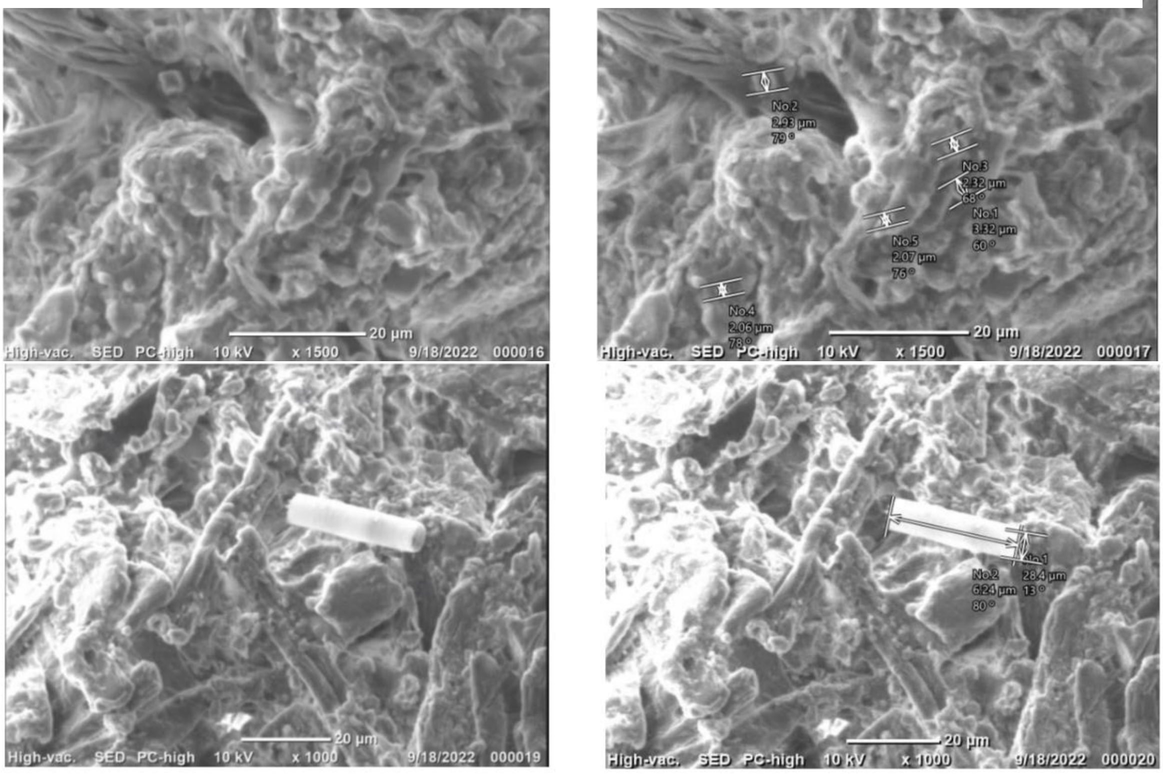
SEM Figure 5: Fungus and Nematode Wormy Bacteria and Fungus round view (x1100)



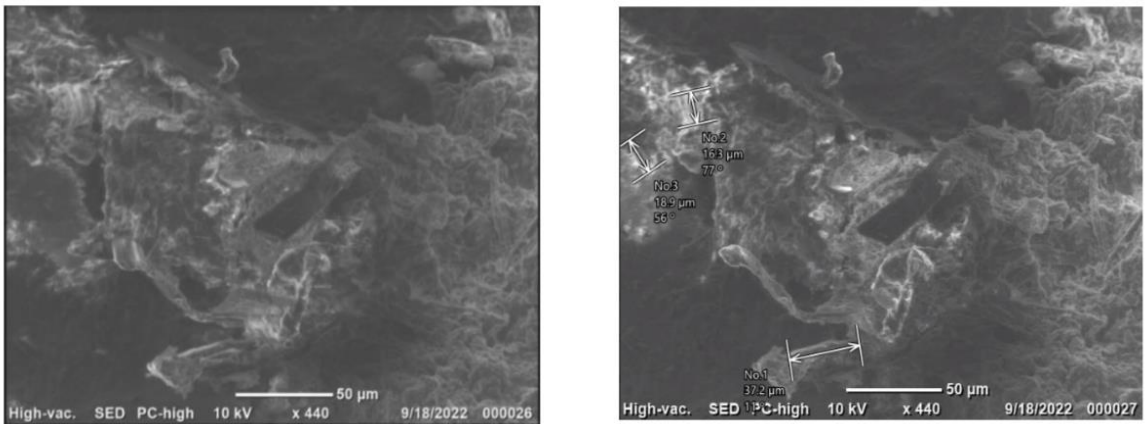
SEM Figure 6: Nematode Wormy Bacteria and Fungus - Another view (x1500)



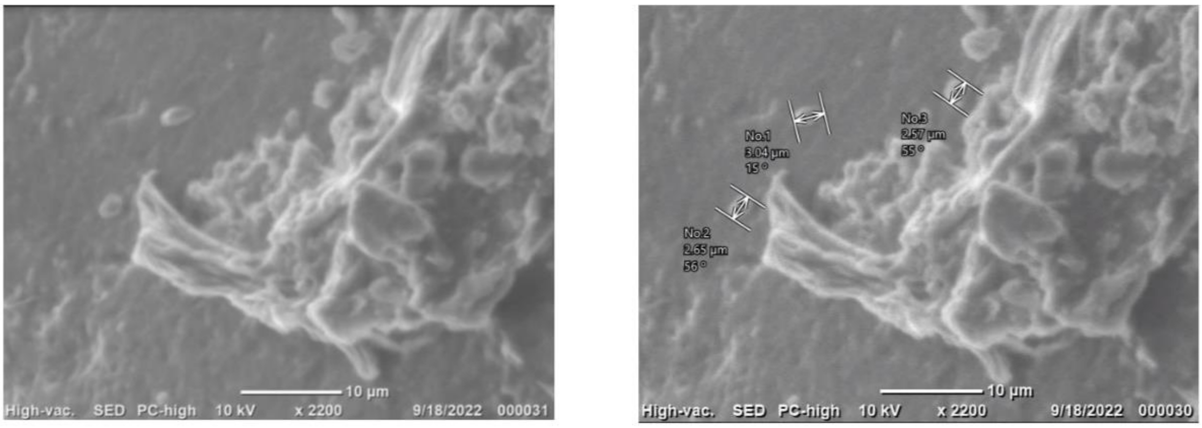

SEM Figure 7: Additionally noticed Nematodes (x1000)




SEM Figure 8: Diatoms forming the Schmutzdecke layer (x1000) and Different Types of Bacteria like Coccus (x1500)



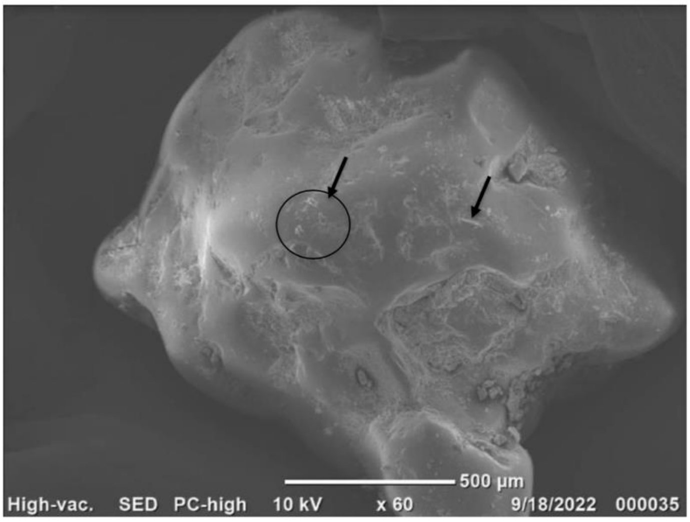

SEM Figure 9: E. Coli (x440)



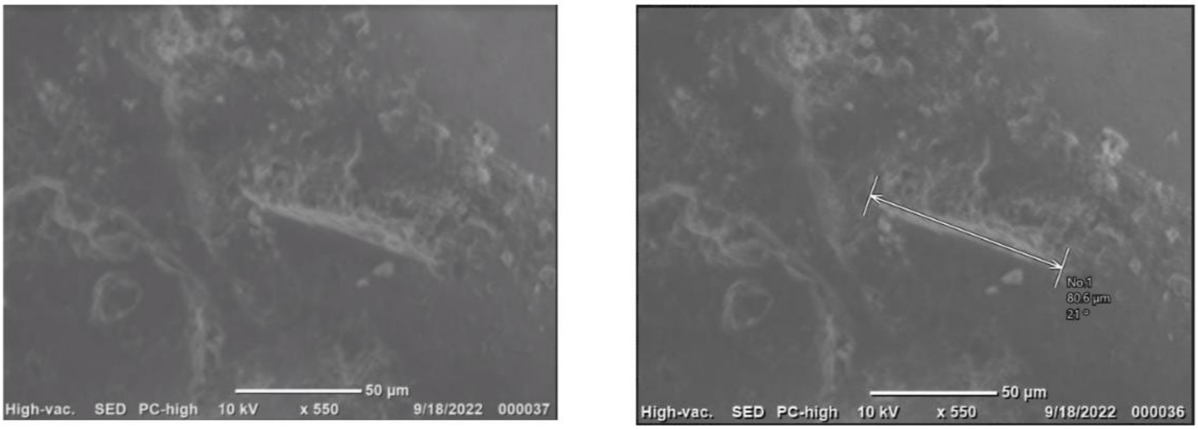

SEM Figure 10: Coccus Bacteria (x2200)

2. Middle Layer Sample:

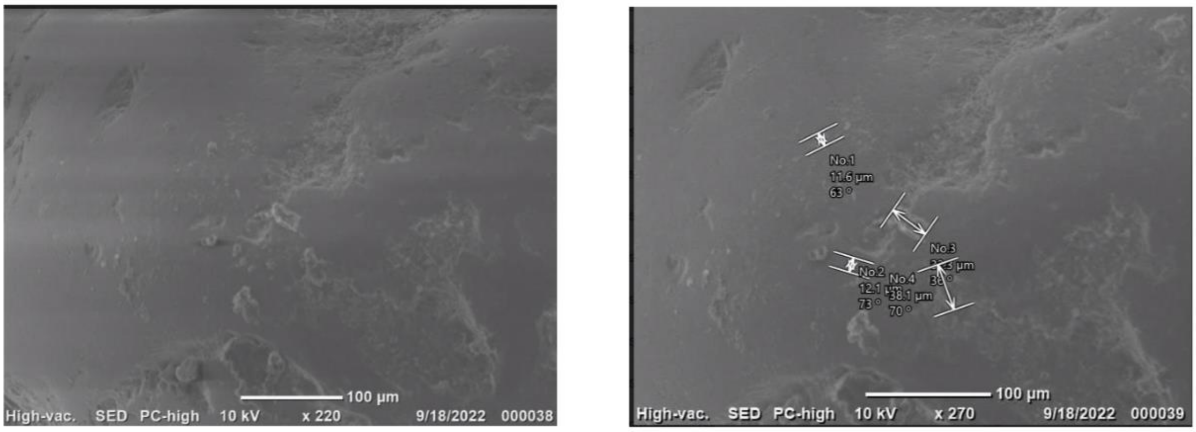
Smoother than the top layer but not as the bottom layer sand granule surface with much lesser types and frequency of bacteria and fungus from the top layer comparison are noticed at the ~30cm depth sand level.




SEM Figure 11: Middle Layer Sand Granule View (x60)



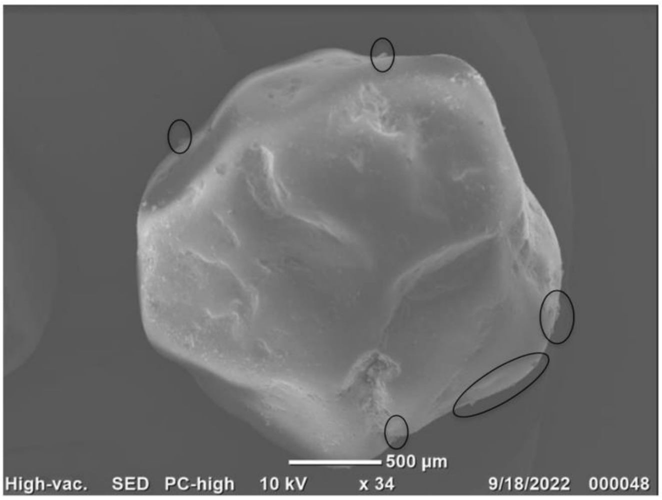

SEM Figure 12: Nematode Bacteria (x550)



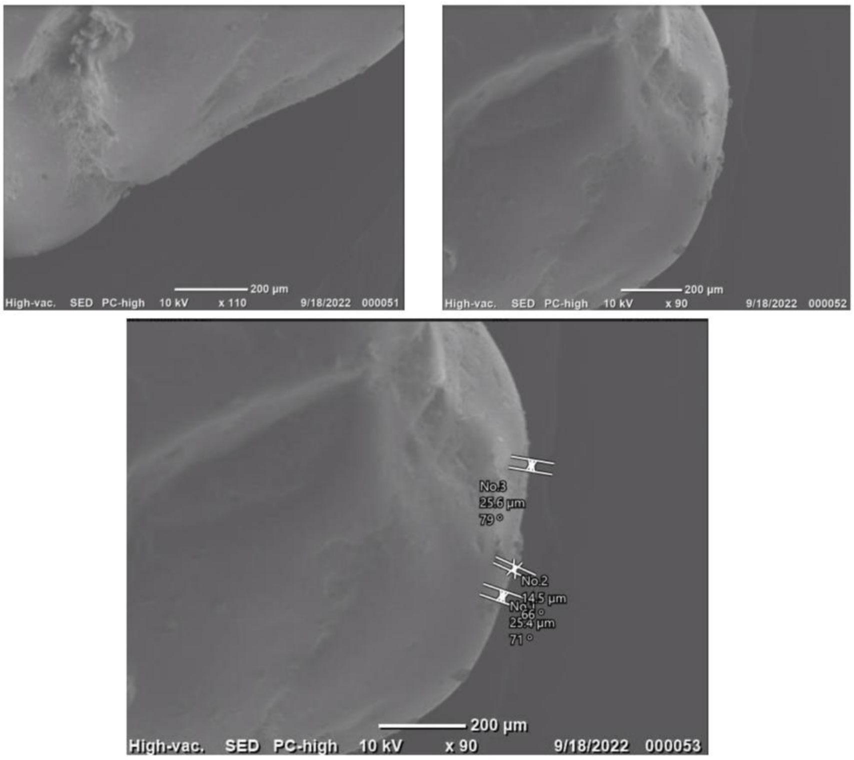

SEM Figure 13: Coccus Bacteria (x270)

3. Bottom Layer Sample:

1Smoother sand granule surface with much lesser types and frequency of bacteria and fungus are noticed at the ~55cm depth sand level as shown in SEM figures 14 and 15.




SEM Figure 14: Bottom Layer Sand Granule View (x34)




SEM Figure 15: Coccus Bacteria (x90)

# Chapter 6

# CONCLUSION

Urban communities are rising faster than ever with the rise in population and urbanization rates and there is a need to build and act sustainably with respect to COP27 and the global direction towards greenhouse gas reduction. A unified sustainability framework for communities will support in ease of application by acting as a guidance to the owner and designers; from these frameworks are the community guidelines like LEED, Pearl and Tarsheed. In the sense of that, the consideration of Net Zero approach implementations became a necessity to conserve natural resources like materials and water.

In this dissertation study, the proposal of an integrated community and occupants' rating system was met by first studying the currently known and used community related rating systems, highlighting the pros and cons of each while checking for the do-ability of application locally in the country of study, Egypt as the first novel approach in this study. The same comparative study was held among the occupants' rating systems which as of date, the currently used ones are focusing on a building scale. Lastly, the consideration of a currently known and barely referred to established integrated community and occupants' rating system is studied as well while highlighting its complexity of application and high-cost issues to be avoided in the proposed local integrated rating system. The first outcome in this dissertation is the addition of occupants' health and wellbeing to Tarsheed-Community rating system with its scorecard suggested credits and illustration for implementation; and an additional novel strategy in the proposed integrated rating system is the integration of the net zero credits for application. The proposal will be serving the Egyptian market and the countries of similar conditions.

Another novel approach that was met in this study is the proposal of a separate net zero rating system scheme that is complimentary to any certified community with Tarsheed Community or any other like rating systems. In this complementary net zero additions, consideration for ease of application and affordability in the Egyptian market is considered.

A third novel approach that was experimentally met in this study is the proposal of an integrated sand filter and aquatic plants filtration in series system for greywater study. 5 phases of experimental work were held in which phases 1 and 2 were focused on the sand filter design with the best sand size, sand bed depth and rate of filtration. It was concluded that medium sand size of (0.8mm-1.2mm) at sand bed depth of 65cm operating at sand filter ROF of 4 $m^3/m^2/$d was the best slow sand filter design to consider for the rest of the experimental work and this result is in-line with the literature studies of reference. Phase 3 was held to study the best plant density integrated with the output of the previous phases, even though ROF 4 $m^3/m^2/$d was the best sand filter design and that is where five different wet water hyacinth plant density were studied at 1 $kg/m^2$, 2 $kg/m^2$, 3.5 $kg/m^2$, 5 $kg/m^2$and 6 $kg/m^2$; yet the other ROFs considered during the slow sand filter rate of filtration study of 2 $m^3/m^2/$d and 6 $m^3/m^2/$d were also studied in parallel with three different plant densities at 2 $kg/m^2$, 3.5 $kg/m^2$and 5 $kg/m^2$and that is to support future studies of relevance as few studies were considering water hyacinth treatment for greywater and very few of which operated at this paper's flow rates. It was concluded that the PD of 3.5 $kg/m^2$is the best for the ROF of study and consideration at 4 $m^3/m^2/$d. Phase 4 of the experimental study focused on running the full integrated system using synthetic greywater mix. This phase is further divided into two main sub-phases where phase 1 is studying the integrated system of treatment under intermittent (9 hours per day, for 3 days) run while the other sub-phase is studying the integrated system of treatment under continuous 3 days run. Phase 5 is the final phase of the experimental run and it included a continuous integrated system run using real greywater. It is concluded from the experimental work that the in-series novel approach integration between the slow sand filter and the aquatic filtration is effective for domestic greywater treatment where it resulted in reduction in turbidity, TSS, COD and E. Coli. Even though the BOD-5 results under the real greywater run resulted in higher values than the allowed by the ECP – Category (A) for greywater treatment for reuse in landscape however, it is justified based on other studies that the influent real greywater of use was of higher BOD-5 levels reflecting more unlikely contamination in the sample and that is due to several reasons including problem with the piping system as black residues were noticed in the real GW samples when left to settle. Yet, as supported by research in this study, if the influent real greywater was of an acceptable BOD-5 parameters as reflected in the literature for are identified ranges specifying heavy and light greywater; the water hyacinth will prove efficient BOD-5 removal as it was shown in several studies while being the only treatment stage; so when integrated with a primary slow sand filter treatment and having the aquatic filtration as a secondary further treatment stage, it should meet the ECP- Category (A) limits and any other code of reference. This experimental study successfully meets the community net zero water approach as by such integration of greywater treatment for reuse in irrigation or toilet flushing, a huge reliance will be shifted from using potable water into reusing treated greywater that meets the standards of the country of use.

A final novel approach that is presented as a high-level idea in the appendix section while being driven from the literature and experimental work is the proposal of conducting a greywater treatment code for reuse in irrigation, toilet flushing and firefighting systems to be used locally in Egypt. As the adoption of such code is challenging and it requires further studies and in other related research; yet in this study the proposal of the idea with a paving framework to act as a guidance for any future work based on my study is of reference.

To sum up, this dissertation study met the purpose of not only proposing local rating system with novel integration and ease of implementation meeting the three main sustainability pillars of being environmentally friendly, economically viable and socially acceptable but also, applying a net zero water experiment to walk the thoughts of acting on saving the natural resources which water is a necessity getting to scarcity of which is met.

# Chapter 7

# RECOMMENDATIONS

## 7.A: Recommendations based on my work

This section is focused on proposing **Greywater Code for Egypt** and that is another novel approach point of study. In this proposal, a local code shall be studied and introduced for greywater treatment and reuse in Egypt. This proposal is built on the recent publishing's for different countries with similar environmental and living conditions; referring to their local greywater treatment codes like in KSA, Jordan, Australia, and California. The main purpose of greywater reuse is for landscape irrigation to non-crops and to domestic toilet flushing. The documents of reference used in establishing the proposed greywater code for Egypt are listed under the references section from reference #112 till reference #122.

## 7.1: Greywater Management Code for Reuse in Irrigation and Toilet Flushing

**Introduction**

Egypt, the #3 most densely populated country in Africa with almost 110 million citizens as of 2022, is facing serious water access problems that can no longer be taken lightly. The rise of population and urbanization levels is leading to an increase in demand and higher pressure on resources. Water, one of the impacted resources needed for daily lives and activities is being at risk of scarcity. UNICEF stated in a 2021 report that “Egypt is facing an annual water deficit of around seven billion cubic meters and the country could run out of water by 2025, when it is estimated that 1.8 billion people worldwide will live in absolute water scarcity” [112].

Even though Egypt has several water sources availability as shown in appendix figure 7.1 with Nile River water share being around 55.5 billion cubic meters. Yet, the poor management and utilization of water resource is leading to water stress and hence, scarcity.

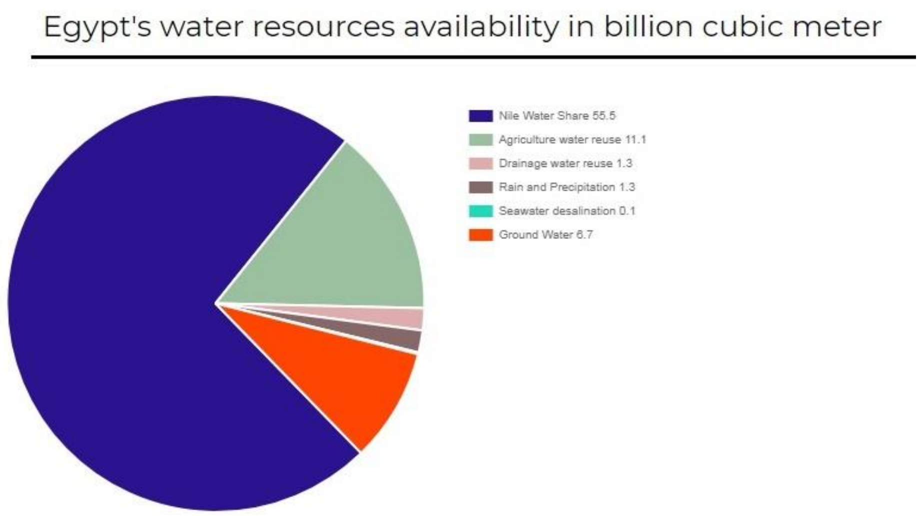



Figure 7.1: Egypt's Water Resources Availability in BCM (115)

The Ministry of Water Resources and Irrigation in Egypt presented a statistic on the annual water consumption per capita. By 2018, 550 cubic meters was the person’s annual intake of water, and it is projected that with the rise of population and urbanization plus lack of water use optimization, only 330 cubic meters of water will be available per person per year; in other words, less than 1 cubic meter per capita per day [113].

Some facts about the water consumption in Egypt includes the Agricultural Irrigation activity. Agricultural Irrigation in Egypt is the highest sector with water reliance and use, around 85%, yet the highest in water losses [114]. Another fact is that around 11 billion cubic meter of drinking water is consumed annually with around 8 billion cubic meters produced to waste and the remaining can be lost in poor wastewater networks [115].

**Wastewater**

Wastewater is the water generated after being used in domestic houses, commercial buildings, and others. Egypt produces around 16.4 billion cubic meters of WW annually with 4.4 BCM in sewage and the remaining in agricultural waste [116] .

Wastewater is known for its high levels of contamination, organic matters, odor, color, toxicity, and health hazards when intact with humans; Hence, when considering wastewater treatment for domestic and agricultural reuse; while also, to reduce the reliance on freshwater supply, an understanding of the produced wastewater mixture of components is necessary.

Wastewater is divided into two main types, greywater, and black water. Greywater is the domestic water produced excluding toilets; it is further divided into light greywater and heavy greywater. Light greywater is that produced from bathroom sinks and showers and other domestic sinks. Heavy greywater includes kitchen sink, dishwasher and washing machines which are high in organic components and chemicals. Greywater is usually around 70% of the total wastewater produced and the remaining is black water and sewage.

**Why to treat GW?**

a. GW accounts for almost 70% of the domestic water use output.

b. GW is easier to treat and reuse when compared to black water due to its lower toxicity levels and organic contaminants.

c. Treating GW will significantly reduce the reliance on fresh water sources, and hence acting with sustainability towards eliminating the impact of water scarcity.

d. Treating GW will reduce the wastewater treatment load by reducing the amount of wastewater needed for treatment.

e. When treated, GW is safe for human contact and reuse in irrigation.

f. Treated greywater has several reuse purposes like toilet flushing, irrigation, car wash, firefighting systems, and many others; all the uses are depending on the type of treatment applied and the quality of the effluent treated greywater ensuring that this alternate water reuse source is safe.

**Greywater Composition**

Identifying a standardized greywater quality is hard as it varies based on the usage from one building to another, from one user to another and even it varies with the same user along the day. This variance is based on the zone, lifestyle and products used like toothpaste, soaps, lotions, shampoos, shaving creams...etc.

**Greywater Quality**

No matter the variance in the effluent greywater source, there are specific parameters to consider as part of assessing the greywater quality to decide on the needed treatment and efficiency of treatment.

a. Biological Parameters like E. coli and Nematode
b. Chemical and Physical Qualities like Nutrients (phosphorus and nitrogen). Also, salts, magnesium and sodium resulting from washing related detergents.
c. PH.

**Egypt Proposed Greywater Treatment and Reuse Code Objective**

Since globally the greywater treatment is getting more attention with lots of technologies in places, Egypt has a wastewater treatment code in place that is divided under 4 uses criteria and parameters. However, since greywater is more reliable for treatment and is produced in massive amounts than black water; there is a need to have a local greywater treatment code that is affordable, applicable to install and apply while meeting environmental aspects.

**Objective**

The proposed greywater reuse code for Egypt will act as a guideline to the designers, engineers, consultants, contractors, investors, and government. The code is intended to be easy for application, effective and affordable for a fast action towards preventing water scarcity in Egypt.

**Code Applicability**

This code shall be applicable for application in greywater treatment and reuse to reduce the need of freshwater supply for non-drinking uses and activities.

The provisions of this code shall apply to all the sectors not limited to, construction, domestic, irrigation and others.

**Greywater Reuse Applications:**

As allowed to reuse, based on the treated greywater effluent, this water source alternate shall be reused in the identified applications where needed like irrigation of agricultural lands (for non-crops lands), toilet flushing, firefighting systems, car wash, street pressure wash and any attractions like water fountains and water parks.

**Greywater Treatment System Design Considerations**

a. Any local permits abiding to the MOH, MWRI and MOE shall be considered and applied for prior to auctioning the below.

b. Greywater Systems shall be abided to green building standards codes or frameworks available locally.

c. Ensuring that the greywater piping is separate than the black water piping in any building or infrastructure. Commonly used in Egypt, 2” pipes for the greywater and 4” pipes for the blackwater.

d. Proper pipes marking/ coloring for the GW and BW is essential.

e. Ensuring the presence of a collection tank/ surge tank placed and anchored for safety underground near the facility to collect the greywater effluent along the day. The surge tank shall have an overflow drain connected to another smaller in size backup surge tank, if the space allows, or to the sewage system.

f. Greywater diversion devices can be considered for immediate redirection of the greywater to the treatment spot.

g. Deciding on the needed greywater treatment technology that is affordable, efficient, and applicable to apply.

h. If collected greywater will be transported via cars to the treatment plants, proper marking shall be labelled (Non-Potable Greywater, Do Not Drink or Touch).

i. Deciding on allocating centralized or decentralized greywater treatment system.

j. After greywater is treated, there shall be a storage tank collecting the effluent treated greywater.

i. The collected treated greywater shall be reallocated for reuse in buildings as per the capacity. This is to be decided by the municipality on a city scale or community designers and engineering on a gated community scale.

j. Holding greywater treatment system maintenance is essential and it is the responsibility of the owner.

k. Holding treated greywater inspection checks every 3 months to ensure that the effluent treated greywater is meeting the standards.

l. System controls like valves, metering devices, pumps, connectors, sensors and others need to be taken into design consideration as per the available local standards.

m. Centrifugal pumps are to be used on a building scale for pumping greywater off the collection tank.

n. Piping systems and pumps used need to be designed as per the area's population based on local related codes, if customization is needed other than the commercially used referred to in points a and k.

**Greywater Quantity Required**

Based on the area population considering greywater treatment, the treatment system shall be designed accounting for maximum greywater production annually. The minimum requirements shall be identified to ensure proper running and treatment of the system.

**Greywater Discharge Estimation**

The greywater systems shall be designed to ensure that all the daily collected greywater is distributed properly on to the greywater treatment systems no matter if they are centralized on non-centralized.

In case of greywater collection and reuse focus for domestic use, the below calculations are needed for consideration:

i. Identifying the zone where the greywater treatment reused is to be applied (e.g., coastal, touristic/seasonal, and urban/rural).

ii. Residential building occupancy (e.g., each building will consist of 5 floors with 2 apartments per floor and maximum capacity of 5 persons per apartment).

iii. Consideration of green areas in front of the building, if available is important as this green area will require a percentage of the treated greywater for irrigation.

iv. The estimated freshwater use shall be calculated per capita or per apartment.

v. The estimated effluent greywater shall be calculated based on the related zone and consumers' behavior including the below:

   a. Is it wintertime or peak-summer time for usage reflections?

   b. Shall the design considerations be accounting for peak weekends or weekdays or all together?

   c. Including number of showers/ person/ days, approximate number of using the basin or sink, number of laundry or washing machine counts, number of toilets flushing and average number of garden irrigation, if applicable.

   d. For commercial areas, identifying the approximate greywater discharge in lavatories shall provide a reflection on the effluent greywater volume.

vi. The final treated greywater quality shall meet local parameters, if available or similar conditions countries with existing greywater treatment codes for reuse in irrigation and toilet flushing.

**Environmental Considerations**

a. Effluent greywater shall be properly collected, contained, and transported avoiding any piping leakage or run-offs in the neighborhood and avoiding any human intact.

b. Waste chemicals, oils, grease, pesticides, industrial waste and other pollutants and contaminants shall be away from the greywater collection point.

c. Proper greywater piping system fittings and inspection is a must to prevent any insects or unwanted objects getting trapped along the greywater collection line.

**Local Related Codes of Reference:**

a. Egyptian Code for Building and Construction (300)

b. Egyptian Plumbing code for laundry and kitchen (301/4)

c. Egyptian Code for Design and Implementation of Pipelines for Drinking Water and Sewage Networks, Sixth Edition

## 7.B: Recommendations for Future Work

### Rating System Recommendations

1. The introduction of a local quantitative net zero rating system that is applicable for both buildings and communities as per the proposed framework.
2. The inclusion of a measurable rewards and penalties scheme within the community and occupants’ rating system.
3. The consideration for a building scale rating system integration with occupants’ credits.
4. The integration of smart technologies for energy savings, water management and waste management within the community and occupants’ rating system, as well as the complimentary net zero rating system.
5. Further framework design for the complimentary net zero rating system including cost reflection, life cycle assessment, carbon-offset, and water-offset equations.
6. Online calculators for energy use and savings, water use and savings, waste consumption and total carbon footprint impact are to be accessible for community investors and designers after 6 months of community occupancy to be applied under the community and occupants’ rating system as well as the complimentary net zero rating system.

**Integrated In Series Sand Filter and Aquatic Filtration Treatment Recommendations**

1. The sedimentation column (SC) can be placed at a higher level from the ground from what was used in the experiment (60 cm). This is to prevent the continuous need of greywater mix being added to the SC while overflowing at times.
2. The Aquatic Filtration tanks can be studied with different designs rather than rectangular and intermediate tank sampling points shall be collected to check for the treatment behavior along the tank.
3. Studying the water hyacinth treatment effect during winter and comparing it with the summer. This experiment was conducted over summertime facing moderate to extreme hot weathers.
4. Additional parameters can be studied specially on the aquatic plants side like nitrates, phosphates, and potassium.
5. An additional flow rates control valves can be added between the sand filter and the aquatic filtration tanks to vary the Q in to the aquatic tanks. In this experiment, the Q in to the sand filter = Q out of the sand filter = Q in to the aquatic tanks.
6. The use of aeration can be considered for in the aquatic tanks for better parameters results however, the total treatment system cost and energy consumption shall be considered to off-set.
7. The same sand filter and aquatic filtration integration can be studied while mixing different components with the sand in the sand bed. Couple of references with mixing materials and ratios were mentioned in the study.
8. A comparison between different types of treatment plants like the water hyacinth, duckweed, papyrus, and others can be considered with the sand filter in series integration for treatment.

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